Towards Search and Rescue and Rehabilitation through Modular Robots and Human Computer Interfaces

Thesis submitted in partial fulfillment
of the requirements for the degree

Master of Science by Research
In
Computer Science Engineering

By

Sriranjan Rasakatla
200907019
infibit@gmail.com

Robotics Research Center
International Institute of Information Technology
Hyderabad – 500032, INDIA
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International Institute of Information Technology-Hyderabad,
India

CERTIFICATE

It is certified that the work contained in this thesis, titled "Towards Search and Rescue ad Rehabilitation through Modular Robots an Human Computer Interfaces" by SRIRANJAN RASAKATLA has been carried out under my supervision and is not submitted elsewhere for a degree.

K. Madhava Krish

Date 12-6-14

Advisor:Prof.Dr.K Madhava Krishna

To

My childhood school teachers, my intermediate lecturers, professors from CBIT and Graduate professors in IIIT-H and family.

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……………… it is curiousity that drives humanity."

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CONTENTS

5. Other explorations

ABSTRACT

This thesis was based on the idea of developing assistive systems for search and rescue and rehabilitation. Imagine a search and rescue scenario. Say there is an earthquake or a tsunami and there is lot of debris with people stuck under the debris. If we can improve the process of search then the rescue would come even faster and more lives would be saved. One part of the disaster management is to provide people affected with the disaster assistive systems to improve the quality of life. With this intention several robots and assistive systems are presented in this thesis.Real biological snakes have the ability to traverse several kinds of terrain. They can swim in water, climb trees, go over desert sand and go over step like terrain. So if me model robots with the snake structure in design then we can overcome challenging terrain which is typical to a rescue scenario. With that in mind we designed 5 different kinds of modular units of snake robot. We also were able to make the snake transition gaits autonomously from one part of the terrain to another. To over come slope like obstacles we designed a 6 legged robot that has a robotic spine. By controlling the amount of current in the robotic spine, we controlled its effective torque and were able to show compliance to slope while climbing up and climbing down. We also designed a universal simulator and controller plugin to reduce the fabrication time and simulate virtual models very close to its real counterpart robotic prototypes. Working on the modular design of the snake robot we engineered a new modular for modular snake like arms which was later extended to robotic hand. The robotic hand uses modular joints where each joint is composed of a pair of rolling magnetic spheres. In this attempt we ended up designing a robotic hand with the highest degree of freedom in the world. We have been working on assistive systems like camera mouse which allows a physically challenged person to use a computer. This research in HCI lead to controlling a snake robot with natural and intuitive gestures. We also designed a quake and crash alert system. We designed an intelligent flash light which can be used by a rescue worker to move in unknown places.

The torch light uses a GPS,a laser projected micro projector and guides a person from a source to a destination.

The work done here uses a combination of inputs from HCI and robotic system building to make search and rescue better. It also reduces the time for the human in loop during rescue

1.Building Robots

Building robots was interesting from the point of view of developing working systems from scratch. The same was the excitement in building the human computer interface systems from scratch or integrate existing systems on the basis of new ideas both at a hardware and software level. Some of the earlier work involved developing different designs of snake robots. Some were initially built to test the existing designs of snake robots at a conceptual level. Later this knowledge was used to combine these robots with intuitive interfaces.

1.1 Initial work on modular snake design

Prototype Module 1: An 8-dof modular snake with one DOF per module was constructed and few gaits were implemented on the same. This snake had 8 servos connected with their rotation axis in parallel to form an 8DOF snake. This snake haD servos of 3.3 kg-cm torque and ran on a 12 V onboard power supply. The Snake has an onboard controller which sends control signals (PWM based position signals) from a circular lookup table. The values in the lookup table have been calculated to represent a traveling differential curve such that phase difference between each of the successive modules is constant over time and each module has a constant angular velocity. To get a true serpenoid curve the successive phase difference should not be constant but increase from the head module to the middle of the snake and decrease till the tail module. To get traction from the ground passive wheels were used in each of the module. The wheels provided more friction sideways but rolled in one direction. This helped in canceling out the reaction forces in a direction perpendicular to the snake's direction of propagation and assisted the force in parallel to the snake's body.

Fig 5.0 Snake P1 planar snake with passive wheels and its power drive unit

The snake was able to rectilinearly propagate in the horizontal direction but when it was flipped over the sinusoidal wave which was in the horizontal plane was now in the vertical plane. This helped in generating traction like an automobile's wheel does and pushed the snake forward. The study on the locomotion mechanism of snakes as to how its body interacts with the contact surface and the forces acting on it was done by Shigeo Hirose in 1974 and he coined the serpenoid equation [1.2].

Prototype Module 2: This module has 3 DOF. Each servo linked orthogonal to the prior having their axes oriented along the X,Y and Z directions respectively. The 3rd prototype module exhibited how a 3DOF module can be constructed but had a basic design flaw that the axial separation of consecutive servos was unnecessarily high. CMU biorobotics developed a couple of oblique 2 DOF joints for Snake like hybrid manipulators [10].

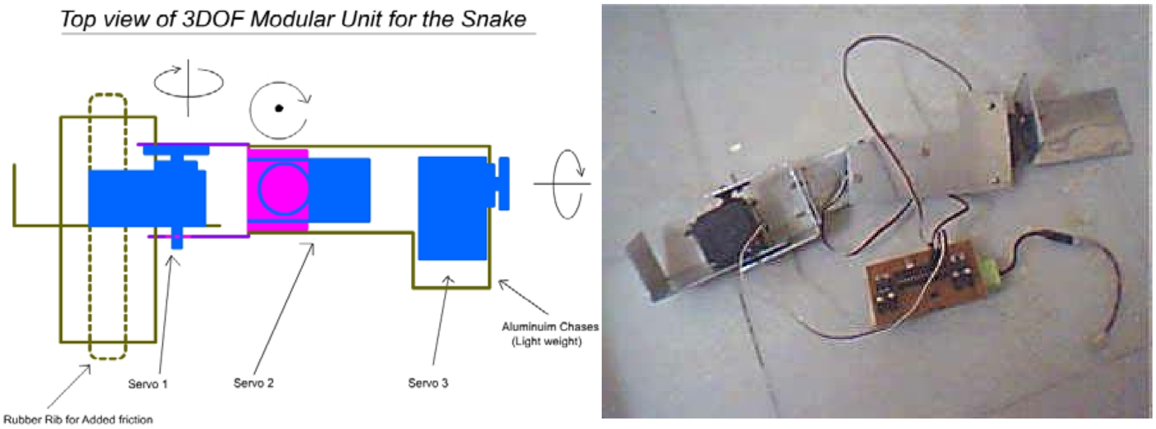


Fig 5.1 3 degree of freedom modular unit design and the prototype module

Prototype Module 3: The natural snake has a modular skeletal structure. The Snake joints are a consecutive ball and socket arrangement. This gives the snake freedom to flex not only in the horizontal but also in the vertical direction (360 solid angle rotation).A joint which closely resembles and enables a robotic snake to flex both in horizontal and vertical is the universal joint. The universal joint is also called the hook joint. The following module built has a universal joint with 2 servos of 11 kg-cm each orthogonally coupled with each other.

Fig 5.2 2 d.o.f orthogonal modular unit usgin Bioloid AX-12 servos and bellow design

The joint was covered with a cylindrical bellow. The cylindrical bellow can expand and compress as well as bend along with the joint. If it was covered just with cylindrical rubber material it would not have been complaint around the joint. This cylindrical bellow is tough as well as flexible. On attaching O-rings at either side of the joint, it can be made water proof and thus the Snake can be made amphibious. Amphibious snake design was explored by the scientist Dr.Shigeo Hirose. In his snake ACM-R5 he used 3 joints of which two actively emulate a universal joint and the other is a passive joint to allow for twisting [9].

The joint was simulated in the ODE physics engine [8] . In the simulation environment the modules were rectangular and contact forces generated were ideally symmetric about the snake's body and thus zero torque was experienced when the joint became vertically undulated. The prototype design was a cylindrical one and when the module was vertically undulated and was made to destabilize with a twist in horizontal direction the module rolled. When this was cyclically continued the module began to roll in several cycles. The direction of rolling depends in which order the modules were actuated. This particular gait exhibited is called a biologically inspired gait "rolling". Some snakes actually pretend to be dead when under attack by a predator by rolling onto their back [5]. Also the 2DOF module was made to exhibit what is called the butterfly stroke. In this the module uses each half of its module or body as an arm to push back the ground and generate traction just as a swimmer who is doing a butterfly stroke places his hand forward and pushes the water back. The rolling gait is more efficient on flat surfaces like roads and office floors but on surfaces like sand, pebbles and grass butterfly gait generates more traction and moves forward better. Especially if the terrain is fluffy like a box filled with thermocol balls then this gait can plough and dig through it.

Fig 5.3 Bellow snake design executing a butterfly gait

Snake P2 : Snake P2 was a 12 DOF snake with 6 servos coupled with the rest in an orthogonal direction. This gave the Snake a 3D motion capability. With the Snake (p2) several gaits were tried out. Some of the gaits that were achieved on Snake P2 are vertical undulation (caterpillar crawling), vertical undulation with S-Shaped trajectory which increased the footprint of the robot and gave it more stability [5], u-shaped turning and rolling. All these gaits were initially simulated as discrete sequences in a physics engine and then the same sequences were dumped onto the micro-controller. The snake p2 had two Atmega-8 micro-controllers, one for generating the horizontal wave and the other for generating the vertical wave. The module was powered from a regulated power supply via the Texas Instrument Turbo-trans power module PTH08220W.

Fig 5.4 12 DOF Snake p2

Later this snake was fitted with a camera in its head to exhibit the snooping behavior which is especially useful if the snake is to be used in a search and rescue scenario where there is an obstacle like a rock and the snake has to look beyond it.

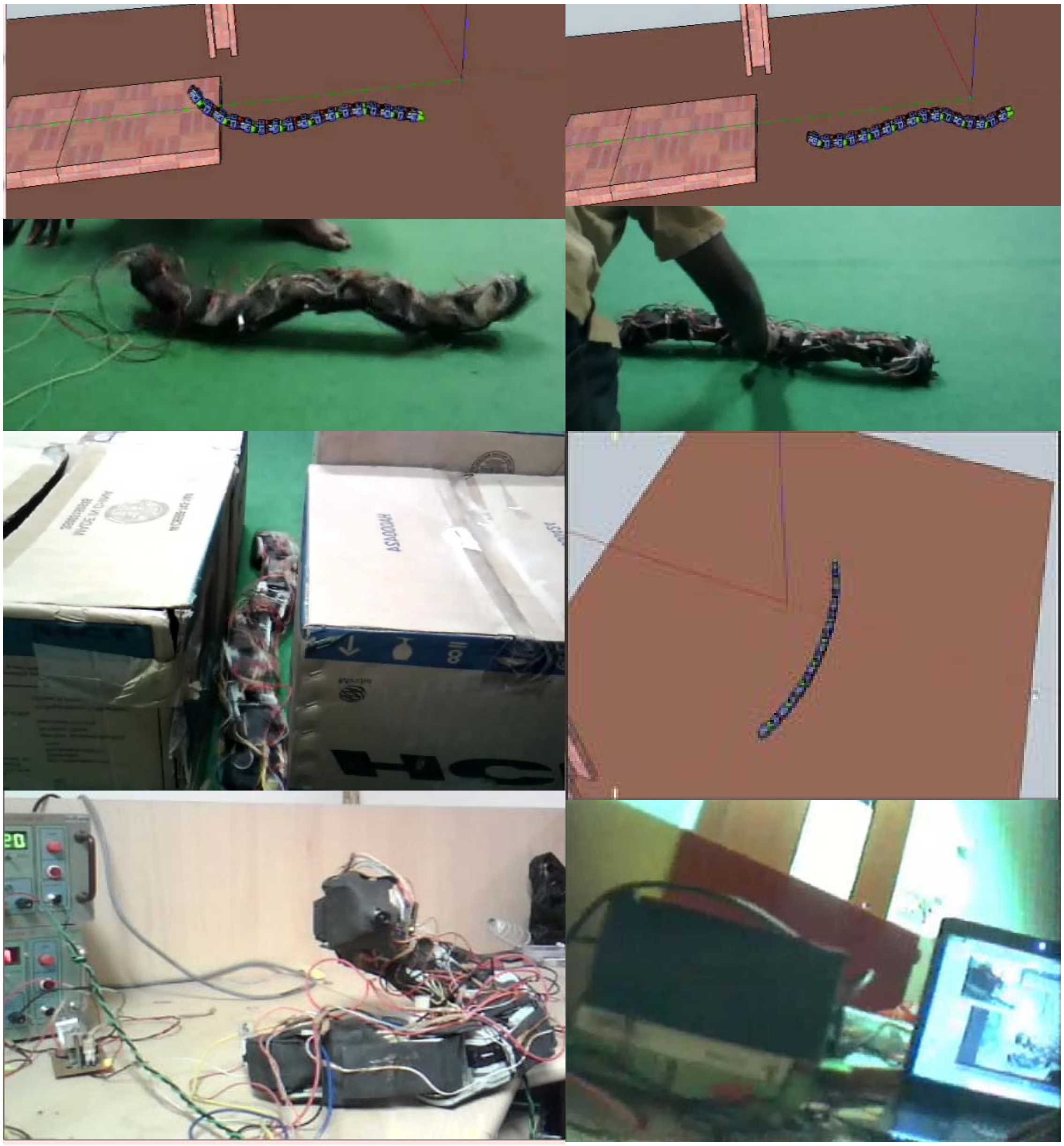


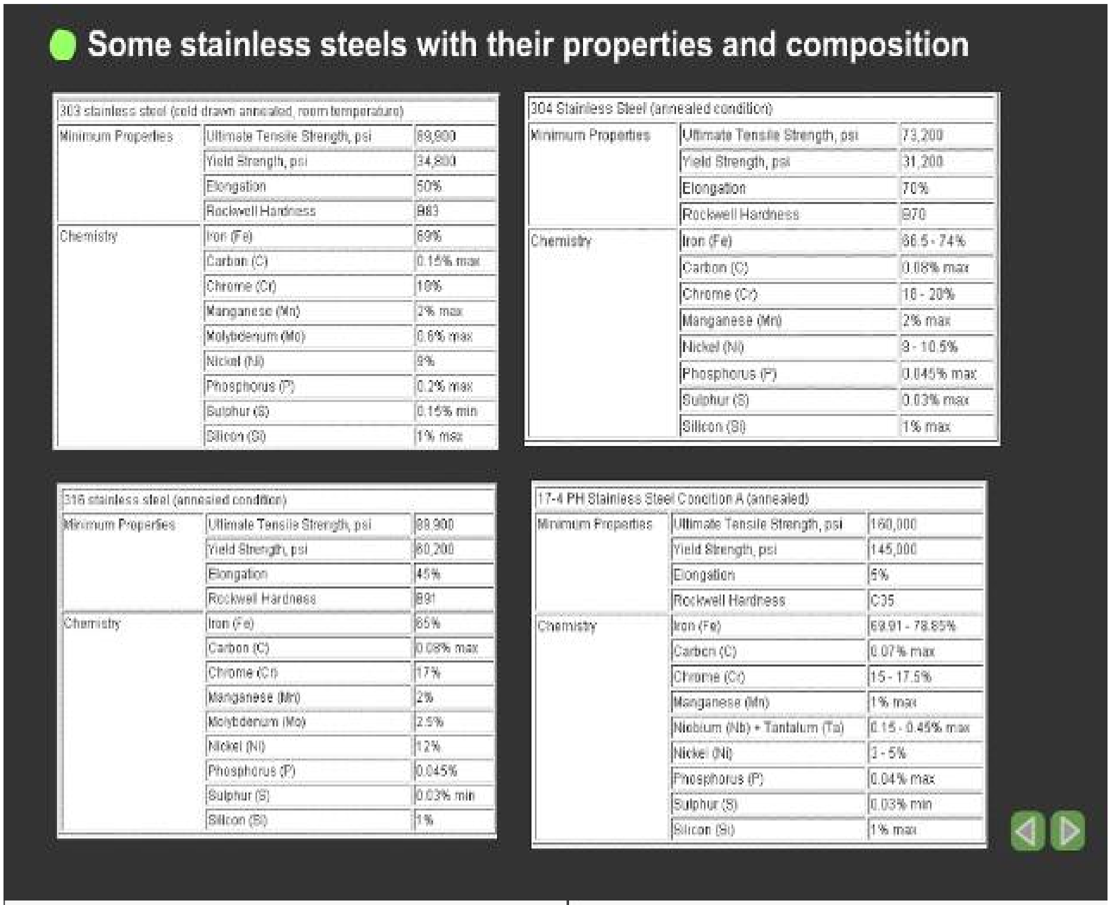
Fig 5.5 Snake P2 gait simulations, crawling through a passage and camera snooping

To improve the snake design and give it better capability the problem of designing a new servo motor with custom gear design that would improve and optimize the output torque of the servo motor within the space constraints of a standard RC servo motor was taken up. For this several combinations of differential stage spur gear design were looked into. Also the constraint was to operate within the voltage and current range of a standard servo motor to give the snake robot a good run time from the standard Li-Ion batteries or an SMPS power supply.

The following was the calculated gear ratio.

```
Pinion 12T 48DP face width 3.5mm, safe torque 1kg-cm

2nd compound gear
2Large 22T 48DP 3.5mm thick
2Small 10T 42DP 5.0mm thick

3rd compound gear
3Large 28T 42DP 5.0mm thick
3small 10T 48DP 6.5mm thick

4th compound gear
4Large 32T 38DP 6.5mm thick
4Small 10T 32DP 8.0mm thick

5th compound gear
5Large 34T 32DP 8.0mm thick
5Small 10T 28DP 10.0mm thick

Output shaft gear
36T 28DP 10mm thick

Reduction ratio
(22/11)x(28/10)x(32/10)x(34/10)x(36/12)
= 1/167

Output torque = 60 kg-cm to 101 kg-cm for a base torque
motor of 12.4 to 63.6 gm-cm
```

Also the materials needed for withstanding such high torque but still be light to keep the weight of each of the snake module low were looked into. Some of the manufacturers of standard servo motors like Hitec, Futaba and JR use Karbonite and aluminum gears in their high torque designs. Some of the stainless steel versions chosen for this task of high speed and high torque gears were Stainless steel 303, 304, 316 and 17-4PH. These version of the metal differed in the percentage of the base metal combinations and other elements like Nickel, Cobalt, Magnesium, Phosphorus and tantalum. They also deferred in their method of preparation like pre-heating, hardening etc. These factors change their ultimate tensile strength and yield strength. A simulation was carried out in Nastran and a Finite element analysis was also done to know in which stage on what gear the stress was maximum.



Some stainless steels with their properties and composition

303 stainless steel (cold drawn annealed, room temperature)		
Minimum Properties	Ultimate Tensile Strength, psi	89,900
	Yield Strength, psi	34,800
	Elongation	50%
	Rockwell Hardness	B83
Chemistry	Iron (Fe)	69%
	Carbon (C)	0.15% max
	Chrome (Cr)	18%
	Manganese (Mn)	2% max
	Molybdenum (Mo)	0.6% max
	Nickel (Ni)	9%
	Phosphorus (P)	0.2% max
	Sulphur (S)	0.15% min
	Silicon (Si)	1% max

304 Stainless Steel (annealed condition)		
Minimum Properties	Ultimate Tensile Strength, psi	73,200
	Yield Strength, psi	31,200
	Elongation	70%
	Rockwell Hardness	B70
Chemistry	Iron (Fe)	66.5 - 74%
	Carbon (C)	0.08% max
	Chrome (Cr)	18 - 20%
	Manganese (Mn)	2% max
	Nickel (Ni)	8 - 10.5%
	Phosphorus (P)	0.045% max
	Sulphur (S)	0.03% max
	Silicon (Si)	1% max

316 stainless steel (annealed condition)		
Minimum Properties	Ultimate Tensile Strength, psi	88,900
	Yield Strength, psi	60,200
	Elongation	45%
	Rockwell Hardness	B91
Chemistry	Iron (Fe)	65%
	Carbon (C)	0.08% max
	Chrome (Cr)	17%
	Manganese (Mn)	2%
	Molybdenum (Mo)	2.5%
	Nickel (Ni)	12%
	Phosphorus (P)	0.045%
	Sulphur (S)	0.03% min
	Silicon (Si)	1%

17-4 PH Stainless Steel Condition A (annealed)		
Minimum Properties	Ultimate Tensile Strength, psi	160,000
	Yield Strength, psi	145,000
	Elongation	5%
	Rockwell Hardness	C35
Chemistry	Iron (Fe)	69.91 - 78.85%
	Carbon (C)	0.07% max
	Chrome (Cr)	15 - 17.5%
	Manganese (Mn)	1% max
	Niobium (Nb) + Tantalum (Ta)	0.15 - 0.45% max
	Nickel (Ni)	3 - 5%
	Phosphorus (P)	0.04% max
	Sulphur (S)	0.03% min
	Silicon (Si)	1% max

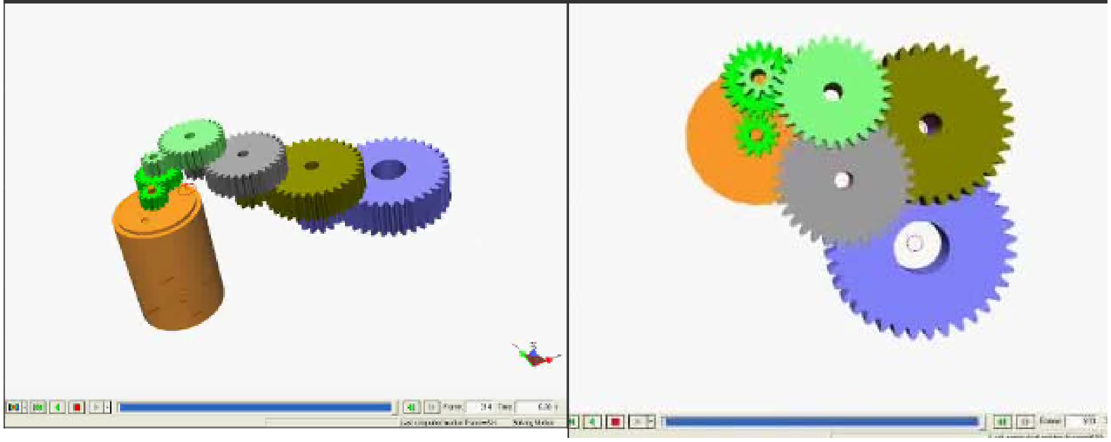


Fig 5.6 Choice of materials for servo gear train and multi-stage differential spur gear simulation in Nastran

The work[7] by CMU bio-robotics group on Snake designs tells that the portion of snake robot lifted above the ground depends on the base joint torque, the distance between the modules and the weight of each module. To understand how the joint torque changes what portion of the Snake robot's body gets lifted off the ground several simulations were done in Nastran varying the joint torque and the number of module's being lifted above the ground.

The following observations were made in the Nastran simulations:

1) The equation held good considering the snake as a statically stable hyper-redundant manipulator.

2) The module could not lift 6 modules at a joint torque of 30 kg-cm. (16 modules total length)

3) With a joint torque of 30 kg-cm 4 modules could be lifted in air i.e 1/4th the length of Snake's body

4) 35 Kg-cm and 37 kg-cm Maximum achievable joint torque as per Hitec 5995 TG could lift 6 modules in air. 5) The proposed design and gear ratio here could lift 6 modules easily. Finally HS7850 was selected which had 480 oz-inch of maximum torque.

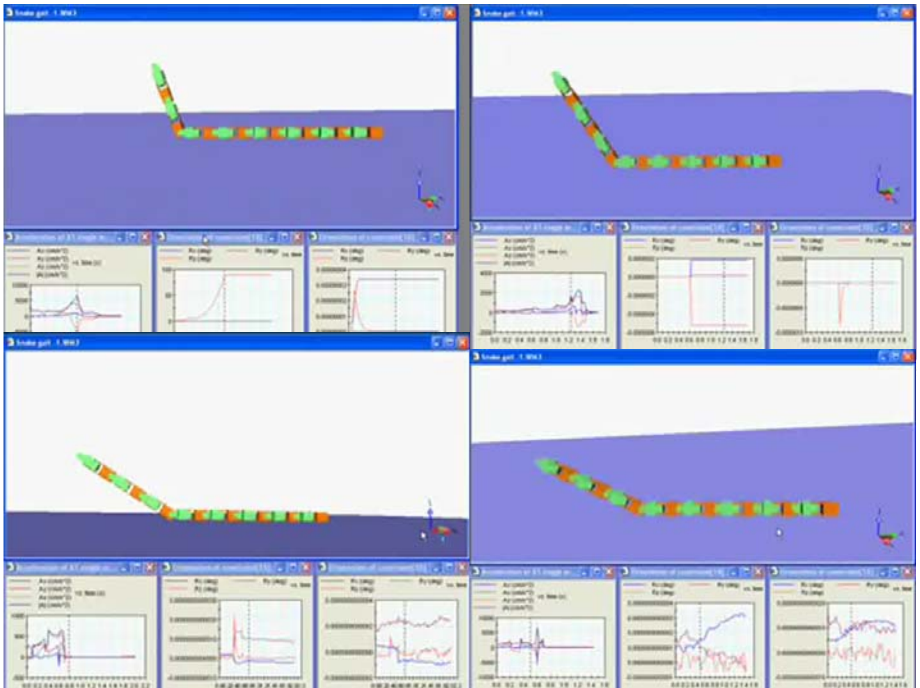


Fig 5.7 Nastran simulation of Snake with various joint torques with a portion of being lifted

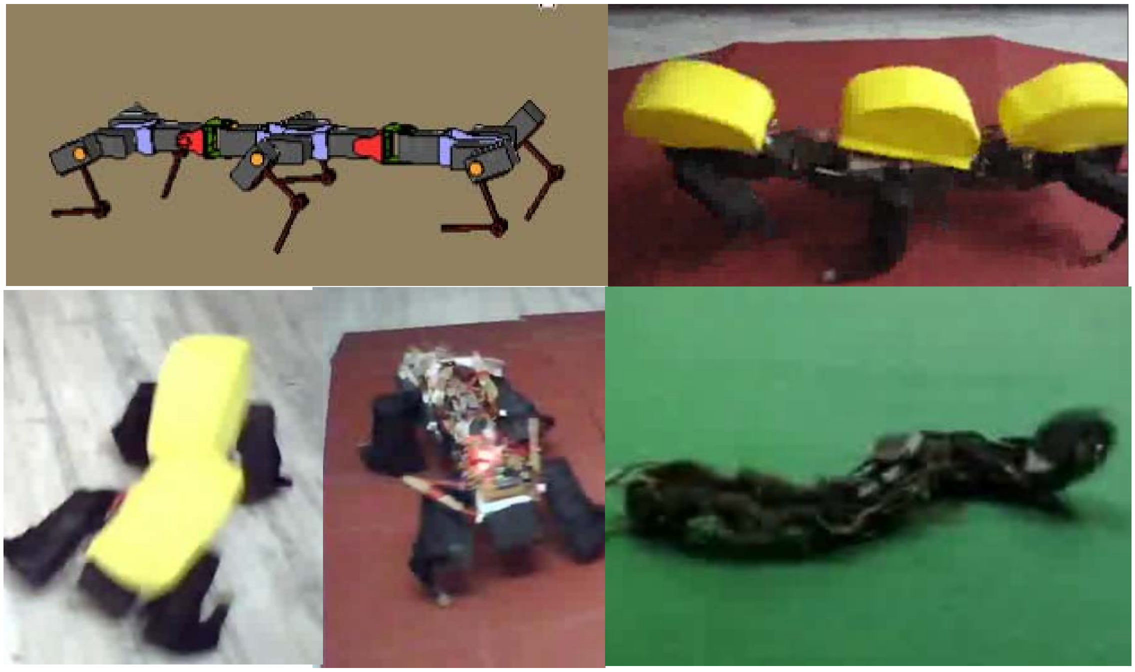


Fig 5.8 Modular legged design showing 4 legged robotic dog, a hexapod and a snake robot

Further exploration into the modular designs gave us the idea of biologically mimicking the caterpillar legged design and the vertebral design found in 4 legged animals and snakes, but prior to building the more complicated caterpillar design we pondered as to how to reduce the design time and minimize the damage due to wear and tear during the phase of gait testing. This thought took the research in a direction to coin few principles in building robots.

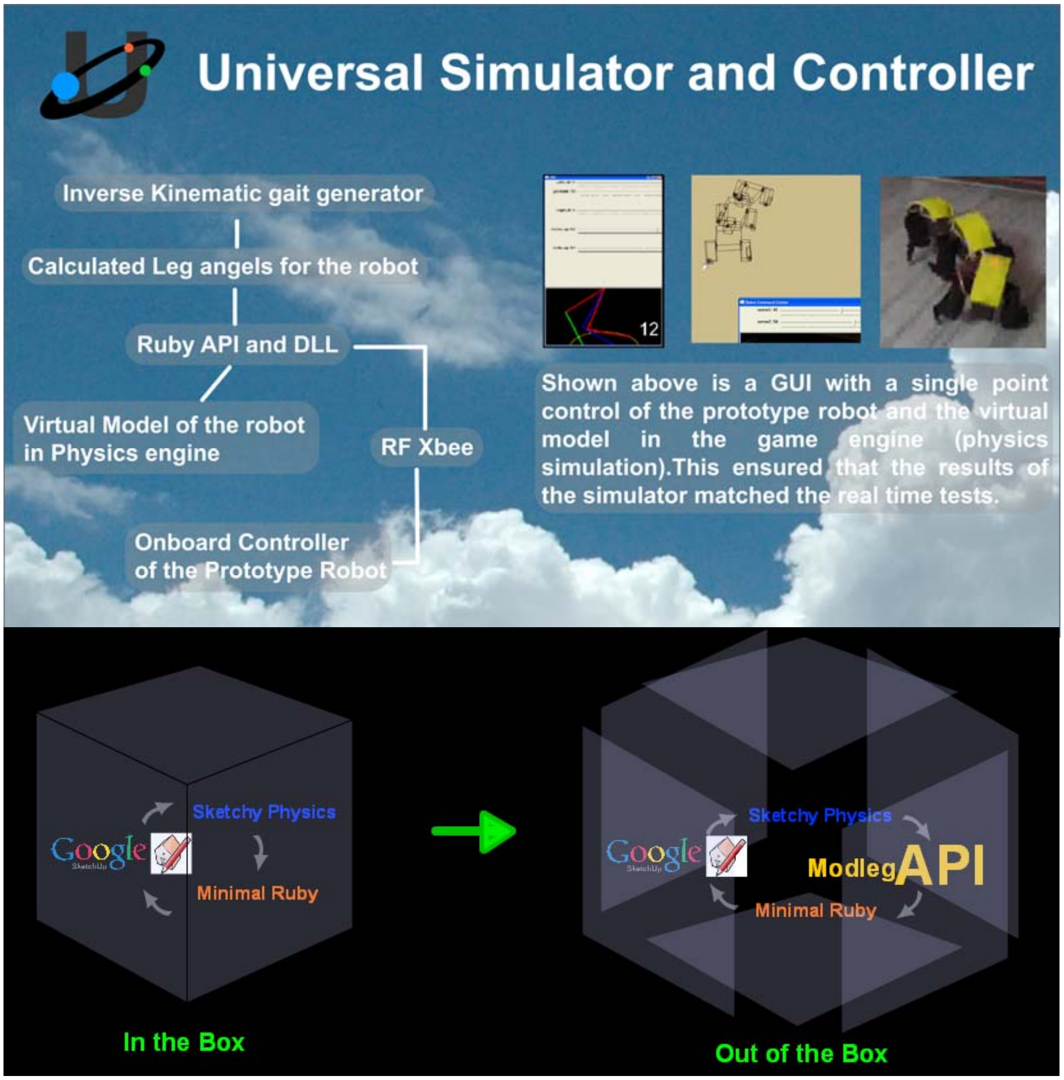
A unique simulator was designed for this purpose. Some of the things we learned while developing this robotic system have been presented below.

1.2 Software Methodologies.

a) We developed an API (modleg API) for Sketchy Physics. The integrated environment of Google Sketchup with Sketchy Physics had limitations due to the inbuilt minimal ruby interface. This avoided programming the virtual models/characters in the physics simulation for full fledged kinematic algorithms. So a ruby plugin was written which would dump the physics engine parameters like motor velocities, joint torques exerted by the piston, servo angle values into a shared memory. A DLL was then written with functions to read and write the values from the shared memory. Using this ruby plugin and the DLL as the bridge a game developer or a researcher looking for a good design and physics simulation package could read the values from the shared memory. This approach provided an API to sketchy physics independent of the language (as all one needs to do is read and write into the shared memory). So a programmer using Java, C, C++, Ruby or python etc could use the API. This was formerly not possible with Google Sketchup running sketchy Physics,

b) The virtual model in the simulator was closely modeled to the real prototype in both design and API. This ensured that the kinematic algorithms tested in the simulation engine worked exactly the same on the prototype robot during real time tests. The common API ensured that no further porting was required to transfer the sequence of actions of the virtual model onto the real robot. This unified development approach greatly reduced design time, development time and saved resources (battery power and replacements for worn out parts) required for the real time tests. We feel this approach would also help in bringing virtual models/characters to robotic reality (life). The templates developed here were easily interchangeable between a caterpillar, a snake robot, a hexapod and a 4 legged robot.

c) Universal Simulator and controller: One can interact with the virtual robot and the real prototype from a single point GUI. We call this the universal simulator and controller. An inverse kinematic stabilization algorithm on terrain with changing and unpredictable slopes was written for the robot. The algorithm adjusts the hip to toe lengths of the robot for making it stable. A handheld interface for playing with the robot’s virtual model was designed. An accelerometer was used as an input device to vary the slope of a test platform on which the robotic dog was resting in the physics simulation. Later during real time tests it was observed that when the accelerometer was mounted on the platform the real robot stabilized itself with negative gains. This was possible because of the universal controller built was developed on a common API.



Universal Simulator and Controller

Inverse Kinematic gait generator

Calculated Leg angels for the robot

Ruby API and DLL

Virtual Model of the robot in Physics engine

RF Xbee

Onboard Controller of the Prototype Robot

Shown above is a GUI with a single point control of the prototype robot and the virtual model in the game engine (physics simulation).This ensured that the results of the simulator matched the real time tests.

Fig 5.8 A flow diagram showing the universal simulator and controller schematic design

Conclusion

Many physics engines were computationally expensive. Most of the engines required the integration with Matlab which added to the computational load of the running desktop computer or the laptop computer. So a need to find a lightweight environment to run the physics simulation was required and so we worked around Google sketchup and the sketchy physics plugin. Also all the robots shares a common embedded control with the same API, the same controller could be fit in all the species of the modular legged robotic system. This universal simulator was our interface to the robot. The universal simulator and controller together with the API act as in interface for the robot. Also all the robots shares a common embedded control with the same API, the same controller could be fit in all the species of the modular legged robotic system.

2.0 Design, Construction and a compliant gait of “ModPod”: a Modular Hexpod robot.

In this chapter we describe the mechanical design, gait and control for a modular hexapod robot which shows compliance to the terrain while climbing slopes up and down. The robot uses a unique electronically actuated 2DOF universal spine similar to the spine of the Snake and the four legged animals like leopard, tiger etc. By controlling the amount of stiffness in the spine we were able to make the robot compliant to sloping surfaces. To our knowledge this is the first modular hexapod robot which achieves controllable compliance by both mechanical design and electronically actuating the robot’s spinal backbone. This design was biologically inspired based on the structure of a caterpillar with legs. Also we present the hardware and software architecture of the robot in this chapter.

