Project Report on

Design and Fabrication of a Spherical Rolling Robot

Project work submitted to
Osmania university, Hyderabad
In partial fulfillment of the requirement for the award of degree of

BACHELOR OF ENGINEERING
in
AUTOMOBILE ENGINEERING
by

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CERTIFICATE

This is to certify that ‘Design and Fabrication of a Spherical Rolling Robot’ is the bonafide work carried out by:

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Date :
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Abstract :

This project involves fabricating an autonomous spherical rolling robot that is able to avoid an obstacle using an ultrasonic ranging sensor. Conventional four wheeled vehicle need a lot of free space to turn away from their current trajectories and also have the problem of rolling over rough terrains. The spherical construction offers extraordinary motion properties in cases where turning over or falling down are risks for the robot to continue its motion. Also it has full capability to recover from collisions with obstacles or another robots traveling in the environment. Spherical robotics is an emerging research field due to a ball's characteristic to be holonomic, have a sealed internal environment, and rebound from collisions easily.

The governing principle for this robot is termed Barycenter Offset(BCO). The term barycenter offset is used in spherical robots to describe the act of shifting a robot's center of mass (the barycenter) in order to produce a desired motion. As its internal mechanisms move inside the sphere, the mass distribution of the ball will be shifted, causing the ball to roll to a new position of equilibrium. An implementation of barycenter offset system, commonly referred to as the hamster ball design is the propulsion mechanism of this project. The design is nicknamed this because, simply enough, it mimics a hamster in a toy ball.

The goal is to make the robot stable and maneuverable on different terrians. This has been done by concentrating the mass of the drive unit as low to the ground as possible. The spherical casing of the robot is made of Fiber Glass and Carbon fibre, one layer each and wood care putty for smothening the outer layer. The internal drive unit has both Bluetooth and radio communications enabled. The sensor unit on the top has two Ultrasonic Ranging sensors mounted at 45˚ to the axis of rotation of the IDU. To this, is attached a radio transmitter and an accelerometer to assist in calculating the range. Both the units are magnetically coupled by high power N-52 Neodymium magnets.

Keywords: spherical robots; holonomic motion; barycenter offset; hamster-ball mechanism

Acknowledgement

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Contents

1. Introduction

1.1 Overview

Spherical robots are a promising area of research and have many unique features that are of interest to study. They can be designed to be sealed off from harsh environments, to travel independent of the orientation of the robot. For example, a car or bike must point its front end towards its intended direction of travel. A spherical robot may change direction at any stage of movement without reorientating itself and to rebound from collisions in a quick and non-destructive manner.

First of all, they are very maneuverable. They can be designed to be holonomic, so they can move in any direction. This increases the options for navigating around objects and prevents the robot from getting stuck in corners. Spherical robots also cannot be overturned. Traditional wheeled robots have the ability to be rendered useless if they land upside-down. This is not the case with a spherical robot. Stairs and ledges are also a problem for traditional robots, and a spherical robot can overcome these conditions very well. This feature also allows them to be thrown or dropped. They have a great capability to recover from collisions with obstacles. Since they can be designed to be totally sealed, they are ideal for hazardous environments. The sensors, electronics, and mechanisms are all protected. This makes them capable of functioning in snow, mud, and even water. Spherical robots be assisted or powered by winds.

1.2 Advantages of a rolling robot.

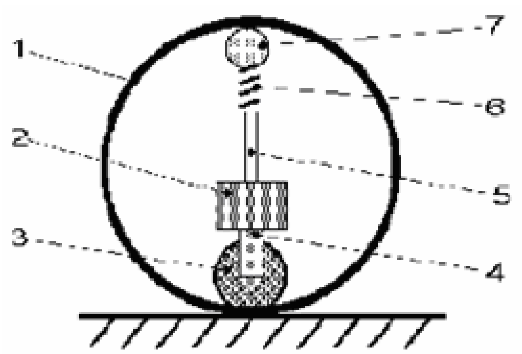
- Can easily move on sand or snow. Since the motion is not because of traction available at the surface of the sand but caused by the sphere trying to reach equilibrium, the sand does not resist the rotation of the robot.
- Needs less torque than it can produce. The torque is only required by the motors to move along the inner surface of the sphere. More detailed explanation is given in chapter 3.
- This design could potentially move on a pool of fluid if designed to float properly. Thus making it suitable for extra terrestrial navigation.
- All the systems are packed inside and isolated from the outside environment which eliminates the need to protect each module separately.
- Has low drag coefficient compared to is existing counterparts that receive lot of air resistance in windy conditions.
- Its Holonomic / Omni-Directional in nature. Meaning the direction can be changed without the robot having to move which makes it an ideal solution to navigate on a terrain full of obstacles.
- Always has a point contact on the surface and has no problem of roll over in any event of collision.

