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Web-Controlled Surveillance Robot with A Robotic Arm

Atharva Kaluskar, Kshitij Avalaskar, Het Gandhi

B. E, Dept. of Electronics and Telecommunications, P.E.S. Modern College of Engineering, University of Pune, Pune, India.

ABSTRACT: It is very important to keep our border security forces well-equipped with the latest technologies to prohibit unwanted occurrences and strengthen our troops. Keeping these facts in mind, we came up with an idea of building a vehicular robot which can patrol our borders day and night and keep a close eye on the sensitive areas. Real-time video captured by the cameras mounted on it will be transmitted continuously to the department of the Border Security Forces (BSF) for monitoring. We have also mounted a robotic arm on it for grabbing or placing objects. In addition to this, it will also be controlled by the BSF from the same department wirelessly via the internet.
This would most importantly help save human lives as it can be deployed into the sensitive areas where the risk of losing human lives is high.

In addition to the main aims of video surveillance and remote control, many more applications can be added. By using Global Positioning System (GPS), we can continuously monitor the location of the vehicle. Also it can be modified in the future for more applications in the fields of artificial intelligence and image processing.

It is also possible to reconfigure and customize this robot according to our needs and use it in various fields other than border security like space programs, automation industries and heavy machinery factories.

KEYWORDS: Arm, Shoulder, Elbow, Wrist, Raspberry Pi, Arduino, GPIO, Python, Javascript, GUI

I. INTRODUCTION

Web-Controlled Surveillance Robot is a vehicular robot which can be controlled wirelessly via the internet. It has cameras mounted on it for the purpose of video surveillance. The robotic arm mounted on it makes it a multi-purpose machine. The main application is surveillance across the international borders for monitoring of any illegal or suspicious activities, intrusions or ceasefires violations.

In this project we are using Raspberry Pi, which is one of the latest state of the art technologies available in the market. It is a mini computer with a powerful Linux based ARM11 processor and an in-built Raspbian OS, with all the interfaces and memory slot being on the same chip. It is customized for user friendly functionality in a compact and portable environment. The main reason behind selecting Raspberry Pi is its excellent performance with respect to speed as well as user friendliness at a very low cost. The main advantage behind using Raspberry Pi is its portability along with a powerful processor, RAM and interfaces with the outside world all on the same chip. It has innumerable applications which can be realized in very less space and money.

We have interfaced the Raspberry Pi with a microcontroller for control of motors of the robotic arm. We are using a 5MP USB Camera for capturing video with the Raspberry Pi. This video will be available on any browser just by entering the IP address of the Raspberry Pi in the address window. We are using Motion software for building a webcam server and WebIOPi software for controlling the robot via the internet. A customized Graphical User Interface (GUI) for operating the robot will also be available on the internet on the same IP address of the Raspberry Pi.

In addition, we have also constructed a robotic arm on the vehicle which can be used for grabbing or placing an object from/to a particular position.

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II. RELATED WORK

While doing the literature survey, our main aim was to find a kind of technology that was suitable for both live video streaming and online control at the same time. We knew that live streaming would require very high data rates and a single microcontroller would not be able to do that. We required a remote device which would be isolated from any sort of computers to do it for us. That ruled out all the software that is available for live streaming from a computer. The first step was to select a microcontroller with a large memory and fast speed of operation. The basic Atmegas and PICs would be futile because of this. That's why we went for ARM. The technologies that we surveyed are:

1] Processor survey

1. Arduino Due: The Due board of the Arduino platform is the only arduino board with an ARM processor. It has a 32-bit ARM Cortex M3 processor. But upon doing some detailed research about it we decided not to use it as it was not suitable for live video streaming as well as online control at the same time. Also it required a Wi-Fi shield as well a GPRS module to be interfaced with it which took it well out of our financial budget.

2. Raspberry Pi: As we continued our research, we came across a new technology developed in the UK known as Raspberry Pi. RPi is basically an ARM processor mounted on a credit card sized chip with the memory and external interfaces along with GPIOs (General Purpose Input Output) mounted on the same circuit board which makes it a mini computer. It not only made our main aims-live streaming and online control easier but also offered many more services which would add more applications to our Project. Hence we selected Raspberry Pi as our main circuit board along with other peripherals.

A very powerful and fast processor along with high memory and latest interfaces, all on the same chip has made it a clear selection over the Arduino Due.

2] Camera survey:

1. USB Webcam

A USB Webcam was the first choice which came to our minds because of its simple interface and satisfactory performance. The USB interfaces available on the Raspberry Pi chip made it easier to connect it to the Pi. Plug n play performance made it the obvious choice over the other types.

3] Motor Survey

We considered using two types of motors for this vehicle viz. DC geared motors and servo motors. DC geared motors are used in applications where 360 degree rotation is required while servo motors are used when a certain angle of rotation is necessary. That is why we used DC motors for the movement of the vehicle i.e. for driving the wheels. Servo motors were used for the movement of the robotic arm where precision is of utmost importance and rotation in a certain angle is required.