2.1 Modpod Introduction

One of the important problems of legged robots is their compliance with the surface on which they are moving .This can be solved using both mechanical novelty, algorithmic solutions for the kinematics and dynamics of the robot and by using sensors for measuring leg contact, leg angle, current, obstacles sensors etc. The impact force between the leg and the surface while landing also governs the stability of the robot and thus its compliance. Improved compliance to the terrain reduces the mechanical wear of the robots parts as well. Rhex[9] the six legged robot uses semi circular passive legs to improve compliance with the ground. These passive legs also helped this robot surpass other robots in its class by climbing human level stairs [1]. Its simplicity is in its design and the minimal actuators it uses. It used a modified tripod gait (3 legs in contact with the ground at a time) for locomotion. Rhex also used four bar mechanism for legs but was later replaced by semi-circular legs which provided more points of contact. We also designed a four bar mechanism (fig 5.0) but did not employ it in further tests because of its reduced angular freedom. We later used the design of the leg shown in fig 5.0.The robot RHex's[1] gait was improved using video analysis of the previous test runs, but in our case since the robot's API and control was tied to the virtual model we were able to calibrate the leg position with respect to the ground (flat surface). As a result the tripod gait was successfully accomplished on the robot during the very first trial thereby verifying the efficacy of our simulator.

The paper [8,9] describes an innovative hybrid wheel and leg mechanism which helps the robot in moving over terrain with mild to medium slope, hard packed sand, loose sand etc. Also the paper[2] gives details on some of the minute but important aspects of the robot's construction which include the choice of material used for the legs, the linkages, the heat dissipation etc which improved its over all efficiency.

The compliance in advanced 4 legged robots like the little dog [3] is implemented by complex gait planning and control strategies. This also involved the use of an external high speed camera tracking system (VICON)[3] with infrared markers mounted on the robot to gets its pose and position. Double dynamic gait was implemented on the little dog at MIT [4].We extended the double dynamic gait's kinematics to our robot "ModPod" and we observed that it matched with the tripod gait of the cockroach statically. In the double dynamic gait two legs of the little dog are in contact and 2 are in air. In our extended gait during simulation we observed that the 3 legs of the robot were in air and 3 in contact with the ground. Such ideal contact was achieved in some cases during testing on the real robot as well.

In Omnithread [6]: a modular snake robot, pneumatic joints were used. By controlling the air pressure in the joint the stiffness was controlled .Use of pneumatic actuators however increases the risk of mechanical failure due to puncture. The robot Kathrina's [11] IVS (Interactive Virtual simulator) simulator helped in optimizing its design and reduced the time for development hugely. In our case instead of testing each trail of the gait on the real robot several trials were conducted in the simulator for the ModPod. Thus it helped in debugging the gait and improving it quickly. Since the real robot exactly resembles our custom virtual model in the simulator the gaits generated were a success either immediately or with in a few trials. The advantages of such a custom simulator have also been discussed in paper [11] for the 6 legged robot Kathrina.

2.2 Mechanical Design

The built of the robot is modular in nature and thus with the addition of similar modules the robot can be changed from a six legged robot to a caterpillar. The robotic spine is composed of 2 DOF joints which connect the leg modules. Several leg designs were tried as given below. Each leg of the robot is like a 2 degree of freedom robotic arm. Also the modular legs are connected with orthogonally linked servos to imitate the universal joint found in a snake's vertebrae. This gave the robot an ability to change its gait direction in the horizontal plane and also overcome vertical obstacles. To improve the compliance the current to the vertical servos was reduced so that the stiffness is controlled but still actuated. Even the natural snakes improve their compliance when moving over small rocks and uneven terrain by controlling their backbone stiffness. Also each leg has a silicon tip at the end to improve its contact and reduce slippage. Silicone gel has been used in some Snake robots (like the modular Snake robots at CMU [10]) especially while traversing a vertical passage to improve traction. In wall climbing robots like Gecko robot [15] Stanford's sticky bot[16] and Mini Whegs adhesive silicon was used to improve the traction. We fabricated the structure using light weight aluminum. The robot has 16 servos for the six legged configuration.

Fig 6.0 Leg design and the hexapod version

2.3 Software Architecture

The robots simulation model was integrated with the real robot as follows:

- An API plugin in ruby was developed for Newton dynamics physics engine.
- The API was accessed using a C code through a DLL talking to the ruby plugin.

- The gaits were defined as path and phase lagged semi-elliptic paths in Opencv. The 2 degree of freedom leg was made to follow the path using Inverse kinematics.
- The respective angles were modified to servo angle values and were sent over USB-RS232 port and an Xbee RF modem. At the robot’s end the microcontroller receives it with an Xbee RF modem and generates the respective PWM signals for the servos.

We observed that the advantage of integrating the robot’s virtual model with the real model is that the robot’s reaction to regular geometric terrain and gait control could be predicted, observed, corrected and thus controlled real time from the virtual model running in the physics engine.

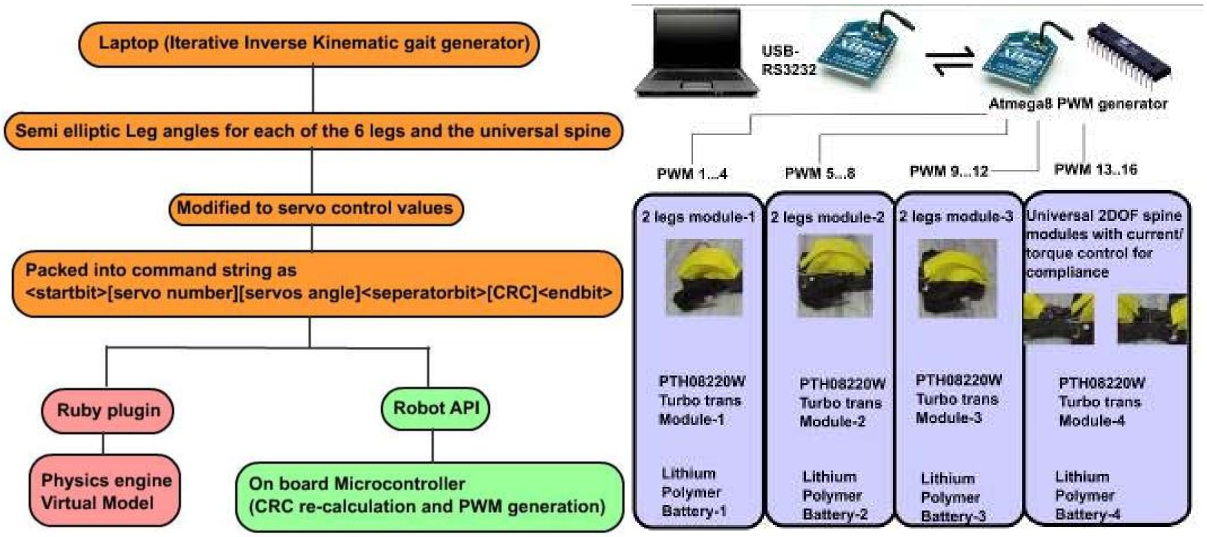


Fig 6.1 Servo command packet and control schema with the embedded architecture schema

2.4 Embedded Architecture.

The robot has an Atmega8 microcontroller which receives servo command packets from the PC using an Xbee RF modem. The controller generates 16 PWMs simultaneously. Also CRC based error control is implemented to overcome communication error under noisy conditions. The current consumption of each servo is around 4 Amps. Here we used plug in power modules “PTH08T220W Turbo trans module” from Texas instruments and on board Lithium polymer batteries to provide stabilized high current to the servos. The current / voltage of the Turbo trans power module of the 2DOF universal spinal joints can be adjusted to either increase or decrease the maximum possible torque and thus its compliance to the surface.

2.5 Locomotion

We were able to generate the following gaits.
a)Galloping
b)Tripod gait based on the extension of double dynamic walk as observed on the little dog robot.

One important thing we observed is that the only difference between the galloping gait and Tripod gait is the initial path and phase difference. Also the motivation to develop this robot was to use such a platform for further research towards using such robots for search and rescue. The search and rescue environments will have challenging terrain where robots with high dexterity will be required. The idea is to use such robots and reduce the risk to humans in the loop. This paper[5] talks about the robot Asterisk which uses limb mechanism with legs having 4 d.o.fs. It uses foot contact sensing and an accelerometer to measure inclination and adjust the body appropriately in compliance with the steps.

Also legged robots can overcome obstacles which are at a height greater than the hip height of the robot. This was verified in Asterisk. We have implemented an open loop gait controller. The paper described a 2.4 g autonomous robot called Roach. Roach uses SCM (Smart composite machining) to produce flexible micro joints. The compliance in this robot was achieved by using a combination of Shape memory alloys and return springs designed with SCM process. This provides the compliance similar to the muscles and tendons in animals. This idea is very close to how compliance and stiffness is controlled in the backbone of legged robots by using a combination of muscle, bones and tendons. Our robot Modpod implements skeletal level compliance. Roach achieves alternating tripod gait with two linear actuators and is thus in this case more optimal than RHex.

Compliance in wall climbing robots like Gecko and Standford’s sticky bot is achieved by using silicon rubber and nano scale fibers [15]. The use of materials for foot contact is also an important consideration for reducing slippage and thus compliance. Hence we used cylindrical silicon tips (fig 1.3) for improved contact. Also the power to weight ratio is an important consideration for modular robots. Since our robot was able to lift the modules in air about the spinal linkage we confirm that we have a considerably good power to weight ratio (p46 [12]).If the design is complex the robot becomes unnecessarily heavy and this decreases its power to weight ratio.

Cockroach motion has been studied and implemented in robots like Whegs [8]. The tripod gait of the cockroach gives the wheel legged robot an ability to overcome obstacles about 1.5 times its height and locomote over uneven terrain. Here in our robot the two legs on one side at the ends and the mid leg on the opposite side are always in phase and thus have a zero path difference. These 3 legs are about 180 degrees out of phase with their corresponding pair of legs on the opposite side. Some robots use passive compliant legs with springs. Compliance was implemented in legged robots like one legged hopper, 3D bipedal and Kangaroo using spring loaded legs [13]. In all these legs the impact is absorbed by the spring which also helps prevent transferring the shocks to the mechanically sensitive parts of the robot and thus protect it against wear and tear. The level of compliance cannot be controlled using spring loaded leg designs as suggested here, but by controlling the maximum possible torque which is governed by the magnetizing current flowing through the coil of the motor one can control the level of compliance and this was implemented in our robot.

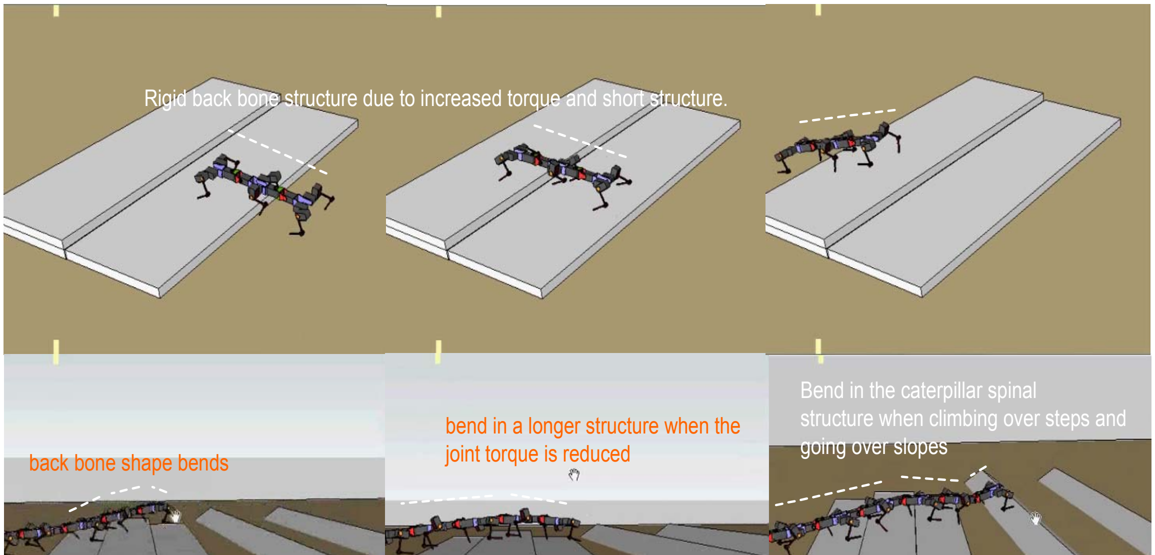
The leg design of KOLT robot [14] uses a single motor coupled with the hip and knee joint using pulley and cables. Also there are two springs connecting the knee-hip and ankle-knee which provide compliance. The leg used in our ModPod here has a single servo in the hip and one servo for the knee with both axes parallel to each other. Also for steering it was initially thought to have single steering servo in each of the leg, but this would increase the number of actuators as well as the weight and power consumption. The use of 2 DOF universal Spinal joint helped in steering the robot left and right in the horizontal direction as well as up and down in the vertical direction.

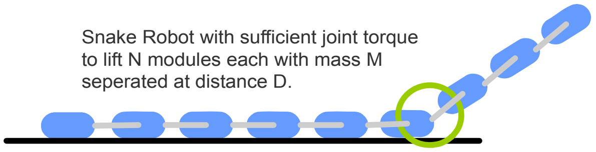
2.6 Bio-inspiration and gait algorithm

The universal robotic spinal joint, the modular legs used in this robot have been inspired from the backbone of reptiles like Snake, caterpillar and animals like leopard etc. The Snake’s vertebrae is a ball and socket joint [12]. There are about 100-200 such joints depending on the type and length of the Snake. When the Snake is moving over uneven terrain the excursions in the vertebra are adjusted such that the snake's body hugs the surface. Even the caterpillar shows such compliance. The caterpillar has several identical leg like projections which help for its forward motion. Also the Leopard's spine helps it in giving the flexibility and compliance when it is running. Using these ideas we tried to mimic such behavior in our robot with 2 DOF legs and 2 DOF orthogonal joints connecting the legged units.

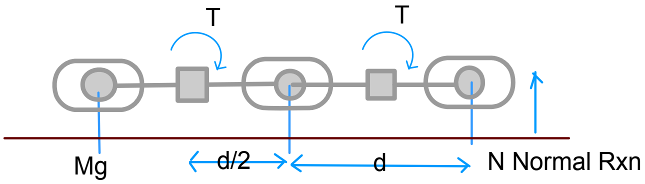
The spine of the animals like leopard and reptiles like snake is controlled by the muscles actuating them and even their operating stiffness. It was discussed earlier as to how the joint torque affects the portion of the snake robot's body being lifted in air. Consider a snake like hyper redundant manipulator that is inverted and is placed on the ground but now the joint torque is not sufficient enough to support the rest of the body in air but also does not have sufficient enough torque to oppose the torque due to the counter acting normal reaction. In such a case the joint collapses and aligns itself to the surface. Thus by varying the amount of current/voltage one can change the resulting torque joint and thus the compliance of a snake like structure to the terrain.

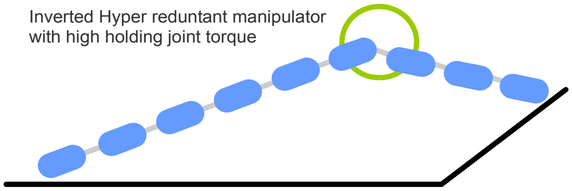
We also found that the mechanical wear and tear of the servos was reduced because the electronic compliance reduced the impact of shock when the legs hit the ground. Shock absorbing foam was used to cover the robot. Also the robot uses a fail safe circuitry to prevent the servos from overheating or get damaged due to high currents. The top of the body was partially covered with vents for air flow to dissipate the heat. Also the modular nature of electronics ensured that even if one of the power modules gave out, some amount of mechanical motion existed with the rest of the legs while the failed legs just slipped. Modular power electronics here prevented the robot from having a single point of failure which is unique to this modular hexapod.



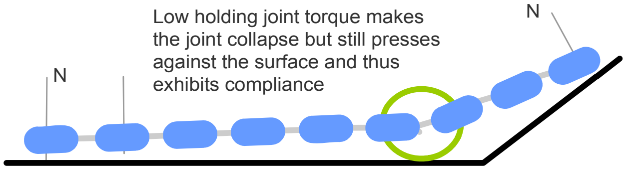


Snake Robot with sufficient joint torque to lift N modules each with mass M seperated at distance D.

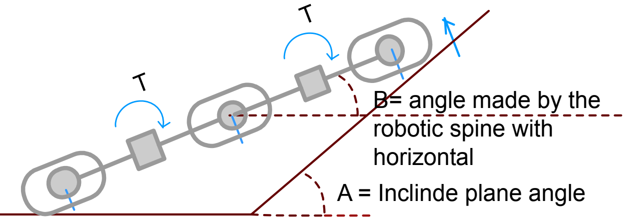


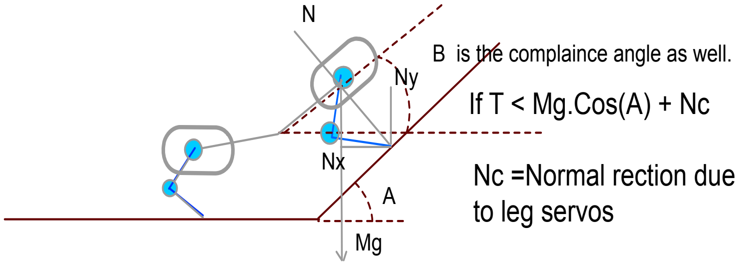


Inverted Hyper reduntant manipulator with high holding joint torque



Low holding joint torque makes the joint collapse but still presses against the surface and thus exhibits compliance



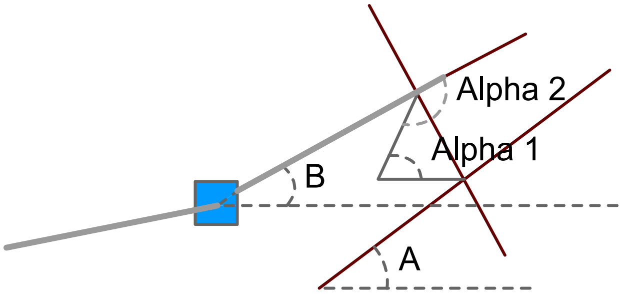


B is the complaince angle as well.

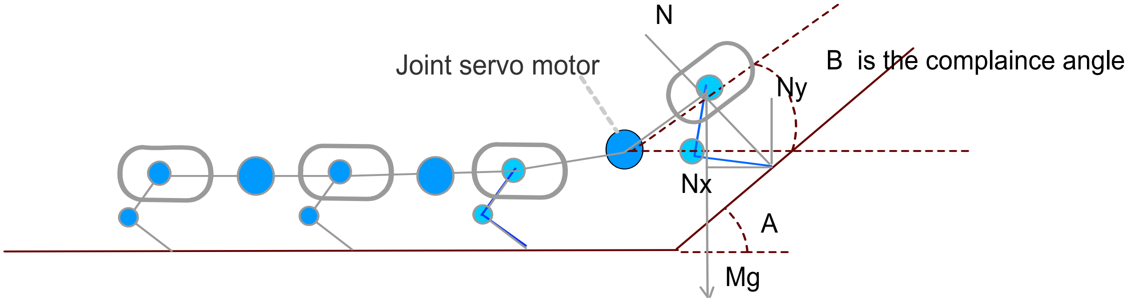
If T < Mg.Cos(A) + Nc

Nc =Normal rection due to leg servos

The extra component of normal reaction due to the leg pressing against the inclined plane in addition to the normal reaction by the weight of the module overcome the torque of the servo in the robotic spine. When this happens the robotic spine bends and compliance is achieved.

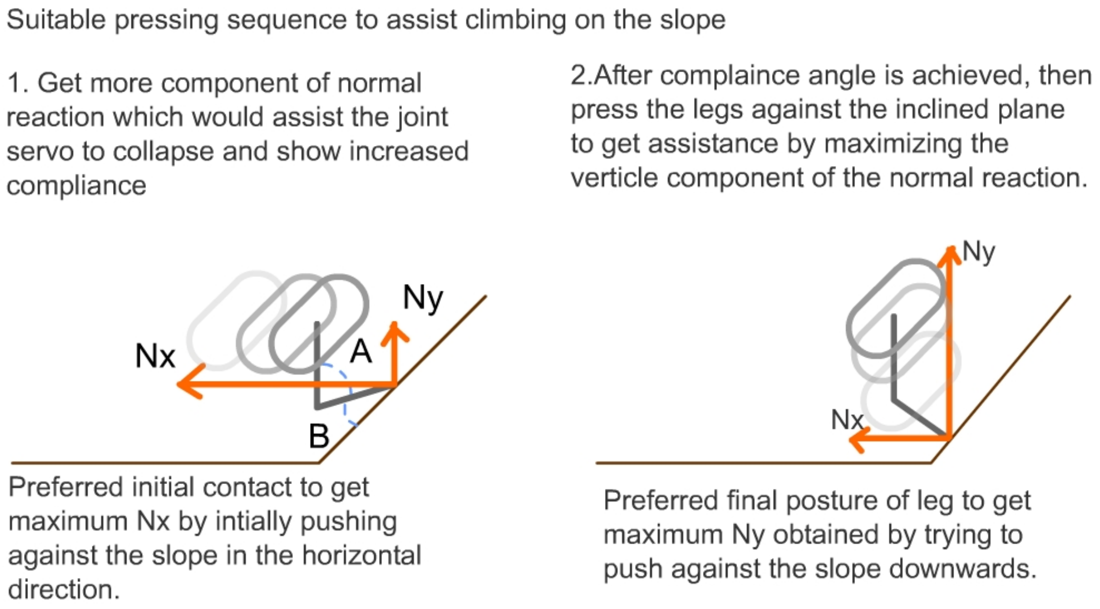


Assuming that the contact between the tip of the leg and the inclined surface is spherical thus making the normal reaction perpendicular to the surface. The angles alpha1 and alpha2 are the angles in the leg (assuming that it is a 2DOF robotic manipulator) determine how much the components of the vertical and horizontal normal reaction forces are.



Say if the joint torque in the servo motor is set to a reduced torque T. The legs of the module press against the slope to increase the X-component of the backward normal reaction.This Nx is further opposed by the friction acting on the tips of the legs of the rest of the modules on the flat surface but not on the slope. This way the net

an



Suitable pressing sequence to assist climbing on the slope

1. Get more component of normal reaction which would assist the joint servo to collapse and show increased compliance

2.After complaince angle is achieved, then press the legs against the inclined plane to get assistance by maximizing the verticle component of the normal reaction.

Preferred initial contact to get maximum Nx by intially pushing against the slope in the horizontal direction.

Preferred final posture of leg to get maximum Ny obtained by trying to push against the slope downwards.

Algorithm for 3 leg simultaneous gait (modified tripod):

Each of the robot's legs can be viewed as a 2 degree of freedom arm. The position of the foot in each of the robot's legs is made to follow a semi-elliptic path. The path and phase difference between each of the legs determines the posture of the robot and their subsequent positions in time determine the overall gait generated. This particular gait implemented on the robot ensures that 3 legs of the robot are in contact at any point of time and the other 3 legs are in air. This was particularly inspired from the Kinematics of the Double dynamic gait of the little dog robot developed at IHMC and MIT.

Semi- Elliptic path defined as :

$$180 \le \theta \le 360$$
$$X = H_x Cos(\theta) + X_c$$
$$Y = H_y Cos(\theta) + Y_c$$
$$\theta_2 = \theta_1 + d\theta$$

Where Hx and Hy determine the maximum Horizontal and vertical stride of the leg for a given ellipse with center Xc, Yc. The next point in the semi elliptical curve is determined by $d\theta$ *. it* $d\theta$ *is small there will be more points defined on the curve and the curve will be smooth but the velocity of the leg about the curve will be small and vice versa.*

$$0 \le \theta \le 180$$
$$Y = H_y Cos(\theta) + Y_c$$

X = X + dX determines the next point during the horizontal stride. If dX is large the velocity of the leg along the path will be more and vice versa. Angles below are mentioned in fig.6.2

Pesudo code:

```
$For I = 0 to 10$
$Calculate$
$b = (pt2.x * pt2.x) + (pt2.y * pt2.y);$
$si1 = a\tan 2(pt2.y, pt2.x)$
$si2 = a\cos(legu * legu + b * legl * legl)/(2 * legu * sqrt(b))$
$alpha1 = q1 + q2$
$alpha2 = a\cos((legu * legu + legl * legl - b)/(2 * legu * legl));$
```

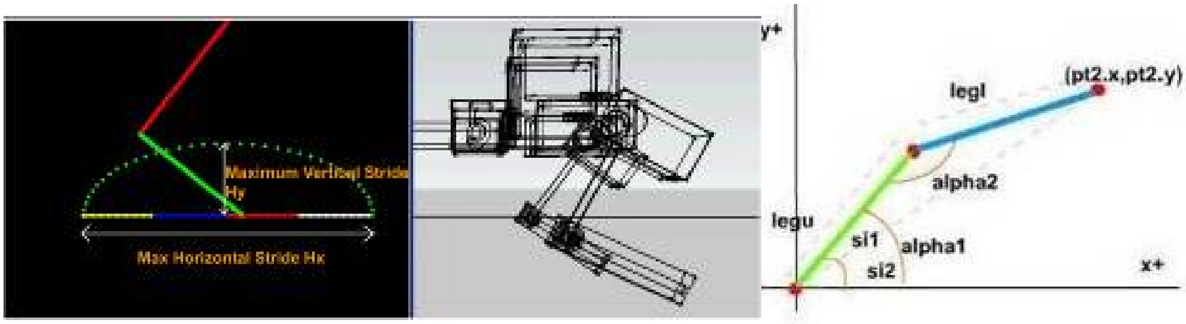


Fig 6.2 Semi elliptic gait parameters with inverse kinematic diagram for leg angles

2.7 Simulation and Testing

We simulated the caterpillar robot and the hexapod robot over small vertical obstacles and slopes as shown in Fig 5.(3).We tested the same in real time on the robot and our robot's spine successfully adjusted to the changing slope while climbing up and down.

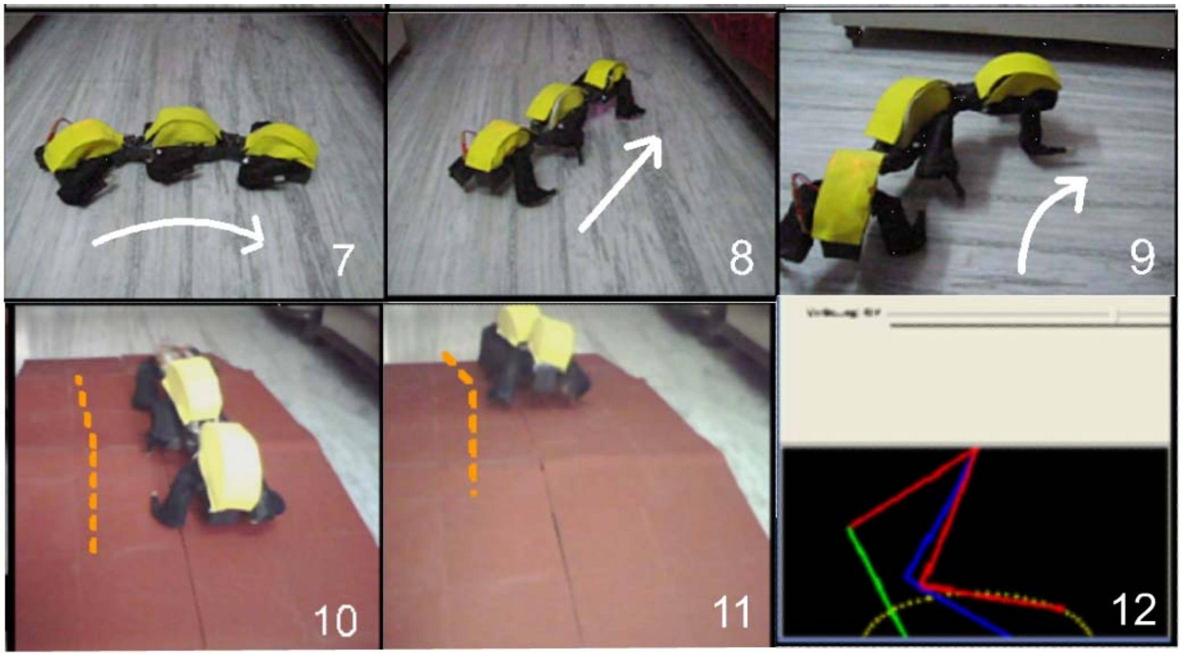


Fig 6.3 Mod pod gaits, maneuvering and its caterpillar simulation with GUI control

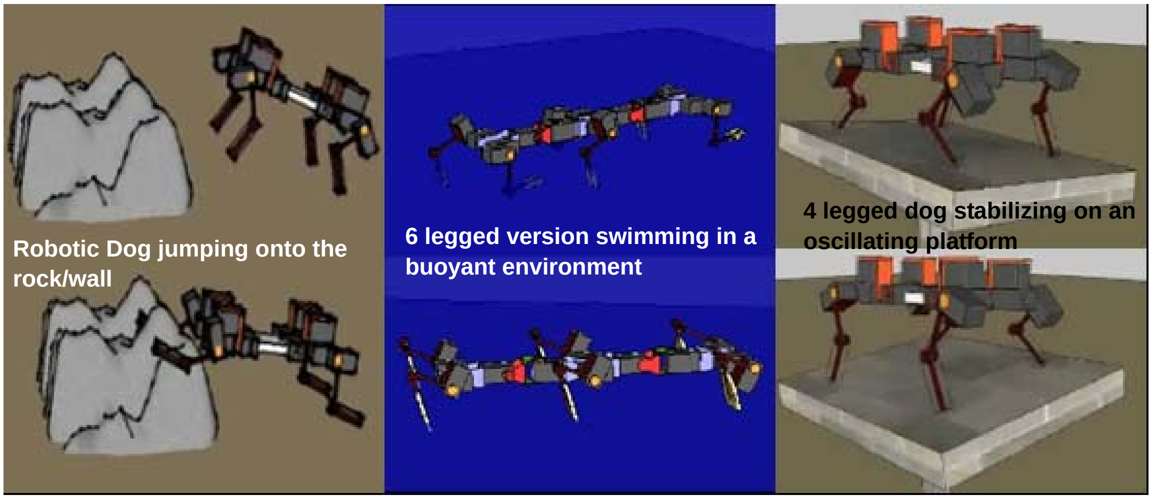
shown in Fig 6.3(10-11).We developed the robot's API in such a way that we could change the robot's speed ,leg's horizontal and vertical stretch from a single point using the GUI Fig 5.3.12. We tested the robot's maneuvering capability by changing the excursion in its backbone in simulation. We were able to successfully do the same in both the horizontal direction left-right and in vertical direction as shown in fig 5.3.4-5.3.9. Controlling the shape of the backbone gave us precise control over directing the robot's motion. Also we observed that whenever the phase difference or path difference between 3 legs in phase on one side changed with respect to the other 3 legs the robot slipped. We were able to get zero slippage by maintaining an initial phase difference of 180 deg. The table below shows the parameters of our robot Modpod.

TABLE 2.0 ROBOT CHARACTERISTICS

S.no	Robot Parameter	Value
1.	Length of the robot	95 cm
2.	Breadth	11.5 cm
3.	Height	24cm (2 legs)
4.	Weight of the robot	6.4 kg
5.	Operation time	25-30 minutes
6.	Max torque joint	34 kg-cm
7.	Max horizontal stride	28 cm
8.	Max vertical reach	34 cm
9.	Max leg swing joint 1 and joint 2	+/-70 (140) deg

The virtual model of the 4 legged robot in the physics engine was made to stabilize on an oscillating platform with varying slope with positive gains in the inverse kinematics. The slope of the platform was given interactively by the user using an accelerometer over a USB-RS232 connection. Later it was found during physical testing that when the 4 legged robot was stabilized on the platform with variable slope whose inclination was measured using an accelerometer the robot stabilized with negative gains. The friction from the slope acting on the tips of the legs assisted further when the front portion of the robot moved closer to the surface by bringing its legs together.

Simulations were also done to make the 4 legged robot jump onto a rock. Here the major axis of the semi elliptic gait was tilted so as to get maximum possible lift from the normal reaction in the vertical direction due to the legs pushing against the ground. Also a 6 legged hexapod capable of swimming was designed where its legs were modeled as flippers. It was modeled in a physics engine environment with buoyancy. The right pattern of stroke which improved the speed in the forward direction was devised.



Robotic Dog jumping onto the rock/wall

6 legged version swimming in a buoyant environment

4 legged dog stabilizing on an oscillating platform

2.8 Future work on Modpod.

Inspired from the biologically inspired modular robots like Snakes robots and their scalability we built this six legged version of modular hexapod. We hope to scale it to a full length caterpillar version and test its maneuverability and its ability to move over several kinds of terrain. We reported the successful design, construction, implementation of “Mod Pod” and its electronic compliance to medium sloped surfaces in this chapter. The novelties of this hexapod robot include a successful maneuverability and compliance to surface through spinal actuation which has been inspired from biological organisms like snake, caterpillar and 4 legged animals like leopard. Also the custom simulator built for this robot allowed for rapid designing, prototyping and testing of the “ModPod” robot. Specifically many of the gaits were quickly transferred from simulation to real time testing without too many modifications and changes to the robot as a result of the universal simulator.

3. Snake P3: A Semi Autonomous Snake Robot.

The biological snakes are known to traverse several terrains like grass covered ground, tree branches, steps, sand covered ground, over pebbles and can even swim in water. Bio-mimicking such a robot is useful in the application of a search and rescue scenario. For implementing such gaits on the snake robot platform several gaits of snake were simulated in the universal simulator. Dr.Howie choset and his group simulated the behavior of snake robots by introducing two mutually perpendicular sinusoidal gaits in the snake's skeleton. They presented two forms of gaits, one set of gaits are inspired from the biological snake from their natural way of motion and the other are a combination of a couple of them called the non-biologically inspired gaits. Another research work by Juan Gonzalez also models the snake's gait using sinusoidal waves. But it was found right from the initial prototype and further simulations that a snake's gait can be modeled as a set of cyclically varying amplitudes which need not be defined by a sinusoidal equation. One can just mention the extremities of a serpenoid shape and oscillate the servos periodically one by one to get the same effect of serpenoid motion. Hirose was the first to coin the serpenoid equation for snake robots. All the gaits exhibited by the snakes like side-winding, vertical undulation, linear progression are difficult to model in a physics engine with friction just as the real world snake's skin interacts with the contact surface and sand. Here in this work the gaits horizontal undulation, vertical undulation, side-winding, concertina were modeled are discrete sequences of amplitude.

Controlling such a robot with several gait parameters is a difficult task. An intuitive data glove interface was design for the same to charm the snake robot.

3.1 Intro to snake robot

Here in this chapter we also present how the snake robot prototype-3 can autonomously change its gait depending on the terrain. Also we present the design and construction details for the same. Here a custom simulator for the robot and an API for the same was developed which reduced the design and development time. For controlling the Snake robot manually a data glove using accelerometers was developed. The Snake robot can also be operated in autonomous mode where an over head camera is used for sensing the terrain and the snake autonomously travels from one part of the terrain to another by switching its gait.

Snakes robots belong to a class of modular robots which have a linked structure with hyper- redundancy in their degrees of freedom. This allows the robot to be arranged in several configurations and be operated in several modes as seen in modular robots like molecubes. [16] . Especially compared to the wheeled and mobile robots Snakes robots have been proved [1] to overcome challenging terrains like stairs, pipes, water etc. This capability also allows one to use Snake robots for the purpose of search and rescue and mine detection. Modular robots like supermechano have varied capabilities for space exploration and can climb challenging terrain .On the more miniature side research is also going on the use of Snake robots in minimally invasive surgery [18]. Wheeled robots have been made autonomous but reaching this level of autonomy in Snake robots is still a research challenge today. The primary being the problem of a Snake robot knowing its position with respect to its surroundings, building a map and then locomote on a determined path. A lot of research has been done by several labs like CMU bio-robotics lab, USC's robotics lab on Superbot , EPFL working on the Amphibot etc.

Howie choset and his group devised several biologically and non-biological inspired gaits. They modeled their gaits as time varying differential curves. The non-biologically inspired gaits like strafing and helical pole climbing were designed to do specific tasks quickly and reliably. The biological gaits like side winding and linear progression were also achieved. For tasks like gap crossing and stair climbing where a single differential gait would not solve the problem, a piece wise differential gaits was used. Their work involved the development and execution of terrain specific gaits. Juan Gonzalez [3] in his work on Snake robots modeled their locomotion as sinusoidal gaits similar to the way in which animals' backbone or spinal cord moves. The robots can be configured in 1D, 2D and 3D topology with different pitch-yaw configurations. Also his work says that by introducing sinusoidal waves of specific amplitude, phase difference and frequency one can generate gaits ranging from side-winding to rotating and rolling.