2. Literature Review

2.1 Different Propulsion Mechanisms

a) Wheel Based

The first spherical mobile robot was developed by Halme et al. in 1996 [2]. The propulsion was derivedfrom a wheel in contact with the bottom of the sphere as shown in Fig. Above the wheel is the Inside DriveUnit (IDU) with power and communications. The wheeland IDU are integrated into a single axis support. On theopposite end of the powered wheel is another stabilizing wheel. By steering the powered wheel, the sphere hasthe ability to turn.



Structure of the Rolling Robot.1. robot body (case), 2. controlling box, 3. driving wheel, 4. steering axis, 5. supporting axis, 6. spring, 7. balance wheel

Fig 2.1.A: Wheel based spherical robot

b) Pendulum Based

A simple spherical robot can be developed using apendulum based design. Figure shows a schematic of theinternals of a robot called Rotundus. This design consists of a motor attached to the horizontal axis that goes through the sphere. In the center there is apendulum that drops down. When the motor is activated, the sphere will move as long as the weight of the pendulum has enough inertia that it is easier for thecasing to spin than the pendulum to go around. The pendulum can move to the left and right, causing the robot to turn.

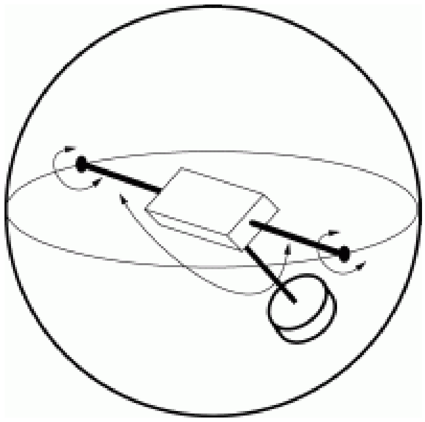


Fig 2.1.B: Pendulum Based design

c)Wind Powered

There has been some work to design large wind-powered spherical robots. This is mostly due to NASA's effort to create wind powered Mars exploration rovers. The high winds of Mars are a powerful natural resource, and could be harnessed. The biomimeticdesign is inspired by tumbleweeds. Some concepts are shown in Figure below.