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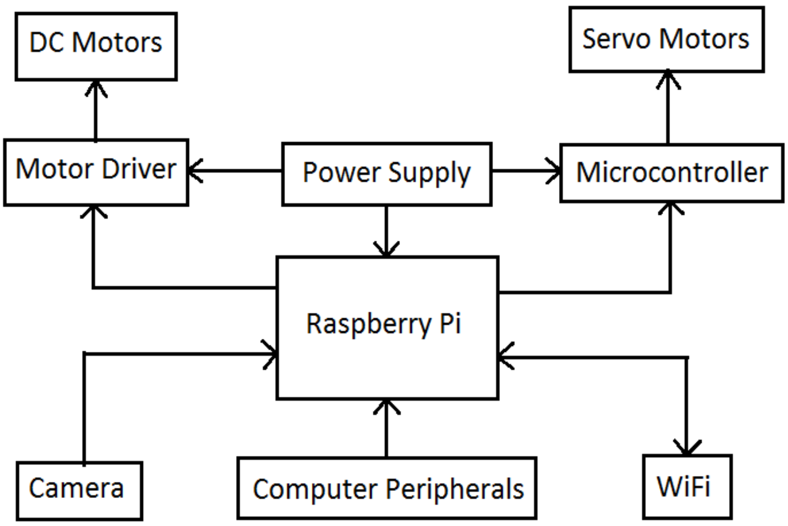
III. PROPOSED ALGORITHM



1] Raspberry Pi: This is the heart of our system, the main control board which will do majority of the operations. It will receive the output of the USB camera. The internet connection will be provided to it via a Wi-Fi router. The computer peripherals like keyboard and mouse are required for regular operation. An LCD with HDMI interface will be required for display purpose. We will also access the GPIOs of Raspberry Pi via the internet and in turn control the DC motors attached to the wheels. The Pi will send out signals to the microcontroller for control of the servo motors required for the robotic arm.

2] Microcontroller: The main purpose of this block is production of PWM signals, which drive the servo motors. This is not possible in Raspberry Pi because of presence of an OS embedded inside the processing chip which continuously sends out signal bursts which is very undesirable for the functioning of servo motors.

3] Motor Drivers:Motors have high current requirements which cannot be fulfilled by the Pi or the microcontroller. That is why; we need motor drivers to produce the drive current required.

4] Motors:

a) DC Motors: These will be connected to the actual wheels of the vehicle and will be controlled remotely. Two additional DC motors have been used for controlling the grabbing & releasing actions of the robotic arm and even for the 360 degrees revolution of the robotic arm.

b) Servo Motors: These are used in the different joints of the robotic arm viz. the shoulder, elbow and the wrist.

IV. COMPONENT-WISE DESIGN

1] Raspberry Pi

The Raspberry Pi has a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor with 512 MBs of RAM. It does not include a built-in hard disk or solid-state drive, but uses an SD card for

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booting and long-term storage. It also has 2 USB 2.0 ports along with an Ethernet port for wired network interface. It contains an HDMI port, RCA video and audio jacks for interface with the outside world. It has 8 GPIOs (General Purpose Input Output), UART, I2C and SPI bus with 2 chip selects. The power is provided by a micro USB adapter.

The various GPIOs of the RaspberryPi are shown below.

2] Microcontroller

The microcontroller is connected to the GPIOs of the Raspberry Pi. According to the signal produced remotely (either high or low) on a particular GPIO, the microcontroller will output the corresponding signal to drive a particular motor. For e.g. if GPIO 5 is made high, then the microcontroller will give a PWM output corresponding to the upward/downward motion of a specific servo motor mounted on the robotic arm.

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The high-performance Atmel 8-bit AVR RISC-based microcontroller combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts,serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed.

3] Motors

These, along with the chassis are the basic mechanical building blocks of the vehicle which are required for its motion and mobility. Drivers are used because the output ports of the microcontroller cannot source the required amount of current.

1. DC Motors

A DC motor relies on the facts that like magnetic poles repel and unlike magnetic poles attract each other. A coil of wire with a current running through it generates an electromagnetic field aligned with the center of the coil. By switching the current on or off in a coil its magnet field can be switched on or off or by switching the direction of the current in the coil the direction of the generated magnetic field can be switched 180°. A simple DC motor typically has a stationary set of magnets in the stator and an armature with a series of two or more windings of wire wrapped in