The work by Auke Ijanspreet on swimming Lamprey generates gaits using a CPG [15] Here a growing neural network is used to control the muscles of a fish. The motion is successful when all the muscles move in a co-coordinated rhythmic fashion. Higher swimming speeds were achieved using this approach. However the Snake's gait was invented as Serpenoid curve by Hirose [6]. Hirose used electro-muscular meters to measure the forces along the Snake's body.

After the gaits are generated the problem was to make the Snake move autonomously. Humans and animals do the locomotion in an autonomous and effort less manner. The level of autonomy achieved in wheeled robots like Kurt3D[10] in solving the problem of SLAM has not been achieved till today on Snake robots. This is primarily because of the lack of position estimation of the Snake robot which is done using encoders on wheeled robots and due to the lack of miniature sensors having capability like the Laser range finders which are used in today's autonomous wheeled robots. Autonomy in Snake robots has been implemented in the form of Obstacle avoidance by the use of IR and ultrasonic distance sensors. Jogurmund[11] is a semi autonomous Snake robot which can do obstacle detection. Range sensors have also been used in the work by Gavin Miller on Snake S7 [5]. Autonomy has also been observed within the modules of modular robots like Superbot where each module can detect the distance and angle at which the other modules are present and then dock with each other. In some cases they use a 3D accelerometer to autonomously sense the change in slope and take a corrective action. To our knowledge there is no Snake robot which can sense the change in the nature of the terrain and switch to the optimal gait. It has been know that the desert Snakes use sidewinding [13] locomotion to move over the sand and slippery surfaces. Where as most ground snakes use lateral undulation. Some works on lateral undulation use obstacle aided locomotion [13]. Here we tracked the Snake using an external camera and were also able to distinguish between the terrain. When the Snake reached the boundary separating the terrain our algorithm was able to detect that and snake automatically switched its gait.

3.2 Electro-mechanical Architecture

The robot uses a modular chain structure where the adjacent modules are connected with each other at 90 degrees. This helps in generating a sine wave in the horizontal plane as well as in the vertical plane. Shock-absorbing foam covered with rubber sheet was used as the skin. This helps in absorbing shock on impact and helps reduce the wear and tear of the metal gears inside the servo. The robot uses 12 Hitec 7950TH digital servos. The robot also has an onboard wireless controller which was developed around an Atmega8 and Xbee RF. The Atmega8 receives servo command packets remotely from the controlling Laptop/PC and generates the respective PWM outputs. The hardware PWM mode of atmega8 limited the number of PWMs generated and thus software based PWM was generated. We were successfully able to generate about 18 PWMs capable of driving 18 individual hobby RC servos with the controller clocked at 16 Mhz.. Though the robot here can be controlled wireless, it uses a tethered power supply. For indoor experiments in the lab SMPS power supply at 20 Amp and 5 V was used. At the laptop end an FT232R USB to TTL converter chip was used which sends servo command packets on the forward channel via the Xbee RF at the laptop's end to the onboard Xbee RF module on the Snake. Also on the reverse channel it continuously receives the accelerometer values forwarded by the Atmega8 which reads the 2 accelerometers in the data glove.

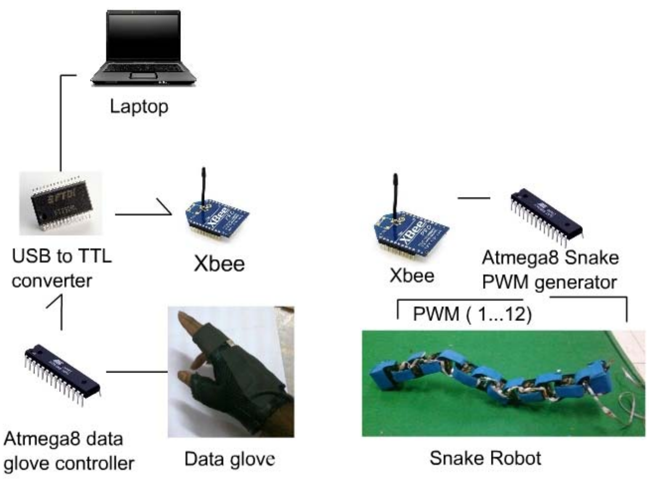


Fig 7.0 Glove control embedded schematic and Snake P3 -3D in raised hood configuration

3.3 Simulation of gaits.

In first version of the Snake that was developed the gait was implemented as a differential curve with its maximum amplitudes stored in a look up table. The limited computational power of atmega 8 was not good enough to generate all the PWMs and at the same time calculate the gait parameters from a sine or cosine differential equation. In this prototype Snake P3 the gait is calculated remotely on the laptop and the respective angles are only sent to the Snake's controller. Several gaits were simulated and successfully achieved gaits were side winding, lateral undulation, caterpillar gait, rolling and concertina. For simulating the gaits Opendynamics engine, MSC Visual NASTRAN , NVIDIA Physx and Newton Dynamics engine were used. Opendynamics engine (ODE) though is a good industrial standard open source simulator did not have the capability for developing CAD designs of the robot. NASTRAN has good CAD designing support but it is computationally heavy to run on a moderate laptop with 1 GB RAM ,also one has to use MATLAB with NASTRAN to write and solve kinematic and dynamic equations. So to solve this, an API was written for Newton physics engine (running as Sketchy physics) in Google sketchup. Google sketchup is a good CAD design software and Sketchy physics provides the ability to run physics simulations in the design environment itself. But the minimal ruby which is run by google sketchup prevents the programmer to write elaborate and complex kinematics equations. So a dll was written and an API was developed which dumps the physics engine parameters like motor velocities, accelerations, servo positions into a memory heap. With the address of the memory heap one can read and write the physics parameters using any programming language. Now we have an environment which provides integrated CAD design and physics simulation. Also it is not computationally expensive and is built on open source software. A virtual Snake model was developed in this. The real robot and the virtual model were closely modeled together. Also a common API was developed for the virtual model and the real robot. This unified approach ensured that the gaits generated in the physics engine could easily be ported to the real robot with zero or minimal trials. This also reduced the design and development time. In many projects in the past the simulation of the virtual robot and real robot were considered as two different tasks. A lot of time and effort goes into transferring the simulations to the real robot. Also the trials for generating gaits if tested on the real robot would lead to wear and tear increasing project costs for replacement hardware. This was prevented with the unified simulation and controller developed here.

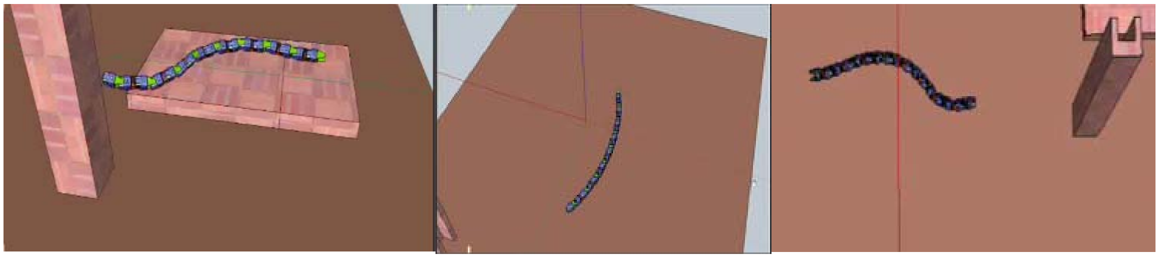


Fig 7.1 Snake P3 simulation climbing over an obstacle, rolling and sidewinding

The servos of 35 kg-cm were chosen after simulating various joint torques with various portions of the Snake's body being lifted from the ground. It was concluded that a joint torque of 35 kg cm with a module weight of 200gm could successfully lift 6 modules. The gaits were generated as a combination of vertical and horizontal sine waves with controllable initial phase, maximum and minimum amplitudes, and phase difference. Several test runs were conducted with the gaits initially being generated as cyclic pattern generators where the points of the motion were discrete with large intervals; these points could later be stored in the lookup table of a computationally minimal microcontroller to generate the gait. But later sinusoidal / differential gaits were used which generated more smoothers gaits. A vertical undulation only provided the caterpillar motion where the direction of the gait can be controlled by controlling the mutually perpendicular set of servos in the Snake robot's backbone. A gait with large horizontal amplitude but feeble vertical amplitude helped in generating the side winding gait. When the two servos are rotated with a phase difference of 90 degrees it resulted in a rolling gait. Also the backbone curve can be curled in the horizontal plane with a differential wave propagating in the vertical plane to turn the robot 360 degrees in place. This is especially useful when the Snake has to maneuver and turn around in limited spaces.

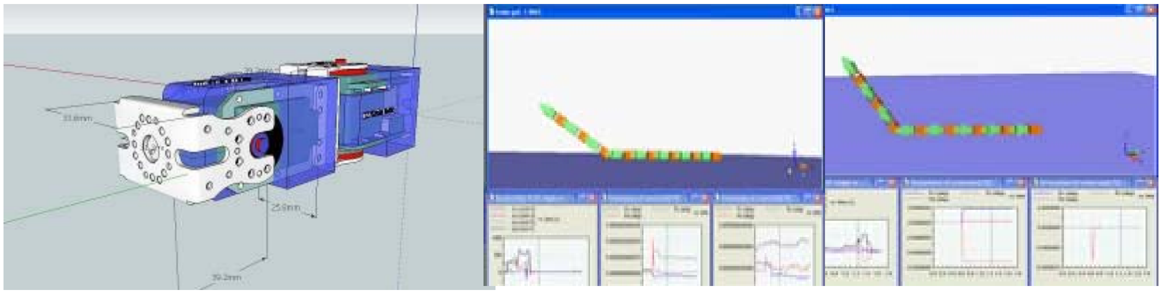


Fig 7.2 Servo module design and Final servo simulation with 35 kg-cm for Snake p3

3.4 Manual Control using a data glove.

Devising new ways to move the mouse pointer, moving virtual objects on the computer screen and integrating it with video game control took the research towards narrowing the line between the physical world and the virtual world. Using an accelerometer as in input device to control a four legged virtual creature's stance, playing with it interactively and using the accelerometer interface to control the stability of the real robot paved a way for using novel input interfaces and devising new input devices for robots. The research in HCI using Microsoft Kinect and the Sixth sense [2] device also aim at fusing the virtual and digital worlds. What if we think in the same way for robots? Not only virtual objects but their associated real world avatars can also be interacted with in a similar fashion. The idea of using Universal simulator and prototyping approach go towards bridging the gap between the virtual robots and their real prototypes. This universal design approach when fused with the idea of interacting with virtual objects on the screen further takes us towards bridging the gap in human robot interaction in the virtual and real worlds. This inspired us towards designing a custom data glove for charming this robotic snake.

We used two accelerometers (ADLX330 and MMA7660FC) one is less sensitive than the other. The MMA7660FC is a less sensitive I2C accelerometer which is generally used in cell phones to detect taping or shaking. The MMA7660FC was used to identify the rotation of the fingers (middle and indexed fingers). A more sensitive analog accelerometer was used to sense the rotation of the hand. Using the values from the accelerometers 2 basic gestures were identified. The natural snake position gesture and mode change gesture. Using these gestures the Snake can be operated in the following modes 1)Hood raised with head roll 2) Hood raised with head retracted 3) Normal crawling mode 4) Gait change mode where the user can cycle through any number of available gaits (here the user can cycle through crawling, side winding and turning 360 in place gaits. The raising of the Snake's hood was detected my measuring the acceleration about X axis and the acceleration value from the MMA7660 FC was used for identifying head roll and head retract. Also the motion of the data glove along a mutually perpendicular axis (Y) can be used for guiding the Snake.

Robot control can be done remotely using joysticks, handheld remotes, the computer keyboard using GUIs etc. Controlled a wheel robot with a joystick manually is easy but a Snake robot with several gaits of locomotion and several adjustable gait parameters is cumbersome. The data glove we developed helps to intuitively control the Snake robot. To use the robot in a lift and snoop fashion the user can raise his/her arm and one can also change the head orientation by using the motion of fingers cupped to resemble a snake. This natural feel of using and interacting with the computer and other devices can also be seen in gaming consoles like the Microsoft's sidewinder wheel where a car's steering wheel like console helps a game player playing video games to steer cars etc. Even in the normal mode one can guide the Snake's motion by tilting the hand towards the left or right. When it comes to changing gait one needs to bend the hand a little and squeeze the fingers towards the palm as if one is applying the brakes on a motorbike or pressing the clutch to change gears. Also voice assistive output is provided with each mode which helps the operator to know the current mode and the respective gait the Snake robot changes to.

Fig 7.3 Data glove prototype and schematic

3.5 Autonomous Gait transition mode

The work done by Howie choset from CMU shows how various gaits can be used to traverse seemingly difficult terrain for wheeled and legged robots. Some gaits called the piece wise differential gaits are to be used to traverse step like structures and rails. There can be a combination of naturally inspired gaits and differential gaits. Here our Snake robot P3 when operated in an autonomous mode exhibits the side winding gait on the smoother and slippery office floor and the crawling gait on the grass like carpet. It is known that the biological snake uses the side winding gait on slippery surfaces and sand with rolling points of contact to achieve better locomotion in terms of speed. So for the slippery office floor side winding gait was used. The caterpillar which moves on the grass uses the vertical undulation. In the caterpillar gait all the modules move in a co-

coordinated fashion to generate traction using friction and thus create motion. Here a vertical undulation was generated by time sampling a sine wave with smaller amplitude. sine waves with larger amplitude are unstable and the snake's body flips. If the footprint of the Snake's body is increased by changing the shape of the curve using the horizontal plane servos the gait can be made more stable. Generally stability is not a huge concern in Snake robots as compared to legged robots because their center of gravity is usually low. Here when the Snake raises its hood the center of gravity also raises and stability decreases. To overcome this a Snake robot's tail can be curved to increase the stability.

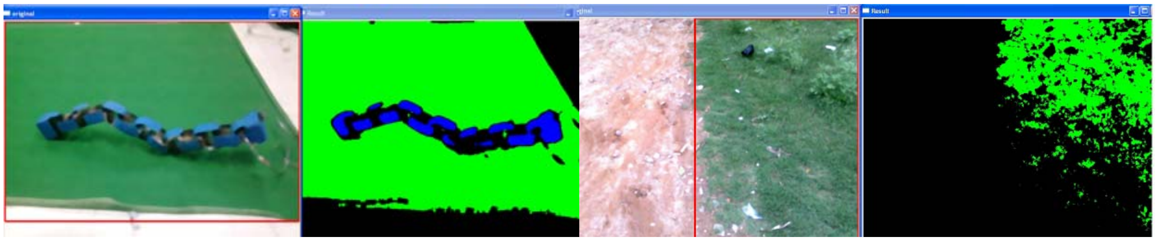


Fig 7.4 Snake P3 autonomous gait mode and terrain classification

An external camera is used to track the Snake's position. The grass region (carpet) is identified with a green color filter by identifying pixels which are greener than the rest. To eliminate noise because of poor illumination, camera quality or other green objects or patches on the floor a blob filter with suitable threshold is used. Prior to this a median filter is used to further reduce the noise in the image. The snake is also tracked using a blue filter which identifies the Snake's skin. In fact many biological Snake's are identified using the colors and patterns on their skin [20]. The gait transition is initiated when a portion of the snake's body reaches the boundary separating the floor and the grassy carpet. The Snake's gait is paused for a moment. This is actually done to overcome the perturbation during gait transition which could cause mechanical damage to the Snake's structure [19] Then the caterpillar gait is initiated where the head portion would gain more traction and pull the rest of the body onto the grassy carpet. Also several picture samples were taken and the terrain classification algorithm is applied. 10 out of 11 cases the boundary separating the ground to grass was correctly identified. In one picture the classification was not possible because of the poor distribution of grass patches on the ground.

TABLE 7.0 SNAKE ROBOT PHYSICAL CHARACTERISTICS

S.no	Robot Parameter	Value
1.	Length of the robot	120 cm
2.	Breadth	10 cm
3.	Height	10cm
4.	Weight of the robot	2.7 kg
5.	Operation time	25-30 minutes
6.	Max torque joint	34 kg-cm

3.7 Future work on snake robots.

Snake robots have always been interesting in the way they mimic their biological equivalents and their complex maneuvering capabilities allow them to be used in challenging terrain compared to legged and wheeled robots. To the best of our knowledge this is the first Snake robot which autonomously travels from one part of the terrain to another and makes an automatic gait transition. Also we feel the intuitive manual control of the Snake robot using the data glove is the first of its kind. We hope to device better terrain specific gaits and improve the level of autonomy in the Snake robot. Few outdoor tests were conducted and they remarkably turned out to be similar to the physics engine gait tests. Given below are caterpillar with maneuvering which was not the intended motion but the when such a maneuver was tried out in the physics engine the result was the same. Also tested was a side-winding gait with an in place maneuver.

4.0. RAMA-1 Highly Dexterous 33DOF Robotic Hand using magnetic spherical joints

Working on the modular design of snake robots and thinking towards creating new joints gave us the idea to create a new spherical rolling and sliding joint. This was used to create a concept snake like arm. Later the same design was adopted in making a face hugging robotic hand. Here in this chapter we present the design of a highly dexterous 33 d.o.f robotic hand. This high dexterity was possible because of the unique design of joints based on magnetic sliding and rolling spheres. The hand is tendon driven and is portable. We believe this is the robotic hand with the highest degree of freedom till date. Dexterity in robotic hands is an important factor that decides the complexity of the tasks they can do. It has been a design challenge to build an anthropomorphic robotic hand that can completely replicate the human hand in terms of its motion, torque and form factor. Here we have looked at the problem from a design perspective and achieved a hand with degrees of freedom more than the human hand in itself.

4.1 Robotic Hand Introduction:

Several scenarios that require highly dexterous robotic hands are discussed here. Today robotic hands with high dexterity find their applications in robotic assisted surgery [24]. The system Da-Vinci which is used for minimally invasive surgery has revolutionized heart surgeries. Heart surgery is a very precise operation and this requires the dexterity and skillfulness found in the human hand movements of experienced and professionally trained surgeons. With the use of the Da-Vinci system a surgeon’s finger motion sitting in a remote cabin is captured and transferred to the tele-manipulators.

Activities like space explorations which involve extravehicular activity can be vary tedious and tricky for the astronauts, especially when it involves the delivery of payloads, installing new hardware on the space station, servicing the existing hardware or fixing fluid connections on the space craft. The astronauts have to spend hours training in zero gravity like conditions for handling tools. The motion of their hands is limited by the pressurized gloves and suits. In such cases the robotic arms come to the rescue. The use of robotic arms also reduces the scope for human error. Especially the dexterous tasks of handling a screw driver, fixing a nut or bolt require a sophisticated robotic hand with high degree of freedom.

Coming to prosthetics the requirement of light weight, high power robotic hands is there. Robotic prosthetics come to the rescue when people lose their limbs in accidents. Several companies like touch bionics [11] and Otto bock have been developing prosthetic limbs. Some of the problems involved in developing the robotic arms include mimicking the human finger like motion.

Developing the perfect anthropomorphic robotic hand which has all the degrees of freedom of a human hand is compact and still being light enough to be used as a prosthetic is a challenge. Many of the robotic arms have fingers which have 3 d.o.f and 4 joints each. An extra joint is provided to the thumb for an additional degree of freedom while helps in making it move in an oblique opposable fashion compared to the rest of the fingers. This motion is very much required in improving grasping and performing other dexterous tasks. This paper solves the problem of universal joints and mimics motion similar to the ball and socket joint found in the human shoulders using uniquely fabricated magnetic spherical joints. The joints in the finger’s metacarpal and flexion regions slide and roll [27] (sometimes even out of the socket). To achieve this mechanically is difficult because the actuation element and the joint are to be separated while doing so and brought back in contact while still being in compliance with the object in touch and should continue to move.

4.2 Related work

The human fingers from their tip to the base of the hand have 4 bones connected by 3 joints. They are controlled by 3 intrinsic and 4 extrinsic muscles [27]. The 4 bones are metacarpal and 3 phalanxes (distal, middle and proximal). The metacarpal joint is a 2 d.o.f joint and the other 2 are single d.o.f joints each. The joint in the wrist is capable of moving forward and backward as well. The shoulder joint in the human body has a ball and socket joint. The elbow joint is a hinge joint [28,29,30].

Tamaku and Gomez[1] in their worked showed a robotic hand that has 18 DOF, is actuated by 13 servo motors, has a strain gauge and PVDF at its finger tip for artificial skin. The TUAT/Karlsruhe[2] hand which has 20 d.o.f uses spherical and sandwiched ultrasonic motors. The joints in its hand are driven by a single ultrasonic motor which reduces design complexity and weight. A simple design also allows for easy control. Construction of anthropomorphic robotic hands is always a challenge. The researchers of the ACT [9,25] hand developed it with an intension to preserve the human like motion by bio-mimicking the muscles in the finger. The extensor [3] in the finger is a complex web of tendons. The ACT hand uses a combination of kevlon and nylon with passive springs to mimic the extensor. The other hardware of the ACT hand includes the use of pneumatic cylinders, off-board motors with pulleys, Teflon tubing and steel cables. The Shadow dexterous hand has 24 joints with 20 d.o.f.s. To emulate the palm curl motion the hand uses an extra one axis joint in the metacarpal region. Another hand called the KDH-2 is a multi fingered dexterous robotic hand where each finger has 4 joints with a total of 3 d.o.f. It uses a 6 d.o.f force sensor at the tip of each finger. It also uses 3 triangulation lasers for calculating the distance and the orientation of the object being grasped. One high speed hand described in paper [5] uses 8 joints with 3 fingers. The fingers are two thumbs (left and right) and one index finger. It uses a massively parallel vision system for knowing the position of the object for tasks like catching a ball and can move by 180 deg in 0.1 s. The use of light weight and power efficient hands in prosthetics is very much required. The hand described in paper [8] has been designed to be used as a wearable prosthetic hand with micro actuators embedded in the fingers.

In tendon driven robotic hands routing of the tendons is a problem and how the tendons are routed also decides the motion of the hand. The tendons in the ACT hand are routed in the same way as the human hand to preserve the natural motion. It uses optical encoder and strain gauge for sensing position as well as bending. The extensor mechanism successfully mimics the motion of human fingers but is very complicated to fabricate.

Fontana [17] describes an exoskeletric robotic hand which uses a mechanical glove with force and position sensors to take feedback from the user's hand movements and transfer it to the actuators in the robotic hand. It uses a 4d.o.f 4R-Serial linkage. In another paper [16] a robust robotic hand compliant to unstructured environments has been designed using shape deposition method where the rigid joints, flexible joints and the embedded sensors are built into a single finger layer by layer using a mould. In another hand designed by ITU the shape memory effect of the shape memory alloys has been used in its robotic gripper for application of mine removal. It uses temperature control with electricity and flowing fluid to grasp and relax. The advantage of using shape memory actuators is that they are silent in their operation and light weight compared to electric or hydraulic motors. One robotic prosthetic hand [12] which is built using rapid prototyping uses SMA Ni-TiNol wires with 3-4% elongation ratio. SMA wires change their length when current is passed through them.

The DLR hand-2 [21] which has 13 d.o.f uses bevel gears and harmonic drives driven by brushless D.C motors. It uses potentiometers for angle sensing. In its advanced version non-contact Hall Effect sensing has been used. In the HIT/DLR [6] hand each finger has 4 joints and 3 d.o.f.s The Gifu hand-3 has 20 joints with 16 d.o.f where each finger has 4 joints with 3 d.o.f and the thumb has an extra d.o.f whose joint is linked by a four bar linkage mechanism. The paper [22] on optical contact sensing describes the use of fiber optics for tactile sensing in 3 directions. It uses a CCD camera, an optical fiber, few silicone rubber elements where a change in the diffusion of light is used for sensing contact. The ADAH [7] robotic hand was developed with an intention to help astronauts in extra vehicular activities especially where dexterous hand motion is required like fitting a nut and a bolt. The ADAH hand has 11 DOF. The NAIST-2 [23] is a human sized robotic hand with a detachable wrist which separates the hand from the rest of its actuators. Some robotics hands also employ a 2 d.o.f wrist. ZAR3 [13] robot uses fluidic air muscles from the company Festo which has a biologically inspired design. The ZAR3 hand has 12 DOF and uses smaller fluidic muscles in its hand compared to its arm. The muscle is its air tube elongates and compresses based on the amount of air in it.

4.3 Design of the RAMA-1 Robotic hand

4.3.1 Mechanical Design

In most of the robotic hand designs it has been observed that either the finger has the actuator embedded in it or a tendon is used to drive the finger joint. Also most of the robotic fingers have a single actuation axis for the interphalangeal [14,fig 4] joints and two degrees of freedom for the metacarpophalangeal joints. The design of each finger here has been bio-inspired from the hyper-redundancy observed in biological snake's vertebrae and the same has been used in Snake robots as well. Having a modular design for the fingers enables ease of fabrication, reduces design complexity and thus can be easily duplicated to produce more joints. Each finger has three joints and at each site of the joint there are two neodymium magnetic spheres with opposite poles. Each joint has two degrees of freedom which can be actively actuated and controlled using tendons to move up or down and left or right. The joint can also roll about the point of contact and this rolling is passive.

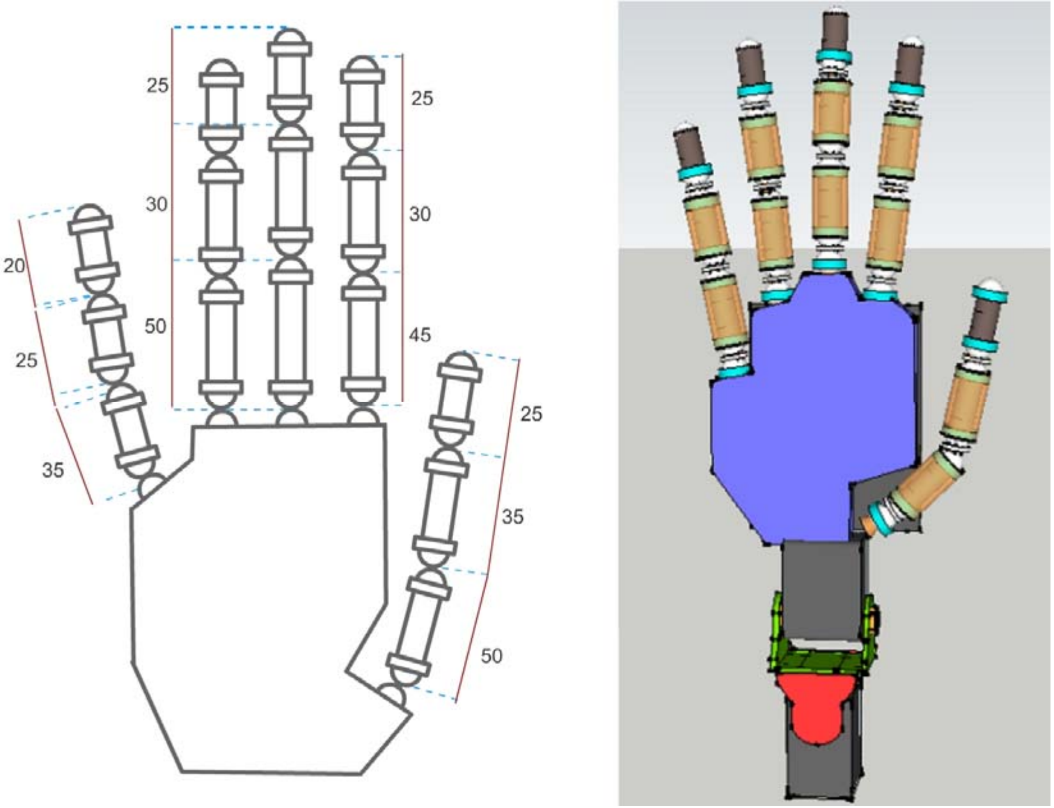


Fig 8.0 RAMA-1 Robotic hand design

The wrist has two degrees of freedom which is actuated by orthogonally coupled servos. The palm of the hand is deformable and the deformation is controlled by a single micro-servo embedded at the metacarpophalengeal joint of the little finger. The palm is made of two layers of foam which allows for natural deformation when objects are placed in the palm and grasped. Effectively the entire hand has 43 degrees of freedom of which 33 can be controlled and actuated co-dependently. The finger joints in the human hand can slide out of contact under force and since the joints used in this hand were magnetic they were able to mimic this joint motion of losing contact and sliding under force. As the point of contact between the magnetic spheres is a point they can roll and slide over each other. Having actuators in the finger limits the joint torque given the small size of the anthropomorphic finger joint. So tendon driven actuation has been used for RAMA-1 robotic hand fingers. 35 kg-cm servos were used to pull the tendons. Tendons of different material and gauges were tried and tested. Copper tendons were more flexible compared to steel tendons but they expanded a lot more. Nylon was flexible and expanded less but would easily break. It was observed that higher the gauge of metal wire lesser was its flexibility. Ultimately steel tendons were chosen.

Fig 8.1 Robotic hand joint using Spherical magnetic rolling and sliding joints CAD and prototype

4.3.2 Embedded system design

The robotic hand uses 23 servo motors (4 each for a 6 degree of freedom finger, 2 for the universal wrist joint and 1 for the deformable palm). The controller board has a master controller which accepts servo command packets from the PC via a USB to Serial link which then are sent to 2 slave microcontrollers over RS-485. Each slave controller is capable of generating 16 PWM signals to control 16 servos individually. The hand is equipped with capacitive sensors on its tips to sense human touch and has a force sensor in its palm to detect objects placed on it. The sensor data is captured using an ADC of an Atmega8 microcontroller over a multiplexer and is then sent to the PC on the receiving channel via the master controller to be processed further. The hand is portable, powered from a 20A 5V regulated DC supply and is USB controlled. The software for processing the sensor data, the GUI to control the servos, grasping actions and visualization for sensor data was written in C using OpenCv. The basic control of each of the finger is by a simple proportional controller. Since the tendons controlling the fingers were routed through routes with different lengths with varied stiffness, each finger moved by a different amount for the same amount of angular displacement of the servo's arm. The maximum and minimum positions of each of the finger corresponding to the maximum and minimum limits of the servo's angular displacement were identified and a suitable proportional constant was calculated. Each of the fingers had to be calibrated to move synchronously with the rest of the fingers while grasping, closing the palm or opening the palm.

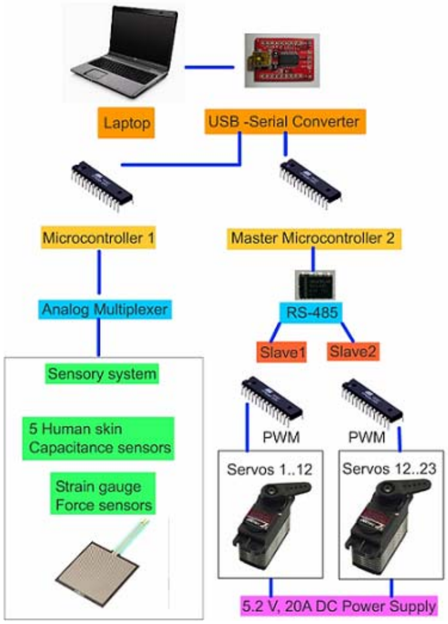


Fig 8.2 Embedded schematic and the prototype I2C 27 servo controller and with force and contact sensing

4.4 Features of the RAMA-1 Robotic hand

4.4.1 Compliance with human touch

Compliance with human skin is detected with the capacitive sensors on the hand's finger tips. When a test subject puts his face with his/her chin touching the palm, by reading the palm's force sensor value the hand was programmed to detect that an object was placed and initiate an action to curl the fingers to form a gentle touch. When each of five fingers individually touches the skin its motion was stopped and fixed. The hand has several mechanical moving parts and metal tendons under high tension which could have snapped under load but the use of this compliance feature made it safe for close human operation. Thus we believe this contribution could be of use in designing assistive robotics especially in the use of hospitals to move patients or the physically challenged.

4.4.2 Unique design with high dexterity.

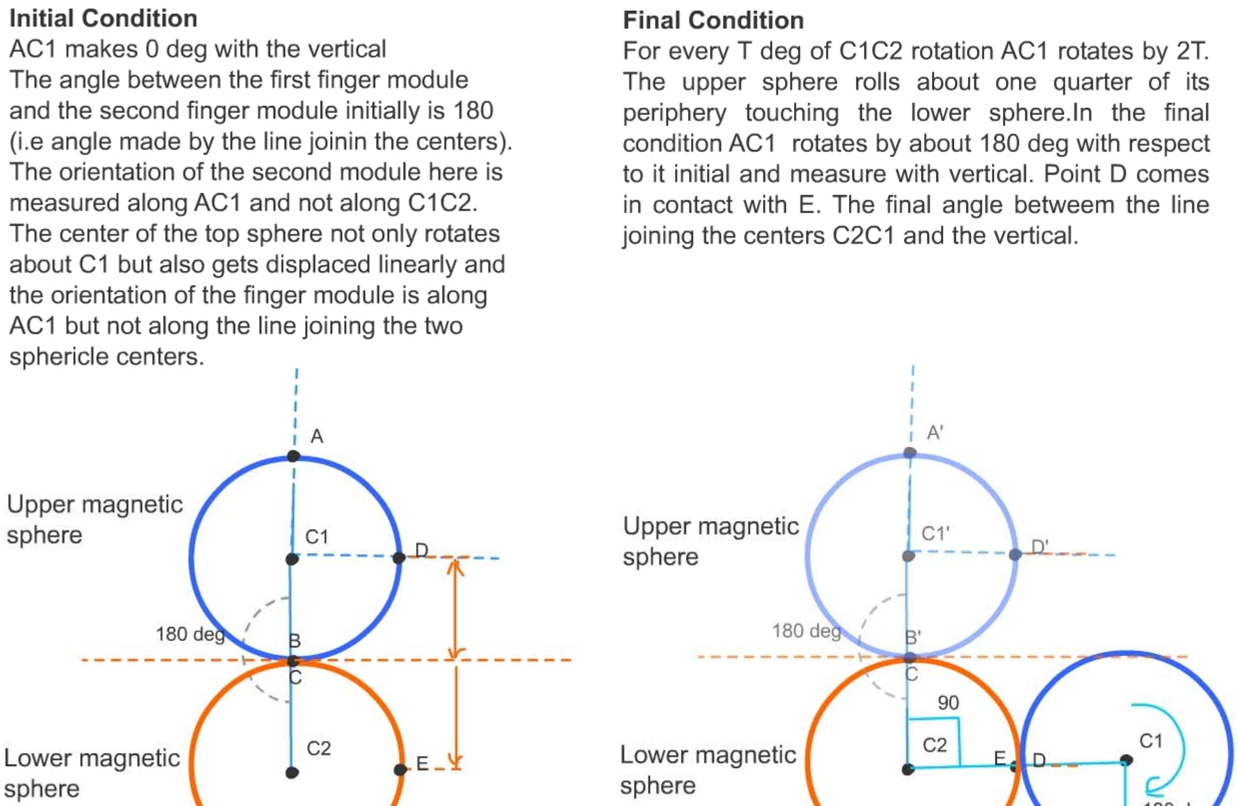
The human thumb has a relatively complex motion compared to that of the other fingers. Here each finger in our design has more degrees of freedom than the human thumb. In the human hand the opposable thumb has a higher degree of freedom compared to the rest of the fingers. The high dexterity of the human oblique-opposable thumb, with the deformable palm allows a human hand to grasp and manipulate objects of several sizes and shape. Unlike the human thumb the robotic thumb of this hand can even touch the wrist. Here each finger in RAMA-1 has more degree of freedom than the human thumb (six against five) and exhibits greater range of motion which is non-biologically inspired because it can curl backwards and away from the palm. This allows for holding an object on the other side of the palm without turning the hand. The RAMA-1 hand can grab cylindrical and spherical objects. It can also detect a gentle touch, a light weighted ball (75gm) placed in its palm and even a heavier object (232 gm). The ball and socket joint in a human shoulder exhibits sliding and rolling in the socket. The magnetic joints designed here allow for such range of motion and beyond.