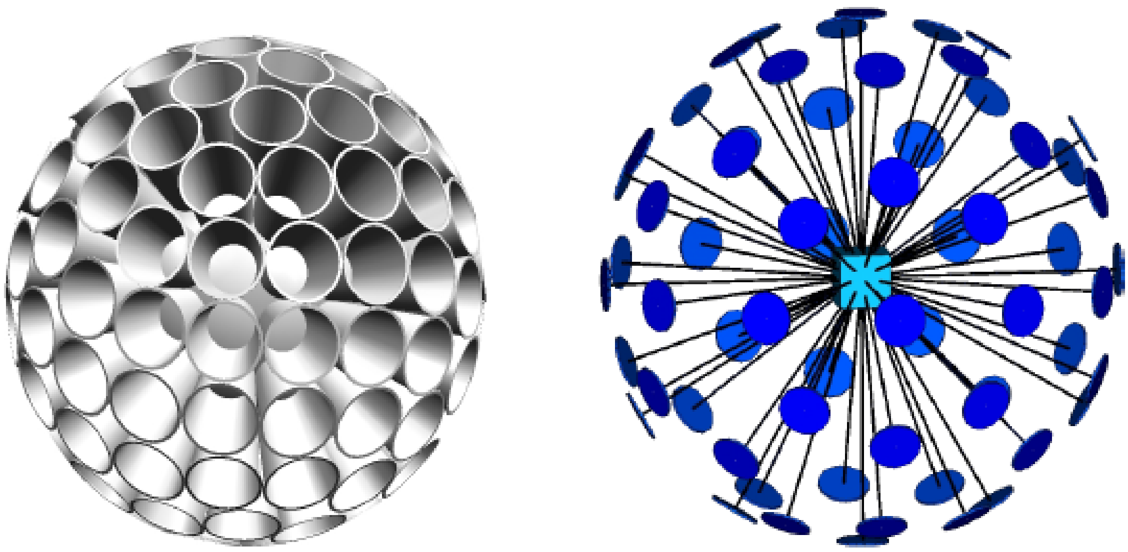


Fig 2.1.C: Wind powered Robot built by nasa

The design would allow for a robot that can go overlarger obstacles than a car-like rover of its size. Other designs have mixed the pendulum design with wind powered, allowing the robot to steer and stop by using a pendulum that can be retracted into the center of the sphere to "coast".

d) Rotundus (Pendulum Based)

There is currently one spherical robot already being used commercially. It was designed by a Swedish company that was formed in December 2004 .The robot is designed as a security robot that detects and reports intruders. It uses a pendulum-type propulsion mechanism which allows it to travel at 10-15 miles per hour. As visible in figure, it shows its robustness by driving in snow.

Fig 2.1-D1: Rotundus rolling on snow without loss of traction.

Fig 2.1-D2: Diametrically oppositely mounted sensors.

2.2 The Proposed design :

The proposed design consists of diametrically opposite mounted motors on a freely suspended drive unit with most mass concentrated in the space near to the ground. When motor is actutated, the driving will move along the sphere's inner surface and shift the system's center of mass and thereby causing motion.

The outer casing will be made of ~3mm thick fiber reinforced plastic with an outer radius of 35.5 mm. The internals will be mounted onto a 5mm thick plywood surface.

The controller will be arduino powered and will be controlled wirelessly via a bluetooth module. Mutually perpendicular ultrasonic rangers are added to the head detect/avoid obstacles along the path of the robot. These range finders are mounted at an angle that are limited by the maximum range of the module. They are magnetically coupled to the unit inside the sphere which will allow the robot to navigate in any direction and move along a given path avoiding the obstacle. The communication is enabled by a 433MHz RF Transmitter-reciever that allows the robot to have a continuous feedback about the path/terrain.

The internal drive unit will be powered by 12v 1.3Ah Li-Ion battery and the processor is powered by regulated 9v battery. The head of the robot is powered by the same 9v battery.

All these are mounted in such a way that the total center of mass is as low as possible and as such, they are located as close to the ground as possible.

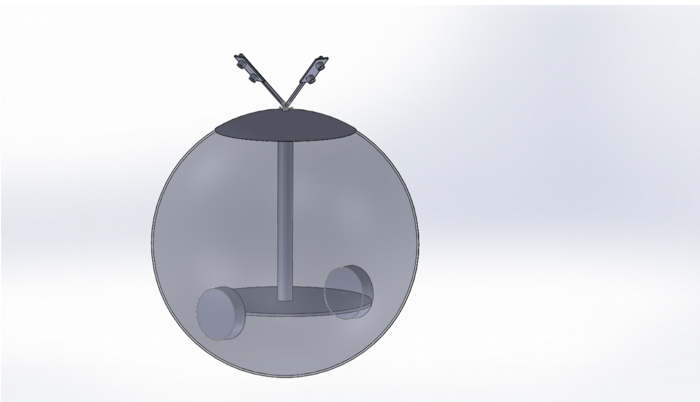


Fig 2.2.1 : Basic outline of the design.

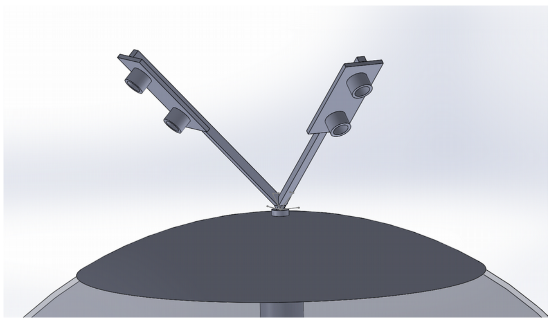
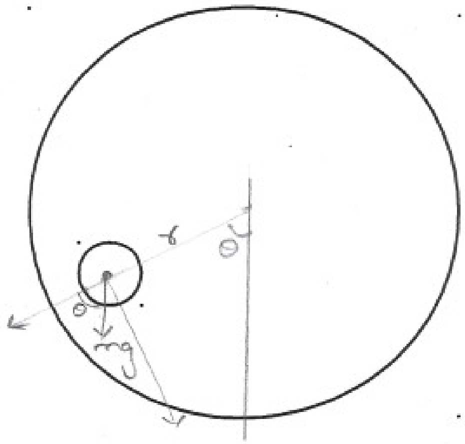


