

Design Analysis of a Remote Controlled “Pick and Place” Robotic Vehicle

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Abstract:- The design analysis of a Remote Controlled “Pick and Place” Robotic vehicle has been presented in this paper. This work unravels the fact that man would always want to adhere to safety precautions at workplace and even in its environment, to be able to handle some specific tasks, like sending the robotic vehicle to hazardous environment to obtain samples for chemical analysis. A typical Robotic Vehicle is capable of traveling over various terrains and traversing obstacles. In one embodiment, the design in this work, includes a Robotic arm of five Degree of Freedom with its base resting directly on top of the vehicle, a body having four drive wheels coupled to the ends thereof. The wheels are selectively powered to propel the vehicle. The design methodology involves the hardware, software part and implementation of both designs. A prototype of the Remote Controlled “Pick and Place” Robotic vehicle was built to validate design specifications. The results obtained were very satisfactory. The use of Robots is highly recommended for Industries especially for safety and productivity reasons.

Keywords: Robotic Vehicle, Microcontroller, Joint Actuator, Remote, Control, “Pick and Place”

I. INTRODUCTION

There are certain problems associated with building a tele-operated robotic vehicle with an embedded robotic arm. Firstly, the problem of integrating the units to form a working machine. Secondly, the problem of using the right actuator (pneumatic, stepper motor, RC servo etc). Thirdly, the problem of appropriate communication protocol to implement and also the choice of material (aluminum, steel, carbon fiber, plastic etc). The most important part of the Remote-Controlled Robotic Vehicle (**RCRV**) is the Joint Actuator. Its choice depends on the maximum weight the arm can carry, response of the arm to command, availability of the actuator, ease of use and price.

In this work, a miniature Remote Control Robotic Vehicle(**RCRV**) with five degree of freedom (5DOF) robotic arm has been designed and developed .The objective is to produce a basic model with four wheels, standard sensors and a robotic arm with the vehicle acting as a base for its mobility. It is also intended that the structure of the robot should be simple to facilitate easy adaptation and upgrading. The housing is designed to create three distinct layers within the **RCRV** to separate elements of the robot, thus leaving room to add more devices when completed. The bottom layer was designed for battery housing and mechanical hardware, such as wheels and gears, the middle layer to contain the main interface electronics, and the top layer for the arm and external devices.

II. LITERATURE REVIEW

Robots have their historical past though they came into existence only in 1961 when Unimation Inc, USA introduced the first servo- controlled industrial robots. Early development dating back to 500B.C shows that the Egyptians, Indians, the Chinese, and the Romans built many automatic puppets which imitate the movement of animals and birds. The Chinese built many amusing devices that depicted sequential motions. Also, the early men discovered many mechanisms and exhibited their innovation skill in building ships and introduced looms to weave. This ushered in the industrial revolution. In the 1940s, remote teleported master-slave manipulators were developed. Later, force feedback and kinesthetic sensory elements were added to them to facilitate better control. Tele-operated devices were used in mars exploration in 1976. In 1948, the transition was invented at Bell laboratories U.S.A. In 1952, IBM’s first commercial computer IBM 701 was introduced. Then came numerically controlled tools in which various slides of machines were displaced by numerical commands through suitable hardware. The development of NC (numerically controlled) machine tools has, therefore, been a turning point in the development of robotics.

The planet corporation in 1959 introduced a pick and place robot. In 1961, the first industrial robot was commercialized by Unimation Inc. Microprocessor technology was brought by INTEL in 1961. The real robot development process continued between 1968 and 1982 when various models of robots were developed by

leading robot scientists in different universities, national laboratories and different industrial houses in the USA, Japan, France, UK, and other European countries.

Some of the robot models of historical interest are the Versatran by AMF, developed in (1963) and Cincinnati Milacron introduced in (1974), Irb-6 by ASLA in (1978). The Kawasaki and Hitachi groups in Japan have also contributed a lot in developing various sensors to make robots ‘think’ intelligently.

Various robot institutions propagate the ideas and ideologies of robotics to the profession. Some of the pioneering institutions are the Japan Industrial Robot Association (JIRA, 1971), Robot Institute of America (RIA, 1975), British Robot Association (BRA, 1977) and Robotics Interaction / SME, to mention a few [1][2][3].

III. DESIGN ANALYSIS

This section describes the functions of the various units of the work and the algorithm/approaches used during its development. The block diagram of the system mode of operation is shown Fig 1.

Mode of Operation

When the operator issues a command from the remote control to the robotic vehicle all necessary tasks will be carried out by sending signals to the microcontroller via the transceiver. The microcontroller then issues command to the respective channels that makes up the communication links. The electric motor response will depend on the type of command issued; and the direction, speed and motion of the motor is regulated by the microcontroller.

The rotation of the powered motor moves the affected link connected to the motor and this in effect affects the movement of the robotic arm.

3.1 System Description

The robotic arm has five degrees of freedom. It's made of various links forming an open chain. The arrangement of these links depends on the adopted design. The arm has a rotating base that is resting on the upper region of the vehicle. The arm terminates with a gripper or a specialized tool holder; it has five (5) degrees of freedom. The first three links of the arm form the body and which helps to place the tool holder at the desired position at a location inside the workspace or environment. The remaining three links make up the wrist of the robotic arm and are used to define the orientation of the robotic arm end points. For the purpose of analysis, the robotic arm will be made of joints, which will be named as wrist, elbow, shoulder, and base [4]. The preliminary sketch from which the detailed design was made is based on the sketch shown in fig.1.

3.1.1 End Effector

This is the gripper to whose operation is to grip and outgrip the objects to be lifted or moved. The gripper is connected to the horizontal rotating servo motor.

