2013

Wirelessly Controlled 7-DOF Robotic ARM/ Mobile Manipulator with Load Carrying and Feedback Mechanism

NARM Robotics

Imagine working in an inaccessible coal mine or inside a volcano where there is every chance of the worker dying due to environmental hazards. This robotic Arm will replace human labour in the near future. With video feedback mechanism and wireless control, this robot arm can go to any place on Earth or even other planets and operate with easy remote control from a place very far away.

NARM

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NARM Robotics

8/26/2013

About Us

NARM (NEW AGE ROBOTICS AND MECHATRONICS) was formed in the year 2012 by 4 students of NIT Jamshedpur. We make different projects in the field of electronics and robotics with practical applications in the society. We have a good depot of state of the art tools and equipments which are needed to help us in our work.
Our previous projects include:

- Mobile phone controlled door locking mechanism
- Solar powered autonomous robot capable of watering plants.
- Autonomous robots helpful in cleaning and sweeping rooms.
- Line Followers, Obstacle Avoiders, Phototrphic and Photophobic robots.
- Visual Image processing robots capable of identifying colour of objects and working autonomously.

Our team members are:

- Shubhojyoti Ganguly (ME112038), *gangulyshubhojyoti@gmail.com*
- Ravi Raushan Kumar (ECE112321), *ni30.ravi@gmail.com*
- Anubhav Pandey (ECE112015)
- Sukanto Mukherjee (ME112063)

Project Features

Title:

Wirelessly Controlled 7 Degree of Freedom(DOF) Mobile Manipulator

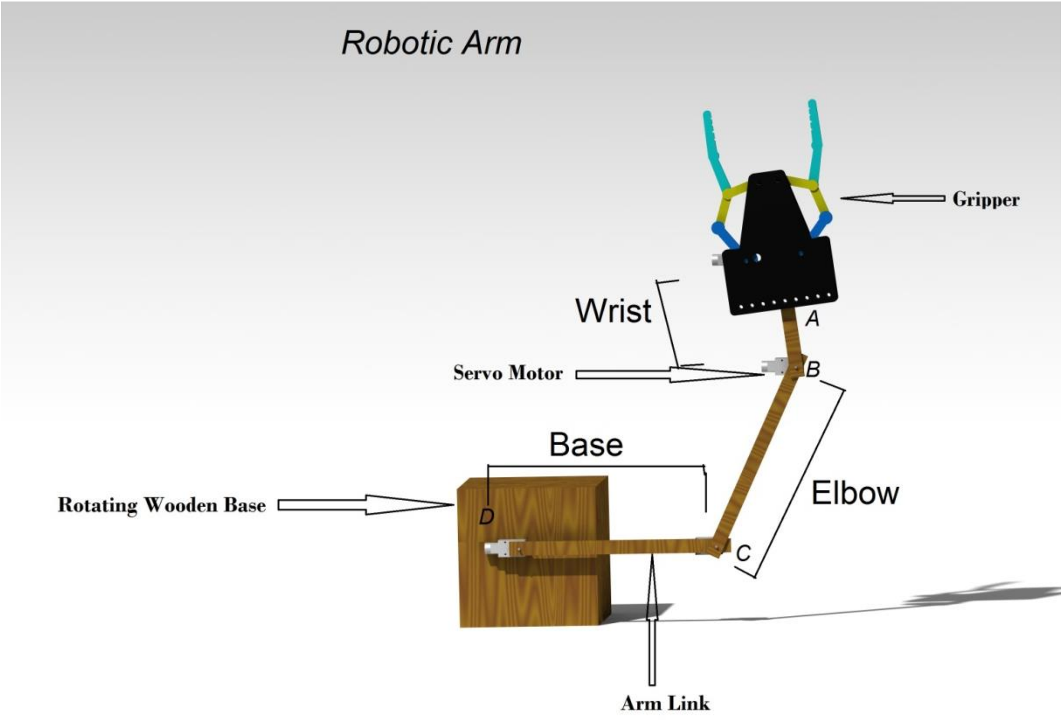
Features:

- Wireless RF Control of portable Robotic Arm within a range of 6 metres.
- Live Video Streaming from Arm.
- 7 DOF can be used to reach any position in a 3D Workspace.
- Portable Arm mounted on a Bakelite Base for easy transportability.
- Arm position Control using a simple phone and is accessible from everywhere with infinite range.
- Lifting and Carrying power of 3kg.
- Strong gripped with rubber grip to prevent slipping of load.
- Connected wheel with gripped belt to improve traction and coverage on any terrain.
- High powered motors run by LiPo battery give good speed and horsepower.