Fig 2.2.2: Magnified view of the Sensors

3. Theory

3.1 Minimum motor torque required.



θ – Angle made by the drive unit with vertical

r – Distance between the center of sphere and center of mass of Drive unit.

m – mass of drive unit ~ 800grams

$F = \frac{T}{r_w} = mg\sin\theta + \mu mg\cos\theta$

Differentiating w.r.t θ for maximum F value

$\Rightarrow \theta_{max}$ is at $\tan^{-1}\left(\frac{1}{\mu}\right)$ $[\mu = 0.01]$

$\sim 88^\circ$

Total torque can be found by substituting θ

$F_{max} = m.g.\sqrt{1+\mu^2} = 0.8 \times 9.8 \times \sqrt{1+0.01^2} = 7.84 N.$

$T = F \times r_w = 7.84 \times 0.035m$ [r_w – radius of the wheel]

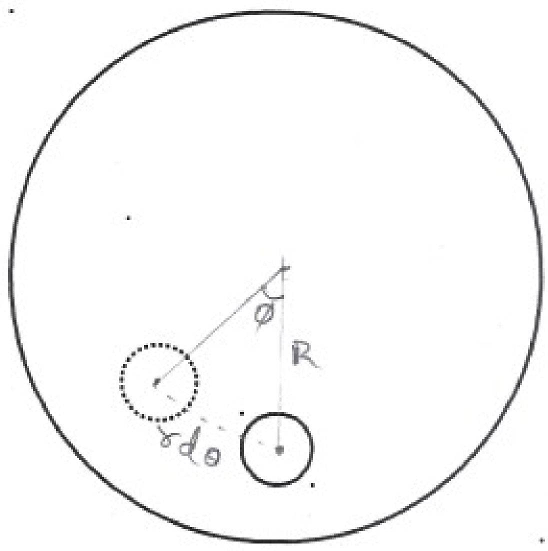
$= 0.27$ N-m

~ 3 kgcm $\Rightarrow$ 1.5kg cm for each mota

Max Torque $= mgr = 0.8 \times 9.8 \times 0.123m$

$= 0.964$ N-m.

3.2 Speed of the bot.



When the drive unit subtends an angle at the center , the arc distance can be related to the rolling radius of the sphere. Thus, differentiating that equation we can find the relation between speed of the robot and speed of the wheel.

$$R d\phi = r d\theta$$

[R - Distance from center of Sphere to center of IDU
r - radius of the wheel.]

Differentiating w.r.t time

$$R \frac{d\phi}{dt} = r \frac{d\theta}{dt} \Rightarrow R\omega_{casing} = r\omega_{wheel}$$