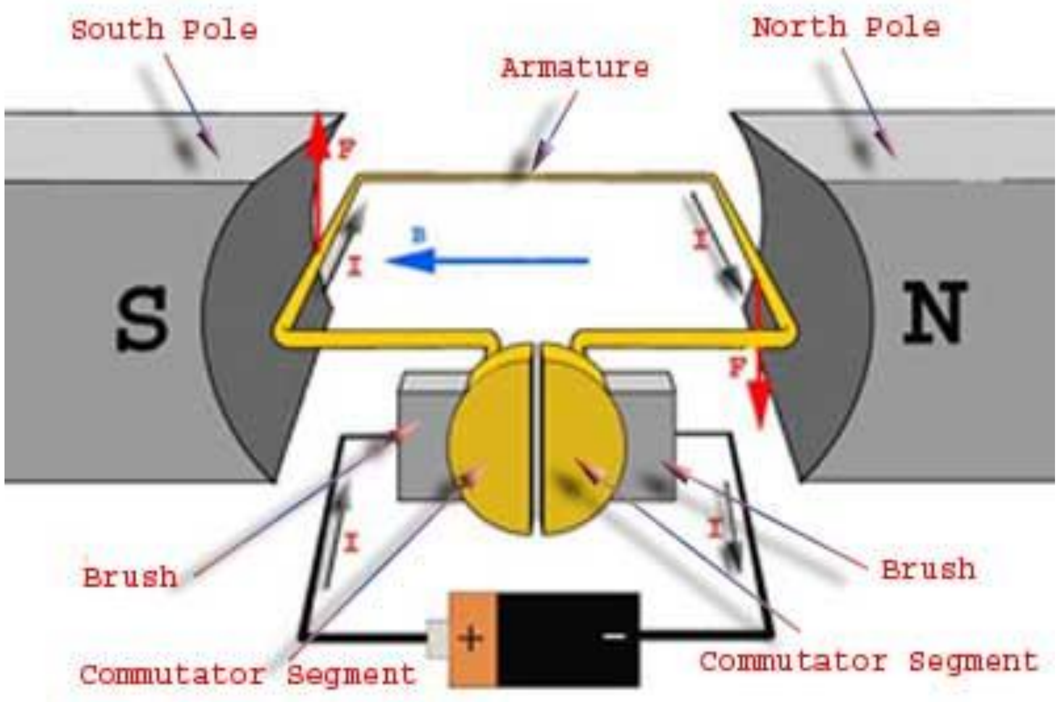

Fig 4.1 Internal Working of a DC Motor

insulated stack slotsaround iron pole pieces (called stack teeth) with the ends of the wires terminating on a commutator. The armature includes the mounting bearings that keep it in the center of the motor and the power shaft of the motor and the commutator connections. The winding in the armature continues to loop all the way around the armature and uses either single or parallel conductors (wires), and can circle several times around the stack teeth. The total amount of current sent to the coil, the coil's size and what it's wrapped around dictate the strength of the electromagnetic field created. The sequence of turning a particular coil on or off dictates what direction the effective electromagnetic fields

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are pointed. By turning on and off coils in sequence a rotating magnetic field can be created. These rotating magnetic fields interact with the magnetic fields of the magnets (permanent or electromagnets) in the stationary part of the motor (stator) to create a force on the armature which causes it to rotate. In some DC motor designs the stator fields use electromagnets to create their magnetic fields which allow greater control over the motor.

2. Servo motors

A servomotor is a rotary actuator that allows for precise control of angular position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.

As the name suggests, a servomotor is a servomechanism. More specifically, it is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is some signal, either analogue or digital, representing the position commanded for the output shaft.

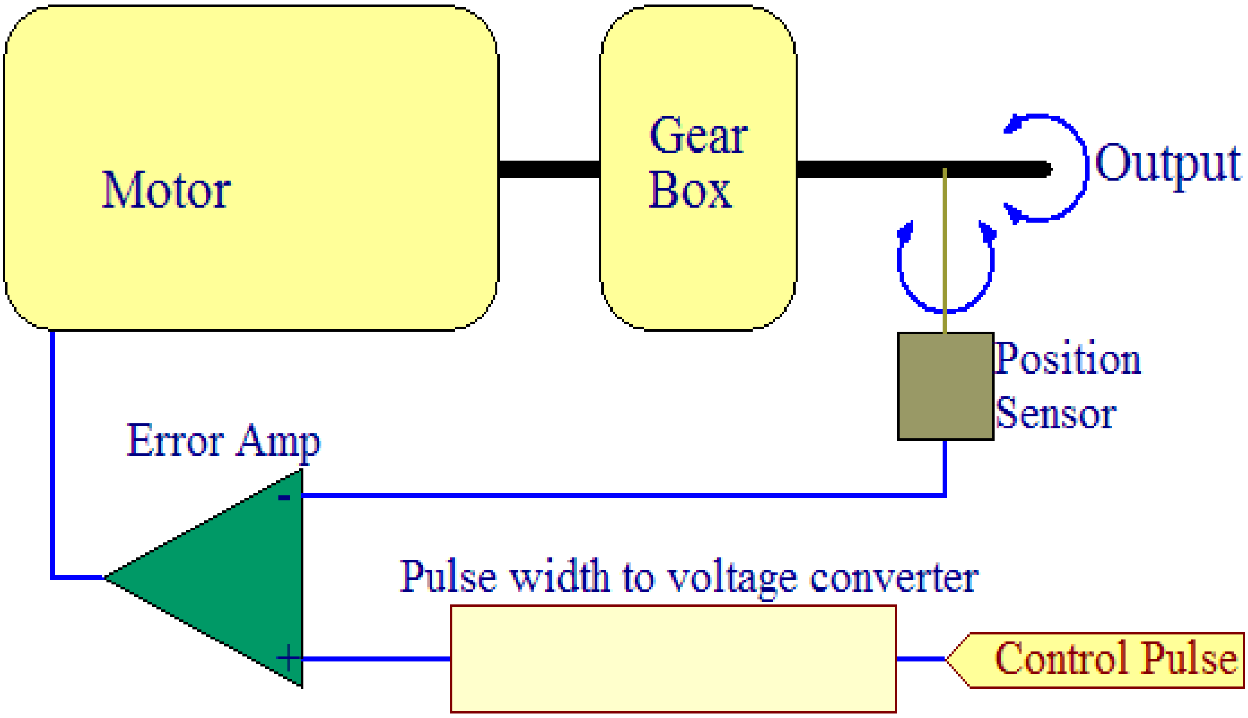

Fig 4.2 Block Diagram of servo motor

The motor is paired with some type of encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops.