4.4.3 Robust controller

The controller was made immune to error in servo control packets due to faulty transmission and noise using cyclic redundancy checking. This prevented sudden and accidental motion of the robotics fingers, prevented damage to the object being handled and prevented the tendons from stretching beyond their elastic limit.

4.5 Kinematics and control

Finding the kinematic equations for spherical joints is a challenging problem. In fact this is one major obstacle for developing encoders and control loop equations for spherical ultrasonic motors. Here the joint consists of two spheres rolling over each other. The upper sphere rotates and translates on the lower which is held by the magnetic force of attraction and the tendons pulling it. The unlike poles of the magnet have been fitted at the opposite ends of the modular cylinders which make a finger joint. The resulting contact angle in a plane as a function of the length of the tendon has been given below which can be changed by rotating the appropriate servo. A combination of the 4 angles in each quadrant will define the 3D angle of each joint.

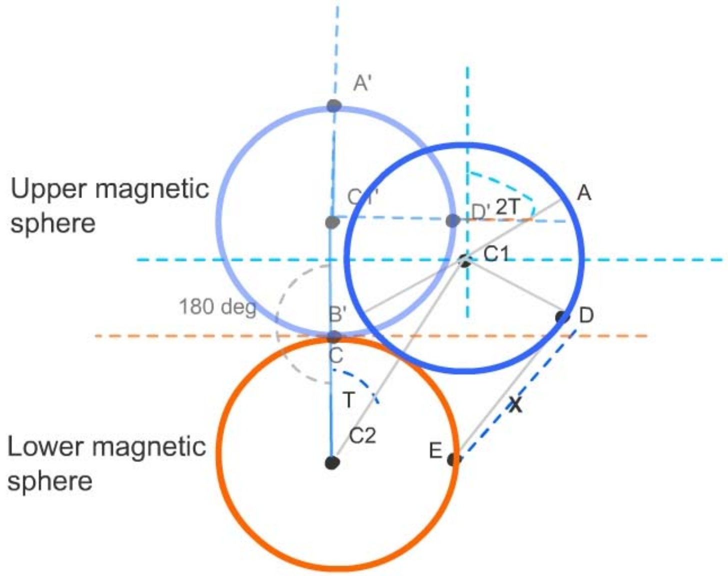


Initial Condition

AC1 makes 0 deg with the vertical
The angle between the first finger module and the second finger module initially is 180 (i.e angle made by the line joinin the centers). The orientation of the second module here is measured along AC1 and not along C1C2. The center of the top sphere not only rotates about C1 but also gets displaced linearly and the orientation of the finger module is along AC1 but not along the line joining the two sphericle centers.

Final Condition

For every T deg of C1C2 rotation AC1 rotates by 2T. The upper sphere rolls about one quarter of its periphery touching the lower sphere.In the final condition AC1 rotates by about 180 deg with respect to it initial and measure with vertical. Point D comes in contact with E. The final angle betweem the line joining the centers C2C1 and the vertical.



The line joining E and D is the lenght of the string between the two spheres. There are four such strings in each quadrant whose lengths control the angle between the two spheres. The string length is changed by pulling it with a servos arm.

So it makes sense to find a relation between the stringth length X, the know parameters like the radius of the sphere and the resulting angle AC1. **X = f(r,T) = ?**

Initial condition
X = 2r, AC1 angle 2T = Z = 0 deg,
Final condition
X = 0, AC2 angle 2T wih vertical Z = +180 deg

So it is linearly decreasing function.
X = 2R- 2Z/ (180 deg)

4.5 Conclusions and Future work

We have fabricated new kinds of universal joints using magnetic spheres to biologically mimic and go beyond the range of motion found in the human finger and the ball-socket joint of the shoulder. We also have made an anthropomorphic robotic hand which has higher degree of motion than the human hand and the highest compared to the existing robotic hands. The new thumb action exhibited by this hand and its 6 degree of freedom fingers have a great range of motion than the oblique thumb which we believe would improve the overall dexterity and manipulability exhibited by the robotic hands. We also believe that the joints based around magnetic spherical joints which can roll, slide and rotate about a single point of contact but which can still be controlled would help in opening a whole new design of humanoid robotic joints for the neck, legs, backbone, hands and the finger.

In the future we would like to improve the control of the hand and design a new closed loop sensing mechanism for these joints. We would then further like to continue the research by designing bigger joints to replicate neck, waist and leg motion.

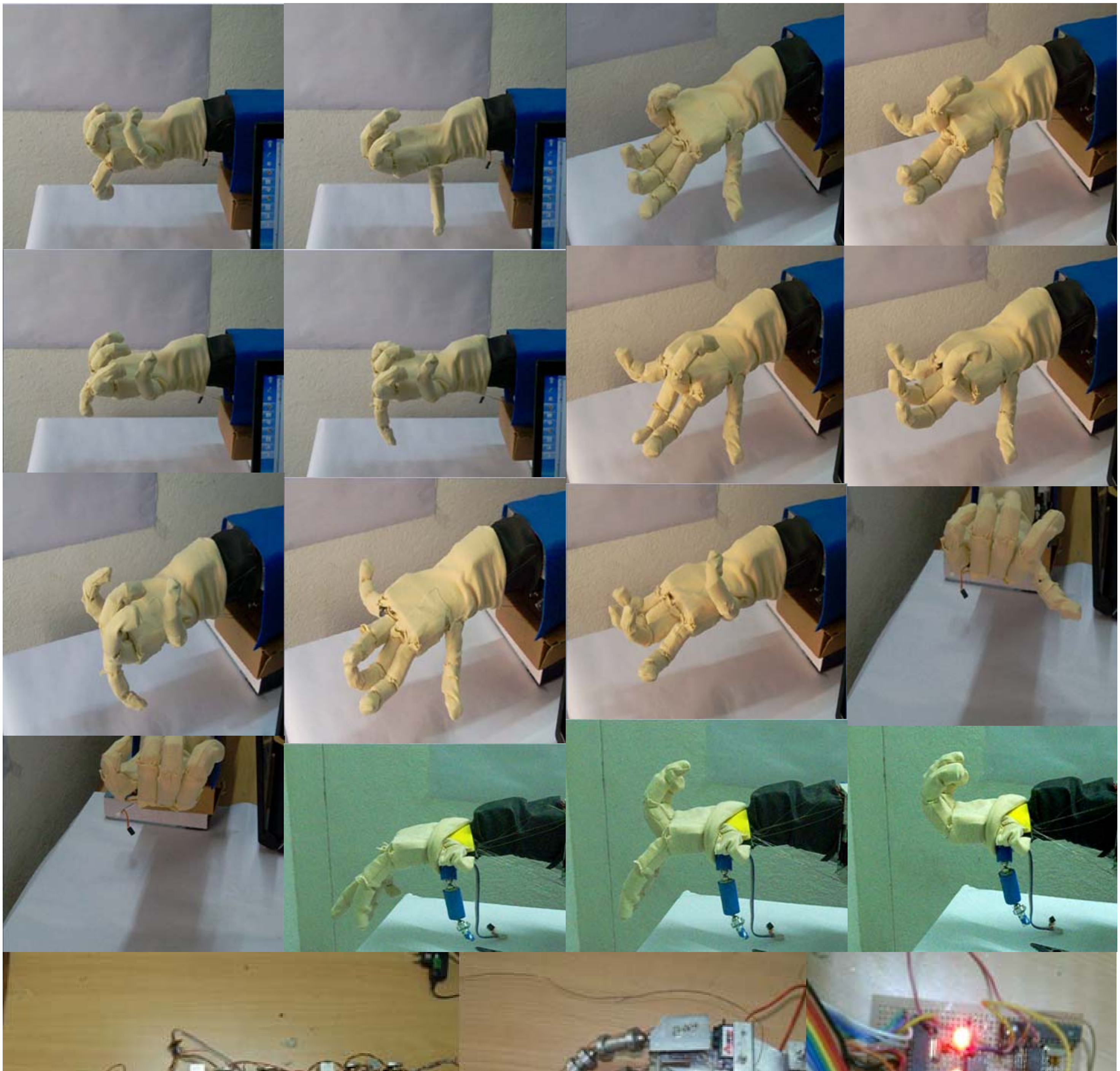


Fig 8.3 Hand with fingers curling in the both the direction, inner skeleton and control PCB

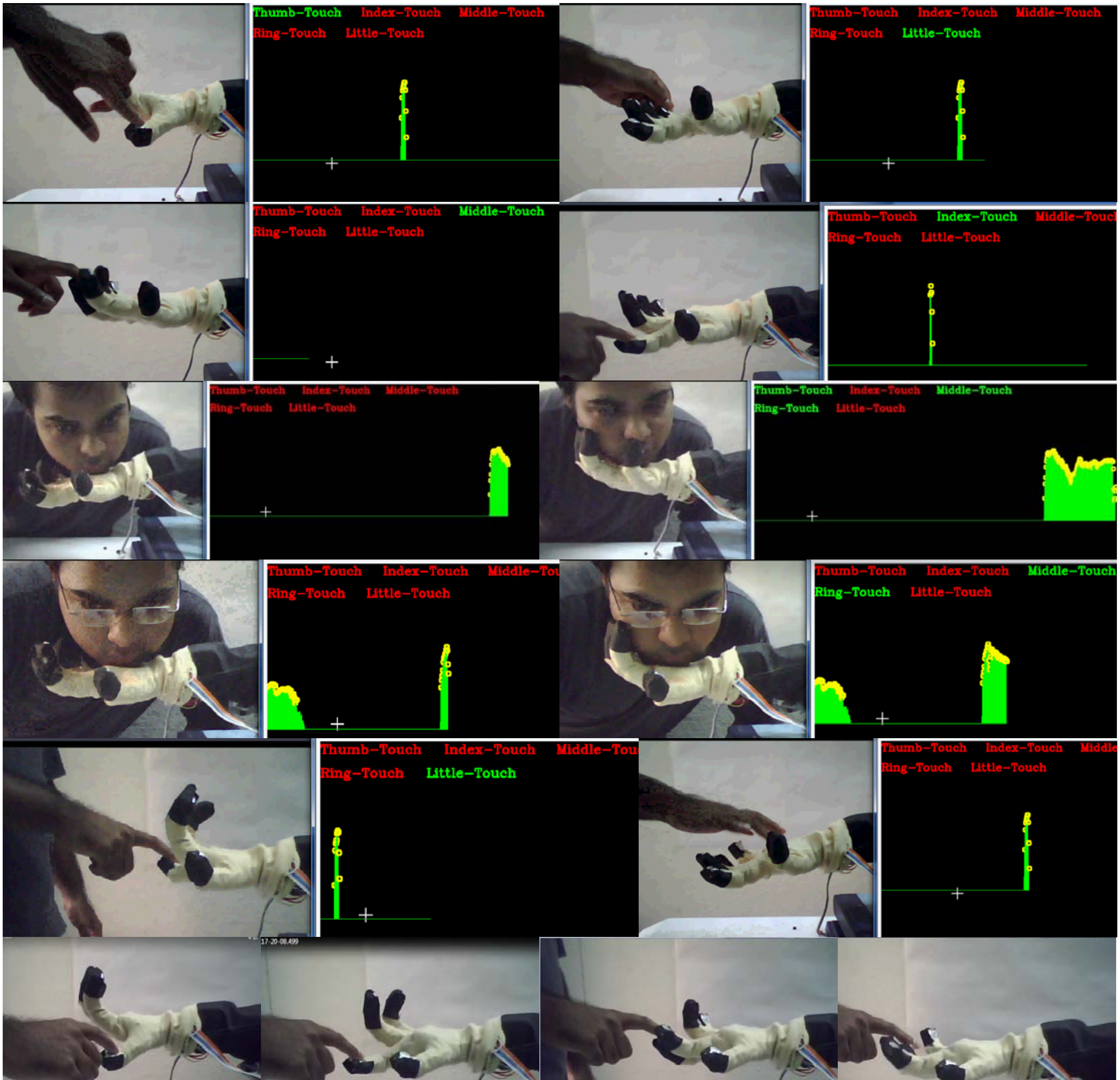
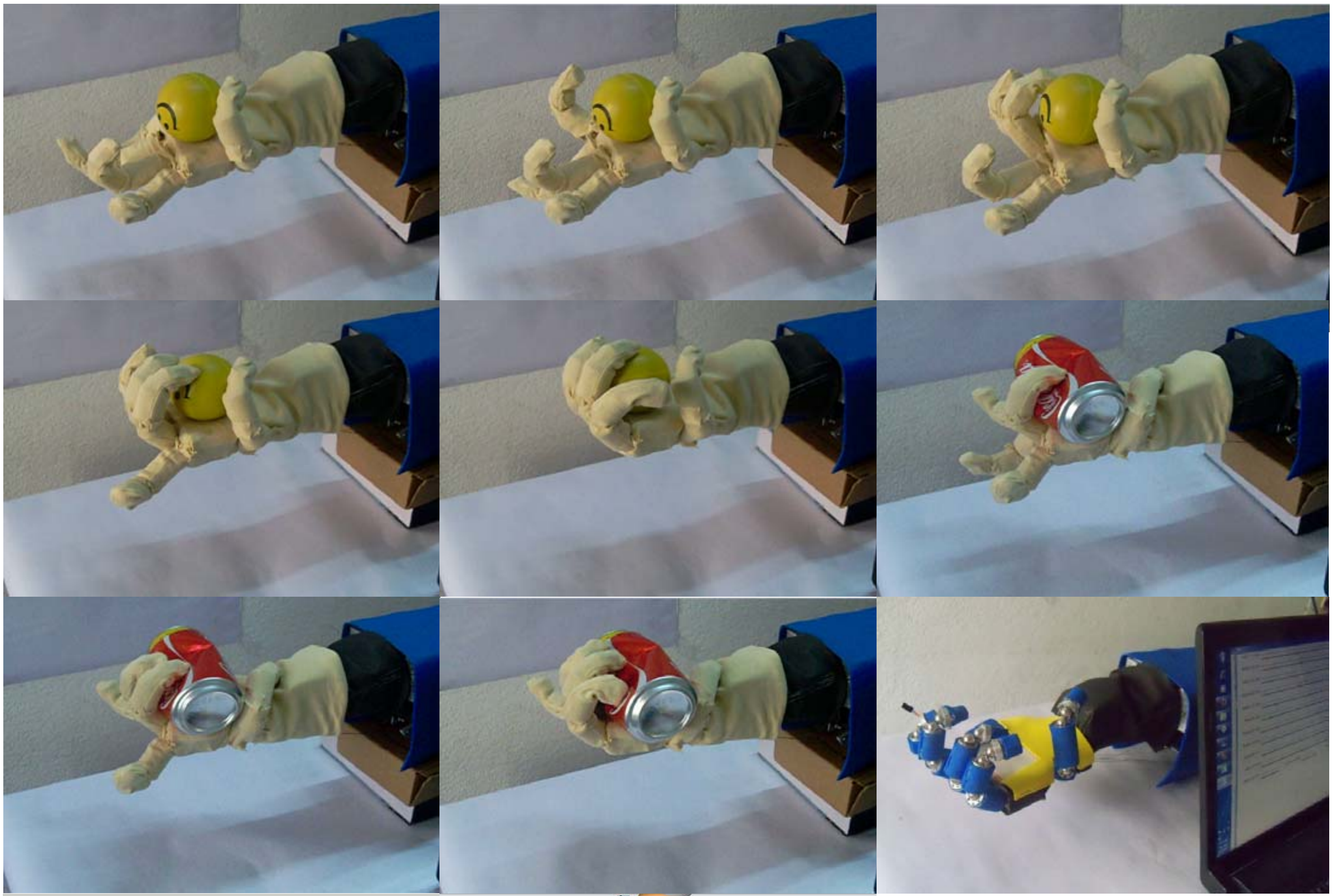


Fig 8.4 RAMA-1 exhibiting compliance to human face with palm force sensing and charge based contact sensors on its finger tips



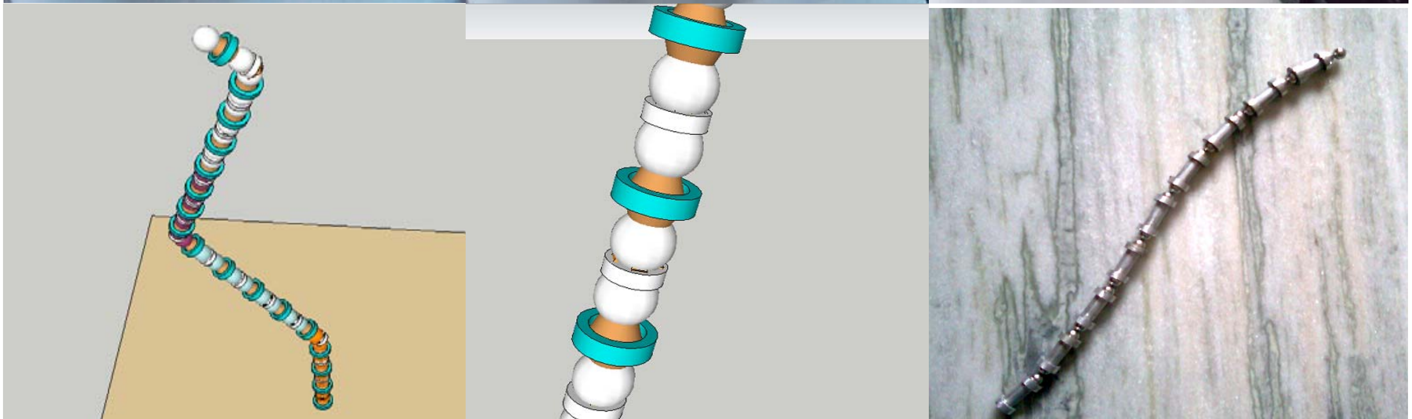


Fig 8.5 RAMA-1 Hand grasping a spherical object (a ball), a cylindrical object (coke can) and a modular snake design using magnetic spherical joint for endoscopy

5.Other explorations

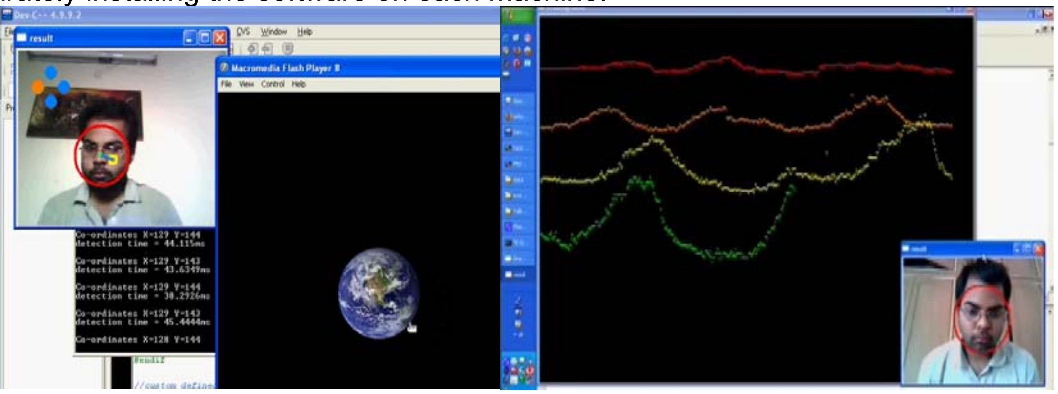
Here in this chapter we tell about some of our efforts in assistive and emergency response systems.

5.1 Camera mouse exploration

The research here initially began by trying to find ways as to how to move a mouse pointer by not using the physical mouse. The idea of controlling the computer without physically touching the keyboard or mouse is exciting and has applications ranging from operation of the computer by the physically challenged, intuitive gaming using body motion etc. Initially the motion of a colored cap being tracked by a camera was used to move the mouse pointer on the screen. Later the idea of tracking facial features was used. Later in this work the optical flow of a user's head was measured using a camera and the same motion was transformed for moving the mouse cursor on the screen. Later this marker less tracking of the user's face was extended for a full fledged application of camera mouse, face controlled photo album application with voice commands, Hands free jet plane game, and Immersive 3D.

5.1.1 Introduction

The makers of camera mouse.org [1,6] have been working over several years to track different parts of the face to move the mouse pointer and also have worked on different techniques to make the left and right click. Tracking a user's facial feature like the tongue, the area near the nose or the eye and using it to position the mouse pointer is relatively easier compared to finding ways of using the same limited motion and the nuances in it to make a left or right click. Most of the times camera mouse is actually used with an on-screen keyboard for typing. The problem is that in some of the physically challenged people even the neck and head motion get impaired to varying levels of difficulty. So positioning the pointer using the head is not always accurate. Most of the on screen keyboards [2,3,4] have small buttons for letters and they do not give the user proper dwell area to accommodate for positioning error. Also they have to be installed separately to work with it. So a web keyboard interface was developed with a good dwell area that can be run off a browser. Also some of the patients have used letters grouped together on a transparent plastic sheet which reduced the time of selecting and predicting what one wants to say because making up a word by conveying each letter from the alphabet is cumbersome and tedious. So, on the same lines several combinations of split interfaces were developed where different sets of letters were provided as groups on different parts of the screen. The final goal would be is to make the camera mouse a browser based application so that it can be just run off a browser at any place be it a hospital, home or even a rehabilitation center with out the need for separately installing the software on each machine.



```
Co-ordinates X=129 Y=144
detection time = 44.115ms

Co-ordinates X=129 Y=143
detection time = 43.6349ms

Co-ordinates X=129 Y=144
detection time = 38.2926ms

Co-ordinates X=129 Y=143
detection time = 45.4444ms

Co-ordinates X=128 Y=144
```

Fig 1.0: Face center being tracked to operate a virtual four directional key on the left. Face size with various gains.

5.1.2 Implementation

In many of the camera mouse applications [1] the problem is to make a click. Here it was solved in 3 ways. In the first method if the user keeps his face stationary without any motion after a preset time the click would be made, this was robust in positioning but it did not allow for fast and convenient navigation. Say, if the user has to quickly travel back and forth between web pages he/she would have to wait for a preset time before the timer runs down and a click is made. Another way is to measure the relative change in distance of the user from the computer screen. The relative distance can in turn be measured by measuring the change in the size of user’s face. If the face size is greater than a particular set threshold a click can be made, but this requires the user to move his head precisely in a direction perpendicular to the screen either towards it or away from it, otherwise any lateral movement in the face moves the pointer to another location. So to overcome this we used voice based commands. To make a click the user can say “open” and then a click would be made. Initially for the camera mouse application we selected either one or two points for tracking the user’s face by clicking manually on the camera captured image of the user’s face but later more autonomy was brought in by face detection. Now the algorithm initially detects the face and selects a point or two in and around the nose region for optical flow tracking. Here OpenCv library was used for computer vision.

Initial explorations involved building an application where the user had to control a four directional virtual key using face movements. The head motion in the 4 directions up, down, left and right would move the cursor up, down, left and right respectively. This was not natural and intuitive since it was not compliant with the direction in which the head is positioned to look at or in the natural direction of gaze. This flaw was because the way the user interface was developed to control the mouse pointer. The face center was tracked and if the user moved his head in any direction beyond a threshold distance the mouse pointer would begin to incrementally move so. An improvement upon this was that the cursor motion was linked directly to the center of the face using the face detection module; here the displacement resolution of the face was at pixel level. Though it was more intuitive than the previous interface it required large head movements for positioning the cursor.

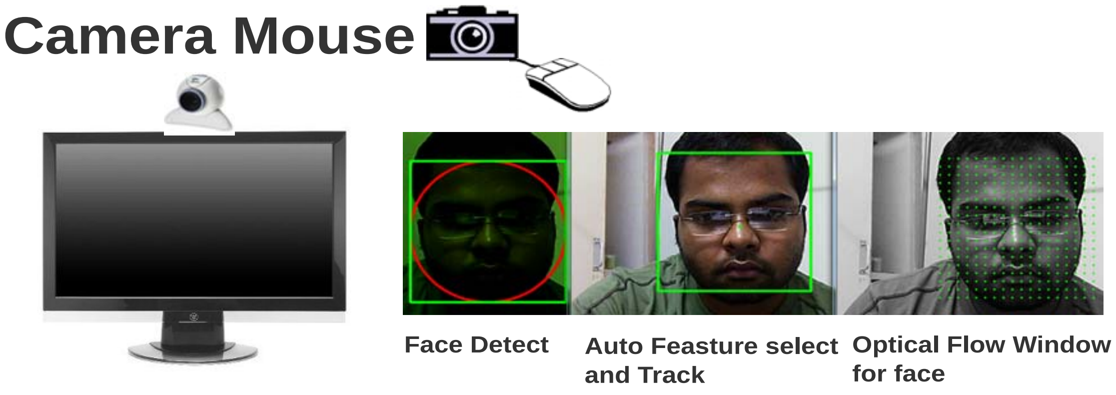


Fig1.1 Face auto detection and auto feature select with optical flow tracking.

Later Lucas Kanade optical flow was used for tracking the user’s face. The advantage of using optical flow based on Lukas Kanade algorithm is that tracking is achieved at a sub-pixel level. This means that the user can control the mouse cursor with smaller head movements. A sample test application was developed in which the screen space was divided into a 2D grid. In this the user had to position the cursor in one of the cells and say the voice command “open” to click. Initially the control was developed for horizontal array of cells which just involved tracking horizontal motion of the user’s neck. Then cursor position control in a vertical array of cells was tried out which involved the user lifting his head up or down. Then both were combined to position the cursor at a particular cell in a two dimensional grid with the head’s motion. Also since the hardware resolution of most of the cameras is 320 x 240 the tracking based on face detection method could not position the cursor properly on the screen but sub-pixel tracking using optical flow extended the cursor control to the entire screen area. In some of the high end cameras 640 x 480 resolution is provided but some cameras also have a software interpolated mega-pixel imaging which reduces the frame rate and is thus not helpful.

5.1.3. Applications Developed

a) Photo Album application:

In this application the user browses through a photo album and zooms into a photo using voice activated commands. The tracking resolution using optical flow was so high that even minor facial movements were moving the cursor on the screen which was not desirable. To limit this a second but a coarser cell was drawn around the cursor’s position (cursor’s position is the cell it is currently positioned in) which does not move for minor motions. With this improvement it was possible to conveniently flip through the photographs and zoom/open them using voice commands.

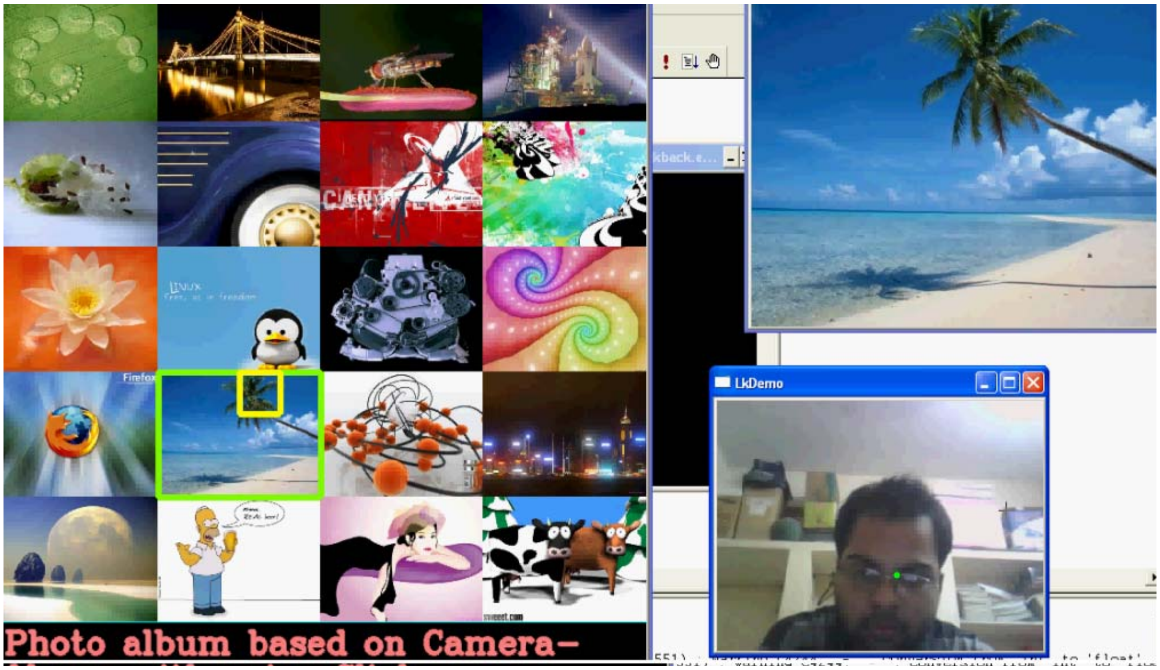


Fig1.2 Photo album application with voice input

b) Hands Free Jet plane game:

The face tracker developed here using optical flow is marker less. The user's head motion in the up-down and left-right direction was translated to the pitch and yaw of a jet plane in a computer game. This gave hands free control in playing games. Games which generally require faster response time require high resolution laser mice(800 dpi or above). This method of head tracking allowed for swift control of the Jet plane. The responsiveness of the plane as compared to the user's head motion is also controllable. Here exponential throttle was given to plane with the head's position as the basic input.

c) Immersive 3D application:

The idea of immersive 3D is to give the user a feel of real 3D on the screen without the use of 3D glasses. "Imagine you are looking through a window into another world. Now if you change your position with respect to the window the view of the world also changes with it. In some cases the effect is so pronounced that the objects appear to come out of the screen." Here the computer screen becomes the window to a new world and the user's head can be tracked using a camera attached to the screen and looking towards the user. Here the optical flow based head tracking was used to invert the view of the virtual camera looking into the 3D world and the effect of immersive 3D was achieved. Depth again could be perceived by measuring the user's face size or even distance between two optical flow dots. Here a second camera was used in a perpendicular direction to measure optical flow along the depth axis.

Fig 1.2 Immersive 3D application with stereo tracking and gaming application

d) Robotics application:

There are certain pan-tilt mechanisms for controlling a video camera's view which are driven by inertial head trackers worn by the controller. This requires the use of an accelerometer with a gyro or a sophisticated IMU. However the pan and tilt of the camera was also achieved by using optical flow head tracking. The displacement in the X and Y directions was modified to servo control values and sent to the custom developed servo controller via the USB- Serial converter and then an Xbee RF modem. This controller was developed as a part of Modular legged robotic system. We hope this application would be useful for controlling the cameras mounted on UAVs for surveillance and entertainment.

5.1.4 Future work and Conclusions:

There are several other technologies for controlling the computer mouse pointer other than the physical input device. Experiments have been conducted to move objects on the screen using EEG. The Emotiv Neuro headset kit [7] reads neural patterns resulting from brain activity from several parts of the brain. This signature motion is further used to play games, rotate and move 3D cubes on screen. Some experiments [9] involved implanting a neural net under the human skull and further use it to move a manipulator. This method is difficult to be adopted for practical usage of moving a mouse pointer on the screen because it is invasive. So a highly sensitive EEG device that is not invasive or a miniature eye tracking hardware that would fit into the desktop and mobile devices would go a long way in providing computer control to people with limited mobility. There are existing projects like the Tobii eye tracker [8] which give better control with the natural eye-gaze and they can be improved further and miniaturized so that they can be embedded into cell phones and tablets.

5.2 Low cost sensors for robotics and HCI

5.2.1 Introduction

When working with tracking the features on user’s face an application into immersive 3D was developed. The reason behind immersion is that we are used to looking at things around us in depth and it is naturally appealing if the interfaces are presented in 3D or the interaction itself is in 3D. One application involved controlling the roll and pan of a jet plane in a video game. The control of the plane was in 3 dimensions using the features of a person’s face. Later the feature tracking was done from two frames of reference to get a sense of depth. This was later used to control the perspective view into a 3D world using the computer screen as a window. Jhonny Lee in his work explains about viewing into another world through a virtual window as an active and dynamic viewing portal. Ramesh Raskar in his work uses a depth sensing technique from behind an LCD to control a 3D object by just gesturing with a hand in front of the screen but not touching it. For getting the depth in 3D special hardware like stereo cameras, time of flight cameras, ultrasonic sensors and even 3D scanners using structured light are used. Around the same time Microsoft developed their X-Box gaming system with the Kinect interface. This 200$ worth interface uses an infrared laser to project structured light into the ambient environment and use the changes in the projected structure to get an idea of depth. Microsoft kinect extends the idea of tracking only select features to the entire body and it was termed skeletal tracking. An additional advantage was that the hardware developed for the gaming interface also served as a useful tool in generating 3D maps for the purpose of visual SLAM in robotics. Many sensors like the laser range finder, stereo vision cameras which help in building a depth perception of the world around it in 3D are very costly. Here we present the designs and prototypes of few 3D perception sensors which have been built low cost using components off the shelf. These perception sensors use structured infrared light projection. The design is miniature compared to other 3D sensors like LIDAR, Laser scanner and Time of flight cameras. These ideas pushed us towards developed a miniature depth sensor that can be used in micro-robots and also for the purpose of developing new depth sensitive interfaces. Another sensor to measure the force using differential capacitance was built. Capacitive sensing is widely used in touch based buttons and screens. This form of contact based sensing also works in a near field fashion even if a person's hand is not touching the sensor. Using such sensors in search and rescue robots like snake robots can prove effective especially when a human body is to be detected. Also a snake force sensor was designed using the same idea. Compliance in snake robots is a challenging problem to solve. One problem is about robust force sensors that would help in sensing contact and force on the side of a snake robot's body.

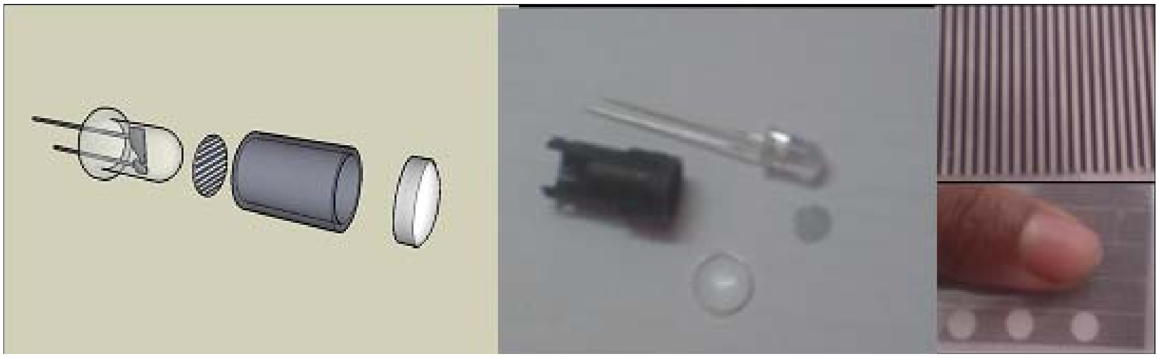


Fig 4.0 Nano projector CAD diagram, prototype and printed diffraction grating on plastic sheets

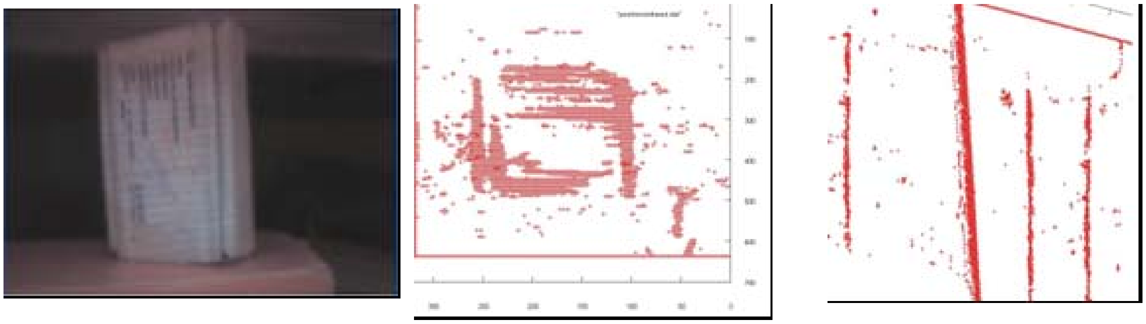


Fig 4.1 Illuminated object with structured IR light and point cloud visualization in GNU plot

5.2.2 Implementation of IR depth sensor

The method involves illuminating the object with fringes which are sinusoidal phase shifted. From a series of images of the object illuminated with traveling fringes the phase information of each and every pixel can be obtained. This pixel level phase information can be mapped to the depth. Also in most of the structured light projects the cost of the projector increases the total cost of experimental setup. To overcome this, a new low cost fringe projector was designed using an IR LED. It is named the "nano-projector" compared to the pocket sized micro projectors. Initially we thought of using fringes formed by a laser pointer with diffraction grating plates but it requires the fabrication of grating plates which is expensive. Also the use of laser could damage the observer's eyes while experimenting or while using the sensor. To capture IR light a web-camera with its IR filter removed and fitted with visible light filter was used. The cost of micro-film development was more than the camera's cost and hence low cost alternatives were looked into for making the fringe films. The best among such was to print the fringes onto a transparent plastic sheet using a Laser printer. The problem was that the intensity of the fringes formed should obey the equation below[1]

$I1(x, y)=I'(x, y)+I''(x, y)\cos[\Phi(x, y)-\alpha)$.