3.1.2. WRIST

This is the joint that links to the end effectors as shown in fig 2. The wrist has one degree of freedom, which is actuated by a servo motor. It can rotate to about 180° about the horizontal axis.

3.1.3 SHOULDER

This is the joint between links C and the base and has 1 degree of freedom which is actuated by a Dc motor (servo motor). It can also rotate to about 180° by link C. A gearing system is also used to actuate the motion.

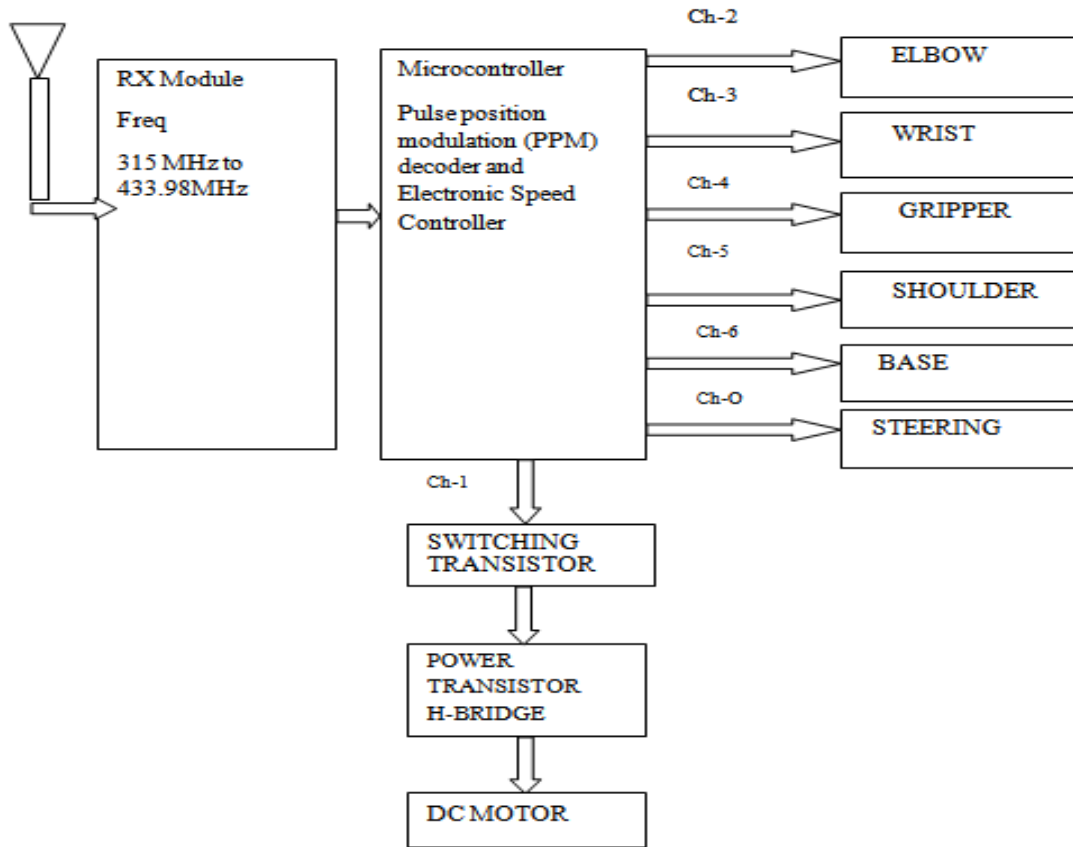


Fig.1: Block diagram of mode of operation.

3.1.4 Elbow

This is the joint between links B and C and it has one degree of freedom actuated by a rc servo motor. It can rotate to about 180° (by design) by link A. The motion about the elbow is actuated by a set of gear brains connected to the links and the Dc motors.

3.1.5 Base

This is the joint between the robotic arm and the vehicle; it has 1 degree of freedom which is actuated by a Dc connected to the gear in the link C. The Dc motor is similar to that used in the shoulder but a different gearing arrangement. The base rotates to about 180° . The base is the platform on which the arm stands and it carries the weight of the arm which in turns determine maximum load the robotic are can lift. The circuit board wiring and other attachments are fixed to the base.

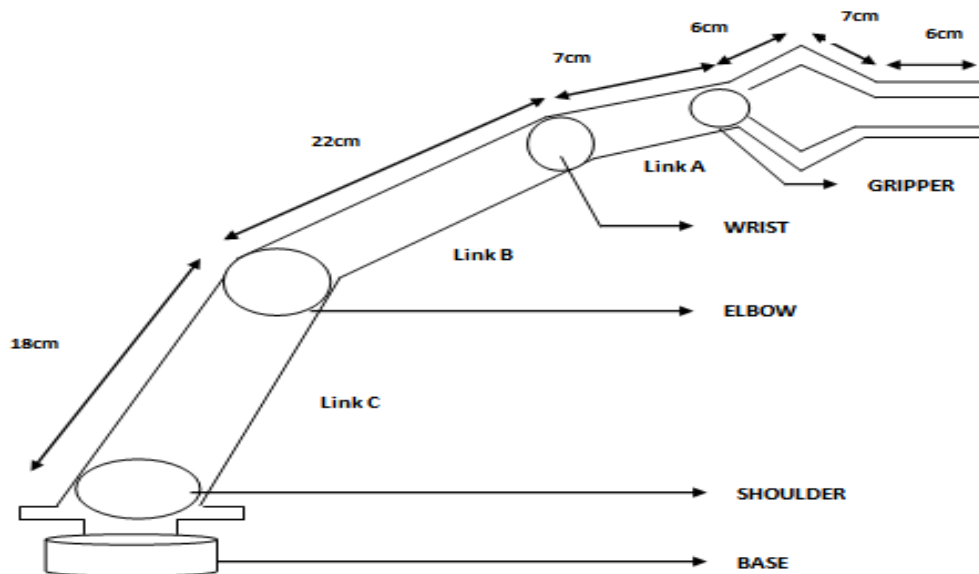


Fig .2: Diagram of the robotic manipulator (arm)

3.2 Design Consideration

The following were put into consideration in the design process.