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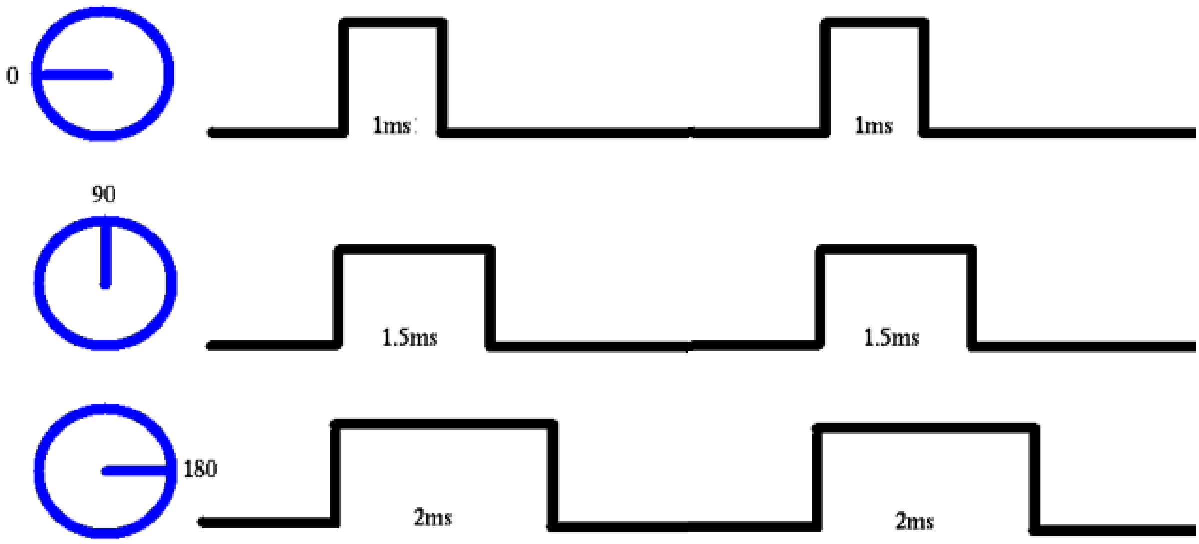

Fig 4.3 Timing Pulses (PWM) for a servo motor

The angle is determined by the duration of a pulse that is applied to the control wire. This is a form of pulse-width modulation, however servo position is not defined by the PWM duty cycle (i.e., ON vs OFF time) but only by the duration of the pulse. The servo expects to see a pulse every 20 ms, however this can vary within a wide range that differs from servo to servo. The length of the pulse will determine how far the motor turns. For example, a 1.5 ms pulse will make the motor turn to the 90 degree position (neutral position).

4] Servo motor calculations:

We know,

Required Torque = Force*Perpendicular Distance

A] For wrist servo motor

We have considered lifting a load of weight 400gms with the robotic arm. So the end weight to be lifted is the sum of the weight of the arm from the wrist and the load weight. Thus
L=400g+100g=500g
Perpendicular distance from wrist to load is L=4cm

Thus,
Torque = 500 g*8cm
= 2000g-cm
= 2 kg-cm

Similarly,

B] For elbow servo motor
Torque = 800g*13cm
= 10400g-cm

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= 10.4kg-cm

C] For shoulder servo motor
Torque = 1100g*18cm
= 19800g-cm
= 19.8kg-cm

According to the nearest torque values of servo motors available in the market, we have finalized the motors with torques 4kg-cm, 15kg-cm and 18kg-cm for wrist, elbow and shoulder respectively.

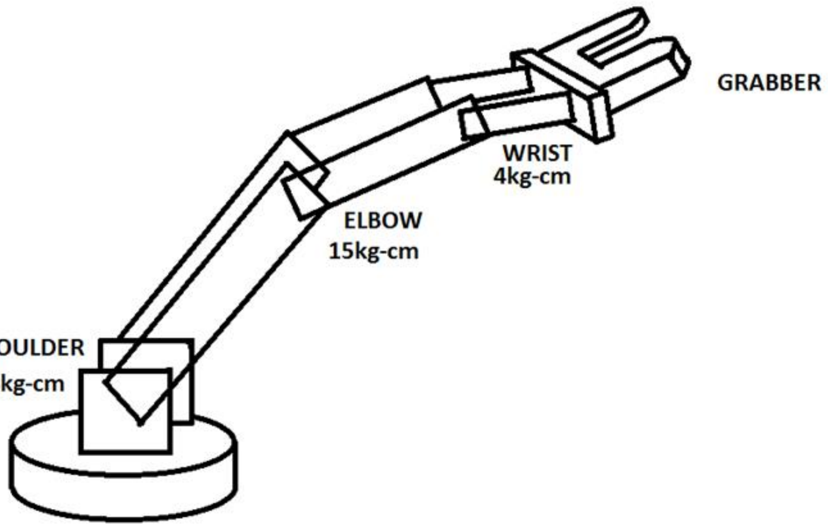

Fig 4.4 A Robotic Arm

5] DC Motor Drivers

L293D is a dual H-bridge motor driver integrated circuit (IC). Motor drivers act as current amplifiers since they take a low-current control signal and provide a higher-current signal. This higher current signal is used to drive the motors.