When the resulting fringe pattern was magnified the fringe lines were in a zigzagged fashion. This happened because the print head of the printer tried to approximate its position to print the image. To prevent this, lines which were of finite intensity (either 255 or 0) and that were in integral multiples of pixel thickness were drawn and printed. Now the print head's position approximation did not occur. Lines of varying thickness were printed. More are the fringes in the film more will be the detail in the reconstructed 3D model. One more disadvantage of increasing the number of fringe lines within the limited area of the projection film is that it comes at the cost of reduced line thickness; as a result the projected fringes will not form properly. Among all the fringe patterns tried and tested, fringes with 4 lines per mm were chosen. There are two reasons for which the fringe pattern formed using IR light was better. One, the Laser printer heats the sheet a bit, so the density of the print material at the center of the printed pixel was more than the density at the corner. For visible light this was dark enough to be opaque and for IR it was translucent. Thus even the constructed 3D point cloud was better using IR light than the visible light. In general longer wavelength of light diffracts more than the shorter wavelength. The infrared light diffracted more than the shorter wavelengths in the visible light and thus the edges of the fringes formed by infrared light were more blurred than the visible light. This thus resulted in a better 3D point cloud using IR light. The code was developed in C using OpenCv. As miniature as the camera and LEDs can get so will the sensor. Also by using more powerful IR LEDs higher projection distance can be achieved. The IR LEDs used here were able to project the pattern up to a maximum distance of 2 meters as detected by the webcamera. Also the current consumption of the sensor is very low compared to a Laser Range finder.

Figure 4.0 shows the exploded view, parts used and the fringes printed. Fig 3.1 shows the illuminated object and the 3D point cloud in GNUplot. Fig 3.4 shows the design of a

3D web camera using nano 3 phase projectors, Fig 3.3 shows the design of sensor for autonomous cars, fig 3.4 also shows the camera capsule design.

Each LED's peak current is 15mA and the camera consumes not more than 500mA. Bigger laser range finders like the LMS-200 weigh 4500 gm and have a power consumption of 20W.

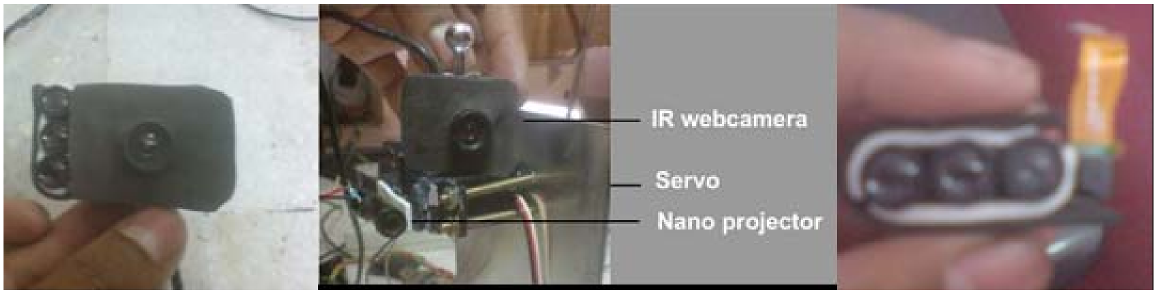


Fig 4.2 Miniature 3 phase nano IR depth sensor

A mechanized version of the sensor using a single projector, using a single nano IR projector and a servo was built. The servo would rotate the projector slightly 2 times and the image would be captured 3 times at each of the 3 projected angles. These 3 images were further used to reconstruct the point cloud of the object. An outdoor version of the sensor was also built. Here to achieve the projection of fringes over a larger distance a more powerful source of IR light was needed and an IR bulb used in medical equipment for heating was used. This light could not be focused properly to form the fringes but the object as illuminated by this IR light source could be detected at a distance of 10m.

Fig 4.3 Outdoor version of the sensor using an IR medical bulb

5.2.3 Possible uses of the nano infrared sensor.

Applications:

1) A 3D web camera capable of generating a 3D point cloud has been designed which just costs 2 dollars higher than the web camera used. It can be used in gaming projects like Microsoft Natal for getting depth. The smallest sensor presented here weighs only 23 gm.

2) The same sensor can be used in autonomous cars, because of the simplicity in the sensor's design it can be fitted into a car's headlight.

3) A camera pill design is also presented here which compared to the existing camera pills would help in getting 3D scans of the body's internals (like intestine and esophagus).Use of 3 phase nano-projection should improve medical imaging and diagnosis.

4) The sensor because of its miniature design can be fitted into the end effecter of a robot's arm. For example it can be used on an exploratory rover's arm to get 3D scans of a rock. The rover can then use this information to position a tool head to drill the rock.

Fig 4.4 3D webcamera design using 3 phase nano projector, car sensor for obstacle detection and camera pill design

5.2.4 Implementation of the force sensor

The force sensor here has been built using tin foils which act as the capacitive plates. Non conductive shock absorbing foam and non conductive springs have been used between the two foils that act as the dielectric and also help in absorbing the contact force on the snake module's body. When the face of the snake module is in contact with a surface or pressure is applied on it, the springs and the foam compress. The distance between the two tin foils changes and this changes the resulting differential capacitance. This was used as a measure to differentiate between gentle touch, when the face of the sensor was hit, when human skin came in contact with the sensor and when plant leaves came in contact with it. When compared to a flex force sensor based on the principle of resistive foil strain gauges this sensor is robust to wear and tear. If a force resistive sensor is punctured or torn it stops working because the continuity of the circuit is broken but this capacitive sensor worked even when it was punctured and torn.

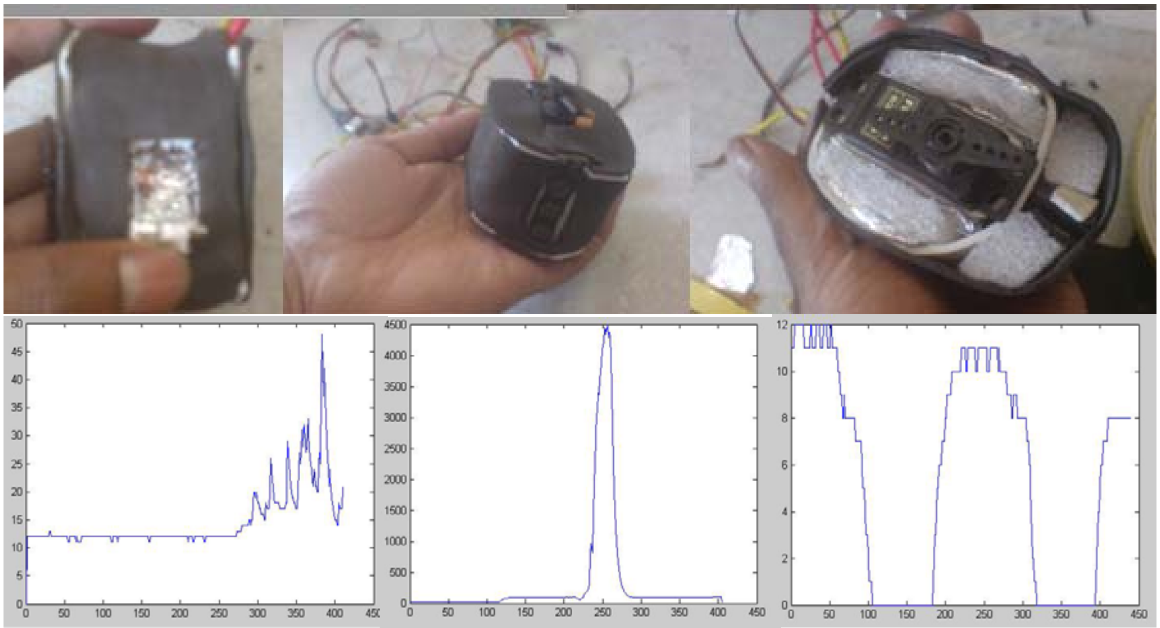


Fig 4.5 Snake module with integrated force sensing skin and IR depth sensor, graphs of external contact

5.2.5 Conclusions

A first snake module with differential capacitive skin was built. The IR structured depth sensor is extremely low cost and is thus significant in driving the cost of sensing in robots low.

5.3 Car tracking and Vibration Test rig using Neo-Freerunner

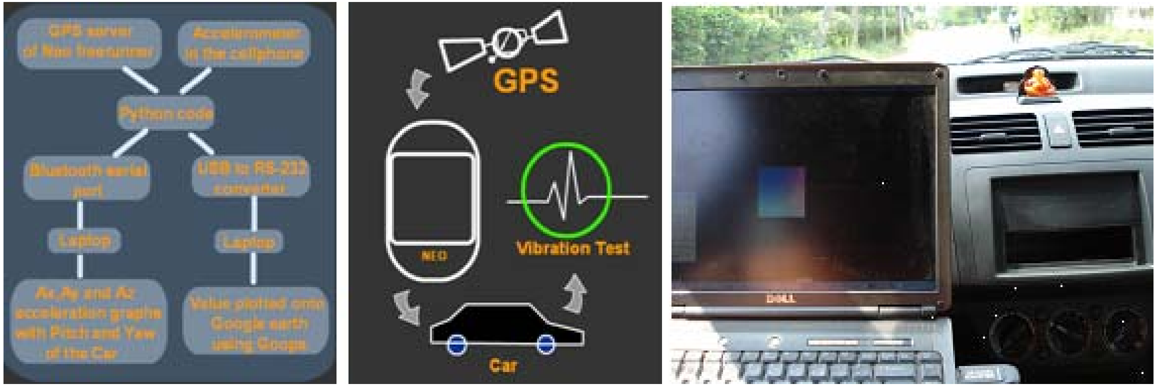


Fig 3.0 Program schema, flow and hardware setup during test run for detecting road quality.

Initially when interfaces for non- contact form of control and intuitive interfaces were being looked into and studied we came across accelerometer driven mouse hardware interfaces. Accelerometer based interface has been widely used in gaming especially in the Nitendo Wii controllers. It was also being used in cell phones for navigation and gesture based interfaces especially to shuffle a song. Initially while trying to experiment with an open hardware and an open source linux phone named the openmoko free runner we experimented with its GPS and accelerometer data over bluetooth. The phone can run many flavors of linux like Android, Qt, SHR etc. Here the implementation was done in SHR. Now depending on the intended use of the component the functionality specification changes and is especially observed with accelerometers resolution. The ones intended for navigation are of a higher resolution than the ones to detect fall, taps or sudden motions to change songs. Here we tried to use the accelerometer in detecting pose and to use it or IMU based applications. The accelerometer did not have enough resolution which was also limited by the API provided and when we visualized the roll, pitch and yaw from the accelerometer data the corresponding change in the pose of the phone were notable. An application was built to view the accelerometer data over graphs along each of the 3 axis and the cumulative change in the pose of the phone. We then used the same interface for observing a road journey's quality by mounting it on the roof of a car.

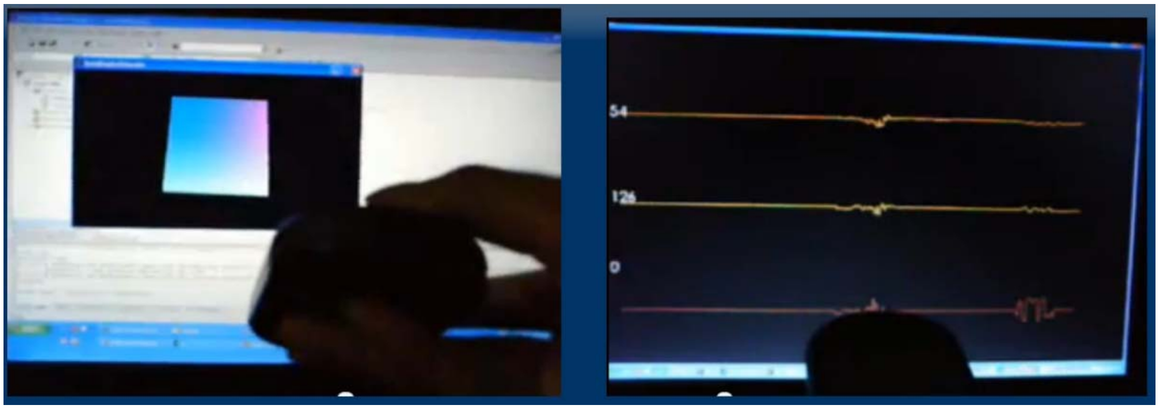


Fig 3.1 Accelerometer roll, pitch and yaw visualization over Bluetooth.

5.3.1 System Description

The phone's GPS server is invoked and the NMEA sentences are read from a particular socket number. For reading the GPS data and forwarding it to the serial COM port we developed a python code. These values were sent over the hardware serial port using a USB to RS232 converter connected to the phones mini USB port. At the laptop's end another RS232-USB converter is used. The values are read using Goops software and plotted onto Google earth. There was even an option to provide the GPS values to google earth on a particular port number but that did not work all the time and hence wasn't reliable. The accelerometer values were read from the phone and forwarded over the Bluetooth serial bridge between the phone and the laptop. At the computer's end the Ax, Ay and Az acceleration values were plotted as individual graphs. The pitch, yaw and roll were calculated from the inverse tangents of values along the respective acceleration axes. These were then visualized as the 3D cube's rotation.

5.3.2 How is this system helpful?

To our knowledge there is no tool to qualitatively and quantitatively measure the road's condition. The video analysis of the acceleration graphs revealed where the road was smooth, where there were bumps and speed breakers. More is the vibration along the respective axis in acceleration more bad was the road quality. Especially this test was more suited for the rugged road conditions. The cube's vibration and sudden jerks were the same as that of the car. We feel that this form of visualization is qualitatively better than just saying how good or bad the road is verbally. Also we were able to visually distinguish between the car applying brakes, the start and the end of the journey. We also feel this is one of the useful features of a cellphone which has not been explored much. The accelerometer can also be used to measure vibration of an automobile. The amount of vibration as measured by the accelerometer is not only a function of the road's quality but also depends on the quality of the vehicle's suspension mechanism. One need not install an external GPS to the car but connect a cellphone's GPS to the car's computer to get GPS data. The same system can be implemented on any two wheeled vehicle like a motor-bike or a bi-cycle.

Fig 3.3 3D cube with acceleration graph visualization indicating cars pose, road quality

5.3.3 Future Possibility:

This application holds great importance in recording the road quality with respect to GPS data. If the road quality is bad at a particular location or if there is a pit, a ditch or a large speed breaker then this information can be recorded and used predicatively by other automobiles. This research shows how a cell phone app can be used as a useful tool by using its accelerometer data for life saving applications. Such hardware meta data like the accelerometer and GPS can be further used to detect vibrations caused by large collision forces during accidents and earthquakes. Not only is the autonomy of the car but also the quality of the road on which the car travels is important if the road travel to be safer. This research shows how a cell phone app can be used as a useful tool by using its accelerometer data for life saving applications. Such hardware meta data like the accelerometer and GPS can be further used to detect vibrations caused by large collision forces during accidents and earthquakes.

5.4 Quake and Crash Reporting system using a cell phone's

hardware meta data.

The idea of recording the events of sudden changes in road quality coming read from the accelerometer data with GPS location took us to the next step that the same idea with different thresholds can actually help in recording vehicle, hits and accidents. The same can also be used to record and detection motion from the average stabile and stationary position especially to detect earth quakes. The application interface and the idea was the same but now where we apply to handle a different but a crucial problem of detecting accidents for minimal lag reporting was different but was of prime importance. Vehicular Accidents have a good probability of human death and to handle such an emergency situation it is crucial to report it especially when it has occurred in remote place and when there is large gap between the occurrance and reporting of the accident. This important accident related meta data can be used to save lives. To test this we wrote a piece of code that would detect large break events and simulated accidents and report it as an accident and to simulate an earth quake.

5.4.1 Introduction

Here in this chapter we describe a cell phone only system which can be used to detect and report earthquakes and especially automobile accidents. The need for detecting earthquakes when the first initial feeble vibrations are felt, the need to gather the real time data of such an event like its progression to know which geographical areas have been hit and the magnitude of the earth quake is very much there. Events in the past have suggested that it is the over-whelming devastation in short time which has prevented the rescue agencies and governments to take proper corrective, planned and effective rescue-rehabilitative actions. So devices which will help people give a better knowledge about the event will enable them to plan the rescue action better. If the rescue comes faster, more lives can be saved.

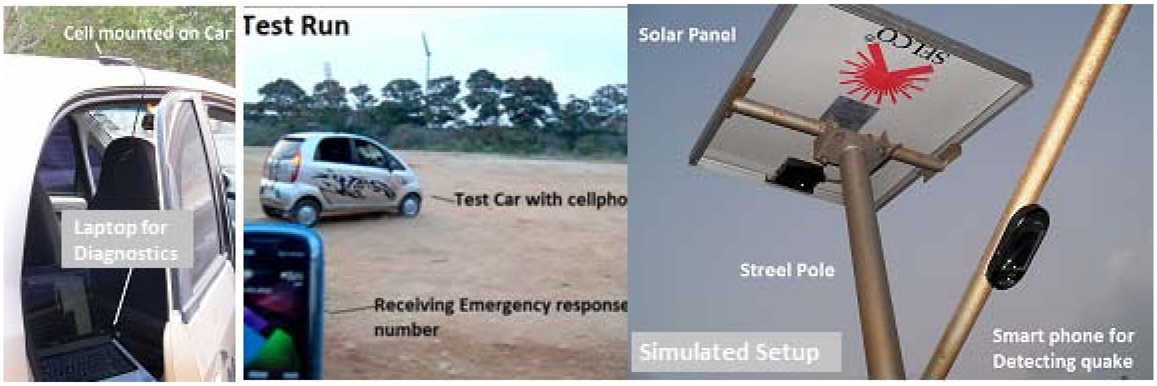


Fig 10.0 Car test with cell phone mounted on the roof with simulation collision and breaking force. Also shown is setup on a street pole for detecting quakes

There has been prior work in this area, for example the Quake catcher network (QCN) [1] developed at the Stanford Univ. The quake catcher network uses low cost community developed sensors and a QCN software running on an internet connected computer to monitor quakes. Another paper [5] mentions about using android phones attached with external USB accelerometer dongles together as a system to measure quakes. Some applications [3,4,5] for android phones use earthquake reports over the internet to get the user updated with latest quake events. In this present chapter we attempt to show that any smart phone with a basic accelerometer can be used to detect motion such as vibrations due to earthquakes and collisions in car crashes. The cellphone itself functions as a node sensor and reports events with the event's position over the CDMA/GSM network. Wreck watch is another system which uses a smart phone with a 3G connection and accelerometers to detect vehicle crashes and generate accident information. Ishake another project shows how cell phones can be used to detect quakes using their accelerometer data. We have provided a single solution using the Openmoko Neo free –runner with a Linux Distro that can be used for detecting and reporting both crashes and accidents with by varying the threshold of the detecting app.

5.4.2 Description

When an earthquakes hits a place it is difficult to know where it first started, whether the area hit was densely populated, was it an industrial area, a residential area, or was it the work place area, or was it a place for public transport etc. So the exact location of collapse with the hit magnitude would give a good idea as to where more people to be rescued could be. It is difficult to plant an earth quake monitoring station in every major street or install a costly earthquake monitoring equipment in every home. Here we present a cell phone only based system which can be mounted on a street light pole or radio towers to measure geological vibrations. The cell phone itself can be powered from a solar street light panel so that it can run during the day, at the same time get charged and even work during the night. The system has been developed using Neofreerunner by Openmoko which is an open hardware and an open software cell phone. The software running on the phone is an earthquake/accident monitoring server written in python. It communicates with the onboard GPS daemon of the phone, continuously polls for the updated GPS locations at a frequency of 5 hz, reads the accelerometer sensor values and if there are vibrations due to a quake it makes a report log. It immediately reports the log over an SMS using its CDMA/GSM network. The advantage of using such smart phones is that they require no additional hardware, can be easily set up and their cost of maintenance is low.

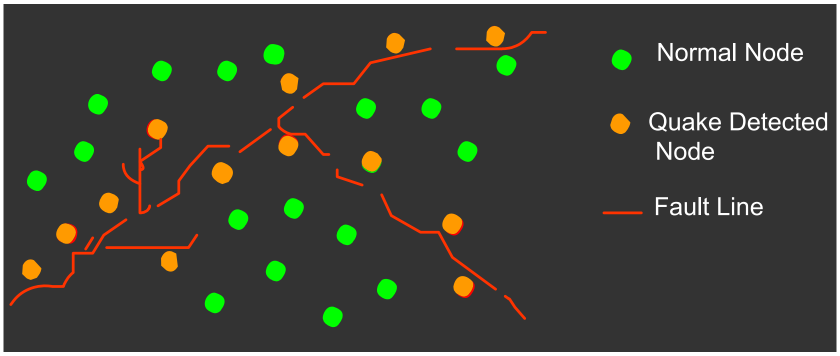


Fig 10.1 Quake detection visualization over a network of sensor nodes

Nowadays phones equipped with accelerometers and GPS cost as low as 50$. They can also be networked using their inbuilt Wifi or Bluetooth chipsets to form a sensor network or can be operated as individual sensor nodes. To simulate an earth quake an experimental platform was made using two robotic servos linked perpendicularly to move with a resultant 2 degree of freedoms. The cell-phone was mounted on the platform and the vibrations were simulated using a micro-controller which controlled the servos with a pulse pattern. The earthquake application running on the cellphone successfully detected these vibrations and sent an SMS alert report to a designated rescue number.

Another scenario where this system can be useful is automobile accidents. Quite a few number of accidents occur in remote places with no one living around or in the wee hours of the day. By the time any passer-by notices the accident and reports it to the medical emergency unit, it could be too late. Now most of the automobile accidents involve a large collision force. So, if one can detect this event just like an earthquake and immediately notify the search and rescue agency or the medical emergency unit with the location of the accident then the medical help can arrive at the earliest. The application we developed here aims at reducing the report time of an accident (specifically the time gap between the accident occurrence and the report) and also provide with a report when there is no one to report the accident itself. As a test run we mounted the cell phone on a car and tested the system with different braking accelerations to simulate an accident. For the purpose of the experiment we set the detection threshold to a lower value. The event of high and abrupt reaction force on the car due to braking was detected and reported back with the cars position using the GPS. The magnitude of braking (simulated collision) was also reported back measured in relative terms of the cell phone accelerometer readings.

To simulate the collision several test runs were conducted where an even with a large breaking force was of interest. The car was made to go on straight paths and curved paths and was braked. With results from every iteration the threshold of the accelerometer detection was changed to record a successful brake event and was reported over an SMS from the running car. This system can also be used for earthquake detection because when mounted on a street pole any minor displacement or vibration out of the normal would be detected by the accelerometer and reported as an earth quake event. The threshold detection for an earth quake would be far less lo compared to that of a car collision. It was simulated in the earth quake simulator setup using the 2 degree of freedom servo setup and was tuned to detect for a minor displacement.

The SMS sent from the mobile itself or the cell phone number itself can be tagged with the type of vehicle it is coming from and from that one can know the type of accident [6,7]. If it is an oil tanker then the emergency response unit will know looking at the SMS tag that this emergency SMS has come for a vehicle which can possibly be involved in a fire accident. Then the emergency response team can send in a fleet of fire fighting trucks and a large team of fire fighters. Say if the truck has chemical containers then there could be a possibility of toxic spill and the appropriate team can be alerted. The phone number itself can be tagged with other meta data like the size of the vehicle. Say if it is a school bus then probably a fleet of ambulances and a larger medical team would be required at the site of the accident. So the number from where the SMS is coming can in itself help device a better search and rescue plan even before the site of the accident is professionally surveyed. Even by knowing the geographic location one can know the kind of buildings, structures, the vegetation (trees if any and the density) and distance to water sources. All this data can be used to generate an immediate and automated plane of rescue action just as the SMS is received. Most of the cases the time is spent in planning and revising the search and rescue action and by the time it arrives it could be too late. Search and rescue planning software can be built using this meta data to generate an automated response plan just as the SMS arrives at the rescue center. So the time that goes in search and rescue planning can be cut to zero.

Fig 10.2 Crash and Quake detection and reporting schema

5.4.3 Conclusions

There are existing systems which are in the form of USB accelerometer keys, community based sensors, android phones attached with external accelerometers to measure earth quakes but this has not been implemented with just a cell phone as a single unit. This particular chapter especially takes up an automobile accident as a specific use case and provides a solution to detect and report automobile accidents. This can also be extended to earthquake detection. This system can serve as the platform with a combination of contact and force sensors for further studying use cases of different possible types of auto mobile accidents.

5.5 Way-Go Torch: An Intelligent Robotic flash light

Here the prototype of an intelligent flash light is presented which helps for outdoor navigation by projecting a directional arrow and guides a user from one point to another.

The torchlight can be used for navigating in new campuses, can be used as a tool for search and rescue and also can be used for trekking and biking. By directly projecting the associated meta data like name of the place, distance to target and the heading information the torch eliminates the overhead involved in reading a map and comparing the features in a map with the surroundings to further decipher the map. It is an intelligent-ubiquitous flash light which overcomes the limitation imposed by limited screen size of a GPS cell-phone, a GPS watch or a GPS navigating device used in a car.

5.5.1 Introduction

This intelligent flashlight is primarily designed for the purpose of navigation. Currently GPS devices exist which provide navigation support outdoors for cars. Also navigation can be done by just manually reading a paper map but be it a digital GPS navigation aid or a paper map, map reading skills vary from person to person. Not every person can decipher all the information in a map. Understanding the symbols and annotations in a map and translating them to physical landmarks like buildings and roads is not a trivial task. Map reading induces an overhead in navigating new paths. So a device which would make this job easy and remove the overhead and burden associated with maps would greatly ease navigating new places. Also map reading is crucial in search and rescue scenarios where the time spent on understanding a map to plan a route for rescue could be an important factor in saving lives. The WAY-GO torch presented here also serves as a tool for search and rescue. This device is an improvement in basic flashlight design which ubiquitously combines GPS, AHRS (attitude heading reference system) and a pico projector in a single flashlight.

5.5.2 Related work

The system tracks a person using a camera and uses a projector with a rotating mirror to project the interface on virtually any surface. Some approaches have combined the projected displays from several projectors and created a large scale display interface. Especially this idea has been used in virtual reality projects where an entire room or a passage is lit up with virtual worlds using projectors.

a) Indoor and outdoor tracking for hand held projectors

Almost in all the projects involving projected interfaces using a handheld projector an IMU or an accelerometer, a magnetometer or a compass has been used to get an idea of the orientation information. The use of an IMU is applicable both in indoor and outdoor environments to get heading information. However the location information for indoor and out door environments vary and in some cases it is challenging. Outdoor localization using GPS or cell phone signal strength is a simple solution but indoors it is not simpler to maintain a map of the physical surroundings and the objects just with the RFID tags and then further recalibrate the projected data to suit indoor environments with curved objects,

The work done by Dr.Ramesh Raskar [1] and his team on the geometrically aware projectors highlight how indoor location to projectors can be conveyed using RFiD tags. Localization in indoor environments is a tricky problem which requires redundant hardware. RFiD indoor positioning in iLamps is a solution which would stand as a bench mark in environments like shopping malls, libraries, and ware houses. Tracking of projectors can also be done externally by using IR tracking systems like The Vicon to get location information as discussed in the handheld projection research by Xiang Cao[2].

The paper on path light [3,4,5] also says that map reading skills differ from user to user but maps have the advantage of greater choice freedom. Guidance can be based either on visual landmarks or be decided from the current position. However the solution to group navigation even in indoors or outdoors is in the nascent stages. Path light project also discusses about using RFID tags for indoor positioning in museums for location and exhibit information like videos and presentations.

The project here[6] implements outdoor augmented reality using a GPS, a camera and a consumer laptop. The importance of this project is that AR applications were limited to indoor regions due to the lack of proper 6degree of freedom localization in outdoor environments but here tracking over large scale outdoors is done using a GPS. Here in Way-Go torch we use a GPS and an AHRS to obtain 6 d.o.f localization.

Some forms of user triangulation [7] in indoor and out door environment don’t use any markers. Multiple cameras are used to calculate the user’s pose and position. This actually has a great implication in simplifying indoor tracking for assistive museum navigation by just using the security cameras, though its ethical implications are a wholly new topic of discussion. Outdoor environments to certain extent can also be equipped with cameras like street cameras for user tracking. Even the cellphone's signal strength can be used for tracking a user to provide location specific information outdoors.

This paper [8] on 3D GIS shows how one can use mobile displays like the HMDs to augment the physical world with virtual data and turn it into a GIS system. It also [8,pg39] throws light on how handheld devices like cell phones and palmtops be used for GIS applications. It still has the burden that one has to read the physical map, the VRML models and there are other UI burdens which act as a overhead in translating the virtual map into the user's understanding about the immediate physical world.

What appears to be essential in all the outdoor and indoor navigation projects using projectors is a way of tracking them, having an idea of the surroundings, an intuitive interface which gives away with the un-necessary details but makes the users understanding easy and relevant to the context or scenario in hand. The pictorial representation especially the over-head view might be easy when seen on a large screen but when one is standing in that real world scene, in a totally new, unexplored environment trying to draw the simile between the physical world and the 2D map of symbols could be quite a task and it needs some experience

b) Flash metaphor and projected Arrows

Path light [3,4,5] uses a mobile projector along with a cell phone and serves as a mobile tool with a projected interface for navigating indoors in a museum. It assists in group navigation and group decision making about choosing which exhibits to see next. It uses a mobile pocket projector along with a cell phone. One advantage of the mobile projector is that it can be used as a collaborative space for planning a team's itenery in a museum.

Navi Beam [9] discusses about using projector cell phones with interfaces for shopping malls. The system discusses about using a projected arrow that rotates and guides a person from shop to shop with in a mall. For localization information they have suggested about using AR markers. The interaction with the projected UI from the projector mounted on the waist belt is done using the shadow of a finger.

The Microsoft “future productivity and vision” concept video [11] shows an interface that projects an arrow on the floor to guide the user towards his friend’s position in an airport and towards the exit.

Another product named the Ecco GPS locator[8] helps locate ones car or any of the 3 stored positions. It shows the directional arrow using a GPS. The design of the GPS keychain is mentioned here.

The map-torch [20 ,pg3] light application uses synchronous projection to illuminate larger maps with several areas of interest

The flashlight metaphor has also been used in creating games like the flash light jigsaw puzzle [16] on large scale public displays. The game uses group collaboration and can also be played in ad-hoc mode. The player has to arrange a virtual projected puzzle using the movements of presentation controllers which are tracked in 6 degrees of freedom.

c) UI consideration in Pico projection research

This paper[20] stresses the importance of pico projectors being used in the research today. Since they are tiny and production costs have come down it is no longer fiction to include such engines in mobile devices. It mentions about several parameters that governs the UI design in pico projected displays. Here in the Way-Go torch the micro-controller generates a 120x90 display. The field of view versus the intensity of projection over distance was a judging parameter in considering the thickness of the projected arrow and even the font size.

Also the alignment of the projected screen as per the curvature of the object being projected at makes the projected data readable and usable. Some of the earlier works by Ramesh Raskar [14] involve stabilization by using fudicial markers on the wall which were then replaced by projected laser markers. The orientation of the projector with respect to the screen was estimated by knowing the distance between the projected markers and their relative angles. This was further used to adjust the projected screen.

UbiSketch[15] demonstrates projection while sketching on a large mobile. Some of applications of ubisketch involved projecting their own digital faces onto themselves. Some applications involve superimposing real world drawings with virtual paintings.

Handheld stabilization and projection onto moving hand-held surfaces is discussed in paper [17]. For this objects are embedded with light sensors which capture the temporal projected sequence and from that their location in the projection plane is known. With this the projected content is transformed accordingly.

The paper on the side by side multi user projected interaction is especially interesting because of the hardware modification of the projector. Interestingly they have modified the projection engine with IR Leds that help in uniquely identifying a projector and thus a user. The simplicity of this solution for shared projected workspaces is really appreciable.

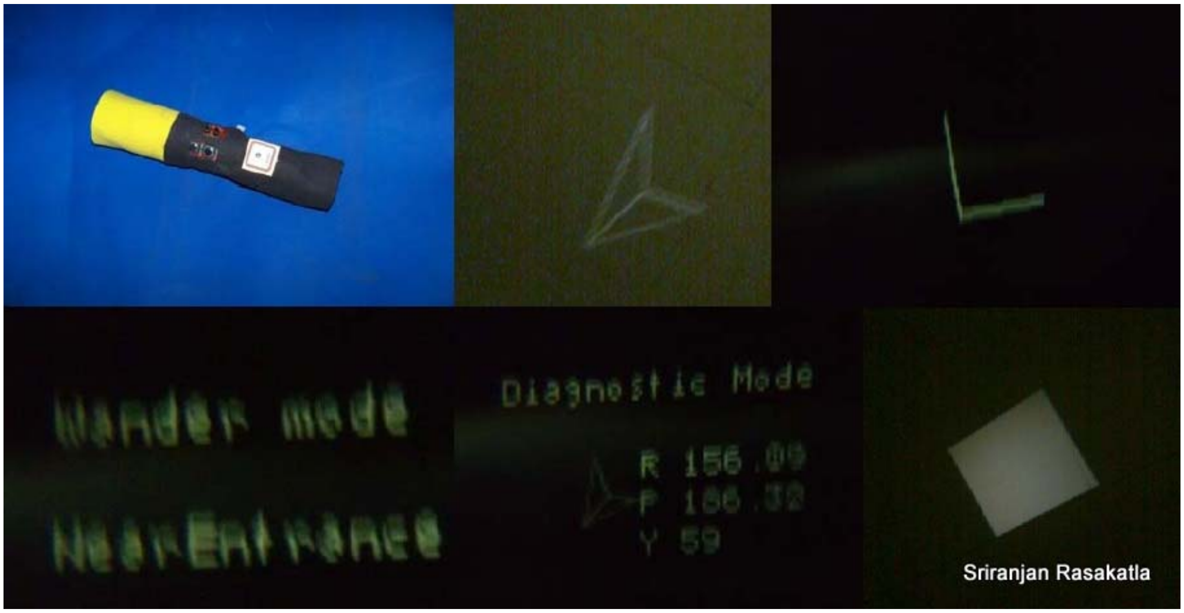


Fig 9.0 Way-Go torch ver 1.0 with CREE Led and projected UI

5.5.3 Hardware Description

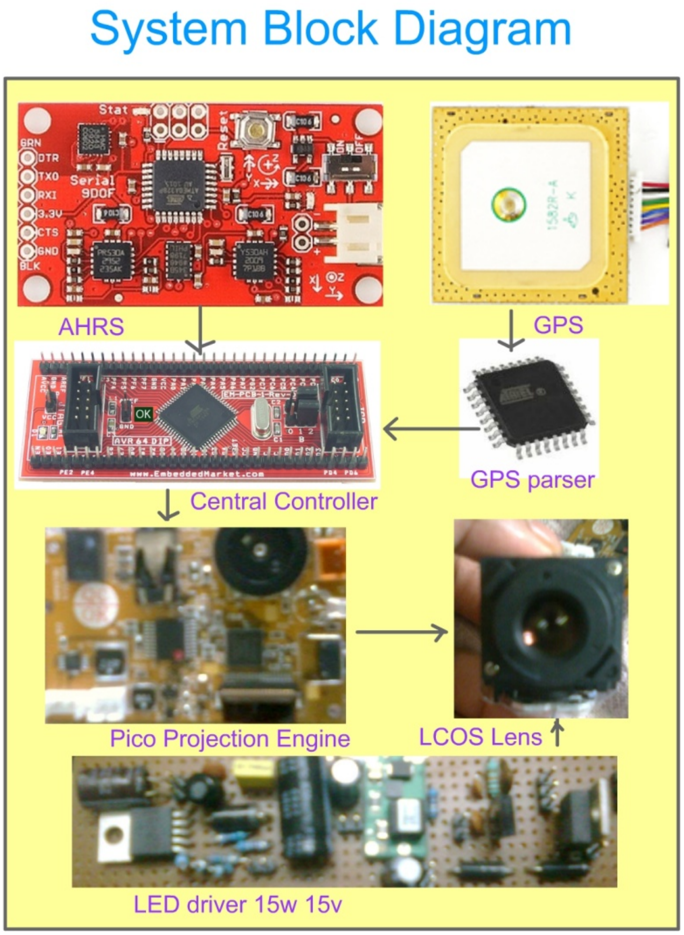


Fig 9.1 Way-Go Torch Hardware Schematic

The WAY-Go torchlight system can be best implemented using a cellphone which has a pico projector embedded in it.