- i. Electrical actuators DC servo are chosen instead of hydraulic and pneumatic actuators because of the little power requirement and its light weight which is suitable for this design.
- ii. The materials which will be used for the design will be light in weight so as to reduce the weight concentration on the base and the shoulder.
- iii. Hollow rectangular bars and sheets instead of blocks are chosen for the links because of their light weight and stability and to reduce the weight of the arm.
- iv. The power supply source will be from a rechargeable nickel metal hydride (Ni-MH) batteries
- v. A continuous path controller was chosen (PIC microcontroller was used).
- vi. The torque is fully balanced by the inertia of the electric motors (see force analysis) and the speed is greatly reduced by gear sets attached to the electric motors.
- vii. Materials used for the fabrication were locally sourced from available materials.

3.3 Design Analysis of Robotic Manipulator

In this aspect numerous calculations was done in order to attain the required servo mechanism that will meet the specification on this work.

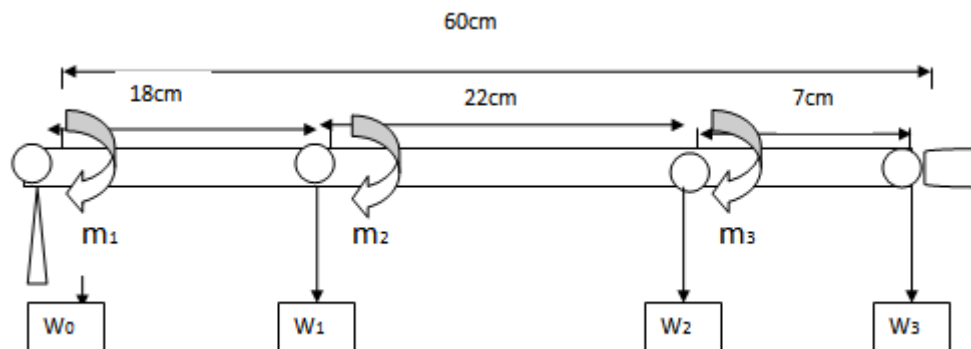


Fig.3. Diagram showing torque calculation on each servo

Moment = force x perpendicular distance 3.1

Assuming that the weight of the material is negligible since it light compare to the servo specification. $W_0=56g$, $W_1=56g$, $W_2=56g$, $W_3=36g$

Moment sustained at the shoulder M_1

$$(0.036 \times 47) + (0.056 \times 40) + (0.056 \times 18) = 4.94 \text{ [kg-cm]}$$

But actual torque of the shoulder servo = 13 [kg-cm]

Excess torque = Actual servo torque – Calculated torque3.2

Therefore excess available torque at the shoulder = $13 - 4.94 = 8.06 \text{ [kg-cm]}$

Moment sustained at the elbow M_2

$$M_2 = (0.056 \times 22) + (0.036 \times 29) = 2.276 \text{ [kg-cm]}$$

But actual torque of the Arm servo = 13 [kg-cm]

Excess available torque at the shoulder = $13 - 2.276 \text{ [kg-cm]}$

Moment sustained at wrist = $(0.056 \times 7) = 0.392 \text{ [kg-cm]}$

But actual torque at the wrist servo = 13 [kg-cm]

Excess torque = $13 - 0.392 = 12.608 \text{ [kg-cm]}$

Moment sustained at the base = $(23.5 \times 0.204) = 4.97 \text{ [kg-cm]}$

Excess torque = $13 - 4.97 = 8.206 \text{ [kg-cm]}$

From the design analysis made the maximum load the robotic manipulator can lift successfully is determine by the base servo. From the above analysis the excess torque of the base is 8.20 [kg-cm] . Hence the calculated maximum load is 8.206 [kg] . The actual load will be less than the calculated value because the weight of the material used in constructing the arm was light and was not taken into consideration.

3.4 Electrical Circuits

The circuits include components for supplying power to the system, controlling the electric power to the system, controlling the electric motors and for interfacing the robot to the computer. The circuit consists of the following parts.

3.4.1 Voltage Regulator

Regulation is achieved using a regulator. The 7805 Voltage Regulator was used to provide a fixed regulated voltage of 5volts at the output because the voltage levels should be maintained to avoid indeterminate logic levels which might result in malfunctioning to the integrated circuits used.

3.4.2 Crystal Oscillator

This electronic device uses a piece of quartz that is cut and polish to vibrate at a particular frequency. Its operation is piezoelectric (a strain generates a voltage, and vice-versa). The PIC 18F425 microcontroller has an on-chip oscillator, which must be run by an external clock signal. a quartz crystal is configured into an oscillator with the capacitors to provide the clock signal. A quartz crystal emits pulses at a fixed frequency when energy is applied to it.[5].