Tools Required

- **MECHANICAL**
  - Chiesel (Firmer &Mortoise)
  - Hammer (ball-pin hammer)
  - Filer (Plane and groove)
  - Mini Bench vice
  - 2 Screw sets
  - Hack saw (mini and normal)
  - A Mechanical set comprising many parts for design modelling & real-time analysis.
  - Gripper, Clamps etc.
- **ELECTRONICS TOOLS AND COMPONENTS**
  - 2 PCBs (Printed Circuit Boards)
  - 3 Breadboards
  - Multicolour LEDs, diode, capacitors, transistors set.
  - Sensors
    - IR Rx Tx (Infrared receiver_Transmitter)
    - Photoresistor
    - Ultrasonic sensor
  - ICs and Decoders
    - MCUs and its AVR Programmer
      - Atmega32A
      - Atmega16PU
    - MOTOR Driver
      - L293D
      - L298D
    - ULN2003N (Darlington Array)
    - Voltage Regulator
      - 7805
      - 7806
    - MAX32
  - SPDT Relays (12V 2A)
  - Hobby SERVOs (4 High torques, 1 Low torque)
- **COMMUNICATION TOOLS**
  - XBee Module and Programmer
  - RF Camera and receiver module
  - DTMF (Digital tone Multi frequency)
- **OTHERS:**
  - Soldering Iron and flux
  - Portable display set
  - Pins and switches
  - Digital Multimeters and different value Adapters

Part 1: The Robotic Arm



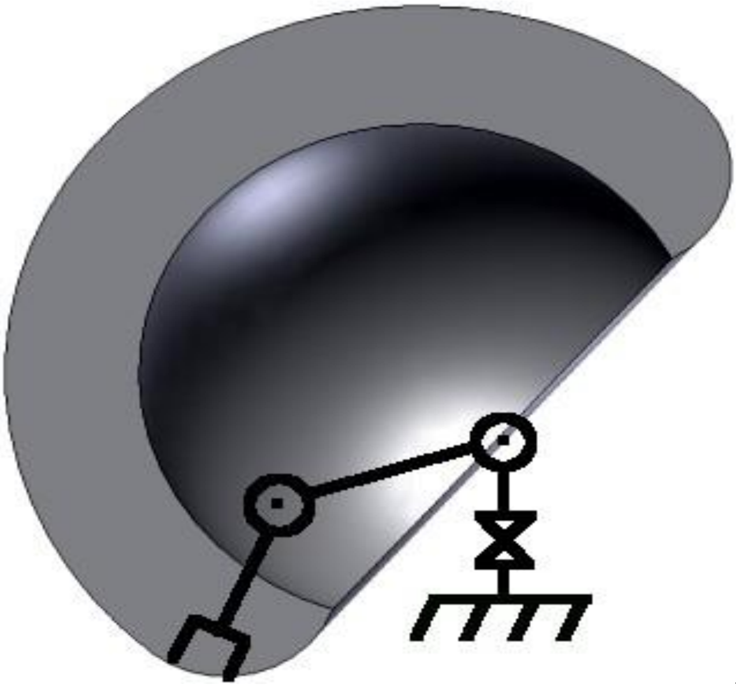
Theory:

The Robotic Arm consists of the following parts:

- Servo Motor: High Torque Motors with position feedback used to rotate joints in the Arm.
- Wooden Base: Heavy Wooden Base on which the 3-DOF Arm is mounted. The Base can rotated by a motor giving the arm an extra degree of freedom.
- Gripper: High powered gripper with rubber grip to prevent slipping can lift loads upto 3Kg.
- Arm Link: The arm links are made of soft wood and are chosen at a particular length so that the bending moment is distributed throughout the beam.

Design:

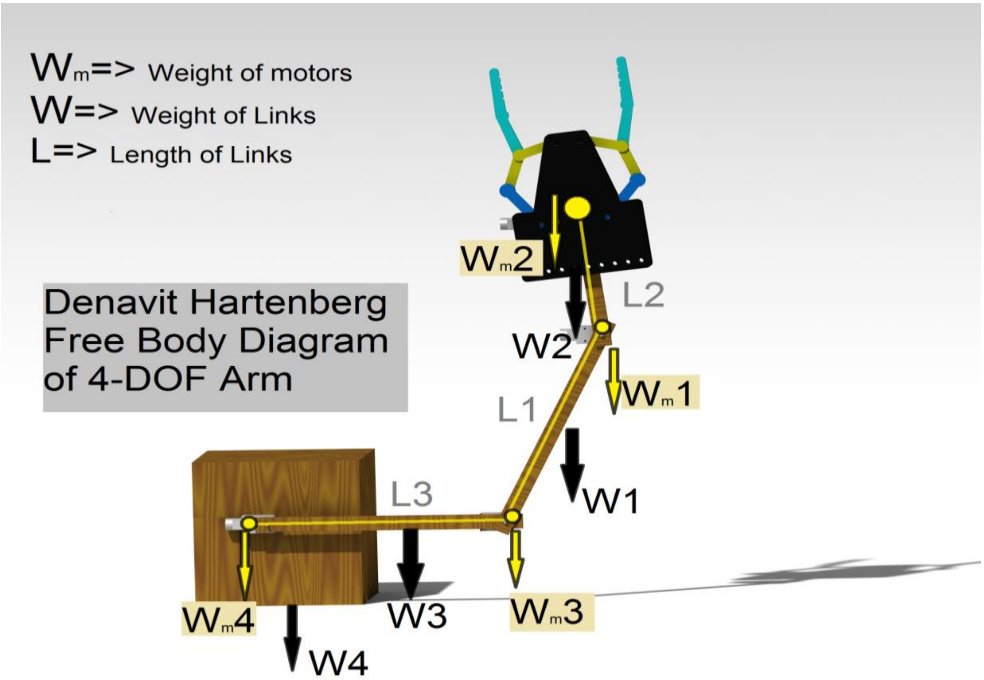
There are three servo motors each controlling a degree of freedom. The base motor rotates to provide a rotational degree of freedom. The high degree of freedom gives a good workspace for the arm. The workspace of the 4DOF Arm is given below .



Arm represented by FBD

The Denavit-Hartenberg Convention is used for drawing the FBD of the arms. The Free-Body-Diagram for the arms is given below. The FBD is used to calculate the bending-moment about each point A,B,C and the required servo motor is chosen in each of these positions.

Let W_m1,W_m2,W_m3,W_m4 be weight of motors; W1,W2,W3 be weight of links, L be weight of Load, W4 weight of Base and L1,L2,L3 be length of Links. Then Moment about A is denoted by M_A , about B denoted by M_B and about C denoted by M_C.



Since the maximum moment is taken so, the maximum projection of each link is taken

$\sum M_B = (W_m 2 \times L2) + (L \times L2) + (W2 * L2/2)$

$\sum M_A \sim = L$

$\sum M_C = \{W_m 2 \times (L1 + L2)\} + \{L \times (L1 + L2)\} + \{W2 \times (L1 + L2/2)\} + (W1 \times L1/2) + (W_m 1 \times L1)$

$\sum M_D = \{W_m 2 \times (L1 + L2 + L3)\} + \{L \times (L1 + L2 + L3)\} + \{W2 \times (L1 + L3 + L2/2)\} + \{W1 \times (L3 + L1/2)\} + \{W_m 1 \times (L3 + L1)\} + (W_m 3 \times L3) + (W3 \times L3/2)$

From the above formulae, we choose a suitable L1,L2,L3 for a list of available servo motors in the market.

$W_i = \rho A L_i$,
where ρ=Density of wood;   A=Area of Cross-section(2cm²)

Thus, the final chosen parameters for design are:

$L_1 = 7cm$, $L_2 = 2cm$, $L_3 = 8cm$

Therefore the required servo motor specifications are:

<u>Motor at B (Vigor VS10):</u>
Max. Torque= 8.0kgf-cm
Operating voltage=6V
Weight=150gms
Price: Rs.1500

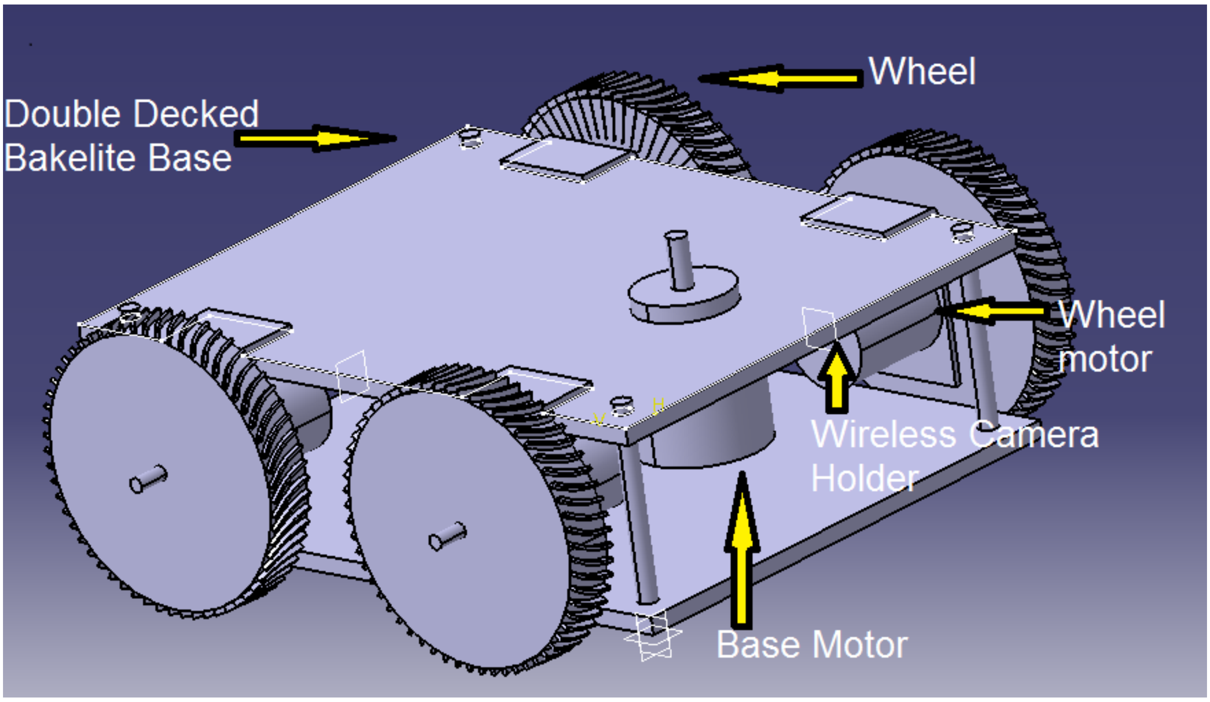
<u>Motor at C(RKI-1240):</u>
Max. Torque=12kgf-cm
Operating voltage=6V
Weight=180gms
Price: Rs 2,900