L293D contains two inbuilt H-bridge driver circuits. In its common mode of operation, two DC motors can be driven simultaneously, both in forward and reverse direction. The motor operations of two motors can be controlled by input logic at pins 2 & 7 and 10 & 15. Input logic 00 or 11 will stop the corresponding motor. Logic 01 and 10 will rotate it in clockwise and anticlockwise directions, respectively.

Enable pins 1 and 9 (corresponding to the two motors) must be high for motors to start operating. When an enable input is high, the associated driver gets enabled. As a result, the outputs become active and work in phase with their

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inputs. Similarly, when the enable input is low, that driver is disabled, and their outputs are off and in the high-impedance state.

Pin Diagram:

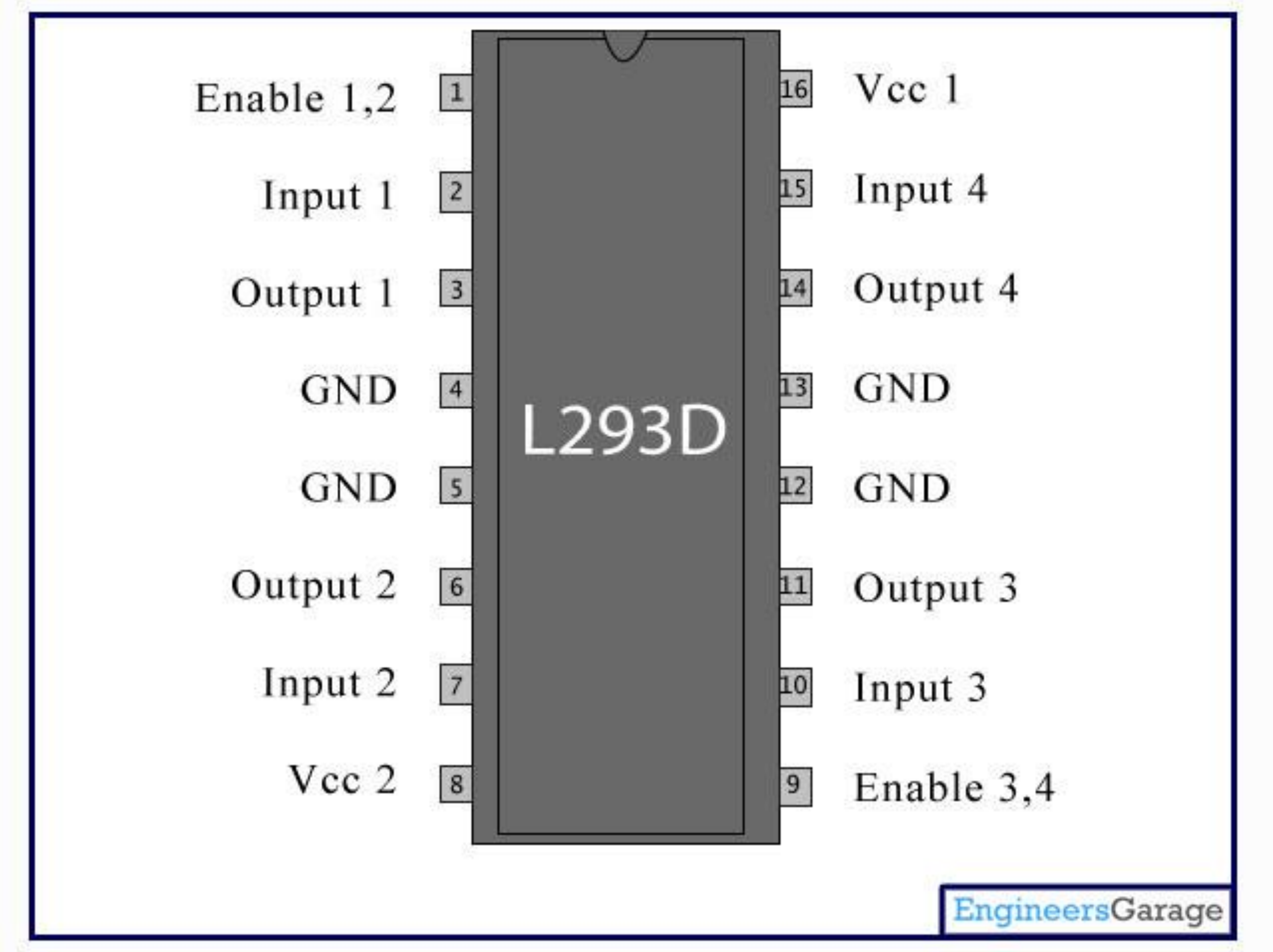

Fig 4.5 Pin Diagram of L293D

6. Robotic arm

The robotic arm mounted on our robot mimics an actual human arm. The movement is made possible by the use of 5 motors - 3 servo motors and two DC motors.

The arm is made up of different links which are a shoulder pivot, an elbow, a wrist, and a grabbing assembly mimicking the human finger.