The PIC 18F425 use the clock signal provided by the crystal to synchronize its operations. The PIC 18F425 operate using what are called “machine cycles”. A single machine cycle is the minimum amount of time in which a single PIC 18F425 instruction can be executed. A 16MHz crystal was used in this work. The number of intrusions per second the PIC18F425 is then;

$$T_{cyc} = 1/(\text{Oscillator frequency}/4) \dots\dots\dots 3.3$$

$$T_{cyc} = 1/(16\text{MHz}/4) = 0.25\mu\text{s}$$

$$\text{Number of instruction executed per second} = 1/T_{cyc} \dots\dots\dots 3.4$$

Hence number of instruction executed per second = 4 Million

The quartz crystal is connected across input CRYTAL (pin 18) and CRYTAL (pin 19) of the PIC 18F425 Micro-controller. Two capacitors, 30PF each are connected to the crystal to make it impossible for frequencies other than that generated by the crystal to penetrate the PIC 18F425 (Fig.4)[6][7]

3.5 Seven Channel Remote Control Transmitters:

The Transmitter circuit consists of a transmitter module, microcontroller and associated circuitry and seven potentiometers. The potentiometer is use to control the six joint actuator of the robotic arm and also, the electronic speed controller (With Forward, Break and Reverse). The analog voltage of the potentiometer pins is read by the analog to digital converter of the microcontroller. The microcontroller performs mathematical calculation on the analog value to determine the channel pulse time .The transmitter uses Pulse Position Modulation. In PPM, the channel (0 to 6) are transmitted serially with the require information embedded in the pulse time of the channel. The signal begins with a synchronization pulse. The receiver uses this synchronization pulse to determine the beginning channel 0[8][9]

3.5.1 PIC 18F425 Microcontroller

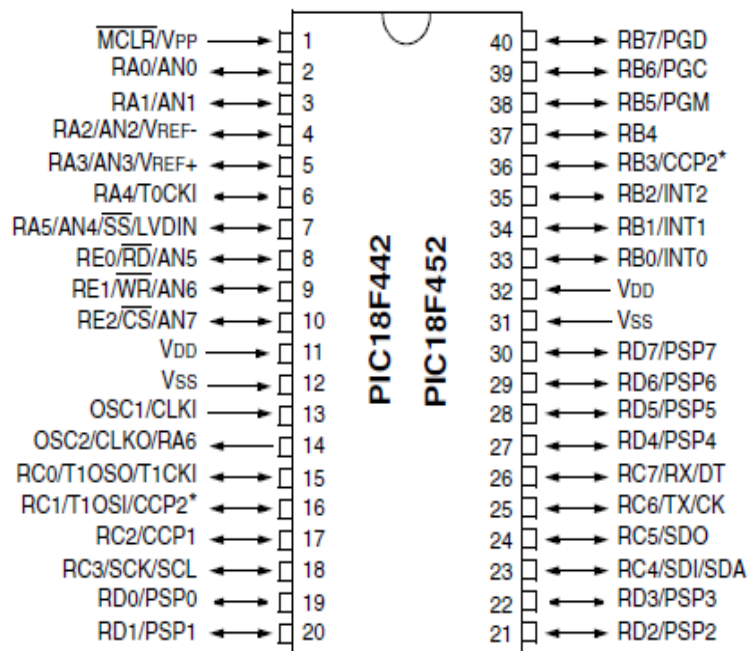


Fig.4. Diagram of PIC 18F425 pins in and out

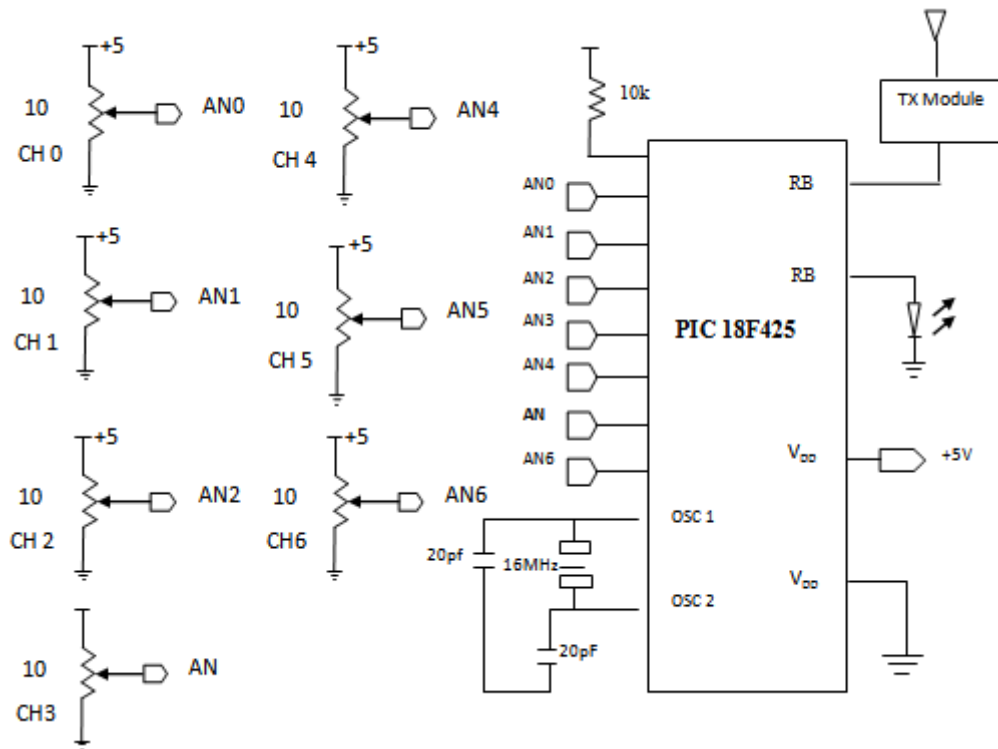


Fig.5 circuit diagram of Transmitter

3.5.2 TRANSMITTER MODULE SPECIFICATION:

Technical specification for wireless transmitter module use in this work

- (1) Transmit power: 1W (1500m)
- (2) Operating frequency: 315MHZ~433.92MHZ
- (3) Operating temperature: -40°C~80°C
- (4) Operating voltage: 3V~5V
- (5) Modulation type: Amplitude Serial Keying (ASK)

3.5.3 SYSTEM CHANNEL DISCRIPTION

- Channel 0 ----- Right/Left movement.
- Channel 1 ----- Forward, Reverse and stop command.
- Channel 2 ----- Elbow movement.
- Channel 3 ----- Wrist movement.
- Channel 4 ----- Gripper movement.
- Channel 5 ----- Shoulder movement.
- Channel 6 ----- Base movement.