Motor at C(Vigor VSD11YMB):

Max. Torque=30kgf-cm
Operating voltage=6V-12V
Weight=250gms
Price: Rs. 5,900

Note: The torque due to acceleration of the motors is neglected as the acceleration acts for a very short time so the net impulse is very less. Moreover, a maximum torque rating well above than the maximum bending moment is taken to avoid complicacies.

Part 2: The Mobile Base



The base of the mobile manipulator uses a differential steering mechanism for fluid control and motion. The main parts of the base are given below:

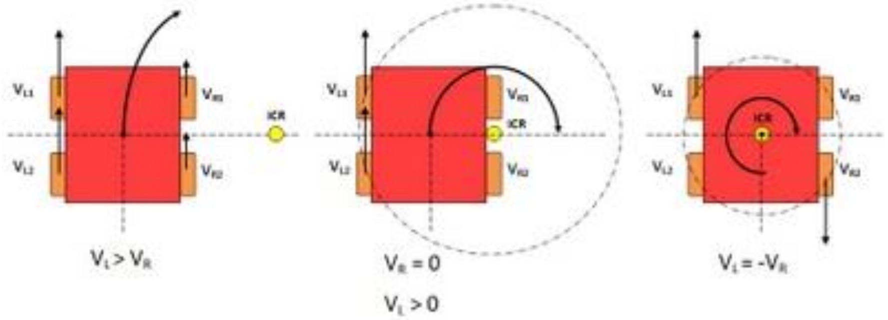
- *Wheel*: Wheels of the robot have reverse grooved rubber gripper to provide high friction between surface and the bot. The grooves are slanted at tangents of 15^o to the horizontal.
- *Wheel Motor*: 12V DC Motors of the Johnson Type is used. The maximum current consumption of the motors are ~2A while it rotates at 100rpm, which provides a good balance between speed and torque essential in functioning in most terrains.
- *Base Motor*: A high torque base motor of 12V-10rpm is used to rotate the base of the arm and thus providing an additional degree of freedom.
- *Motor Clamps:* All motors are attached to the Bakelite base by used of strong metal clamps.
- *Bakelite Base*: Two Bakelite sheets parallel to each other and about 5cm apart are used to make the main chassis of the robot. The upper base is used for placing things which the mobile arm picks up while the lower base contains the electronic circuitry and driver circuits used for running the arm.

- *Nuts and Bolts*: Long 9cm bolts of 2mm diameter are used to join the two Bakelite sheets together leaving a gap of ~6cm. The bolts are used to sandwich the Bakelite in between them.
- *Wireless Camera:* The wireless camera sends a video feed from the arm to the control station for feedback analysis

The Differential Steering Mechanism

The Differential Steering mechanism is used to drive the robot. In this mechanism, two set of wheels are aligned in straight lines along the left and right side of the robot. The mechanism works in five possible ways given below:

- When all the left wheels turn clockwise and all the right wheels turn anticlockwise, the structure moves forward.
- When all the right wheels turn anti-clockwise and all the left wheels turn clockwise, the structure moves backward.
- When the right wheels and the left wheels both move in the clockwise direction, the structures takes a quick turn about the centre to left.
- When the left wheels and right-side wheels both turn in the anti-clockwise direction, the robot takes a quick turn about the centre to right.
- When the left side wheels moves forward and the right wheels remain stationary, the structure takes a long turn to right.
- When the right side wheels moves forward and the left side wheels remain stationary, the structure takes a long turn to left.