1. The 360 degree rotation: The 360 degree rotation occurs in a horizontal plane and uses a 200 rpm DC motor for the same. The shaft of the DC motor is fitted with a Worm gear. This worm gear runs a Spur gear which helps in converting the lateral movement of the motor's shaft into a longitudinal movement. The spur is fitted on a cylinder which holds the base plate on which the arm is mounted.

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Fig 4.6 Meshing of worm and helical gears

In the image shown above the small gear is the worm gear. The shaft of the motor is attached to this gear. The bigger gear is the spur gear which is actually hollow from inside so as to attach the cylinder of the base plate.

2. The Shoulder: The entire arm is mounted on a base plate which rotates and the first link of the arm is the shoulder link. For the angular movement of the shoulder link a servo motor of 17 kg torque is used. The motor rotates from 0 to 180 degrees which is similar to the movement of a human arm. The use of a high torque motor facilitates in lifting the weight of the links along with the grabber and the object to be picked.
3. The Elbow: This link is driven by a servo motor of 17 Kg torque. This links extends from the elbow to the wrist similar to the way it is for a human arm. The servo motor rotates from 0 to 180 degrees to mimic the human elbow. The use of a high torque motor helps in lifting the weight of the wrist, the grabber assembly and the object which is to be lifted. This link consists of another motor on its opposite end which is used for the wrist movement.
4. The Wrist: The motor for the wrist movement is placed on the elbow link itself on the opposite end. The motor used is a servo motor of 4 kg torque and rotates from 0 to 180 degrees mimicking the movement of a human's wrist. The use of a high torque motor helps in lifting the weight of the grabber assembly and the object which is to be lifted. The grabber assembly is fitted directly adjacent to the end of the link. The webcam will be placed on this link.
5. The Grabber: This assembly is fitted to end of the elbow link. It facilitates in the grabbing of the object which is to be lifted. Its mechanism depends on a DC motor of 100 rpm. It has 2 crab arms which are moved with the help of a motor-gear assembly. The motor drives one of the crab arms along with a gear which in turn drives another crab arm. This assembly mimics the grabbing movements of the thumb and the index finger of a human's hand.

All the above entities when assembled together form a robotic arm. The 360 degree rotation of the arm makes it convenient to operate the robot as turning the entire robot is not mandatory every time the arm's direction needs to be changed.

The usage of 5 motors lends accuracy to the movement of the arm and even facilitates in smoother functioning.

Working of the robotic arm

To lift an object from the ground level the robotic arm would follow the followings steps:

a. The arm would be rotated in the direction of the object using the 200 rpm Dc motor.
b. Then the shoulder link would be moved in the downward direction using its servo motor.

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c. Once the limit of the shoulder link's movement has reached the elbow link is moved in the downward direction.
d. Then the wrist's servo is moved to move the grabber assembly.
e. In the end the grabber is released and clutched to grab the object.
f. Then the wrist, elbow and the shoulder are moved one after the other to lift the object.

7. Interfacing Schematic

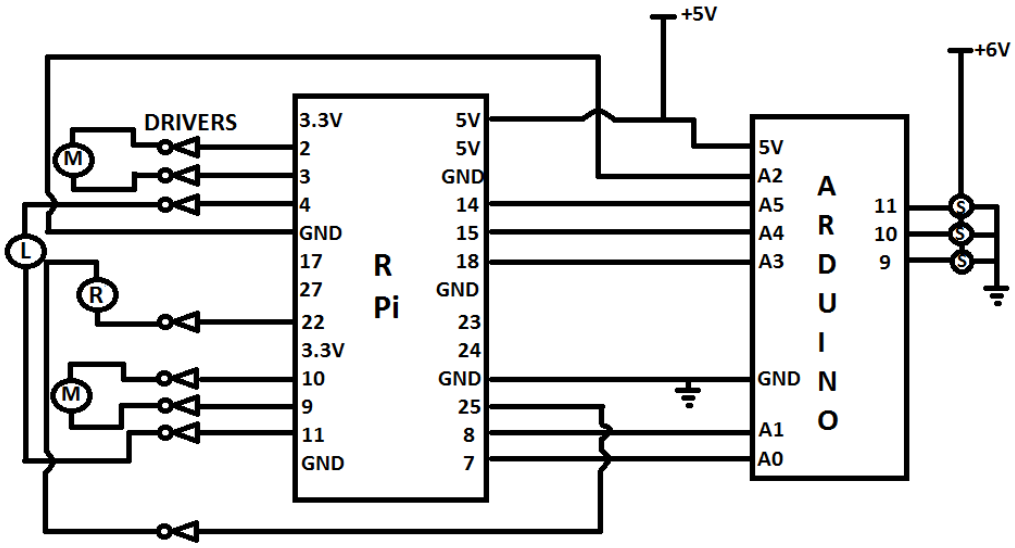

Fig 4.7 Interfacing Schematic

As explained in the hardware design, Raspberry Pi is the heart of our system. It is the web server which will upload video over the network and will allow its general purpose pins to be controlled remotely. The microcontroller is used for providing the PWM output (controlled by the Raspberry Pi) required for servo motors for the motion of the robotic arm whereas all the DC motors in the robot will be controlled by the Raspberry Pi directly. Let us see how this will work.