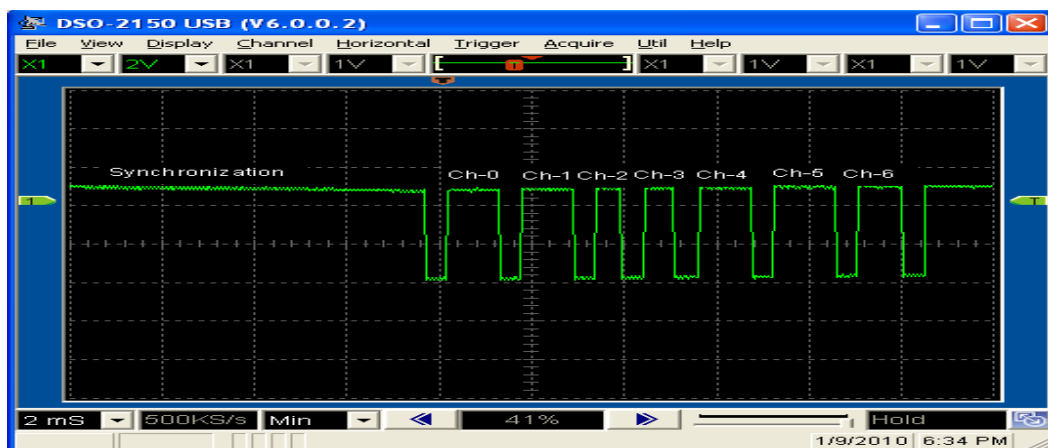


Fig.6: Transmitted Signal view from Oscilloscope

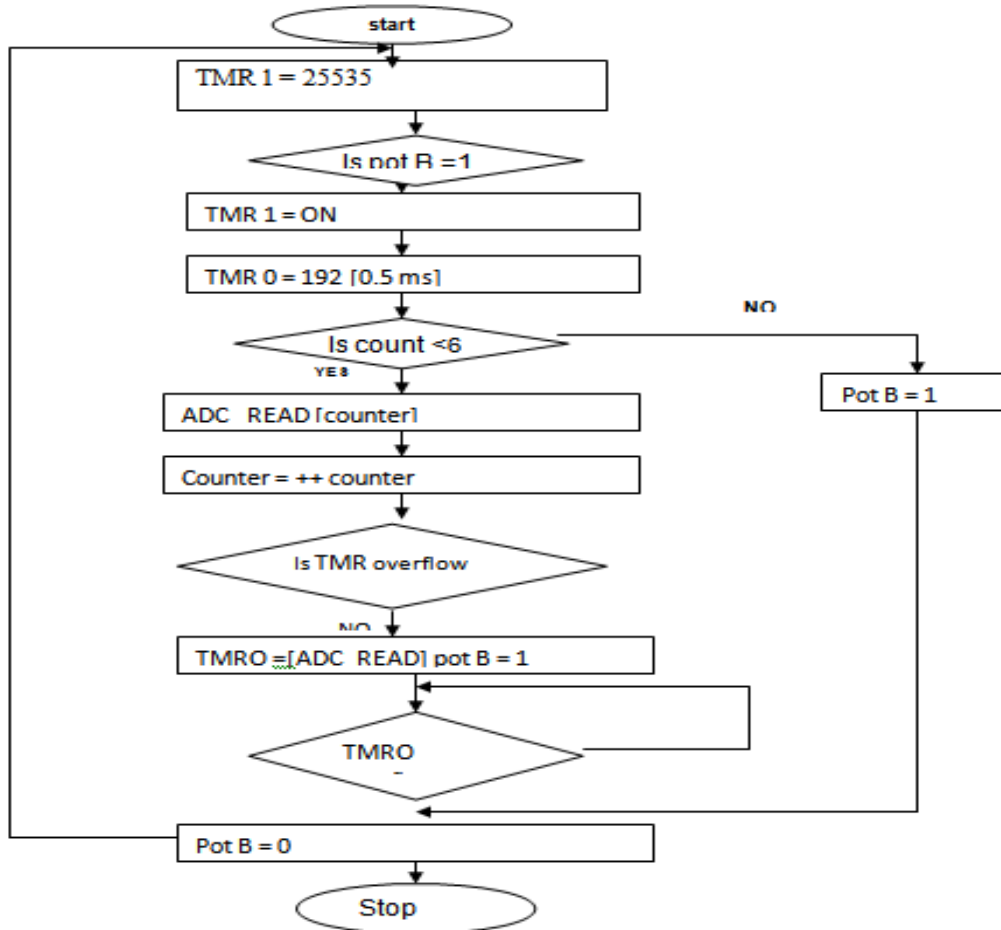


Fig.7 flow chart of the transmitter

3.6 Channels Calculation Analysis:

All standard servos use the Pulse Position Modulation (PPM) language. A pulse is simply whether or not the control voltage is on or off. The amount of time that a pulse is on during a 2ms time frame dictates the servos position. This time frame, or sequence, repeats around 50 times per second. During the first half of this 2ms time frame, the pulse is always on. This starts a counter, so to speak, to tell the servo to start listening for the command. The second portion of this 2ms time frame is the command that dictates the position of the servo. From fig. below the amount of time during the designated 2ms time frame that the pulse will be on for the three most extreme positions (far left, far right, neutral). There are an infinite amount of positions in between these values and amount of time the pulse is ON changes in proportion. This is what makes Pulse Position Modulation analogue.