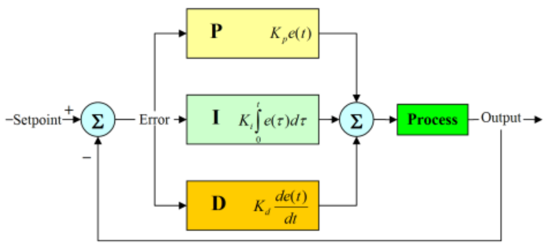


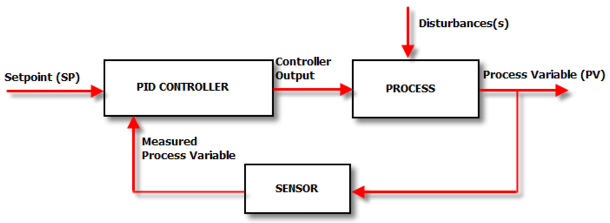
Part 4: Algorithms Used in Control

Different algorithms and control systems are used for proper co-ordination of different parts of the mobile manipulator. They are given below:

The PID Control

The Proportional-Integral-Derivative Control is used in the servo motors for holding position and angles of the arm to carry out actions. A block diagram for the PID control and the formulae for calculating the error in position is given below





The pseudo code after calibration is given below:

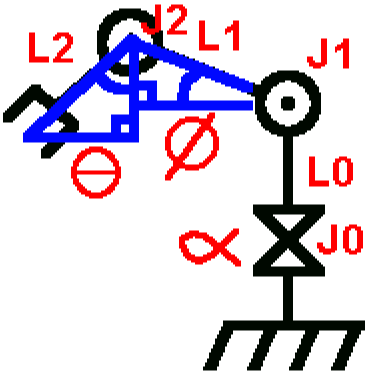
```
float PID(float cur_value,float req_value)
{
  float pid;
  float error;

  error = req_value - cur_value;
  pid = (200 * error)  + (0.2 * eInteg) + (120 * (error - ePrev));

  eInteg += error;               // integral is simply a summation over time
  ePrev = error;                // save previous for derivative

  return pid;
}
```

Forward and Inverse Kinematics

The inverse kinematics concepts are used to calculate the angular positions of Servos (M1,M2,M3) when the final co-ordinates of the gripper end is known.

The forward kinematics concepts along with the Newton's fundamental laws help in calculating the final co-ordinates of the gripper arm when the angular positions of the servos (M1,M2,M3) are given.

All formulae are derived taking the base motor(M4) as origin.



Joint 1 (with x and y at J1 equaling 0):

*cos(psi) = x1/L1 => x1 = L1*cos(psi)*
*sin(psi) = y1/L1 => y1 = L1*sin(psi)*

Joint 2 (with x and y at J2 equaling 0):

*sin(theta) = x2/L2 => x2 = L2*sin(theta)*
*cos(theta) = y2/L2 => y2 = L2*cos(theta)*

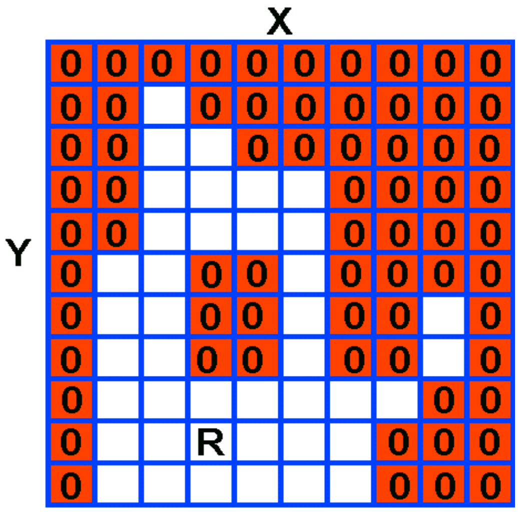
End Effector Location:

*x0 + x1 + x2, or 0 + L1*cos(psi) + L2*sin(theta)*
*y0 + y1 + y2, or L0 + L1*sin(psi) + L2*cos(theta)*
z equals alpha, in cylindrical coordinates

Wavefront Algorithm

The wavefront algorithm is used in autonomous control of the robotic arm. A 2D matrix is used as an environment map where cell containing obstacles are marked and this matrix is used for mapping the motion of the arm from a given point or a cell to another. The pseudo code for the algorithm is given below.