1] Interfacing between the Raspberry Pi and the DC motors

We saw the necessity of motor drivers in the hardware system design. The motor driver IC L293d which we are using, contains 2 H-bridge circuits, which can drive 2 motors at a time. We can see an H-bridge circuit with 2 inputs for each motor in the schematic. The applied input decides the direction of rotation of the motor.
There are 6 DC motors used in this project. 4 attached to the wheels for the movement of the robot, 1 for the rotation of the arm and 1 for the grabbing or releasing motion of the arm. The motors attached to one side of the vehicle require the same signal at any time. That is why, we are controlling 2 motors on the same side at the same time by giving them

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the same signal. As we can see in the diagram, pin nos. 4 and 11 are used for driving the left side motors while pin nos. 22 and 25 are used for driving the right side motors. For the rotation of the robotic arm we are using pin nos. 2 and 3, while pin nos. 9 and 10 have been used for grabbing/releasing by the arm. The detailed control signals are shown in the following table.

Pin Nos.	State	Action
4, 22 11, 25	HIGH LOW	Forward Motion
4, 22 11, 25	LOW HIGH	Reverse Motion
4 11, 22, 25	HIGH LOW	Right turn
22 4, 11, 25	LOW HIGH	Left turn
2 3	HIGH LOW	Clockwise Rotation of Arm
2 3	LOW HIGH	Anti-clockwise Rotation of Arm
9 10	HIGH LOW	Grabbing by the Arm
9 10	LOW HIGH	Releasing by the Arm

Table 4.1 Control signals for DC motors

2] Interfacing between the Raspberry Pi and the Microcontroller and Servo motors

We have seen the utility of the microcontroller in the robot. As we can see in the schematic, pins 7 and 8 have been attached to the inputs A0 and A1 of the Arduino board. These 2 pins will be used for the appropriate motion of the shoulder servo motor of the robotic arm. Similarly pin nos. 17 and 18 and pin nos. 14 and 15 are connected to A2, A3 and A4, A5 of the Arduino for the motion of the elbow and wrist servo motors respectively. The servos shoulder, elbow, wrist have been attached to PWM pins 9, 10 and 11 respectively. The detailed signalling between the Arduino and Raspberry Pi is shown in the following table.

Pin Nos.(RPi)	Pin Nos.(Arduino)	State	PWM OUTPUT pin nos.(Arduino)	Action
9 10	A0 A1	HIGH LOW	9	Shoulder up
9 10	A0 A1	LOW HIGH	9	Shoulder down
17 18	A2 A3	HIGH LOW	10	Elbow up
17 18	A2 A3	LOW HIGH	10	Elbow down
14 15	A4 A5	HIGH LOW	11	Wrist up
14 15	A4 A5	LOW HIGH	11	Wrist down

Table 4.2 Control signals for Servo Motors

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8.Software System Design

Software Components:

1] Raspbian OS

The Raspberry Pi primarily uses Linux kernel-based operating systems. Raspbian is a Debian-based free operating system optimized for the Raspberry Pi hardware.It is based on ARM hard-float (armhf)-Debian 7 'Wheezy' architecture port with the LXDE desktop environment, but optimized for the ARMv6 instruction set of the Raspberry Pi. The downloaded Raspbian "wheezy" image file is unzipped and then written to a suitable SD card, formatting it for use.

2] Motion

Motion is a streaming software used for making a live webcam server using Raspberry Pi. We first installed it using the command

“sudo apt-get install motion”

in the terminal and then obtained the IP address of Raspberry Pi using ipconfig.For starting the webcam server we enter

“sudo service motion start”
in the terminal.

We can access the video stream in any browser by entering the following in the url bar:
http://192.168.x.x:8081
(or whichever IP address the raspberry pi has obtained).

3] WebIOPi

WebIOPi is another software used to control, debug, and use the Pi's GPIOs locally or remotely, from any browser via the internet. First we installed it on the Pi using wgetand by typing

“sudo python–m webiopi”

We accessed the pins by entering the IP address of the Pi in any browser. The interface that we obtained was thus.

Just by clicking on any of the GPIOs mentioned, we can make it high or low(1 or 0). Similarly, we can also make it an input port or an output port. We have used all the GPIOs as the output ports.