The torch light uses a 60 channel San jose GPS receiver, an AHRS from Sparkfun, an Atmega128, a 3M LCOS modified pico-projection engine. It has a 2 degree of freedom servo setup that can make the projection head move in 2 directions. The Atmega128 parses the roll, pitch and yaw sent from the AHRS and the GPS data. Currently the torch light is run with a 1100 mAH 7.4V Li-Po battery. It gives about 15 minutes of run time with the servos of and about 8 minutes with the servos on. The LCOS projector initially came with an inbuilt driver on the projection board but it got burnt during experimentation. A more reliable constant power driver was designed using TI's constant power modules. Driving the Led with separate driver boards rather than the projection engine's driver improved the life of the projection engine and also reduced the heat produced in the board itself.

To improve the luminosity the default CREE LED was replaced with a more powerful CREE Led. CREE LEDs are widely used in hand held pico projectors and long distance focusable flash lights. To further improve the luminosity several LEDs from different manufacturers were experimented with in the design. Parameters of the LED like the drive current, operating voltage, power consumption, luminosity per watt were taken into consideration to decide the best LED for projection. Though, some of the LEDs provided very high luminosity there was no sufficient place to put in a cooling mechanism using a fan and a heat sink. Some LEDs did not have the proper bin structure and a lens profile to be fit into the LCOS pico projection engine. Lasers were another option and mono-chromatic green lasers of 20mW showed good contrast ratio in the projected data. Unlike ultra-violet and read lasers the human eye is 20 times more sensitive to green color than red or blue and hence green lasers were chosen. Though higher the power of he laser more will be the intensity of the projected data and its visibility in day light. The problem is higher the intensity more quickly the lasers get heated and it requires the installation of bulky cooling mechanism. 5mw-20mW lasers were sufficient enough to conduct eye safe experiments wearing goggles and turned out to be a good choice because they generated less heat, had a sufficient on time and had low power consumption. The pico projector setup had two half silvered mirrors with a convex lens setup. It was difficult to spread the entire beam on the LCD aperture. So to sufficiently illuminate the aperture 4 lasers were used and precision aligned using a custom designed laser holder

Table 9.0 A comparison between different LEDs used

S.no	**LED Model**	**Lumens**	**Power**	**Current-Voltage**
1.	CREE XLamp XRE	107		1000mA
2.	CREE XLamp MCE	430	4	700mA
3.	LedEngine LZ4-00CW	703	15	1500-14.5
4.	Seoul Semi Conductor	900	10	900
5.	Green Laser		20mW	60-3.5

Different lens setups were also tried out using a combination of diffusing plastic sheet, Fresnel lens and convex lens. The diffusing plastic sheet spread the luminosity but the projected image did not have good intensity. Later the lasers were directly mounted on top of the half silvered mirror in the projector.

Today phones are equipped with mobile projection engines can serve the purpose of such applications in indoor environments with moderate ambient illumination. However such projectors do not have sufficient luminosity in their projecting LED to form a high luminosity high contrast ratio image.

Some of the DIY projects show how a high powered laser can be used to get projection over a long distance with a good contrast ratio. Nowadays PICO projectors from micro-vision usea a laser with a MEMs reflector to achieve a high contrast display. These also do not require focusing optics because the image is actually a laser dot being swept vertically and horizontally at high speeds.

The initial version was made from a flashlight shell available off the shelf. The version 1.0 and 2.0 were CAD designed and printed using a rapid prototyping machine. This helped us print parts with precision alignment for the laser diodes. The model was designed to accommodate all the electronics in the standard form factor of a flashlight. This was important because the flashlight would look more ubiquitous in design.

5.5.4 Software Description

The WAY-GO flash light uses an AVR atmega128 running at 16 mHZ. The technical challenge was to store the entire campus map in the form of 25 GPS waypoint where each point was two units of floating point data, parse the GPS data and calculate distances correct to 4th decimal point, parse the IMU data at the same time, decide the heading and distance information and also generate a PAL video signal for the projector. The micro-controller also handles the geometric transformation from the IMU frame to ground frame and then to the projector's reference frame. The AVR controller also uses error control techniques to identify faulty GPS and IMU packets. Coming to the computational requirements it is possible to handle several instruments and sensor data with the localization data and command the onboard actuation module using such minimally computational micro-controllers. For example, the recent Mars Exploratory Rover [20] uses a computer that runs at just 20 Mhz but handles several instruments and precisely control them.

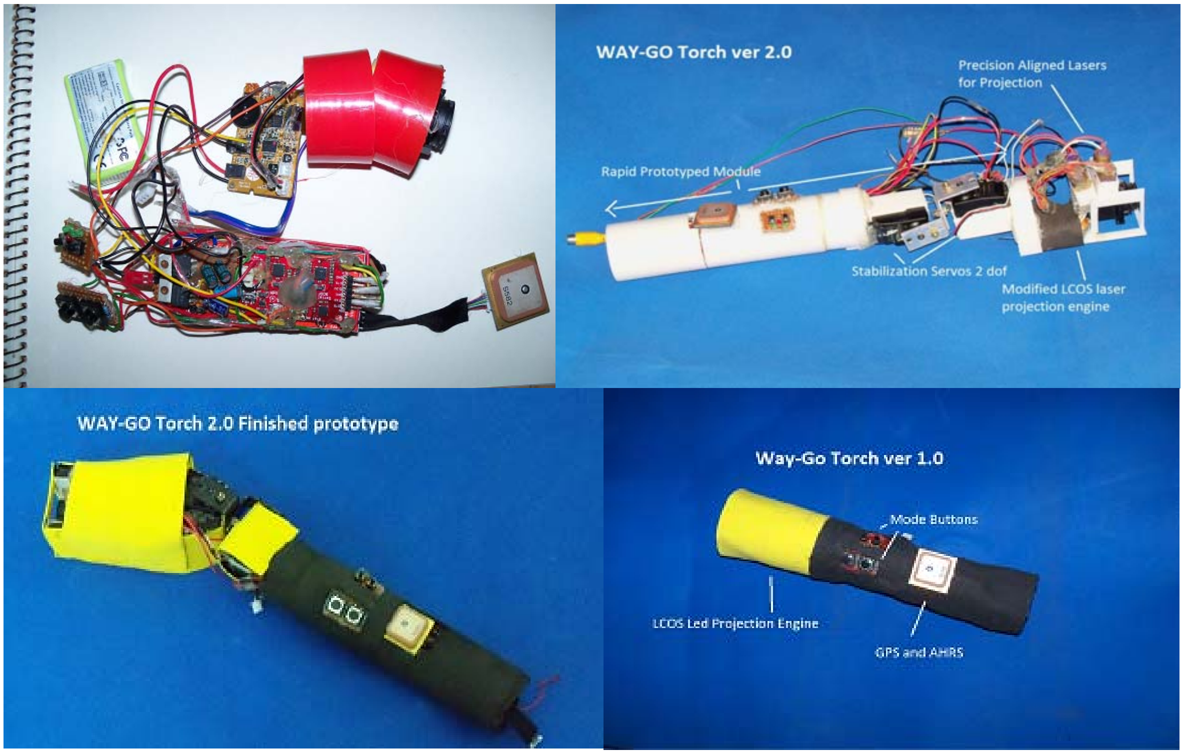


Fig 9.2 Way-Go Torch assembled prototype, Rapid-prototyped shell with custom laser mount for Pico Projection Engine using a 2DOF servo stabilized setup.

5.5.5 Operating modes

The torch operates in the following modes

a) Show path mode

Initially when the torch is booted it finds all the possible paths from the entrance gate as its source to other destinations in the map. During this process it sets up the look up tables for each path containing the intermediate way points. One can select the source in source selection mode and the destination respectively. It would then chose the appropriate look up table or calculate again if necessary. While navigating in a chosen path it would show the nearest intermediate way point considering the current GPS location. During this the user has to proceed in the direction of forward projected arrow. If the user tends to rotate or move away the arrow changes its direction with appropriate correction. After reaching a waypoint it calculates the heading to the next way point and the distance to it. When ever the user is in about 1.5 m radius from the waypoint it sets a reached flag. The GPS accuracy of 1 m was achieved in the flash light with the current GPS device.

b) Diagnostic mode

This mode projects the meta-data from the IMU-AHRS (yaw, pitch, roll) data, the GPS latitude, longitude and signal strength. The microcontroller calculates if it is a valid IMU packet or a GPS packet using cyclic redundancy checking and this helps in diagnosing if the WAY-GO torch is working properly or is showing the wrong direction. The diagnostic mode can be used especially for indoor environments where getting is GPS fix is impossible. One can still get an idea as to where the magnetic north is from the IMU data. This in turn can be used to identify blocks in a hostel building say if it is the north block or the extended block. It can also be used to get an idea as to where a room with a particular room number can be, say if one is new to campus and wants to meet a friend. Generally the first time experience to find a particular hostel or a block or even a room in it can be pretty tiring, but this diagnostic mode coupled with classifying the 3D space with directional data from the IMU solved the problem.

c) Flash light mode

The torch can also be used as a basic flash light in the full lit mode. The LCOS projector uses an LED as a source of illumination, so with the entire pixels set to white it would function as a flashlight.

d) Wander mode

The user need not set the path in this mode but can just move around the campus and the torch would project him info about the nearest position. Especially if one has to use this for hiking, for exploring a new place, touring a new campus this mode will be helpful. People who are new to a particular locality say a college campus can be given this torch light to go around and explore new places in the campus. One more use of such a tool is in shopping malls where the buyer is directed to the appropriate stall. The meta data can be used to know the direction of nearest exit say in a shopping mall or an airport.

e) Biking mode

Blaze[1] is another product designed by Emily brighton which projects a static laser image onto the road in front of the bike. As she says about 80% of the accidents occur when cyclists are traveling straight are hit by motorists driving into them. The bright green share lane symbol would help motorists see the symbol and get an indication that a cyclist is near by even if he or she is in the blind-spot. Some of the products [2] create a virtual bike lane to give a visual indication for other bikers on roads to join when there is no physical divider. This also warns other high speed vehicles.

This projector can also be used on bikes to project the desired heading information on the road ahead. The biker always looks on the road that is directly in front of him. At a distance of 8-10 feet holds the decision making region. Say if there are any pits on the road ahead the biker can actively use this information to maneuver his bike around or apply brakes. If a hand-held GPS device is installed on the dashboard of the bike it would be difficult for the biker to change his foveal attention from the road and onto the screen again several times. This change in foveal attention would be tiring, inconvenient, distracting and could also cause accidents. On the other hand if the relevant information is projected on the immediate path ahead the biker can effortlessly drive and make decisions as to where he should turn, especially if the projected meta data falls in the portion of the road which is conventionally illuminated by the bike’s head light. If it is a car the information can be displayed on a transparent and flexible OLED display attached to the front wind shield or the data can even be projected using a roof mounted flashlight.

f) Bio-Logically inspired Head Lock stable projection mode

Some of the birds exhibit head lock mechanism such that even if the rest of their body moves their head stays fixed to a particular position in space. Some de-blurring techniques for cameras estimate the direction or motion and remove the photo blur after it has been shot. Some of them even use accelerometers to change the orientation and align it properly after the shot has been taken. Optical flow can also be used to remove the video shake and stabilize it. Well if we extend the same idea on output video devices like the projector it can also help in stabilizing the projected data. Here the torch’s roll and pitch were measured using the IMU and the same were used to counter the change using a two degree of freedom servo setup. Here the stabilization using the 2 degree of freedom servos does not take place at video frequencies but the mechanism can also be used to bring robotic animated features in the torch's behavior.

5.5.6 Usage scenarios

. GPS aided navigation in cars is achieved using hand held devices with LCD displays fitted to the dash board that show the path with an arrow and give audio cues about direction. If the vehicle driver has to look at the road and then change his focal attention on the tiny LCD screen on the dash board for details about the position and landmarks could be inconvenient and in effect could be dangerous. It would be better if the road itself is augmented with necessary driving guidelines. This is done to some extent using traffic lights, sign board which show meta-data like how far a landmark is, if there is a sharp bend or a speed breaker ahead.

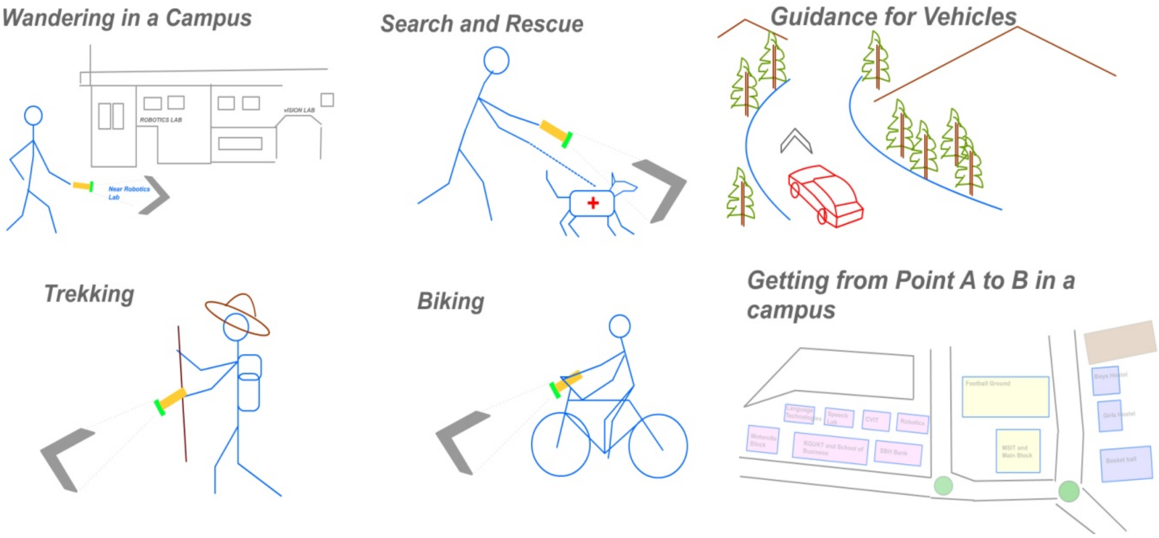


Fig 9.3 Use cases for the Way-Go torch

One need not have a co-driver when the data is projected on the road ahead or the front wind shield. This is especially useful for people traveling in cars over mountainous roads and there is no proper street lighting, for bikers who are riding up a hill and for people who go on trekking. Many people take minimal gear with them when they go for hikes. If equipment like the WAY-GO torch is facilitated ubiquitously, then people would never forget nor require specialized equipment like a compass, or a professional GPS device with a map or a GPS enabled watch.

The beauty of this device is that one need not limit oneself to the limited screen-size that the GPS devices in cars, cell phones, or watches offer. One can project the data any where they want to, be it on the road ahead, their palm, or the wall of a building. Map reading skills are varied among people, not everyone can decipher the symbols in the map and relate them to the physical surroundings with ease. This device gives away with such a limitation as the map itself is stored and related useful information is projected ahead. It is an overhead to read the map, learn how information is represented in it and then use it. This especially induces a delay in navigations. Probably for this reason the GPS devices in the cars come with assistive voice messages which tell how far a way point is, where and when one has to take a turn. Mostly people set their source and destination in the GPS device before they start their journey and listen to the voice messages. If one has a friend sitting in an adjacent seat he can look into his phone and guide the driver accordingly. In case of small size vehicles like bikes traveling on roads with less traffic density the WAY-GO torch would be useful. It projects a directional arrow to the next pit stop and gives the distance-heading information.

Imagine a search and rescue scenario. Say there is an earth quake or a tornado and people are stuck under the debris. All the houses and buildings around are collapsed; there are no clear road ways as they are covered with debris. Typically a rescue worker looks up a map, identifies possible locations of homes as they are the places where people could be stuck. Then he takes a team and spends time in understanding the surrounding, looks into his handheld GPS aided device or a printed map , tries to identify the possible landmarks from the collapsed structures and then sorts a plan out. The planning and search process is slow. It can be speeded up by using these torch lights which directly project the landmark information giving away with the over head in reading the maps and identifying the places. The search and rescue personnel can use the same torch to search for people in dark areas but also navigate in the night. The cost involved in Search and rescue scenarios is too high that one cannot wait for daylight and it needs to progress with the same speed as could in the daylight. The flashlight proposed here would greatly aid a rescue worker.

a) Meta data to save lives

The idea of projecting context specific meta data using a projector stems from the Sixth sense project. In the pioneering work my Pranav mistry and Pattie maes it shown that relevant real time meta data projected onto any surface near by when in a shopping mall, in an air-port, or in a library while browsing a book can actually augment the user experience. If the same idea of seam less access to data in a search and rescue scenario is used it should improve the process of search and rescue. The relevant data of landmarks, waypoints, GPS position, distance to the rescue location and the magnetic north can actually give a rescue worker the needed edge to save lives in time. The same has been done here and we feel is an important use case. The system can be made further sophisticated by using Maps feature to provide a better understanding of the surroundings as per the user's needs.

5.5.7 Conclusions and Acknowledgements

We would like to replace the IMU from Sparkfun with its latest hardware revision to make the flashlight's performance robust. Finding good intensity lasers was difficult. The current 20mW version used is just good enough for day time palm projection. Replacing it with higher 1W green lasers will make the projected image visible even during the day on roads.

We would like to sincerely thank CRE for sponsoring LEDs with whose initial contribution this project would not have taken a step further and DST (Department of Science and Technology- India). We also thank T.J David of the Innovation department for helping machine laser diodes and with his guidance on using the workshop.

6.HOW IT ALL WENT- FROM THE BEGINNING TILL THE END

To the Reader,

"….In this thesis we explore natured inspired design and how some features can be used in robotic system building. We also use interfaces which are natural and intuitive in controlling such robots. We also discussed on how we can use interfaces to build assistive and life saving applications. Some of the interfaces designed here are bio inspired and use to control bio-mimicking system. We also discuss about how computer interfaces that have been built to move mouse pointers have been extended to the real world. We also present an evolution of modular designs which are bioinspired. Building

newer systems that would be useful, help the process of search and rescue thus saving lives, for improving the quality of life and help in devising critical application has been the idea behind the engineering presented here…."

We use nature to take shelter; we learned how to interact with nature to stay in harmony with it. What if we use some of this knowledge to build systems to protect ourselves in the times of disaster? Most of what we engineered initially had its roots in nature and what we learned from observing it. Most of the robotic equivalents like bipedal robots, 4 legged robots is about our desire to learn about nature's engineering and to master it. How we caress and pet our animals can also be used to develop better interfaces that are nature inspired in interacting with bio-inspired machines. This way it would be more intuitive because if we interact with machines as to how we deal with objects and other creatures in the real world it would add the spirit of a living interface between us and the machines. Be it for search and rescue or guidance or critical applications an interface and design that is more nature would achieve engineering supremacy and help out designs mimic that of the best engineer that is nature."

Through this evolution we discovered that interfaces used to move objects in the virtual world that can also be extended to mechanical objects in the real world and thus we also worked upon closing the gap on how HCI evolved into HRI. The spirit of HCI actually stems from how we interact with objects around us in the real world and this metaphor was then extended in making the use of computers easy through a mouse pointer which could access the objects on a screen.

Now when we extend the same idea to robots we are addressing the same metaphor of interacting with objects. When a life less object is given a spirit, a form of robotic life through motion and when it can be intuitively controlled through gestures as we were handling it in real life then we are closing the loop further. Building such interfaces can actually enable us to use such systems better. We humans always engineered systems which would make lives easy, improve the quality of life and made systems that can be easily handled. So an interfaces plays an important part even if it is acting as a bridge between the user and the operating system, even if it about controlling a simple machine which is for a daily routine task like a washing machine controlled with a single button, or per say an autonomous car which can be turned from manual to safe auto mode through the touch of a simple switch or an interface for a more critical and complex system like a search and rescue robot. Interface not only would allow a machine to be used easily but in many cases the interface in time critical systems like a search and rescue machine would allow a search and rescue worker to use it better, in a more efficient way. Because if we can make the process of search better and faster then the amount of time taken to search would come down and rescue would come even faster and more lives can be saved. Because in a time critical situation especially after a disaster like an earth quake or tsunami it is the amount of time from when a person gets trapped in the debris to the time he/she is found by the rescue team is what saves the life. As Steve jobs said if we can make the computers a bit more faster and the life of people a bit more productive through applications like business calculators then we will be saving few tens of seconds in each lives and when this is applied over all the users using computers we would have saved much more time and pushed humanity a bit further a bit faster. Interface not only works in the direction of a person controlling and commanding a machine in an intuitive manner but if a robotic object that is being handled is to appear more friendly then how it interfaces back to the human also matters. Can it convey an emotion, exhibit a form of spirit or exhibit a form of life, mimic it at some level using cyclic motions giving humans a visual clue that it is actively responding back. The robot exhibiting a behavior to the person who is interacting with it actually matters. In this way an interface is not only making the command and control of a machine easy in one direction but it is also about how the machine responds back. So interface here even in controlling a robot is not unidirectional but also bidirectional as to how the robot responds to a person's gestures. We exist with the world around which has both the living and non-living by interacting with it. We are never isolated with the world around us and for every action we have on the surroundings there is some form of a feedback. Even if the earth is considered as a non-living object what ever we do to it there is a response back from it. So here our interactions with the environment around us are in itself through a hidden interface and which is so trivial that we do not observe it distinctly. If it is a living object like an animal say a dog as to how we interact with it could be the root cause of making it a domestic animal. Here the interaction between a man and a dog went far and it became the man's best friend. Today the same friendship that we share with a dog also made it trustworthy and reliable that it could also be used in a search and rescue scenario to find people stuck in the debris. The domestication of a dog through actions is a form of interacting with it and how we interface with it and how it interfaces back. The same naturally observed interface paradigm was taken a bit further through Sony’s invention of the robotic dog Aibo. The dog was given sensory skills by embedding tactile, light and force sensors through which it would detect how a person is playing with it and it would respond appropriately back with actions like wagging a tail, running towards and nodding its head. So here in this Sony has bio-mimicked the dog's structure through a robotic form and also the behavior and relation that we share with it through software and hardware to detect the interaction. Wild animals when domesticated through the right relation can actually save people’s lives. That is how we interface with an animal can actually turn it into your friend and be your savior. Now if we try to mimic the natural counterparts through robots and make their control or rather the relation between the robot and the human more natural it can be better used in critical applications like that of a search and rescue scenario to save lives. This in a way would also improve the relation between the robot and the human. The interface would also give a life and a spirit to a non-living mechanical object with cyclic motion because when actions become responsive to an event and to an event that is a human gesture then the correlation of the mechanical robot to life increases further.

Now given that we make mechanical objects and engineering to make lives easy but there is more to it. The engineering spirit not only serves for the spirit of invention, discovery and design and not only it is for adding to the quality of life, making it more comfortable but also we engineer to make our lives safe. Automobiles were not only invented to make our travel comfortable over longer distances but now the effort is to make them safer through autonomy. Global positioning devices have not only been invented to provide useful place specific data, provide semi-autonomous navigation but nowadays to track things which value the most and are also being used as a beacons to signal during the time of an emergency. As envisioned in the movie I-Robot we are designing robots which one day would save our lives, make our lives easy through their actions. Autonomy in robots as such would push towards saving time on routine tasks that we can use our valuable time to improve the quality and enrich our lives. Building robots which would handle a specific task with full autonomy in all cases is still far away but it does not stop us from engineering better systems. Bringing science fiction to reality has taken place in several scenarios of gesture interfaces especially with the movie “Minority Report”. In the movie the hero who is a policeman uses a futuristic non-contact interface to use a computer, manipulate a video file, move pictures and virtual objects on the screen around which was a futuristic interface. This was turned to reality during our life times by the pioneering efforts of Pranav Mistry and Dr.Pattie Maes through the Sixth sense device. Here the sci-fiction was taken one step further that there was no physical device just as the transparent monitor in the Minority report but a mobile projector which can make any surface informatory by projecting relevant information. Projected applications to draw and move photos around would turn any surface into an interactive device. Such relevant meta data can not only be used for general applications of drawing, photo viewing but for critical applications of weather and more which involve navigation. Our struggle and co-existence with nature has pushed us towards engineering systems that are built around our own observations of nature and what we learned from it. We used this to protect our selves from it and also to enrich our knowledge that could prove critical to our survival. Weird thing with nature is that though on its basis we survive, life is supported but also we face its wrath from time to time. We have to prepare ourselves to learn from it, live with it, be in a peaceful co-existence without pushing ourselves to an unstable equilibrium but towards a more stable equilibrium by protecting ourselves from it in critical and dire situations during the time of natural disasters and calamities. As we engineer better systems we improve our working knowledge through research on the same and this contributes not only to our development but more importantly for our survival and when we say better systems , systems that are not only an engineering marvel by their design and complexity but also through autonomy and through interfaces which make them autonomous. Today we have built robots that can negotiate terrain which was previously thought to have been non-negotiable by wheeled automobiles through bio-mimicking legged animals. The invention of the aerodynamic design of the plane and the first flight were from observing the flight of the bird. Through most of our engineering innovations we have observed nature and bio-mimicked it in several forms as we try to achieve mastery and try to parallel nature in several areas. Today we were (ref MIT legged lab Cheetah) able to build the fastest 4 legged robot which runs faster than a human and the design is again bio-inspired.

The idea of bio-inspiration is through our observation and interaction with nature since human life first took form on earth. How we interact with bio-inspired design and the systems we engineer is also in a way closely related to the Newton observation of nature in third law. Any action results in an equal and opposite reaction but in case of interfaces we design the system in such a way that our action will result an action that is desirable and needed, an action which characterizes the function of the system and that is useful to us, an action that the system is intended to do which again contributes in making our life better. So the spirit of innovation and research in engineering and design has been to enrich our knowledge and we use this working database of knowledge for safe guarding life and moving it a step further. Another reason we follow a bio-inspired design is that life in its struggle with nature for survival has adapted in form and functionality that it became more robust and more rigid to its harshness but also flexible that it sustains itself through the change in nature as time progresses. So when we are taking a bio-inspired design we are actually using a solution that nature provided to us through its several iterations that is better than its form when it first originated, we are taking a winner from a form of genetic evolution. So using such designs and adding our engineering ingenuity and new thoughts would further add upon the nature’s solution.

The evolution of this research began with trying to find new ways to move a mouse pointer. When personal computers were initially designed at Apple the idea of using a mouse to access the software functions and programs depicted as virtual objects was to provide a more intuitive feel just as in the real world we would pick up objects on a desk like a pencil or a cup with our hand. If we really have to manipulate software which is the rapidly changing state of the semi conducting transistors on a computing board we might have to shrink our selves to micro-meter or nano-meter scale depending on the architectural scale of these devices and appear simultaneously at the location of each of these gates. For a single computing machine to work at even 1 Mhz several hundreds of transistors change their state to give an equivalent computation speed of 1 Mhz and if we would have to do it, we would have to appear at the position of these gates several hundred times to manually switch the position of these gates multiplied by their actual switching rate which would give an equivalent speed of 1Mhz. Well it was a great idea that the switching can actually be controlled electronically without having to appear at each position but by sending a pulse of voltage along a main bus. Then came different settings of these output stages through a different combination of flags which would give a different state to the device. A sequence of such states given through a machine level code improved the programming of a machine. We tried to improve the interface further that is its programmability by using high level commands and then came further high level interfaces through flow charts, symbols and picture based programs. Even depicting the code as a picture or as an icon or as a block in a program flow code is a form of interface that helps in managing the function of the machine for a particular purpose well. One way to define a function is a set of lines which runs a specific task again and again when called for but function also sets the state of the machine and it is what defines the machine's behavior and behavior is a form of interface. So how we set the state of the machine and how we define its behavior is also of interest when we interface with it by either writing a piece of code or depicting it with a different form pictorially or controlling these pictures or icons by the means of external physical devices. Because if we could be the characters in Tron we can actually view the state of a machine, it sub blocks and peripherals and the code that defines its behavior as physical objects that we can feel them, manipulate them with physical touch and change it function, shape, configuration and behavior. It is actually through a graphical user interface and an output device like a screen that we improved our access to a machine. Because if no one ever envisioned a screen of a graphical user interface we would have just been limited to observing the state of the machine through a set of bulbs switching their state or through mechanical cogs as Charles Babbage once envisioned its design or we should have waited for the day until we can enter into the machine’s virtual world like Tron or Neo in the movie Matrix did. Even the movie Matrix envisions a different form of interface to a machine that which is different from using a GUI with a keyboard and a mouse but that which is close to nature, to be right an exact replica of nature as we observe around us and the programs envisioned as people, physical artifacts and other living and non-living objects in motion. Invention of the mouse and GUI was a break through in depicting the state of a machine through an output device which was an active form of paper with symbols describing its function. The motion of mouse through a physical motion in the real world was our connecting link between the real and virtual worlds. It is this link which is one step closer in making movies like Tron and matrix a reality. We were plugged into the virtual world through a single manipulable object. Devices like the new Microsoft Kinect actually help in creating a physical virtual replica of our body in the virtual world that we can manipulate the virtual world just as if it was real. Imagine that instead of moving a physical device and instead of routing our action indirectly via a secondary object to access the virtual world, we make the mouse pointer move with features on our own body. All we needed was a moving link between the physical into the virtual world to get a sense of interaction with it. So any physical motion like the head motion, hand or leg motion or the motion of eyes if can be sensed and co-related with the motion of the pointer on the screen then we are removing the via link but gaining a more direct and a real form of interaction and of control over the virtual objects. So in the virtual world instead of using a virtual pointer to manipulate virtual objects if we also remove the “via” link we are actually moving further closer to replicating our motion and our physical presence in the virtual world. The Kinect did the same in fully replicating the entire body’s motion which is essentially the motion of the skeleton through skeletal tracking. Skeletal tracking would make our virtual presence unidirectional complete that we now have a virtual replica which is active, which mimics our every motion, which helps us in creating an actual virtual presence in a digital world. The idea of using avatars in the games like second life is also about creating a digital equivalent of the real self. What more is that the digital world unlike the real world can be shaped as per our interests, our imagination and fantasies. The virtual avatar in a way gives more freedom of manipulation that defies the laws of the physical world as was rightly said my Morpheus in the movie “The matrix”.

So in an attempt to move a virtual object we tracked the motion of a colored cap. This colored cap was a real world equivalent to a flash object “the earth” on the screen. The motion of this object was tracked using a camera and the virtual object was also given the same motion. Now here still the object was acting as a via link but better than a wireless or a wired mouse in the sense that it could be any generic real world object with color which can be given a digitally defined custom avatar. Later we thought of improving this interaction by linking directly the motion of the body here a human face. Initially the control was crude like a 4 directional joystick but here a 4 directional virtual key. The head itself was the controller which was working as a 4 directional joy-stick. There was no need for any other form of electronic controller or a physical controller but the one who itself thought of the control was directly the controller and was directly the interface to the digital world. Because to remove the via link and make the user who generates the intention to interact with the virtual world the source in itself improves the intuitiveness of control and pushes it one step further in bridging the gap between the digital and the real.

The control itself was made intuitive just as the transition of the mouse pointing devices from joystick to a roller mouse was made by directly mapping the motion of a facial feature to a selection block considering the screen as a matrix of cells. When one replicates his action in the digital world the job is just not done if just the motion of the body is replicated but also other actions like speech, hearing and other sense are to be served. So here a selection of a particular cell was done through natural voice. A voice detection module runs along with a face feature tracking module to replicate and bio-mimic the action further into the virtual world.

Not only does the idea of replicating the human motion onto the virtual application is driven with this but the idea of interfaces is to improve the ease of use to an extent that even a physically disabled person can use a computing machine. The movie Matrix also envisions the idea that a person with a physically challenged form can have a fully working physical form in a virtual world that gives a real feed back to a person by a system that taps into his central nervous system. This was taken one step further in the movie “Surrogates” where people are given time less bodies with their robotic equivalents and even the movie “Avatar” where people have a different physical form giving them access to the real world though a biologically synced body both at a physical and meta-physical, sensory and perceptual levels. The camera mouse experiments and the applications developed give a real user a virtual surrogate in the form of a virtual plane that he can fly through a graphical scene using his natural head motions. Not only is the user’s head a controller but he also has a surrogate virtual object in the digital scene. One another interesting application that emerged from a real world behavior is about arranging objects on the screen in a grid pattern and accessing it through mimicking natural motions like that of the head and the voice. Here when we build buildings, arrange objects at home, design shelves or design UIs on the screen we do one very trivial thing that is to arrange objects and in case of UIs it is about how we tile them up over the screen. When objects are tiled up on the screen you then get to see every object as a preview and open it when needed and with this the UI becomes more intuitive. It is similar to this say you go to a shopping mall and you go the garment section. You see several clothes put in the shelves, arranged neatly. You just browse through them, have a glance at them looking at the color, feel the texture and then you touch to try it out. So also the photos were arranged in a larger grid pattern and the selection overlay was running in a smaller grid pattern where a person could just have a glance at it and open the photo for a larger view to have a complete look at it. So as we try to bio-mimick our interaction with objects in the real world in designing interfaces for computer operating systems, applications, 3D scenes or virtual worlds we are actually making the interface more intuitive in the sense that is we are trying to replicate the real into the digital and make it better with customization driven by imagination.