Image mapping of the environment



Converting map to matrix

check node A at [0][0]

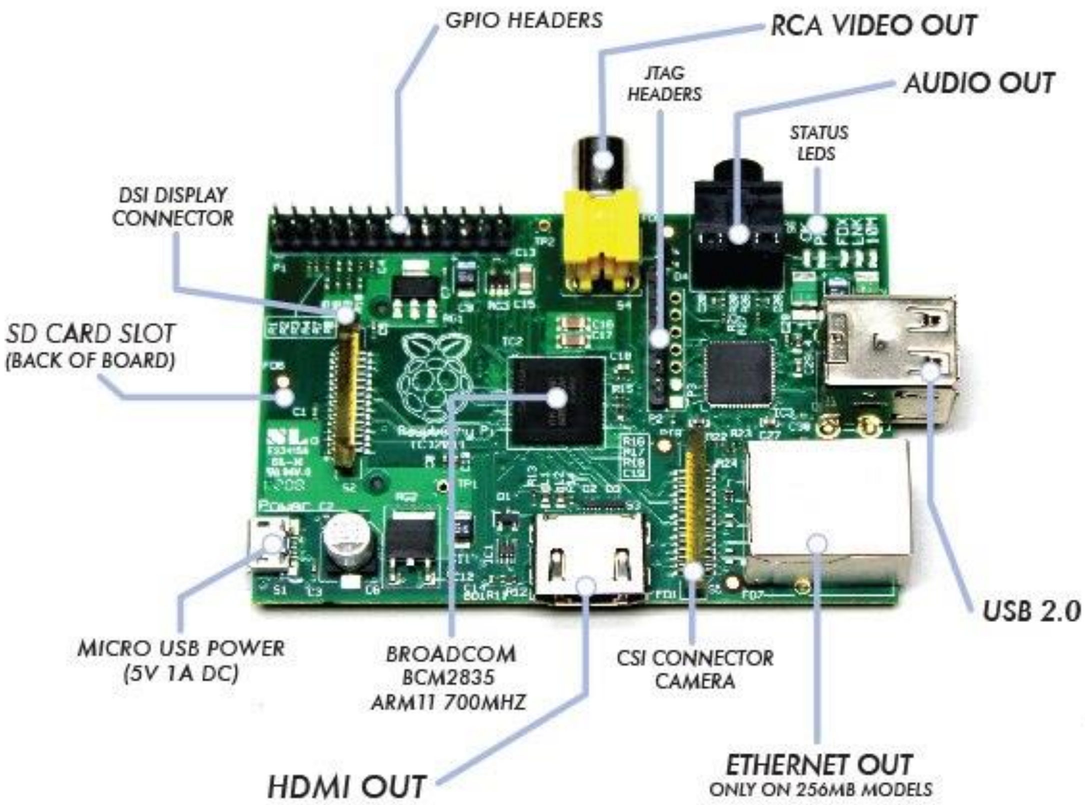
```
now look north, south, east, and west of this node
        (boundary nodes)

if (boundary node is a wall)
        ignore this node, go to next node B

else if (boundary node is robot location && has a number in it)
        path found!
        find the boundary node with the smallest number
        return that direction to robot controller
        robot moves to that new node

else if (boundary node has a goal)
        mark node A with the number 3

else if (boundary node is marked with a number)
        find the boundary node with the smallest number
        mark node A with (smallest number + 1)

if (no path found)
        go to next node B at [0][1]
        (sort through entire matrix in order)

if (no path still found after full scan)
        go to node A at [0][0]
                (start over, but do not clear map)
        (sort through entire matrix in order)
        repeat until path found

if (no path still found && matrix is full)
        this means there is no solution
        clear entire matrix of obstacles and start over
        this accounts for moving objects! adaptivity!
```

Wireless Control and Image Processing

The Broadcom based ARM processor with its development board packed as the Raspberry Pi is used to control the Mobile Manipulator via wi-fi networks or radio frequency. Image processing is carried out to detect objects and implement the wavefront algorithm. Python script in the raspberry pi helps to control the robot. The pseudo code for image processing is given below:

```
import imgproc
from imgproc import *

# open a webcam to take pictures
camera = Camera(160, 120)

# Open a viewer window to display images
viewer = Viewer(160, 120, "Colour Key")

# take a picture from the camera
img = camera.grabImage()

# display the image in the viewer
viewer.displayImage(img)
```