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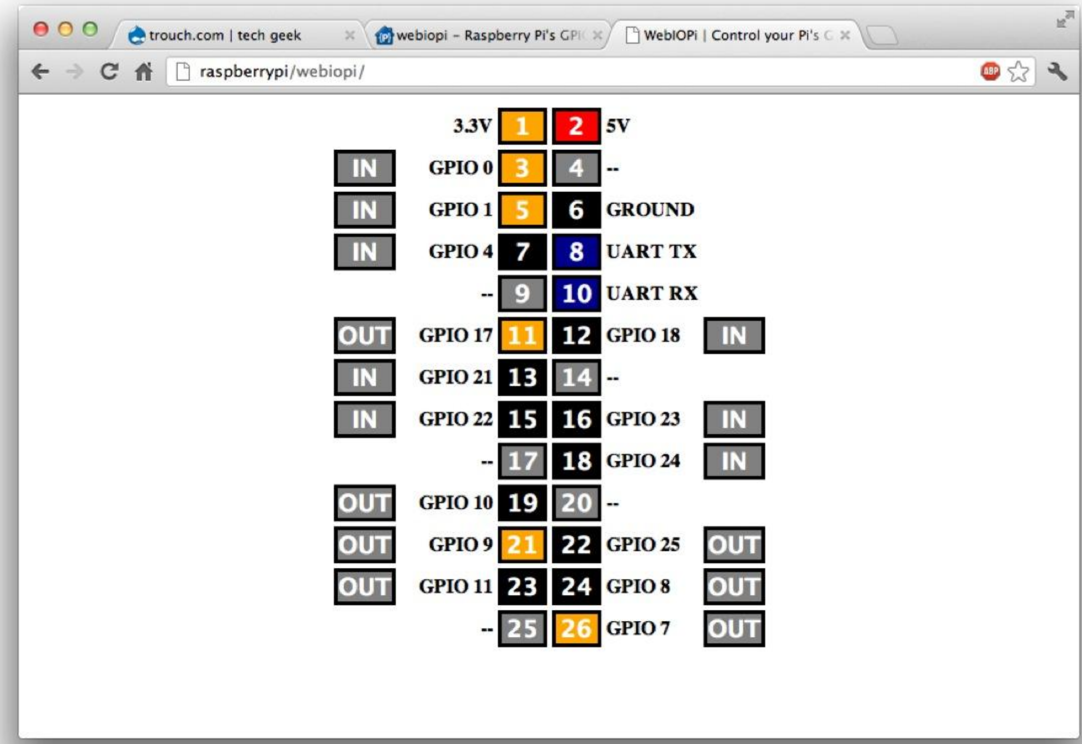

Fig 4.8WebIOPi GPIO GUI

4] Python script

Python is a popular programming language with which the Raspberry Pi was built with in mind as being the core language to be used (actually that's where it gets the Pi part), although you can use other major languages such as C, C++ and Java. It is an extremely powerful and flexible language that will let you build virtually any software system you wish to, and you can even use it to control hardware on the Pi.

Python is a language that is easy to learn which makes it a good language to get started with and will give you a good basis to run with if you choose to learn another language later on. This doesn't make it any less an important language as Python is one of the most popular languages used in industry at present with projects like YouTube, Reddit and Eve Online (MMORPG game) written in Python. In fact some of the biggest users of Python are Google, Yahoo, CERN and NASA.

The main coding for the motion of the robot has been done in Python 2.7. In the code, different macros have been written for each function of the robot. These macros have been called by the html code used for the GUIs.

5] HTML coding

HTML or HyperTextMarkup Language is the standard markup language used to create web pages. The purpose of a web browser is to read HTML documents and compose them into visible or audible web pages. The browser does not display the HTML tags, but uses the tags to interpret the content of the page. HTML describes the structure of a

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website semantically along with cues for presentation, making it a markup language rather than a programming language.

HTML elements form the building blocks of all websites. HTML allows images and objects to be embedded and can be used to create interactive forms. It provides a means to create structured documents by denoting structural semantics for text such as headings, paragraphs, lists, links, quotes and other items. It can embed scripts written in languages such as JavaScript which affect the behavior of HTML web pages.

We have used HTML for designing the GUI. Buttons for every function have been created. When a button is clicked upon, the corresponding macro is called from the python script resulting in the corresponding GPIOs being made LOW or HIGH.

9. Algorithm

- Start
- Install OS, Python, Webiopi, Motion

Python code:

- Initiate gpios as outputs
- Declare variables for each gpio
- Define macros for various functions like forward,reverse,left,right,arm rotation and movement and make gpios high or low accordingly

HTML code:

- Initiate buttons for each function
- Call the corresponding macros from the python script on pressing of respective button
- Initialize video window
- Provide the IP address and port no. of motion running in the background
- End

1] The first and foremost application of this vehicular robot is surveillance across the international borders. It will provide live video of the LOC (Line of Control) or the sensitive areas across the border to the BSF (Border Security Forces). The security forces will also get to control it via the internet for snooping and spying.

2] Home Surveillance: It can be used at home by customizing it according to our needs.

3] Surveillance at banks, high security vaults, laboratories.

4] After customizing the robot according to the requirements, we can use it in the fields other than security surveillance like space programs.

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5] The robotic arm mounted on the vehicle makes it a multi-purpose object which can be used for lifting or placing objects. It can be majorly used in the automation industry and in heavy machinery industries. It can also be used for spying purposes as well as in bomb defusing.

V. CONCLUSION AND FUTURE WORK

After successfully manufacturing our robot and arm, and programming the same according to our needs, we tested the following things:

1. Motion of the vehicle on irregular surfaces which was simplified due to the use of conveyor belts.
2. Camera Interfacing and video output on the GUI.
3. Working of the arm in all possible movements – motion of the servo motors as well as rotation of the whole arm in both directions.
4. Action performed by the robot according to the corresponding command from the Graphical User Interface.

Future scope:

If this prototype were to be realized actually by the defense ministry, it could do with a lot of modifications like:

- Mobility on the ground as well as air
- Mounting of artillery
- RADAR installation
- GPS installation
- Image processing
- Night vision
- Landmine detection
- Bomb defusing
- Installation of more cameras will give a 360 deg view.
- Temperature detection

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