Finding ways of making the mouse pointer move with colored objects and facial features also got me interested in the “Sixth sense” like device. An attempt was made to build one but through this effort custom gestures as to how gestures are basically characterized was learned. Now gestures are similarly defined as body postures. A body posture is defined through different absolute and relative angles between the hands, the legs, the torso and between them. A comfortable posture is the one which we don’t feel difficult to be in and which can be easily replicated and be maintained in for a long time. And gestures are a subset of the body posture in the sense that they are much more uniquely identified with the nitty-gritty that goes into it. A physical gesture can include the entire body which gives a visual cue, which relates to an action that is performed frequently and that is symbolic of a particular scenario. Now gestures can also be actions devoid of the object they are being performed on. When Atarii designed an electronic wheel for a video game they were actually trying to take the real gestural metaphor of driving a car using its wheel. So using such physical action metaphors and tracking their motion using electromechanical sensors gives a much more real world meaning to interfaces. For example instead of using a keyboard to type on a screen if one actually uses a pen that senses the user’s motion of fingers and hands to a level that is can also bring out the letters and the transition between the letters then we have not only made the interface better, intuitive but by replicating the human motion we have generated a bio-mimicking interface. This way of replicating the real world into the digital world through interfaces that bio-mimic is better that other forms of electromechanical interfaces or devices because they move the virtual world closer to the real world. So while designing a sixth sense like device we learned that interfaces are defined through minute nuances in gestural position. For example a time based click was used in a grid selection UI of the camera mouse and this was further replicated in a time based click by measuring the distance between two fingers which were in turn tracked using colored fudicials. The distance between the fingers of the two hands indicated a choice making for a selection in a particular part of the screen. Some times the distance between the fingers within a hand itself signified a particular gesture and initiated an action. For example the pinch UI which indicated the selection of virtual object and is equivalent to putting the left mouse button down to select an icon is governed by the distance between the thumb and the index finger or the index and the middle finger. These distances give an idea of a planar positioning of the fingers in the camera's frame of reference which are translated to the UI's reference frame on the screen. There have been several forms of converting motion of the palm, fingers and the hands onto the screen, even other body features and even the entire body. During this a new idea for multi-touch was envisioned. A multi-touch basic draw application was developed using the idea of persistence of vision. This emerged from the idea that two independent hands can convey two different gestures and can be used to perform two independent actions. What if the mouse pointer is flipped between two positions at very high speeds that for a user it gives the impression that there are two pointers capable of performing independent actions? So a simple draw application was designed where the pointer was rapidly flipped between two positions at high speed and when it is at each position it performs a part of a bigger routine. If it has to draw two lines separately each time it is at a line's position it would put the pen momentarily down and would draw part of the figure. Now when done at high speed it would give user the impression that both are being draw simultaneously. This stems from the idea that in the real world we could actually do two different things with a hand. For example we could hold a jar and open the cap with another hand. In the "Bugs Bunny" cartoon Bugs once plays a base ball game where it performs the action of bowling, hitting the ball with a base ball and that of the umpire all at the same time by rapidly changing places and characters. The idea of multi-touch is about the same. To perform two different things at two different positions and may be simultaneously. So does a DJ on a music dash board. Multiple actions using a single body are also found in the nature. A humming bird control its flight with its wings and dexterously moves it head using its beak like a tool to suck nectar from a flower. Gestures are also thus actions found in the nature that we try to extend into the virtual world.

One another device is an accelerometer. Using an accelerometer one can measure tilt and also the extent of tilt and how quickly the tilt is achieved. When the head motion interface to the jet plane video game was designed an important characteristic of the gesture was the inclination. The tilt of the head was being measured using two optical flow tracking dots on the face. The extent and the quickness in tilt were mapped to the exponential throttle control of the plane. Exponential in the sense that a small control input leads to a large resultant motion. This exponential motion is also seen when an optical mouse or a roller mouse is moved quickly on the desk surface. When such a small motion leads to a large displacement on the screen it actually helps in making the UI experience better, faster and seamless that there is no lag but is also natural that one would expect with force. Thus bio-mimicking interfaces also helps in making them better because any natural form of interface is closer to how we interact with the real world. So an initial UI was designed using an accelerometer of a Linux phone over Bluetooth. Just as the physical displacement of colored object being tracked by camera, just as the linear displacement of person face being tracked was mapped to the motion of a mouse pointer in a selection block in UI so also the tilt of an accelerometer was mapped to the tilt of a virtual cube rather than its displacement. Just as gestures are defined both by distance and angles so also UIs can be described based on the linear displacement and even using the tilt. A graphical interface was designed using this idea where a cell phone was mounted on a car and the car's tilt was measured and visualized using the cell phone. This was in a way a port of the real world object a car into the virtual world. When we are mapping the motion of a human we are actually tracking the pose and mimicking it in its virtual model. Human pose tracking is a good problem using computer vision and much more complex than tracking the pose of the car. Now when we port a real object to the virtual world we are mimicking its characteristics into its virtual equivalent, now when want do the same with a rigid body like a car it becomes easy. Human pose tracking could require several inertial trackers to be placed on the limbs, the head and the torso. In some cases facial expression is further resolved using IR dots but a car is a rig body and its entire motion can be tracked using a simpler state tracking device like an IMU system using accelerometers, gyros, magnetometers and a GPS position tracker. Now when a car's motion was mimicked in this UI and tested real time we found that this system helped in visualizing the road quality and the car's suspension quality. For the first time we had both a qualitative and quantitative visualization of the road quality using a cell phone. This observation was accidental. The car tracking emerges from the same idea of state tracking for mapping the motion of a virtual object. It was done with camera mouse like interfaces for video game application, for digital desktop like application, for a grid based selection and a photo album application. In all these we were actually trying to bring the real world into the digital world. The same when done for a car gave a whole new application and a whole new solution for a new problem. Accelerometer interface aid bio-mimicked interfaces when used for human pose tracking. Nintendo also used the

Wii-mote to capture the natural wrist and hand motion and used it for moving a virtual tennis racket and to control a player in a boxing game.

Nature inspired design has always been inspiring to observe, coin and implement. In the first place identifying the design of nature is difficult because we observe it daily and it is so trivial that it escapes our mind. It could be simple on the outside but defined by a beauty of complexity from the inside. Nature has given each both living and non-living objects a different function and shape that is best suited for its job. When it comes to nature, design is everything and it is the design that defines an object with respect to its task. Even when life adapted itself to the changing environment and the natural events there was a change in design, a change to adapt better to the new habitat, new terrain and to do its task better. Animals and the change in their body due to the surrounding habitat is one good example. The same species of cat has different varieties where each is marked by its need to survive and also co-exist with its habitat. Some types of leopards found in the mountainous regions have more fur covering their body, a lower metabolic rate suited to hibernation, stronger fore legs that better help in climbing cliff sand the leopards that are found in warmer regions and grassy lands do no have much fur on their skin but their body and spinal cord are flexible. These actually marvel at one task speed on the land. Some species of fish which can fly in the air come with larger fins which assist their short flight out of water. Large flippers in whales are provided for giving them the paddle force needed to push their large bodies through water. Reptiles like snake exhibit different abilities to locomote on different terrain because of their rope like structure. This gives the snake an ability to negotiate different forms of terrain and go over obstacles with different shapes. The snake’s body is more like a discrete rope where each segment can be discretely set to a different angle in space. Not only can the snake change the excursions in its body to different curvy shapes but also can sense the terrain with its skin and accordingly change its shape. The way the snake actuates itself exerting a force on the surface in contact and the way it moves is remarkable. In fact this behavior was a mystery as to how the snake sequentially exerts force through a cyclic motion and moves forward until the experiments done by Dr.Hirose helped in clearly understanding and coining its motion. Snake just like other animals adapt to different locomotive behavior depending on its habitat. A water snake actually has a flatter body and has a fin like structure running along all its body’s length. This structure gives its body a more paddle like form that through its cyclic motion can cut through the water and swivel forward. Also the tail end of a water snake is a bit broader where the paddle design becomes more significant. Rattle snakes which move in the desert have their locomotion adapted to the slippery sand surface. The way the excursions in its body are managed give the desert snake a sideways force on sandy surfaces. These forms of different locomotion can actually be defined by discrete sequences or through analog sine curves. The snakes back bone is simple design with a complex control. Simple because it is single unit through repetition and complex because of the way a control is exerted on it by the connecting flesh and tissues. In many cases nature's design is modular, simple but also complex and beautiful. A tree's design is modular in the way that the same unit a leaf is repeated all over it so also flowers and fruits. A flower design is modular because the petals are repeatedly arranged as per canonical numbers in a beautiful fashion. The human body is modular with a cell as its repeating unit. The scales on snake's body which give it both a slippery nature but also purchase when needed in another direction are modular. When we build architectural structures we use a brick as the repeating unit and though the structure of the brick is simple and trivial the resulting structure of the building is not so. We in design, we in engineering, we in our interaction with the machines mimic nature in form or the other and cannot detach ourselves from it because we are a product of nature and humanity grew up, moves forward by observing and learning from nature so any inputs to the engineering and science with our brain as a black box of imagination has its input seed from nature itself. Modular design found in the nature is also robust because if one part is lost, the whole structure is robust because of similar units with similar function in large numbers and if the object has life another grows back. So nature has also taught us that repeatability in design gives robustness to design because it is in large numbers we ensure our survival and prosperity. Take the example of caterpillar it is both serpentine and has locomotion compared to limb like animals. Animals were given limbs to move over uneven terrain, to negotiate obstacle and for a reptilian insect like caterpillar grass is a good obstacle as a stone or rock is to a cheetah, the uneven surface a tree's bark has to offer is good enough obstacle just as tiny rocks are to a snake. So a caterpillar though a small creature has a more complex design compared to a 4 legged animal or a snake in its locomotion. The wavy nature of its motion is predominant in the perpendicular plane and this combined with the motion from its tiny leg like projections gives it a good traction and grip even on vertical surfaces. Here is a great example of nature using a multitude of design in a seemingly simple and tiny creature. Nature's design and complexity is always mysteriously fascinating. Humanity in our attempt to understand nature has engineered mechanical birds in the form of helicopters, rockets and jet planes and have mastered the skies and beyond. In trying to understand the modular design we made several attempts to study the existing designs and understand why other researchers adopted few design and so on. Well one interesting thing with robots is that they are an extension of the virtual world into the real. They can be programmed better as per the needed behavior and thus unlike the biological counter part they are trying to mimick their intended function can go beyond it. This was especially noted when Dr.Howie choset was trying to understand the different postures that can be generated by changing the excursions in the snake's robotic equivalent. He found out that the a robotic snake can be shown a multitude of locomotion varying from a desert snake, a caterpillar and combine a couple of these as per a given scenario over a given terrain. We initially made a version of the snake with wheels. Since the design is modular the innovation that can take place in its design has to take place in single unit both mechanically and in the form of software behavior and if possible electrically as well. Even in the course of evolution if anything changes in a particular species or from one sample of the same species to another the repeatability found in the form of the basic building block a DNA changes. Just as the DNA, a building block has the program to define the entire body so also a modules design dictates the capability of the snake. The gait that was generates in the first snake which was capable of showing locomotion in a 2D plane where each unit had a freedom of motion along a single axis also used a cyclic sequence. Just as the DNA is a sequence with the unit A,C,T and G repeating each other so was the locomotion of the first version that we built was composed of locomotory limits arranged as a per a sequence. DNA contains the nature's rhythm and the tiny nuances that were brought about in the arrangement of the basic units brought about the entire change, variety and the beauty that we see today around us. So also tiny variations in the discrete sequence that goes into defining a snake's gait brings a great change in it behavior as if it was moving on the ground like a caterpillar to moving like a desert snake. When nature's design of locomotion took origin in reptilian motion where animals were capable of moving only over the ground closely hugging it then life was limited only to the horizontal plane. The strength in its backbone gave it power enough to extend its body slightly above the ground in a vertical plane. Well this was also studied in the form of simulation where we designed newer gear ratios of motor with different input torque. A python though being a massive snake has limited ability and agility to lift its body above the ground where as a cobra can lift a portion of the body graciously and swiftly. As we studied this difference comes because of the weight to actuation ratio of a single module. Thus changing the characteristics of how freely a single module moves either vertical or horizontal or both and what force can I exert also changes what type of the snake it is bio-mimicking. The diversity in a given species itself is based not only on the locomotry behavior but also in the design of the snake itself. The use of bellows helped us understand how the snake's skin elongates and contracts with the body's excursions. Some species of snake are also known to roll onto their belly in the time of danger and to give the snake this capability we designed a cruder form of the module with a 3rd kind of motion which is to roll. Snakes bone structure is really unique. Just as single ball and socket joint in the shoulder there are multiple joints linked one after the other which is actuated with muscles. To mimic the same we built an actuating universal joint where motors were coupled oppositely with the individual degrees of freedom vertical to each other. As the evolution took place in nature animals were given limbs to counter the gravity and lift themselves more strongly above the ground. Such an evolution also took place in our design when we were trying to bio-mimic nature in its robotic form. Initially the snake robot we built were limited to a planar motion, then their motion was also extended to a vertical plane with the addition of an additional degree of freedom. To make this capability more vivid and clear the torque of the motors in a given module was improved. When nature also gave animals the power to locomotion vertically from reptilian form it initially strengthened their back bone gave them smaller legged and then stronger limbs that they can lift a portion of body up in the air and later they could exhibit vertical gaits like we humans do. Our modular approach also evolved in such a parallel fashion. After improving the joint torque we gave it a robotic spine with legs so that it could overcomes smaller obstacles like slopes. Such combination of spine with legs is seen in an alligator, a caterpillar and the salamander. These gave animals an amphibious locomotion capability. To move in water they would just wiggle their snake like spine and to move on the land they would have legs. Later the caterpillar design was changed to that of a 6 legged hexapod and then to a robotic dog. We captured a part of locomotory evolution in our study of the robotic spine with and without legs and by changing the modular design. Studying the evolution through robotic design gave more insight. For example where a cheetah climbs onto a rock or a tree or runs very quickly it changes the shape of its back similar to the shape of a snake and controls its actuation. Even when a snake hugs the surface and moves it is actually changing the amount of torque, the amount of strength it puts into moving a particular joint. So we mimicked this behavior by trying to change the actuation of a motor with the amount of current that flows through it. This level of bio-mimicry was fundamental in the design and our observation of nature. As we have been working in porting the physical into the virtual world though camera mouse like interfaces we can also work the reverse way in building mechanical prototypes that are equal to their digital self. Simulation in prototyping helps a lot in cutting the time involved in developing and helps us save on the hardware costs. We developed a physics environment where the bio-inspired robots could be modeled and tied to their prototypes through a common API. When we tie a single control to both the virtual and real we are also bridging the gap between the two worlds. We termed this the Universal API approach using a universal simulator. The simulation environment also helped us clearly study the evolution of reptilian design, amphibian design and how the same can be adapted on the land using limbs.

When studying about the design of 4 legged robots and their ability to manage obstacles, maneuver about them and the stability of gaits we got an idea to use accelerometer as the interface to change the slope of tilt table on which a virtual model of the robot was resting. The tilt table was interfaced similar to that of cellphone with its cube interface to track the pose of a car. Here through inverse kinematics the robot was programmed to stabilize onto the moving platform. Later when the same accelerometer was used to detect the tilt of a tilt table which was being actuated externally the real prototype of the robot stabilized with negative gains. The stance of the 4 legged robot observed here was accidental and was similar to how mountain goats stabilize themselves while climbing down a hill slope. Here the dual nature of devices like accelerometers was seen that they can be used as active input devices for virtual objects but also be used as a sensor to read back the real world.

Active sensing was not only used here in the 4 legged robots but we also made an attempt to give the snake a sensory feedback for this we designed a module with skin that uses differential capacitance. With this skin we could detect human touch, when the skin was compressed with a gentle force and a large impulsive force. When the real snake moves on the ground it gets a feel of it through the skin and appropriately adjusts its backbone changing the force it exerts at the extent of its curves. Working on the sensory part for slender snake like robots we though about several forms of sensors which can perceive depth. Many insects also have a compound eye which is their only way to sense motion of the object around it. Some animals like the ones in the cat family use night vision to even move in the dark. So we devised a night vision camera from an ordinary low cost web cam and that can also perceive depth using structured infra-red light projection that understand the surroundings with the deformation of the shadows and project patterns.

India has been long known as land of snake charmers. Well there is a different twist to it and a bio-inspired twist. We have always been trying to co-exist with nature and tame its violent form to a more friendly a domestic form. Even some of the most potent and dangerous snakes in the world like the King kobra whose venom is so potent that it can kill an army was tamed to a charmer’s music. Is it that the snake falls into a conscious sleep like state when the notes from a charmers pipe land on is scales? Or is it the design of the musical pipe which fascinates the snake? Or is the snake like posture of the charmer’s hand which makes the snake thinks of it as its twin that puts its mind to question and confusion? Even if the snake raises its hood in order to protect itself or to warn the user of an impending attack we have done our part in turning it from a wild animal to a more manageable domestic one. This is again a classic example that our interface with nature is critical to how we use it for our survival. Now if use the loop of a interface to a virtual object, replicating the virtual behavior in a real mechanical object and then convey the same interface to it we are following the path of our interaction with nature. Now why would we design a mechanical snake and charm it. We are experts in charming some of the deadly biological ones. Why do we need to design a mechanical one? Can we play with it better?

Well the study of interfaces as to how to make the machines respond to us and that we use them fluently we looked into graphical interfaces that would give a better control of the snake through its complexity. The knowledge of using gestures and a form of sign language to operate machines was learned when tried to integrate finger basic fudicial tracking with few applications. The use of natural accelerometer interface to control the pose of their digital equivalents helped us design a data glove which tracked the motion of palm and the fingers. These gestures were mapped to the physical postures of a biological snake. So when the snake robot has to raise its hood to perform a snoop operation and look beyond an obstacle all that the user needs to do is make a similar shape with his hands. When this was built and the gestures were bio-mimicking that of a snake’s back bone we understood the importance of moving gestures closer to real world natural postures and actions because they are more appealing. If one looks at the Indian classical dance it is also about postures and gestures through hands. When a dancer wants to convey a particular scenario he/she makes an appropriate gesture or mimics a symbol with the hand.

Snakes also have the tendency to avoid contact with a predator or human and go towards the bushes and hide themselves. We also tried to mimic this behavior and bring a level of autonomy in its response to the surroundings. As Dr.Choset said the robotic snake gives us an opportunity to go beyond the biological one and bring in a multitude of behavior in it. So when the snake was moving over a smooth office floor it was programmed to move like a desert snake and when it reached a grassy carpet region it would be commanded by a tracking system that it can autonomously change its behavior to that of a caterpillar. Here the interface was in how the snake interacts with its surrounding and reacts pro-actively to it.

The idea of studying both these robots and design was that because their biological counters parts are really good at traversing a multitude of terrain and if we can study their design then we can possibly use them in similarly challenging terrain that is typical to a search and rescue scenario. The important thing about serpentine structure is that the same design is found in tiny organisms which can be observed under the microscope to large animals like the anaconda. If the same structure is replicated at a smaller scale they can be used for the purpose of inspection and even search and rescue. For designing a small snake like arm we bio-mimicked a joint that mimicks the sliding joint in the human finger and the rolling ball socket joint of the shoulder. It was designed in a modular fashion where a single module was composed of two opposite poles of spherical magnetic whose joint angle can be changed through running tendons. This design is astoundingly similar to the ball and socket arrangement in a snake’s vertebrae with the muscles acting as tendons to control the joints. But because of the weight and fabricating limitation we failed in making a snake like arm but when we failed here we used this design in making one of the most dexterous robotic hands. Each finger of the hand a has 3 joints where each joint has 2 degrees of freedom with an additional not so significantly actuated rotatory joint. Because of this sliding and rolling motion of the spheres our mechanical joint perfectly mimicked the motion of the joints in a human finger. If an object would be placed in the hand it would detect it and initiate a grasping action around it. The idea of passive rotational joint is that if irregular shapes objects are grasped these passive joints would roll and adjust a bit to give more compliance to the object that is grasped. If robots are to be made human-friendly their interaction with us is to more human. Here, if a person places his face in the hand the fingers curl and compliantly hug the face gently. The hand uses capacitive sensors on its tip to detect human touch. Here also while designing the hand we were trying to bio-mimic the relation that we find between a baby and its mother because even interfaces for robots built on relations would make them more real, natural and most importantly give them a human touch. So the interface is just not limited to software GUIs but how we adapt it to the robotic hardware as well. In one way both HCI and HRI are the same if we bring the robot in a simulation environment alive with a fabricated prototype. So a computer-interface is to a virtual object in a simulating environment would become one to its real robotic counter part.

We went a step further in a search and rescue application when we designed an intelligent robotic flash light called the way-Go torch. The torch light is on the idea of embedding electronics in every day objects around us making them more intelligent and give them more functionality beyond their existing design than the originally intended function. Imagine this scenario that people are stuck under the debris after an earth quake or a Tsunami and the rescue worker is having a tough time in finding them. Reading a map and trying to figure out the landmarks of a collapsed environment to navigate can be very tedious. Also map reading requires some skill and drawing similarity between the cryptic symbols on the map and the surrounding involves lot of over head. To over come this, the Way-Go torch illuminates the road ahead with relevant meta data. If one has to travel from the main entrance to a particular location in the campus the torch projects an intuitive directional arrow to the next intermediate way point. By trying to fuse the digital data onto the real world with a projected over lay we are also moving towards bridging the gap between the physical and the virtual world. The torch also has a robotic neck with a universal joint. Its head is stabilized by reading the pose of the rest of the body using an IMU which is actually bio-mimicking the head stabilization found in some of the birds like a rooster. A rooster actually has the ability to keep its head fixated to a point in space with the direction of the gaze by changing the excursions in the neck even if the rest of the body is moved. Here an accelerometer based hardware was again used to mimic a naturally occurring behavior in animals.

What is more to the torch light? Imagine as a kid when you go to knew places with your parents and that suddenly you are loose them. You get lost in a new land. Well devices like these can show you the way. Just as a helper dog guides a blind person go about the neighborhood so also can this torch light be the guide. Just as the pull of the dog's tag felt by the person's wrist guides him/her in the right direction so also would this torch guide a person by projecting an arrow. One can also explore new places and wander about discovering each new location naturally. We have sign boards in college campuses but this torch can act as your virtual tour guide. It is better than a GPS on a small screen device like a cell-phone or a car navigator because it is not limited by a physical screen size, one need not read the map and compare the surroundings but the guiding arrow in the screen itself is projected onto the real environment as if it was a map to it. After working with the GPS and this guiding behavior we took the embedded intelligence and functionality of these devices a little step further for critical applications.

The earlier accelerometer application that was developed to track a car's state was accidentally also an experiment to detect road quality. This was further used to detect large peaks that occur due to collision force and impulsive forces that act on an automobile during the time of a road accident. Detecting crashes has been used on devices like laptops but here our idea of detect automobile crashes emerged from the state tracking of a vehicle through the UI and its visualization using magnitude graphs. In many cases it so happens that the accidents take place in remote locations and in places with sparse or no habitation. When there is no one to watch and report the accident devices like these can come to the rescue. The time between an accident happens and is reported is actually automated through such devices. No person physically needs to be there to report the event. Especially in critical applications time is of essence and how we use such interfaces and devices matters a lot. The same when mounted on a street pole can detect motion that is more than the normal and thus can report earth quakes. Here the interface is in the sense of not just the input but what response we get back from it. In both the case of accident reporting and earth quake detection the interface through the device remains the same. So meta data which is a critical part of the communication between a machine and the user is of great importance and can actually save lives even if it is a robotic flash light that is used for search and rescue or a cell phone that reports quakes and accidents. The cell phone's visual accelerometer interface is the one that united it from measuring road quality to being used in a life saving application.

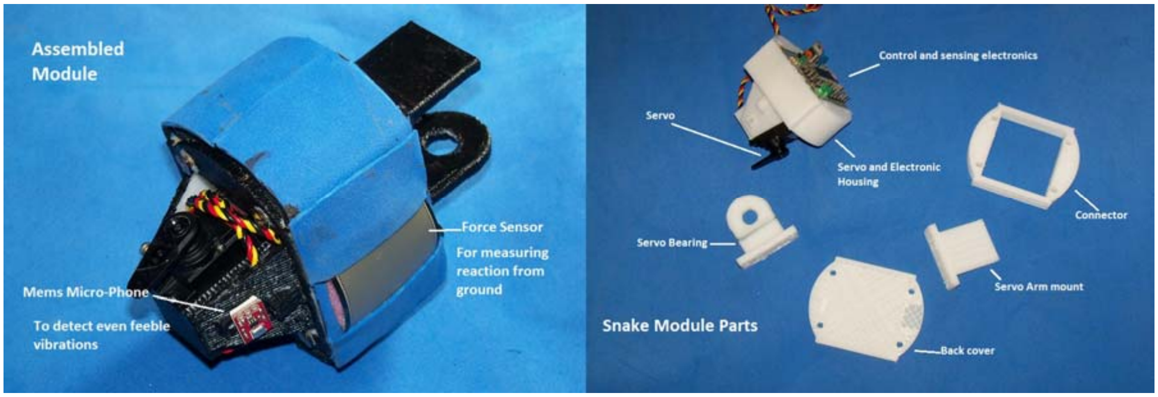
While mimicking the nature of a snake we also dwelled in a direction to understand and engineer a system that is responsive like a snake’s sensory system to sound. A snake detects sound and vibration in the surroundings through it body and scales. To implement the same we built an interface that calculates the direction of sound and triggers a gait pattern away from the source of sound. The sound interface was built around the snake's virtual model and the same can be extended to the real prototype through the universal API approach that we discussed earlier. This behavior of snake moving away from an obstacle can also be reversed in a sense that it can move towards the source itself. The anti-biological behavior of sound following is of great importance when it comes to search and rescue. When people are stuck in the debris they sometimes shout out or call out for help. Snake robots which are especially engineered for such application can actually localize onto the sound source and move towards it. So interfaces in a way also can give dual behavior to the robots so is the nature around us.

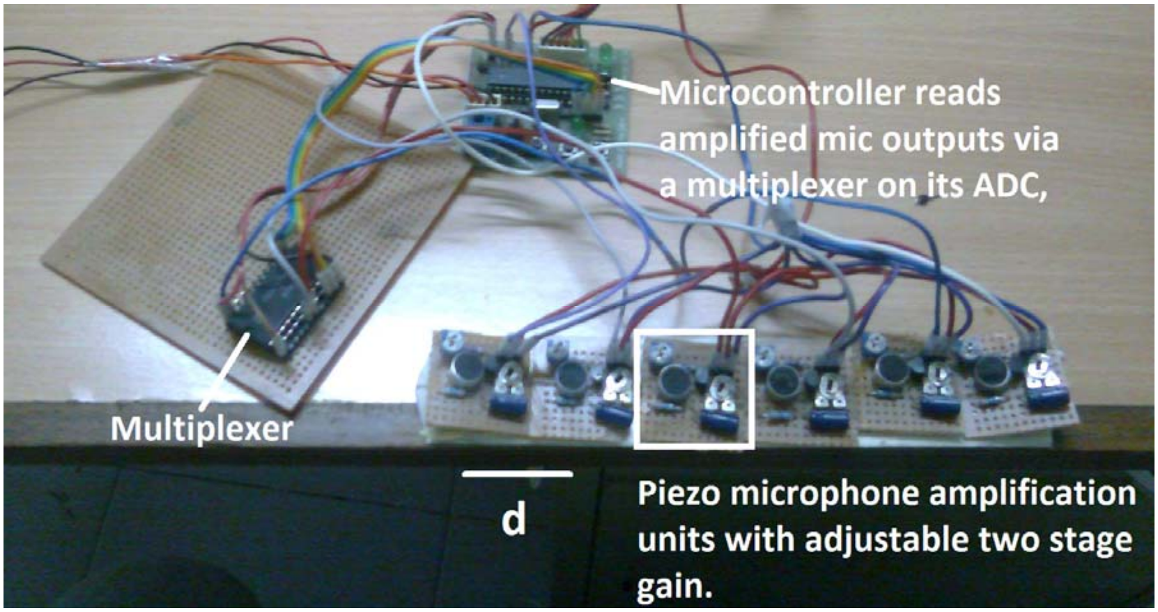
We in this discussion have studied about how interfaces evolved from the virtual into the real, how they helped in bridging the gap between the digital and the physical prototypes, how interfaces also inspired from nature and how mechanical design of robots can be inspired from nature’s design through bio-mimicry and its solution for adapting to harsh environments. How both interfaces and robots come together in helping us design life saving systems and applications.

7.Appendix:

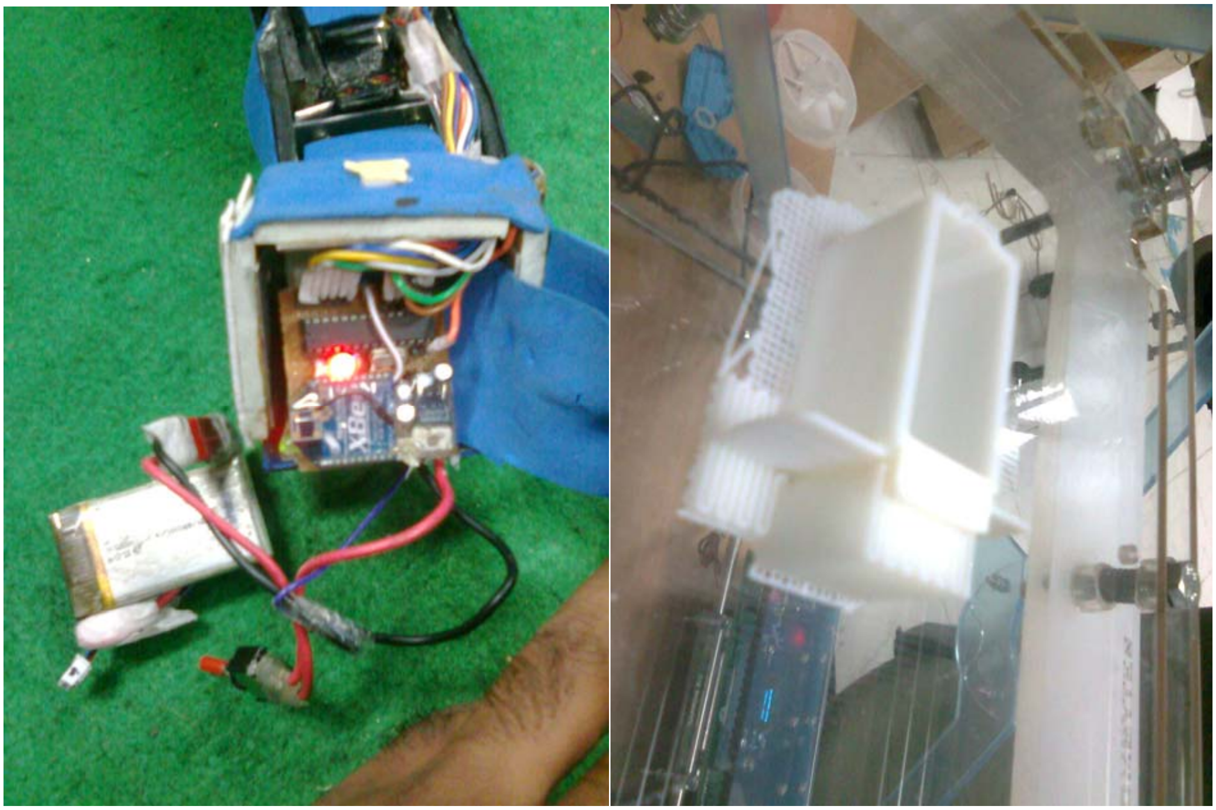
A) Sound Repulsive Snake

Snakes are know be to extremely sensitive to vibrations. They can sense vibrations that are as feeble as a human feet rubbing against the carpet or even grass. Generally most the species of the snake have a tendency to avoid human contact and move away from the source of vibration. So with the idea of simulating this behavior a sound repulsive snake module was constructed. It houses a Mems micro-phone. Custom circuitry to amplify the sound signal by a factor of 50-100 times was designed. At such amplification even a piezo electric mic showed improved sensitivity to feeble sound.



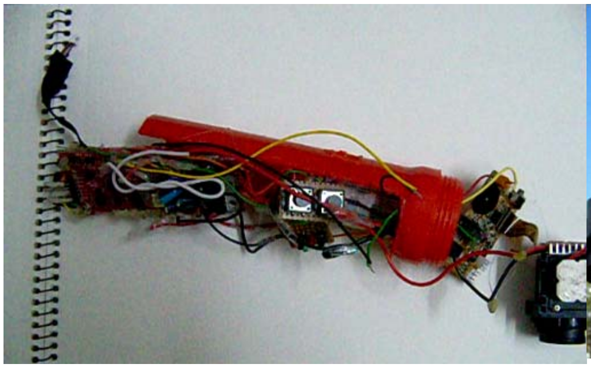


The sound reaches each of the micro-phone separated at a distance at different times. This difference in time at which the sound arrives from a single source to each micro-phone can be used to locate the sound source. Some factors that govern this task are the minimum distance “d” between the microphones, the frequency of the ADC, the sampling frequency of the micro-controller, how fast it can compute the cross – product between the two waves for finding the number of samples by which one wave lags or leads the other which further define the spatial resolution. This spatial resolution can be used to identify in which sector the sound source is in and thus the snake can decide its gait, direction and the curvature to move away from the source. Planar sound source localization has been achieved here using a 72 Mhz arm processor which computes the cross product real time. A UI was also designed to visualize the location of sound source.



B) More on the Way-Go Torch and the earth quake simulator:

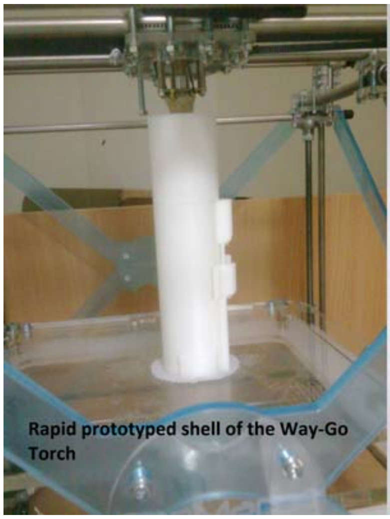
Animated Robotic Ubiquity: The core idea here is to bring human like motion cues to seemingly non-living objects. A sense of expression and emotion can be conveyed by augmenting every day non-living objects around us with actuators that seamlessly integrate into their physical form. The idea of bring non-living objects alive was seen in the story of the wooden boy Pinocchio and in the animated virtual character “The Lamp” which is Pixar’s logo. Some research efforts like the “Augmented product counter” of the MIT media lab that use a robotic lamp with its bulb replaced by a projector and a robotic desk assistant lamp from the Personal robotics group also convey the idea of augmenting objects with robotics and giving them human like motion cues to make their interaction with the users more friendly. The idea is to give them an artificial robotic spirit.



Robotic 2DOF unit attached to a cell phone and a street pole.

Program Flow code:

1) On boot calculate all possible dijkstra paths from source to destination way points in the map.
2) Select mode.
3) Select user source, default = Main gate.
4) Select user destination.
5) Select the path from generated look up table for the given pair of source and destination.
6) Calculate distance to next way-point in path mode. Calculate the heading to the next way-point.
7) Do transformation from compass frame to campus map frame and then to the projector frame.
8) After reaching a waypoint increment way point flag, display way-point meta data and calculate distance and heading to next way-point.
9) When way-point flag equals number of way points +1, set reached flag.