$$N_{wheel} = \frac{R}{r} N_{casing}$$

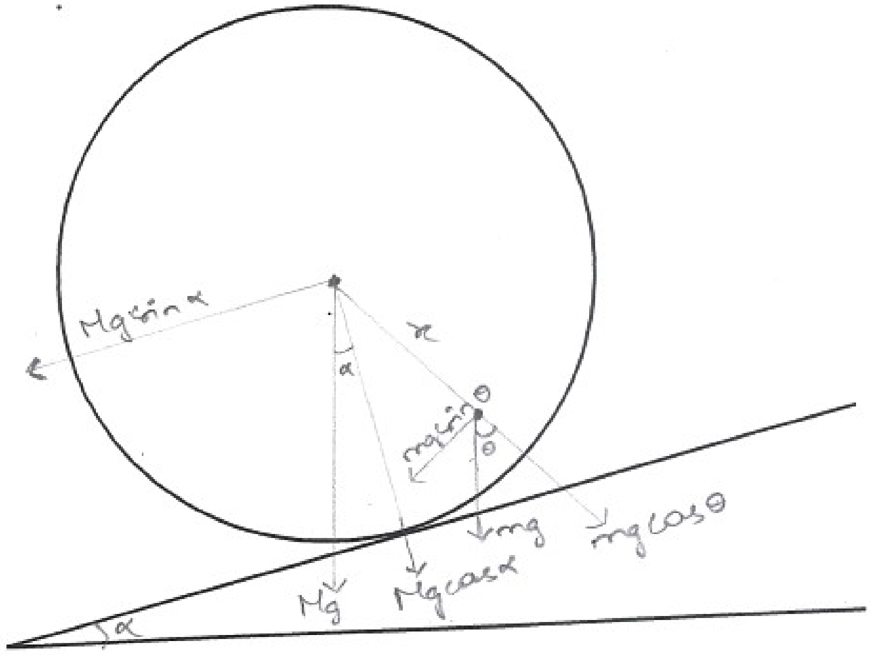
$$\begin{bmatrix} R = \cancel{35.5/2}\ 12.2cm. \\ r = 3.5cm \end{bmatrix}$$

$$N_{wheel} = 3.43\, N_{casing}$$

18 Kmph of bot => 273 rpm of Casing

=> 935 rpm of wheel.

3.3 Maximum slope of the hill.



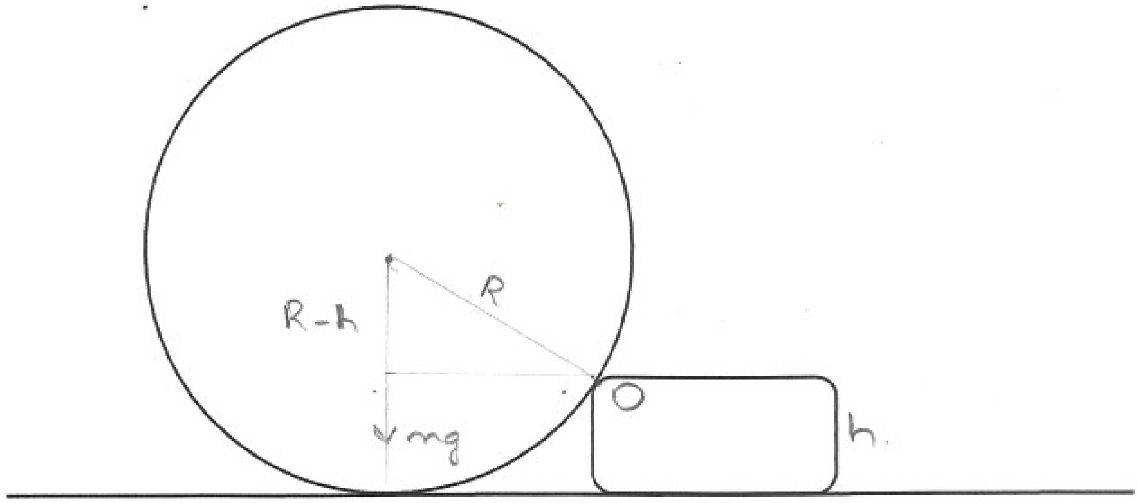
$$mg\sin\theta \cdot x - (M+m)g\,R\sin\alpha > 0$$

$$\sin\alpha < \frac{mx}{(M+m)R} \qquad \left[\theta_{max} = 90^\circ\right]$$

$$\alpha < \sin^{-1}\left[\frac{0.8 \times 0.123}{(1.4+0.8)\times 0.172}\right]$$

$$\alpha \sim 9.05^\circ$$

3.4 Maximum obstacle height



Torque need to roll over point O,

$$\tau = mg\sqrt{R^2-(R-h)^2} = mg\sqrt{2rh-h^2}$$

$$\tau > 1.5 \times 9.8 \times \sqrt{2 \times 0.174 \times h - h^2}$$

Since the maximum torque is ~ 1 N-m

$$\left(\frac{1}{1.5 \times 9.8}\right)^2 = 2 \times 0.174 \times h - h^2$$

Solving for h, max height is ~ 1.9 cm

Considering the available kinetic energy of the sphere, it can climb over an obstacle that are over the theoretical limit.