Servo #1: Far Left Command (0 degree): Time ON = 1 + 0.0 ms = 1.0 ms

Servo #2: Neutral Command (90 degree): Time ON = 1 + 0.5 ms = 1.5 ms

Servo #3: Far Right Command (180 degree): Time ON = 1 + 1.0ms = 2.0 ms

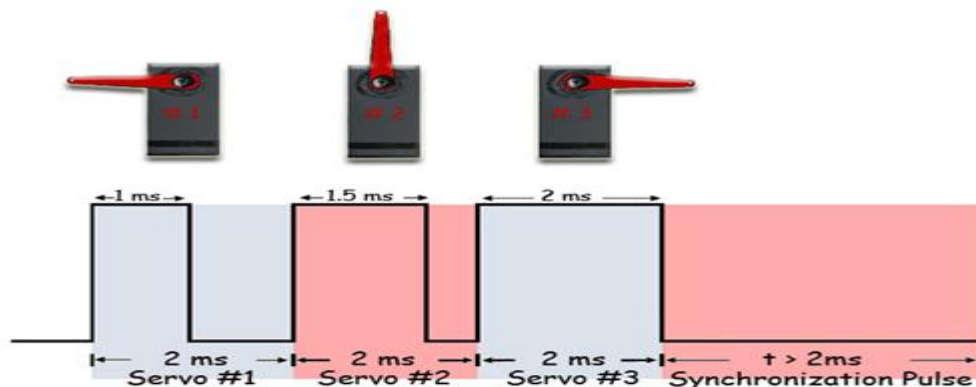


Fig 8 square signal to the servo input

Microcontroller oscillator frequency = 16MHz

Time for to perform one instruction $T_{cyc} = 4/16\text{MHz} = 0.25\mu\text{s}$.

Timer1 (16 bit) and Timer0 (8-bit) increment on every T_{cyc} .Timer-0 overflow from 0xFF to 0x00 and Timer-1 overflow from 0xFFFF to 0x0000.

Timer-1 configures to use 1:2 prescaler.

Overflow occurs = $2 \times 0.25\mu\text{s} \times 65535 = 32.7675\text{ms}$.

Timer-1 provide the 20ms repetition time of the PPM signal.

Timer-1 value = $65536 - 40000 = 25536$

Timer-0 configures to use 1:32 prescaler.

Overflow occurs = $32 \times 0.25\mu\text{s} \times 255 = 2.04\text{ms}$

Timer-0 provide the fixed and variable time of the PPM signal. The Analog voltage read from the potentiometer is manipulated to provide the variable time of the PPM signal.

Timer-0 Value = Variable time = $254 - (\text{ADC_VALUE}/8 + 62)$ 3.5

X= analog channel

AC_Value = Analog Voltage.....3.6

3.7 Seven Channel PPM Receivers:

The receiver circuit consists of receiver module and a microcontroller which decodes the received PPM signal, decipher the signal and feed it to the appropriate joint servo. The microcontroller also functions as the electronic speed controller.

3.7.1 Theory of Operation:

The output from the receiver module is a PPM (pulse position modulation) streams that is common in the RC control world. A “cycle” begins with a high-going synchronous pulse that is about 6 milliseconds in duration. At the end of the synchronous pulse the PPM pin will go high; this is the beginning of the Servo 1 timing. At this point the Servo 1 output is enabled and will stay on until the next low-to-high transition of the PPM pin; at this point the Servo 1 output is turned off and the Servo 2 output activated. Note that if you look at the PPM waveform on an oscilloscope only the high-going portion of each servo frame changes; the (low-going) framing pulse is constant (~500 us); the high portion will vary from ~500 to ~1500 us.

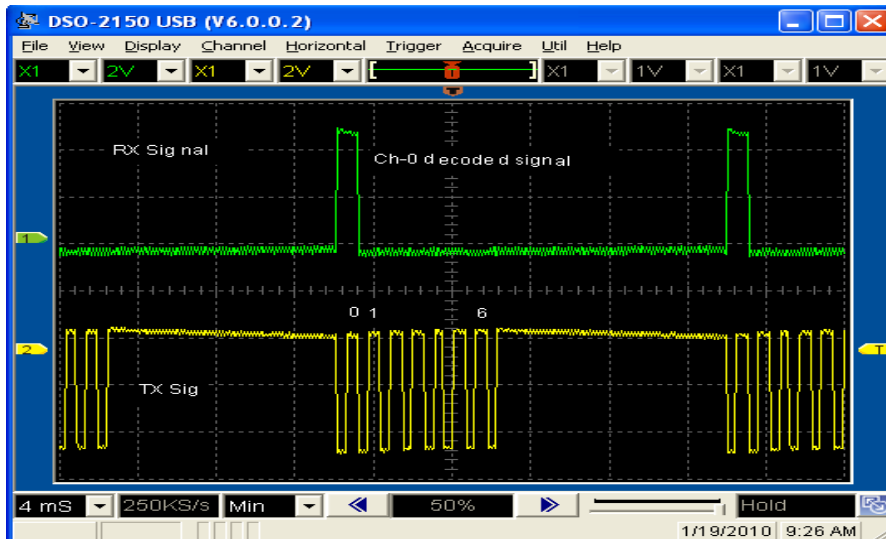


Fig.9 waveform of Transmitted PPM Signal and Decoded PPM Signal view from the oscilloscope.