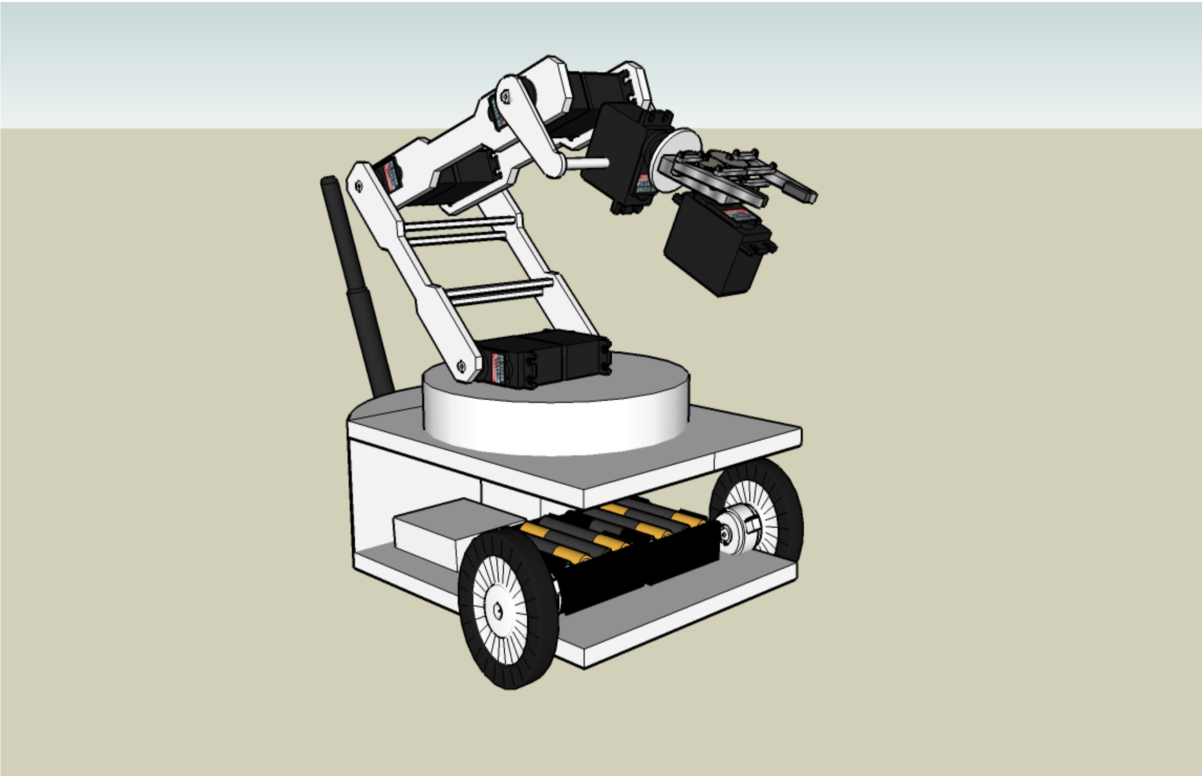
```
# iterate over each pixel in the image
for x in range(0, img.width):
        for y in range(0, img.height):

                # respective arm position


# display the image again
viewer.displayImage(img)

# delay for 5000 milliseconds to give us time to see the changes, then exit
waitTime(5000)


# end of the script
```



The Raspberry Pi

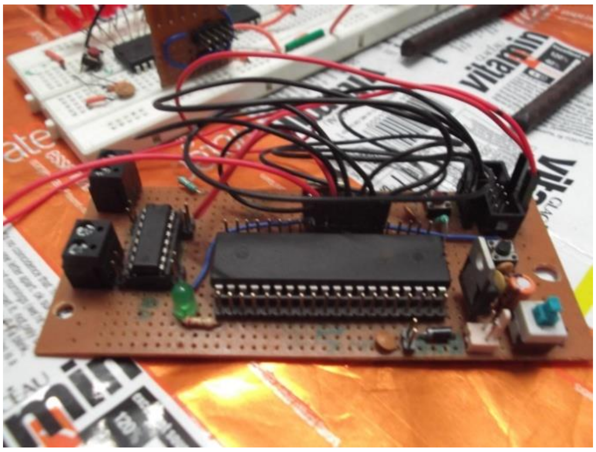
Part 5: Assembling it all together

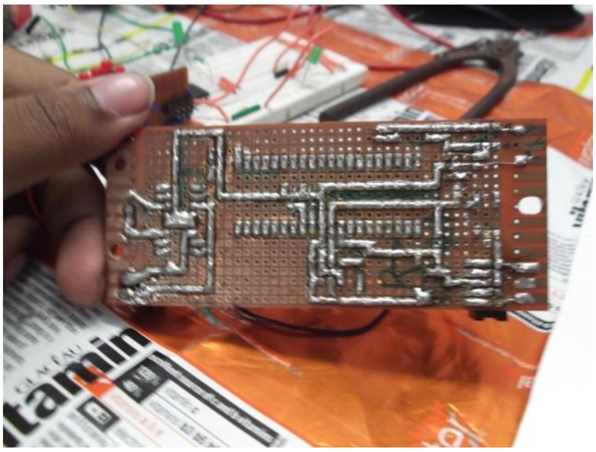
The final assembled product –the 7DOF mobile manipulator is given below.