4. Building the robot.

4.1 Casing.

For the casing to have a high strength to weight ratio and also keeping the cost in view, a layer of fiber glass and carbon fiber was chosen because of their market availability and their exceptional mechanical properties.

a) Fiber Glass

Woven fiberglass fabrics offer the widest range and the best control over thickness, weight and strength of all forms of fiberglass textiles. This offers the materials engineer a wide choice of controlled fabric properties to satisfy design needs and objectives. In general, woven glass fabrics have the following properties:

High Tensile Strength:

Glass is one of the strongest textile fibers, having greater specific tensile strength than steel wire of the same diameter, at a lower weight.

Dimensional Stability:

Low elongation under load, generally 3% or less. Glass fibers produce fabrics with excellent dimensional stability under various types of conditions.

High Heat Resistance:

Glass fabrics have excellent heat resistance at relatively low cost. They retain approximately 50% of room temperature tensile strength at 700°F (371°C); approximately 25% at 900°F (482°C); with a softening point of 1555°F (846°C) and a melting point of 2075° F (1121 °C).

Fire Resistance:

Composed of inorganic materials, glass fabrics are noncombustible, a natural choice where flammability is of concern.

Good Thermal Conductivity:

The rapid heat dissipation of glass fabrics is particularly important in electrical insulation applications.

Good Chemical Resistance:

Like glass itself, fiberglass fabrics are highly resistant to attack by most chemicals.

Durability:

Being inert, glass fabrics are unaffected by sunlight, fungus or bacteria.

Economical:

Glass fabrics are lower in cost than many other fabrics for similar applications.

b) Carbon Fiber

Carbon fiber, alternatively graphite fiber, carbon graphite or CF, is a material consisting of fibers about 510 μm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber.

The crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric.

Carbon fiber is a high-tensile fiber or whisker made by heating rayon or polyacrylonitrile fibers or petroleum residues to appropriate temperatures. Fibers may be 7 to 8 microns in diameter and are more that 90% carbonized.

These fibers are the stiffest and strongest reinforcing fibers for polymer composites, the most used after glass fibers. Made of pure carbon in form of graphite, they have low density and a negative coefficient of longitudinal thermal expansion.

Carbon fibers are very expensive and can give galvanic corrosion in contact with metals. They are generally used together with epoxy, where high strength and stiffness are required, i.e. race cars, automotive and space applications, sport equipment.

Depending on the orientation of the fiber, the carbon fiber composite can be stronger in a certain direction or equally strong in all directions. A small piece can withstand an impact of many tons and still deform minimally. The complex interwoven nature of the fiber makes it very difficult to break.

The mechanical properties of Fiber glass and Carbon fiber are give in the appendix.

To harden the fiber glass cloth, commercial grade 1:10 W/W Epoxy resin and hardener was used. A 35cm beach ball was bought and inflated. The cloth and resin where applied over the ball and left to cure for 1 day. The outer most layer has been treated with wood care putty to soften the surface.

4.2 The Drive Unit

The motors are clamped diametrically oppossite on an 18 cm wood of 8mm thickness. In the centre, an axially placed flange is glued to mount the mast, to which, on top, the magnets are mounted. The battery is mounted below the wood plate so as to lower the center of mass.

a) Bluetooth

A HC-05 bluetooth module is connected to the processor for manual control of the unit. The data sheet is included in the appendix.

b) Radio Receiver

The radio receiver is also similarly connected to the processor to communicate with the robot above the head.

c) Motor Driver

L293D is a typical H-bridge Motor driver or Motor Driver IC which allows DC motor to drive on either direction. L293D is a 16-pin IC which can control a set of two DC motors simultaneously in any direction. It means that you can control two DC motors with a single L293D IC.

d) Arduino Uno

Arduino/Genuino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.. You can tinker with your UNO without worring too much about doing something wrong, worst case scenario we can replace the chip for a few dollars and start over again. It is powered by a 9v battery and regulated by a 9v-5v voltage regulator.