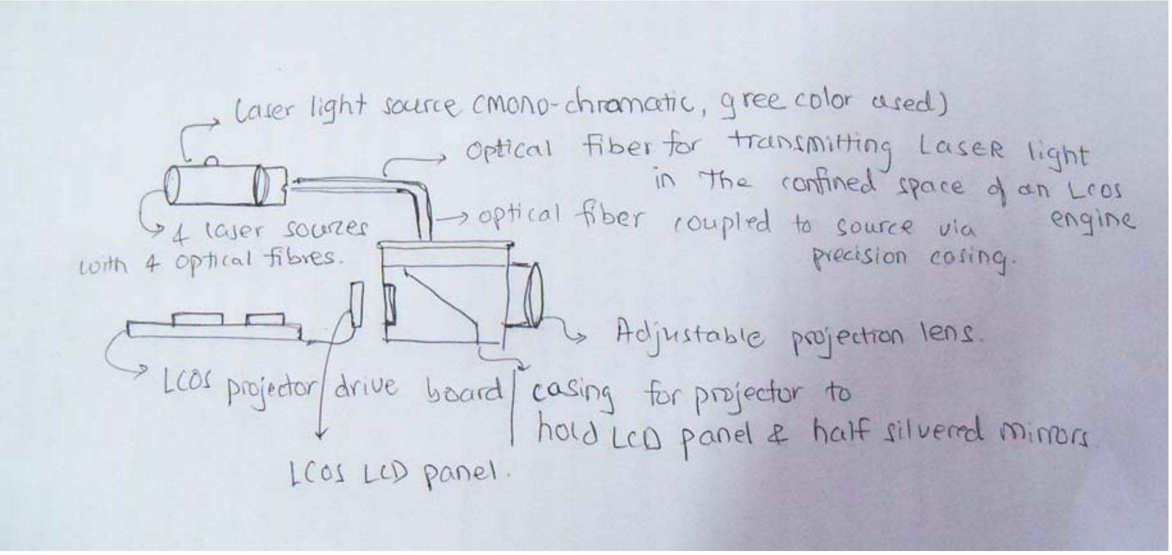


Rapid prototyped shell of the Way-Go Torch

An alternate setup for green lasers on the LCOS projection engine

Laptop data collection set up using an IMU, GPS, battery and dual USB-RS232 connection

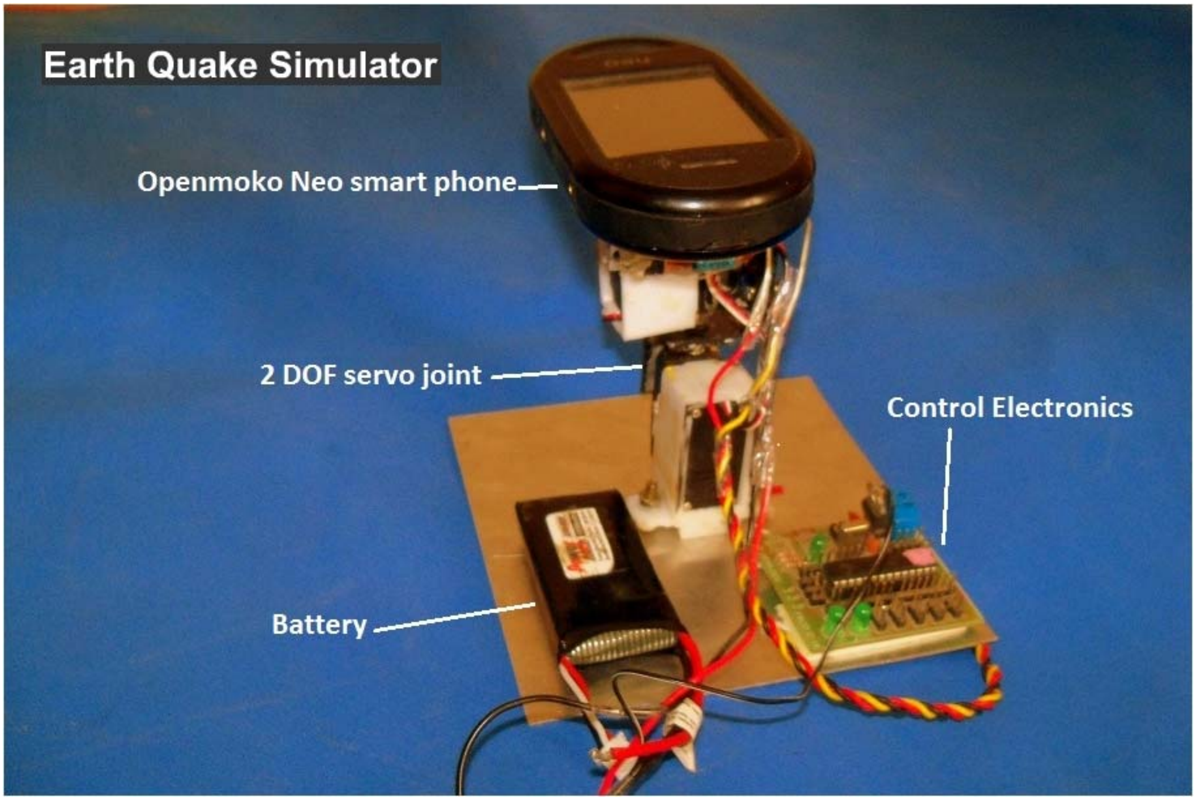
Another configuration of the projector for the Way-go torch light was experimented with. Given the confined space of the LCOS projection engine and the casing for the projector it was difficult to fit in a powerful and larger light source than a single LED light source. Fitting the Laser pointers for the precise illumination of the LCD aperture was a difficult task. Instead of fitting the 4 laser pointers using precision printed 3D casing we used optical fibers to transmit the light from the pointer to the aperture. This alternate arrangement helped in keeping the hotter and larger light source away from the aperture but the illumination energy was transmitted to the projection aperture through optical fibers. Given below is a figure explaining the same setup.



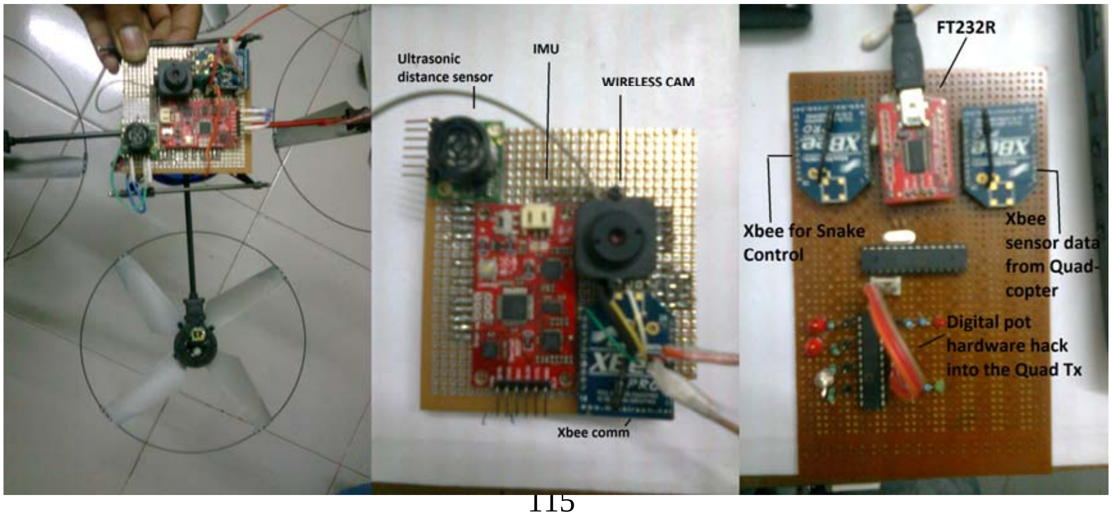
C) The idea of Ubiquitous prototyping:

The main idea behind ubiquitous prototyping is to embed daily life objects with smart electronics and actuators making the environment around us intelligent. The best example of Ubiquitous prototyping emerged in sci-fi movies and in spy gadgets from James Bond series. The Way-Go torch was also about embedding smart sensors and guidance systems in the simple form of a torch light to further augment its functionality, make it more intelligent and more useful. Even the Snake robot was modeled with a form of ubiquity by smartly embedding the controller, power and communication units with in its cubical form factor. Converting every day objects into intelligent input devices, sensors, output devices and computing units is the final goal of ubiquitous prototyping.

New forms of device with ubiquitous electronics will give a whole new functionality to the environment around us.



D)Snake robot + Heli and quadcopter applications.



The idea of using a snake along with a quadcopter or a Heli was use to use an aerial assistant in helping the snake understand its surroundings better and thus making it move better. In outdoor environments the quadcopter can be an eye in the sky can, know the extent of the terrain better and even the target location. This information can be conveyed to the snake in turn to know its position relative to the target in the visual map as observed by the quad. This can help the snake in taking better decision as to which gait it has to use in which part of the terrain like side-winding on sand covered ground and crawling in grassy regions. Since the odometry, obstacle detection and path planning in non-wheeled robots like the snake is not as developed as its wheeled counterparts, an aerial scout can better help the snake in understanding its surrounding and taking further decision on where to move and how to move.

E) Snake motion sequences

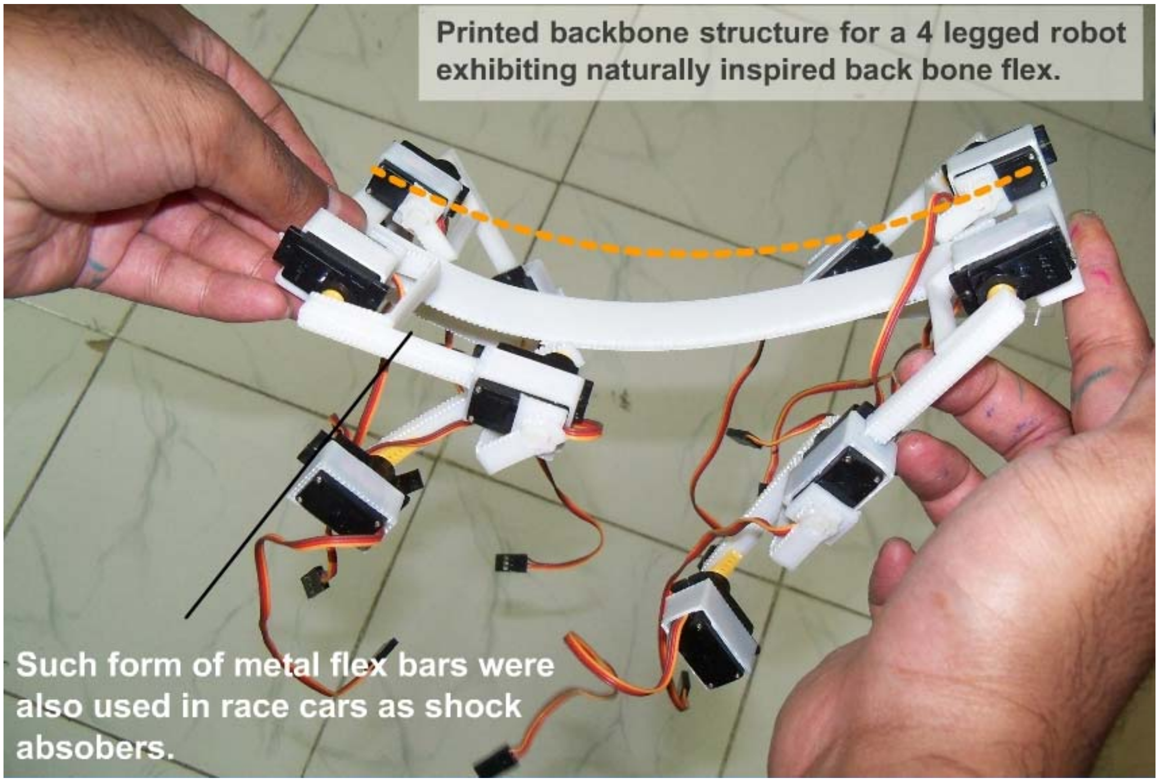
Theo Jansen in his talk mentions that he builds artificial creatures that sense and locomote on the sea shores. The way they move is defined by preset numbers and the ratios that go into defining the lengths of the creatures' legs. All his robots use the same ratios and sequences. In a way those sequences and ratios define the path the end effectors of the leg takes and the gait of the robot. One such approach was co-incidentally figured out and used as the first cyclic sequence in the 1D snake prototype.

Initial configuration of the snake's back bone.	Continuous undulating sequence defined in terms of the extremum and delay function.	Concertina Sequence frame wise definition
S(1,L); D(); S(1,L); D(); S(0,R); S(2,L); D(); S(1,R); S(3,L); D(); S(0,L); S(2,R); S(4,L); D();	S(0,R); S(2,L); S(4,R); S(6,L); D(); S(1,R); S(3,L); S(5,R); S(7,L); D();	frame<10?0.5:[0.1,0.1,0.1,0.1,0.1,0.1,0.5,0.5,0.5, 0.5,0.9,0.9,0.9,0.9,0.9,0.9,0.5,0.5,0.5,0.5] [(frame/5)%20-1]; frame<10?0.5:[0.5,0.9,0.9,0.9,0.9,0.9,0.9,0.5,0.5, 0.5,0.5,0.1,0.1,0.1,0.1,0.1,0.1,0.5,0.5,0.5] [(frame/5)%20-1]; frame<10?0.5:[0.5,0.5,0.1,0.1,0.1,0.1,0.1,0.1,0.5, 0.5,0.5,0.5,0.9,0.9,0.9,0.9,0.9,0.9,0.5,0.5] [(frame/5)%20-1]; frame<10?0.5:[0.5,0.5,0.5,0.9,0.9,0.9,0.9,0.9,0.9, 0.5,0.5,0.5,0.5,0.1,0.1,0.1,0.1,0.1,0.1,0.5] [(frame/5)%20-1]; frame<10?0.5:[0.5,0.5,0.5,0.5,0.1,0.1,0.1,0.1,0.1, 0.1,0.5,0.5,0.5,0.5,0.9,0.9,0.9,0.9,0.9,0.9] [(frame/5)%20-1];

Rolling sequence definition (horizontal servos only as it is a 2D gait	Side winding sequence (horizontal and vertical servos)
frame<40?0.45:[0.5,0.5,0.5,0.5,0.55, 0.55,0.55,0.55,0.5,0.5,0.5,0.5,0.45, 0.45,0.45,0.45][(frame/10)%16]; frame<40?0.45:[0.5,0.5,0.5,0.5,0.55, 0.55,0.55,0.55,0.5,0.5,0.5,0.5,0.45, 0.45,0.45,0.45][(frame/10)%16]; frame<40?0.45:[0.5,0.5,0.5,0.5,0.55, 0.55,0.55,0.55,0.5,0.5,0.5,0.5,0.45, 0.45,0.45,0.45][(frame/10)%16]; frame<40?0.45:[0.5,0.5,0.5,0.5,0.55, 0.55,0.55,0.55,0.5,0.5,0.5,0.5,0.45, 0.45,0.45,0.45][(frame/10)%16];	frame<30?0.5:[0.3,0.35,0.4,0.45,0.5,0.6,0.65,0.7] [(frame/10)%8-1]; (H) frame<30?0.5:[0.3,0.35,0.4,0.45,0.5,0.6,0.65,0.7] [(frame/10)%8-1]; (V) frame<40?0.5:[0.35,0.4,0.45,0.5,0.6,0.65,0.7,0.3] [(frame/10)%8-1]; (H)
	Vertical Undulation (same sequence for horizontal as well)
	frame<100?0.5:[0.37,0.38,0.4,0.44,0.5,0.54,0.58, 0.6][(frame/10)%8-1]; frame<110?0.5:[0.38,0.4,0.44,0.5,0.54,0.58,0.6, 0.37][(frame/10)%8-1];

F) Rapid prototyping robots: Quadzinga (a wall climber) and a micro snake

The low cost rapid prototypers especially in the open source realm primarily the derivatives of the RepRap print a 3D object using ABS in layers. The volume of the object if filled up using several kind of draw patterns like meshes, circles or haphazhad lines. Depending on the kind of weaving/printing pattern and the print density profile used the flexibility of the printer structure can be altered. Especially this was of filling up the print volume appears to be inspired from the nature. A tree's trunk in its cross-section has radially varying density[2]. It has the least density at center and the maximum density on the outer layers. This makes the tree trunk robust and flex when high speed winds blow across it. This way the tree exhibits a form of compliance to perturbations in the nature. What if we use the same principle in building robots? Especially biologically inspired robots like snakes, caterpillar like robots and 4 legged robots can mimic their natural counter parts in their back bone structure. The appendages in a snake adjust to the varying terrain and hug the surface. Even animals like Cheetah flex their back bone accordingly to make their gaits better and adapt to varying terrain. Such form of compliance has been implemented in the robot Modpod by using a robotic spinal cord and varying the amount of current in it. This in turn controls the actuation of the robot's spine and makes it flex to slopes.


Printed backbone structure for a 4 legged robot exhibiting naturally inspired back bone flex.

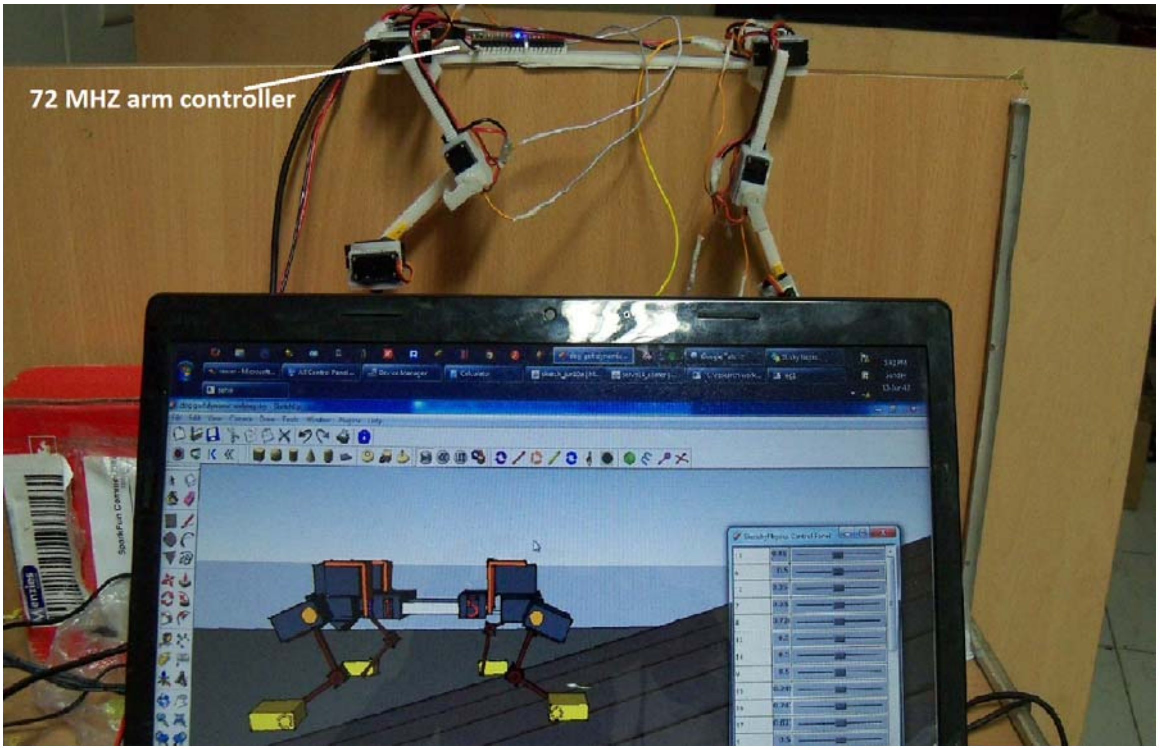
Such form of metal flex bars were also used in race cars as shock absobers.

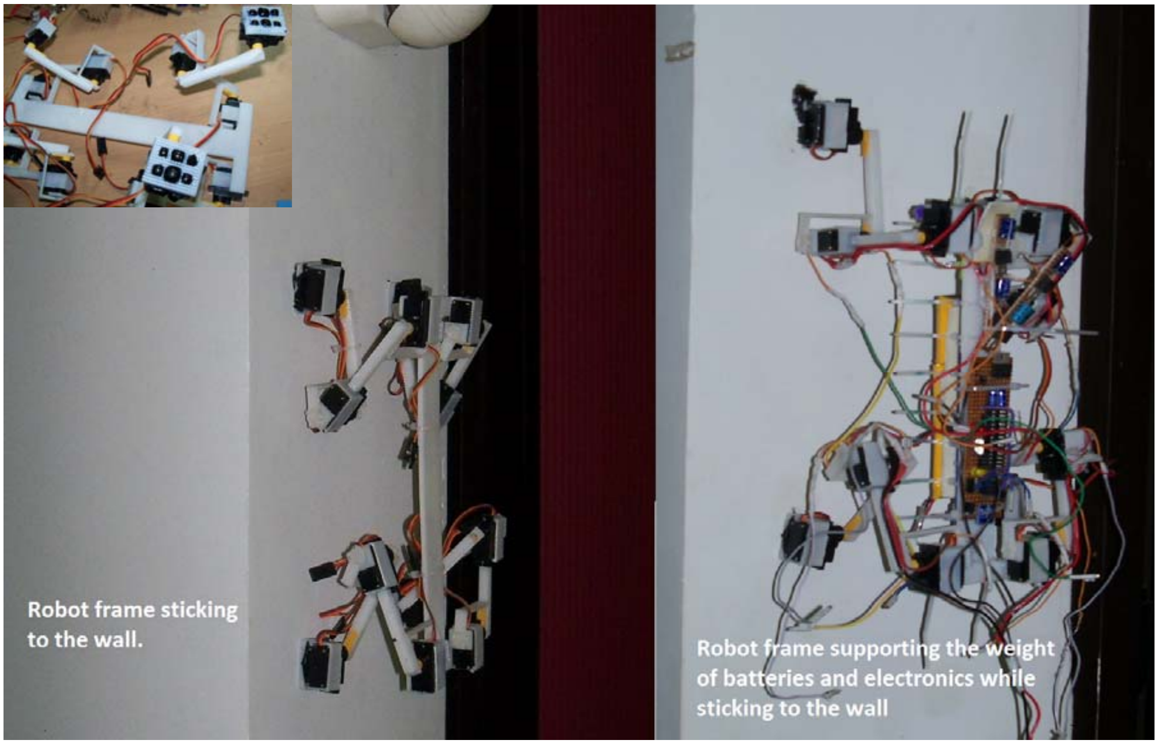
The big question: Can we make a 3D printed material whose flexibility/stiffness can be electronically controlled?

By weaving Ni-Tinol muscle wires in to the printed weaves and by using rubber as the binding material in the ABS plastic structure it should be possible to create a smart material which can be made to electronically flex. This could pace the way for new forms of actuators for robots and even building materials that could just come alive.

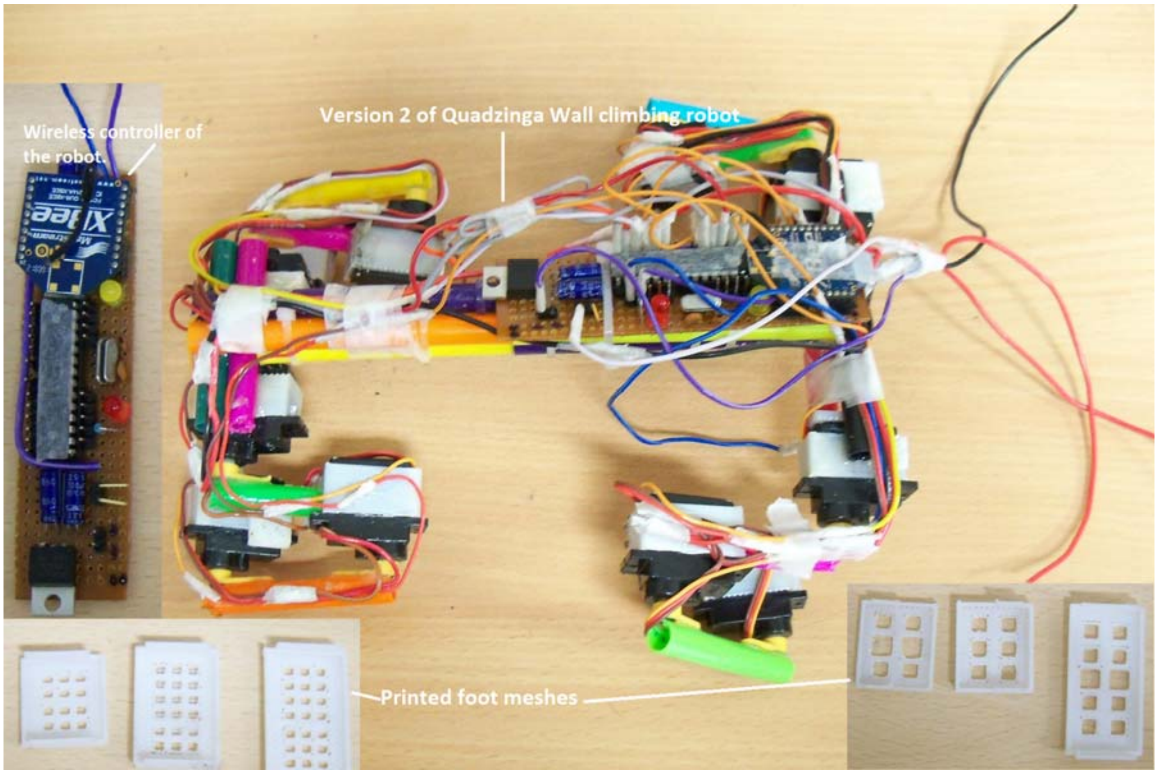
Wall climbing robot:

Using the sticking property of polymer binding/bonding a 4 legged micro robot was rapid prototyped. This robot has 4 legs where each leg is a 3 DOF robotic arm including the arm as an end effecter. The kinematics of the robot was programmed in a way that the feet always move parallel to the flat contact surface it has to climb. The initial rapid prototyped version used a 72MHz ARM controller for controlling the servos motors in its legs using PWM



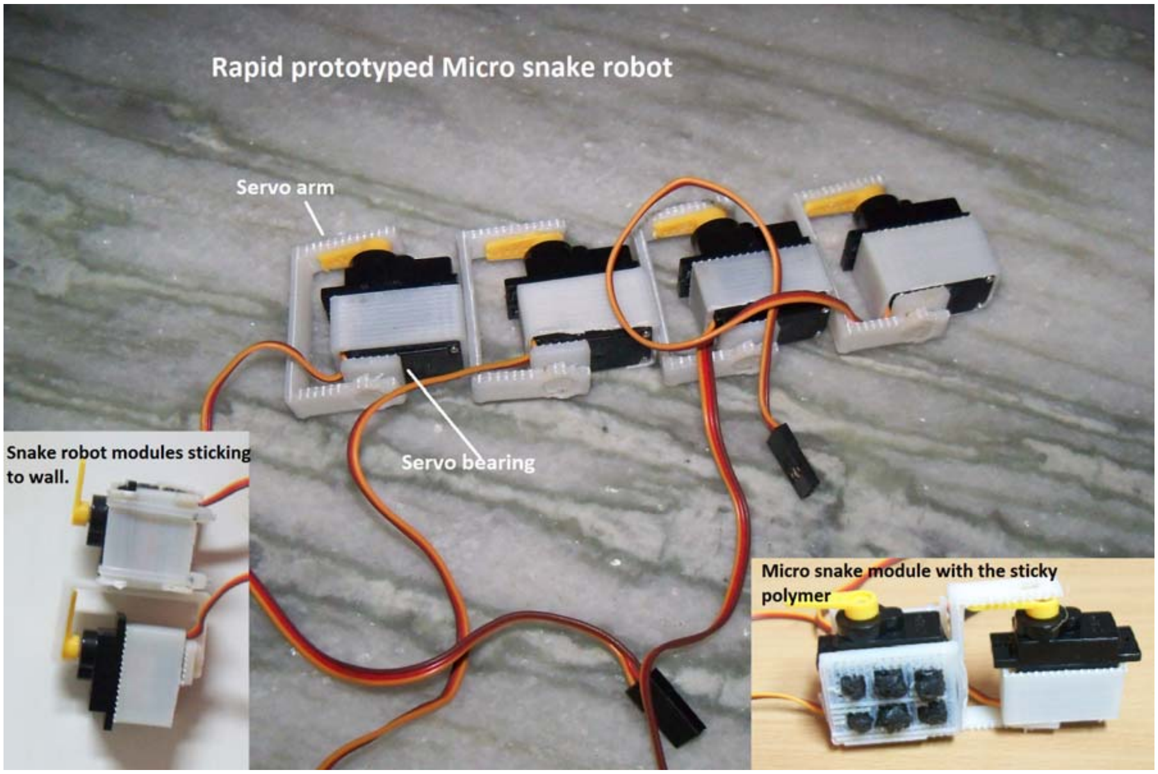


A lot of prior work has been done in the wall climbing robots. Stanford's sticky bot 1 to 3 uses directional adhesive polymer in its feet and a tail for balancing the load on each of its legs. The sticky bots design has been inspired from the gecko. CMU's nano robotics lab fabricated a dry adhesive polymer which was used in their Waal bot. Waal bot has a hybrid wheel legged design. Upenn's Kodlab designed the Rise V1 to V3 in association with Boston dynamics which uses claws to hook onto the trees bark to climb. Rise robots also use a tail for load distribution on its legs to get further support while climbing Ben Gurion University's bio-robotics lab designed 3 wall climbing robots using different adhesion mechanism. One prototype uses magnetic wheels to climb on ferrous surfaces and another uses hot melt glue to climb on non-ferrous surfaces. Some of their other designs uses sticky tape from 3M. Georgia tech bio-robotics also uses a stick tape in their micro wall climbing robot. Our robot Quadzinga uses a polymer to bind to surfaces temporarily. The robot sticks to the wall in a static configuration; its design is to be further iterated to make it walk while sticking to the wall. A tail would possibly be included in its design to assist its climbing dynamically. Integrating the sticky polymer into the robot's legs is a difficult task. One solution is to fabricate the legs separately by culturing the polymer into the design. Here we attached the polymer by pressure fitting meshes. The polymer sticks out of the holes of the mesh and sticks to the wall.



Rapid prototyped Micro snake robot

We also designed and rapid prototyped a micro snake. The servos arms and the bearings for mounting the arms were printed in ABS.



*G)*The tables given below are only minimally informative and do not bring out the research ideas, spirit of each work and are not exhaustive.*

***Table showing various robotic hands and their features**

Hand prototype	Hardware architecture	DOF	Other features
Shadow Dexterous hand	Pneumatic air muscle C6M2 Servo motor based actuation	Each finger 3 DOF and 4 joints, Thumb has 5 DOF and 5 joints.	PID controller,CAN bus
HIT/DLR Robotic hand	Actuators in finger design. DC brushless with all effect sensors.	Each finger has 4 joints with 3DOF and thumb has 4 dof. Total 16 dof.	Strain gauge based torque sensor. High speed real time 25 Mbps serial communication with FPGAs
DLR-2 Hand	Brushless DC motor with Harmonic drive and tooth belt gear	Total 13 DOF	Temperature, torque, position and speed sensors.
ADAH Robotic hand	HMI glove interface	11 DOF	Foe extra vehicular activities
MIT/UTAH Hand	Tendon tension sensors, Penumatic value controlled actuation, remotizer	25DOF	For industrial applications, PUMA manipulator integration
Gifu Robotic hand	5 series elastic actuators driving 12 joints	20 joints with 16 dof. Thumb has an extra joint with 4 bar linkage mechanism	M3 Ether CAT interface. 5 axis force sensor, in hand perception using Firefly cam.
Meka Arm	Motors not in hands	Total dof 12,	13 different automatic hand modes lateral grasp, precision pinch and natural hand position. Proportional control

I-limb		5 individual articulating finger with rotatable thumb and wrist	CAN bus control, with human contact charge based sensors and one force sensor in palm.
Karl’s ruhe robotic hand	Spherical and sandwiched ultrasonic motors	20 dof	Open loop controller.
RAMA-1 Highly dexterous hand	Uses magnetic spherical spheres with Tendon driven mechanism	Total DOF = 48 Each finger has 3 joints with each joint having 2 actuated and 1 passive roll joint	Maximum grip force 140N, RF controlled. CAN bus system, 470g weight.
Be-Bionic hand	Carbon fiber body, with natural silicone cover	Opposable thumb feature,	
Elumotion robotic hand	Tenden driven robotic hand. Motors are not embedded in the fingers.	9 dof Hand	

***Table showing several modular robotic systems and their features**

Modular system	Hardware architecture	Robot features
Superbot PolyMorphics Robotic lab, USC	2 micro computers, 3DOF rotational, on-board power,3D gravity sensor, IR communication	Capable of Morphing into Multi-shapes, Connectivity, Motion sensing
EPFL Amphibot	2.8W DC motors, RS232 I2C interface	Swimming and crawling with Central Pattern Generator
CMU snakebot	Super servo electronics controller, Magnetic contact less positioning, Hitech 5995 TG servos, RS485	Biologically inspired and Non-biologically inspired differential gaits
Woodstock- HRR mobile robot hybrid (USAR)	Moxon RE motor, 4.5Nm torque, 12V DC	Search and rescue, inspection robot, 14DOF redundant robot arm
Omnitread robot	13.6 Kg, 127 cm treaded snake robot	Pneumatic below based compliance
Octarm III	Pneumatic snake arm	Torsion control and Integrated sensing
Snake ARM Robot OC robotics	Steel cable tendon based manipulator	For automobile and security inspection
Cornell univ Snake ARM	Micro Modular Arm made of Aluminum disks and tendon driven with Ti wires	For surgical inspection
Hyper cube (University of Real Madrid) Juan Gonzalez	PIC16F876 controller, RS232	Pitch Yaw connection for sinusoidal, turning, rolling and rotating motion.
Polybot GIV3 (other variants)	Motorolla, 68HC11, RS232, Motorolla Power PC 555, 1.5NM to 5.6Nm torque	Conforms to obstacles, loop configuration mode and snake sinusoidal mode.
ACM R-3 Hirose Fukishima robotics lab	20 dof planar snake with parallel joints	Tactile sensing for compliance around obstacles, Active chord mechanism

ACM-R5 Hirose –Titech	18 DOF , amphibious snake robot with paddles and , passive wheels	Helical swimming, Universal joints with passive roll for counter byoyancy.
Molecube Cornell univ	AX-12 embedded in a custom rapid prototyped casing, Atmega16 micro-processor, RS232 bus,49.5Kg Max torque	Polymorphic structures
Snake P3	12 DOF robot with Hitech 7950TH servos, tethered and un-tethered	Custom data glove based gesture control developed to measure and finger and palm motion. Semi autonomous gait changing behavior.

*Range and depth sensor survey			
Sensor model	Operating principle	Depth/ Resolution range	Other features
Sharp IR Range	Triangulation (different incident angles on the linear CCD sensors in the receiver corresponds to different distances)	4cm- 550cm	Uses infrared light, runs on ADC
Max botix sonar sensor E01,E2… E4	Ultrasonic sound TOF	6.45 m with 1inch resolution	I2C, Serial interface
Velodyne 360	Laser TOF	360 deg horizontal FOV, 26.8 deg vertical FOV	905nm laser, 64 laser emitter 3D.
Lms200 SICK laser range finder	Laser TOF	80m 180 deg arc with 0.25 deg resolution	RS232, RS422, 20W 4.5 Kg
Hokuyo laser scanner UTM-30Lx	Laser TOF	100mm to 30,000 mm, 270 deg FOV horizontal plane	25 msec/scan
Microsoft Kinect	Structured light called Light coding	Infrared laser project with monochrome CMOS sensor	2.3to 20 ft tracking, 3D
Mesa imaging SR4000	TOF light pulses	50 fps, 12V	850nm illuminator
Bumblebee2	Stereo vision camera hardware with pre-calibration	640x480, 48FPS, 1/3rd CCD	100deg – 43 deg FOV
Low cost 3D depth sensor IIIT- RRC	Infrared structured light	Modified web camera with IR led nano projector,870 nm , 100 ma, 1.8V , 640 x 480 resolution	Mechanized and non-mechanized scanner

*Quake and Crash detection systems			
Quake/Crash Detection system	Platform	Sensing	Other features
I-Shake	I-phone 3GS	i-phone piccolo accelerometer data	Ishake server interaction with USGS survey
Quake-Crash detection system (IIIT- RRC)	Neo-Free runner running SHR, 400 Mhz arm, 128MB RAM	2-3D accelerometer ,GPS	Road quality qualitative estimation, vehicle tracking, accident and quake reports over SMS
Wreckwatch	Iphone and Google android, HTC Nexus with 1 Ghz RAM and 512 RAM	Accelerometer data, photographs, GPS, VOIP channel and accident data recording	3G connection
Stanford's quake detection network	O-Navi USB based sensing and integration with latest low cost Raspberry PI computers	Mems (accelerometers) in Mobile computers, USB accelerometer sensor	Community based global quake sensing network
Sound sense	Sound based detection of emergency events	Microphone input of a mobile phone	

***Mobile HCI projection for navigation and location based navigation.**

Name of the HCI device	Features	Projection and sensing hardware	More notes
Sixth sense (MIT media lab)	3M projector and camera based fudicial interaction	Ticket picture tag based airline identification	Place specific meta data.
RFIG lamps Lamps (MIT media lab)	Location aware lamps	Photosensitive RFID tags, Mini/Portable projector,	Applications in Surveillance, Libraries and Factory robotics
Way-Go Torch (IIIT- RRC)	A flash light based design with laser projector with AHRS and GPS	Modified pico laser projector, 3 Atmel controllers	Wander mode, path guidance mode and flash light mode.
Path light (University of Haifa)	Indoor group navigation in shopping malls	RFID sensing with compass and mobile projector with a cell phone	Navigating in museums, planning group navigation, place and artifact specific info
Bike Laser Emily brighton	Lane navigation, aid and guidance for bikes	Laser symbol projection with custom diffracting plate	Aids in making the bicycle navigation safer by projecting separate lane.
Navi Beam	For guidance indoor in shopping malls	Mobile projector with indoor location sensing hardware like RFID.	Guidance arrow projection for indoor navigation

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