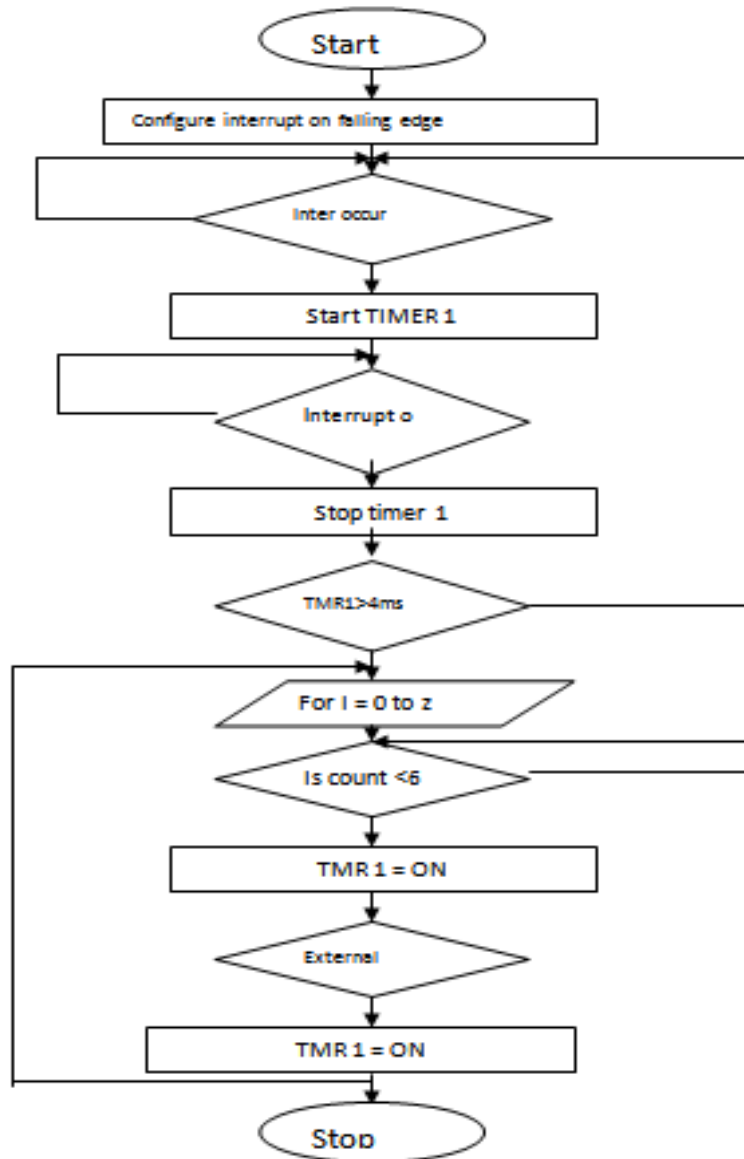


Fig. 10 Flow chart of the Receiver

3.7.2 Receiver Module Specification:

KST-RX806 is wireless data transmit and receive module with VHF/UHF super high frequency. This module was chosen due to the following characteristics:

- i. The receive sensitivity is up to -105dbm; the receive distance is twice of others.
- ii. It has reasonable receive bandwidth, excellent ability of suppress coordinate frequency, strong anti-jamming, adapting to all kinds of environment.
- iii. It has excellent ability of suppressing assembling and scattering radiation, easily passing all kinds of criteria
- iv. Due to excellent shield, it can adapt to kinds of installing environment, consistency is nicer.
- v. It has ability to restrain the radiation, can work with several pieces of modules (one transmit module and several receive modules) but neither interfering to each other nor influencing the receive distance.
- vi. It is easy to adjust. Between frequency range for 250-450 MHz
- vii. Strengthen the ability of anti-disturbing against mobile phone and improve the shape of decoding waves.

3.8 Electronic Speed Controller:

The Electronic Speed Controller is implemented inside the Microcontroller with external circuit. The external circuit is made up of H Bridge Power PNP (TIP117) and NPN (TIP112) Darlington Transistor and a switching NPN transistor (2N2222).

3.8.2 H-Bridge Circuit:

The H-bridge, named for its schematic appearance, is able to move current in either direction through the motor winding.. Referring to fig. below

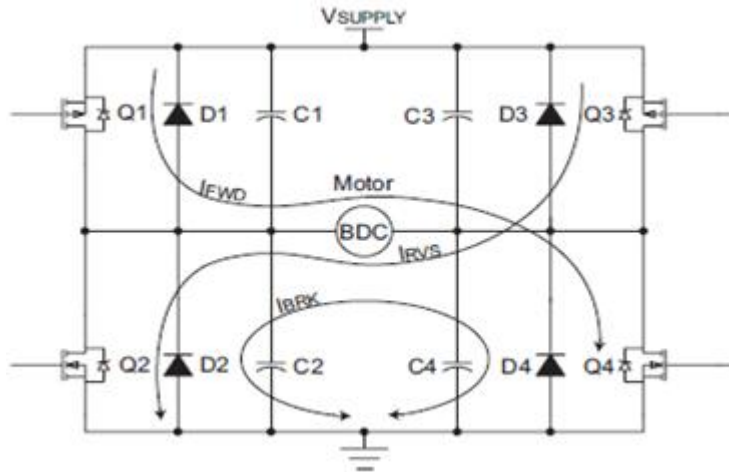


Fig 11: Bidirectional DC motor drive (H-Bridge) Circuit

Q1 and Q2 make up one half-bridge while Q3 and Q4 make up the other half-bridge. Each of these half-bridges is able to switch one side of the BDC motor to the potential of the supply voltage or ground. When Q1 is turned on and Q2 is off, for instance, the left side of the motor will be at the potential of the supply voltage. Turning on Q4 and leaving Q3 off will ground the opposite side of the motor. The arrow labeled IFWD shows the resulting current flow for this configuration.