4.3 Processor Code – Arduino Uno.

```
#include <VirtualWire.h>  // radio receiver library

#define m1a 19       // pins for motors
#define m1b 18
#define m1s 5
#define m2a 7
#define m2b 6
#define m2s 11
#define ledpin 13


char signal; //character to read bluetooth
int acc;

void setup(){

  Serial.begin(9600);

  pinMode(m1a,OUTPUT);
  pinMode(m2a,OUTPUT);     //setting the motor input pins as output
  pinMode(m1b,OUTPUT);
  pinMode(m2b,OUTPUT);
  pinMode(m1s,OUTPUT);
  pinMode(m2s,OUTPUT);
  pinMode(ledpin,OUTPUT);
```

```
  vw_set_rx_pin(8);
  vw_setup(2000);  // Bits per sec
  vw_rx_start();       // Start the receiver PLL running
}


void loop(){

    uint8_t buf[VW_MAX_MESSAGE_LEN];
    uint8_t buflen = VW_MAX_MESSAGE_LEN;


    if(Serial.available()>0){    //proceeds if data available in buffer

      signal = Serial.read();

      if(signal !='S'){
        switch(signal){

          case 'B':
            mgoF(255);     //go forward
            break;

          case 'F':
            mgoB(255);     //go backward
            break;

          case 'L':
            steerLeft_a();   //rotate left
            break;

          case 'R':
            steerRight_a();     //rotate right
            break;

          case 'X':
            mStop_a();     //stop
            break;

          case 'x':
            mStop_a();
```

```
          break;

        case 'w':
          mAcc();   //accelerate slowly
          break;

        case 'W':
          mAcc();
          break;

        case 'S':
          mStop();
          break;
        default: break;



        }
      }
  }

    if (vw_get_message(buf, &buflen)) // Non-blocking
    {
      if(buf[0]=='1'){
        digitalWrite(ledpin,HIGH);    //sensor unit sends ‘1’ if obstacle
        mStop_a();                    // detected
      }
     if(buf[0]=='0'){
        digitalWrite(ledpin,LOW);    //keeps sending ‘0’ if not detected
      }
    }

}
void mgoF(int m){
  analogWrite(m1s, m);
  analogWrite(m2s, m);
  digitalWrite(m1a,HIGH);
  digitalWrite(m1b,LOW);
  digitalWrite(m2a,HIGH);
  digitalWrite(m2b,LOW);

}
```

```
void mgoB(int m){
  analogWrite(m1s, m);
  analogWrite(m2s, m);
  digitalWrite(m1a,LOW);
  digitalWrite(m1b,HIGH);
  digitalWrite(m2a,LOW);
  digitalWrite(m2b,HIGH);
}

void mStop_a(){
  digitalWrite(m1a,LOW);
  digitalWrite(m1b,LOW);
  digitalWrite(m2a,LOW);
  digitalWrite(m2b,LOW);
}

void steerLeft_a(){
  analogWrite(m1s, 180);
  analogWrite(m2s, 180);
  digitalWrite(m1a,LOW);
  digitalWrite(m1b,HIGH);
  digitalWrite(m2a,HIGH);
  digitalWrite(m2b,LOW);
  delay(100);
  digitalWrite(m1a,LOW);
  digitalWrite(m1b,LOW);
  digitalWrite(m2a,LOW);
  digitalWrite(m2b,LOW);
}

void steerRight_a(){
  analogWrite(m1s, 180);
  analogWrite(m2s, 180);
  digitalWrite(m1a,HIGH);
  digitalWrite(m1b,LOW);
  digitalWrite(m2a,LOW);
  digitalWrite(m2b,HIGH);
  delay(100);
  digitalWrite(m1a,LOW);
  digitalWrite(m1b,LOW);
  digitalWrite(m2a,LOW);
```

```
  digitalWrite(m2b,LOW);
}

void mAcc(){
  digitalWrite(m1a,HIGH);
  digitalWrite(m1b,LOW);
  digitalWrite(m2a,HIGH);
  digitalWrite(m2b,LOW);

 for(acc=155;acc<256;acc+=5){    //accelerates from half to full speed
                                 // in 3 seconds over 10 steps.
  analogWrite(m1s, acc);
  analogWrite(m2s, acc);
  delay(300);
 }

}
```

4.4 Sensor Unit

The sensor unit is placed on top of the sphere and is magnetically coupled to the internal drive unit. Thus, it demands low weight so as to be more stable. For that reason wood is chosen as the chassis material. The ranging sensors are mounted at 45 degrees to drive unit's axis and are mutually perpendicular to each other. One will act as an auxillary sensor when an obstacle is detected.

a) Ranging Sensor

A popular ranging sensor SR-04 is used to evaluate the range to the ground. It has a range of 4 meters with a resolution of 1cm. The data sheet is included in the appendix.