The image given above is a simulation of the prototype designed in CATIA V5. Since the actual model is not yet complete so the snapshot of the complete prototype could not be obtained.

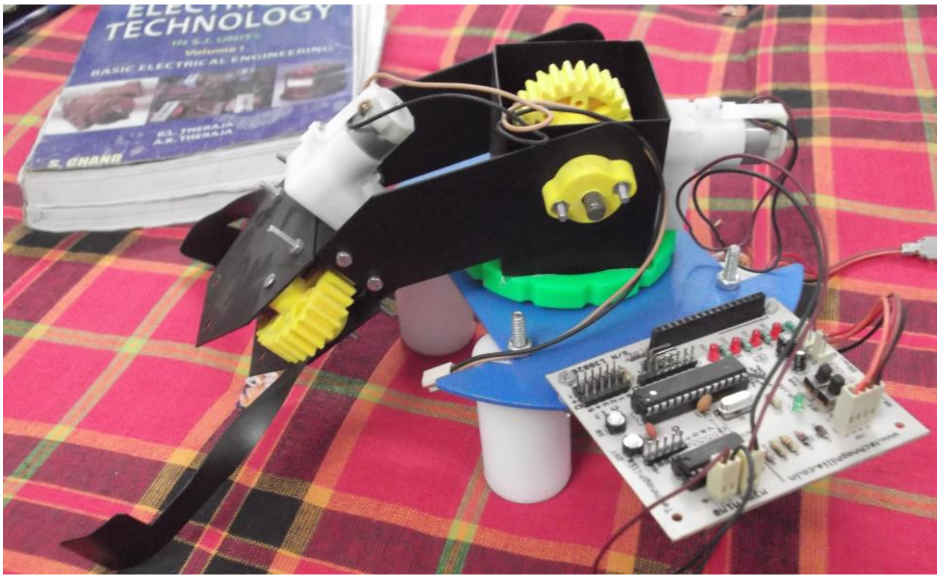
Snapshots of our work






eXtreme
Electronics
Electronics

Raspberry Pi
(c)2011.12


TECHNOLOGY
BASIC ELECTRICAL ENGINEERING
S. CHAND

Budget of our project

Items Required	No. of piece	Expected Cost/piece
Extreme Burner	1	1000
USB AVR Programmer	1	500
Stepper Motor	5	1500
Vigor VS10	5	1200
Vigor VS10A	5	700
IR Rx Tx pair	10	25
Line Sensor Array	2	200
IR Range finder	2	1500
Ultrasonic Range Finder	2	610
Triple Axis Accelerometer	2	535
X-Board mini	1	1800
GSM-GPRS MODEM	1	1800
LCD Display	3	450
PIC MCUs	3	350
Servo Motors	4	10,000
AVR MCUs	4	250
Raspberry Pi and it accessories	1	9,500
TOTAL		INR 31'900/-

We need extra devices but we couldn't get the product in the Indian Dealers' Website so a large import duty is being charged to order from abroad. So, we request you to please **help us with some additional amount. I.e. approx. Rs 32000/-** for purchase of digital oscilloscop, function generator, PCB Etcher and Etching Fluid.

We also **require a room for our work** because it is getting tough for us to manage such a big project in a room. So, kindly allow us a space for the work.

So, our **total budget** for completing the project amounts to

RS. 65,000 (APPROX.)

Applications of the Mobile Manipulator

- The bot can take snapshots of locations which are unreachable for human
- The bot can be used to bring out suspected/required objects from caves/holes/mines
- It can be used for taking the overview of the activities taking place under and below the bot.
- It can be used in bomb diffusion process and activities in which human intervention is dangerous.
- It can push-pull the objects.
- It can be controlled wirelessly from anywhere. So it is better security guard.
- It can perform multiple task simultaneously like video recording with arm actions.
- It can self-balance itself under rough and bumpy terrains.
- It can automatically detect required/defined objects.
- The whole system can be switched on/off automatically
- It can follow the suspects or the suspect vehicle automatically.
- It can be as a speed detector in traffic as well as it can control the serios jamming condition.
- It can automatically switch on/off the traffic lights and lights in mines/tunnel/cave depending on natural atmospheric condition.
- If it is installed in every home ,then it can prevent the power overconsumption, transformer and grid failure
- In defense, it can be used to send bombs in enemy territories

Future Scope of our project

The 7-DOF robotic mobile manipulator can be further enhanced with Artificial Intelligence (AI) algorithms to automatically detect entities from its environment and fabricate its own algorithms to solve tasks. One common example is the task to make coffee where milk, coffee, water and sugar is given.
Furthermore, the robotic arm can be equipped with advanced image processing techniques of pattern analysis whereby it can detect complex structures like human faces and automatically respond to them.

Thank You