Table 1 truth table circuit

INPUT	FORWARD	REVERSE	BREAK
Q ₁	1	0	0
Q ₂	0	1	0
Q ₃	0	1	0
Q ₄	1	0	1

of the H-bridge

3.8.3 H-BRIDGE Circuit Analysis

Q₁ Collector current

Q₁ Base current $I_{B1} = \frac{V_{CC} - V_{BE}}{R_B}$ Equ3.7

$$I_{B1} = \frac{5 - 0.7}{1 \times 10^3} = 4.3mA$$

Q₁ Collector current $I_C = \beta I_B$ Equ3.8

$$I_C = 25 \times 4.3mA = 1.075A$$

Q₁ is operating as a saturated Region; hence it will draw the maximum current as specified in the data sheet (1A).

$$V_{CE} = V_{CC} - I_C R_C$$
 Equ3.9

$$V_{CE} = 12 - (1 \times 12k) = 12k \text{ [saturated voltage]}$$

Similarly Base Current $I_{B2} = \frac{V_{CC} - V_{BE}}{R_B}$

$$I_{B1} = \frac{12-0.7}{1 \times 10^3} = 11.3mA$$

$$Q_2 \text{ Base Current} = I_{C2} = 11.3mA$$

$$\text{Collector current } Q_3 \quad I_{C3} = 11.3mA \times 300 = 3.39A$$

$$Q_4 \text{ Base Current } I_{C1} = 4.3mA$$

$$I_{CQ4} = 4.3mA \times 300 = 1.29A$$

Q₁ is 2N222 NPN power transistor

Q₂ is 2N222 PNP power transistor

Q₃ is TIP 122 NPN transistor

Q₄ is TIP 127 PNP transistor

IV. Results and Discussion

The various static tests and functional tests on the respective components are described below.

4.1 Microcontroller

The microcontroller was powered and the entire output pins were high as seen in the Oscilloscope graph. This shows that the microcontroller is in good order. A simple test program was written and burnt into the microcontroller to make blink LED every 1 second, the result obtained was satisfactory.

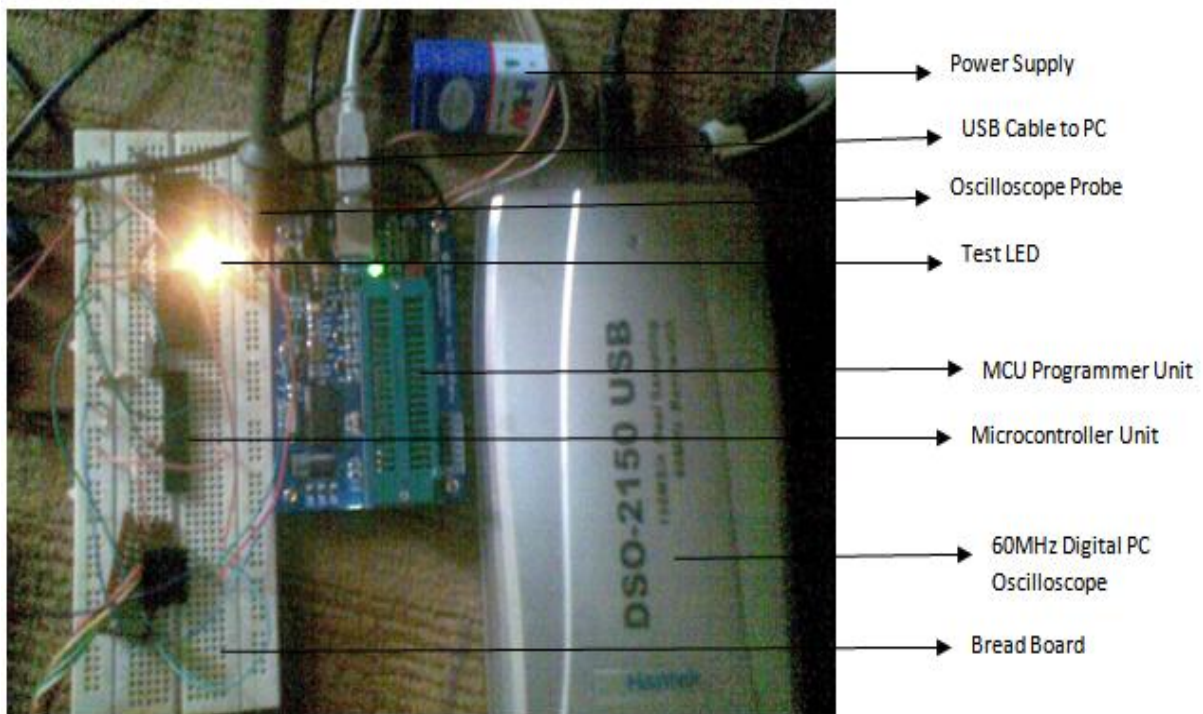


Fig 12: Work Station Showing Test on MCU

4.2 Voltage regulator

When 9V was sent to the input of the regulator, the output was measured with a (DVM) and it gave the desired result, which is 5V.

4.3 Potentiometer

The potentiometers gave resistance values varying from 0 Ω to 10k Ω in a fairly linear fashion. The 10k Ω resistance value of the resistor used in the MCU and the transmitter was also confirmed.

4.4 Capacitor

The capacitors used in the work were tested with a DVM in the Capacitance mode. The measured value correspond to the value written on the body of the capacitor.

4.5 Crystal Oscillator

When the entire circuit was powered, the voltage drop across each terminal of the crystal oscillator was between 2.3V to 2.5V . Which shows that the crystal oscillator is good.



Fig. 13: Side View of the prototype “ Remote Controlled Robotic Vehicle

IV. CONCLUSION

The design of a Remote Controlled Robotic Vehicle has been completed. A prototype was built and confirmed functional. This system would make it easier for man to unrivalled the risk of handling suspicious objects which could be hazardous in its present environment and workplace. Complex and complicated duties would be achieved faster and more accurately with this design.

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