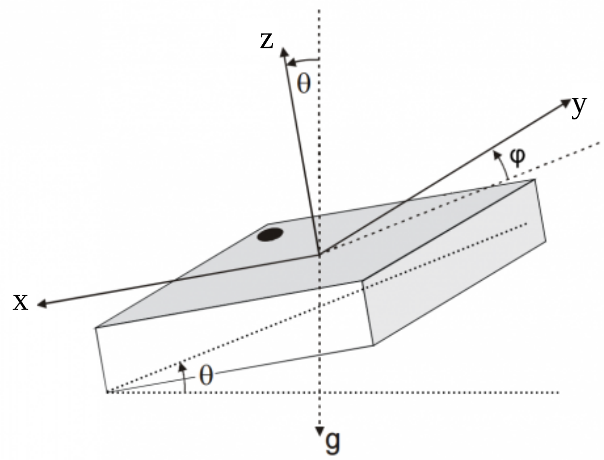
b) Accelerometer

A 3-Axis ADLX-333 accelerometer is used to evaluate the angle with the vertical. It has a maximum sensing capacity of +3g/-3g. The data sheet is included in the appendix.

$$acc\_x = 1g * \sin\theta$$

$$acc\_y = -1g * \cos\theta * \sin\varphi$$

$$acc\_z = 1g * \cos\theta * \cos\varphi$$



Thus the tilt can be found using :

$$\arctan\left(\frac{acc_x^2}{\sqrt{acc_y^2+acc_z^2}}\right)$$

c) Arduino Nano

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). It has more or less the same functionality of the Arduino Uno, but in a different package. It lacks only a DC power jack, and works with a Mini-B USB cable instead of a standard one. It is power by 9v battery.

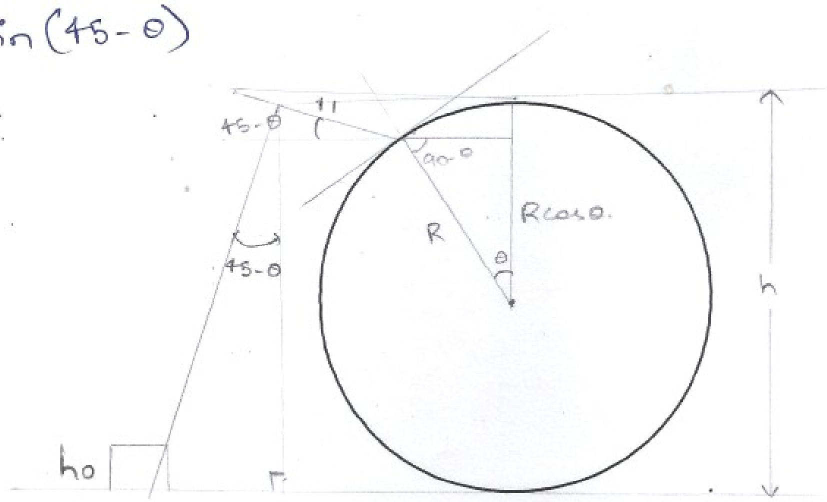
4.5 Calculating the Range.

Since the unit is not always vertical, the range keeps changing constantly. For this reason the range has to evaluated as a function of the angle of the unit. The final formula to calculate the range is obtained below.

$$h = R\cos\theta + 11\sin(45-\theta)$$

Range to ground:

$$= \frac{h}{\cos(45-\theta)}$$



If the range is less than

$\frac{h - h_o}{\cos(45-\theta)}$, the sensor unit transmitts a signal to the internal unit.

4.6 Processor Code – Arduino Nano.

```
#include <VirtualWire.h>   //transmitter library
#include <math.h>


//Ranging sensor pins
#define trigpin1 5
#define echopin1 6
#define trigpin2 7
#define echopin2 8
#define ledpin 13


//accelerometer pins
const int ap1 = A5;
const int ap2 = A4;
const int ap3 = A3;


//accelerometer variables

double x_Buff = 0.0;
double y_Buff = 0.0;
double z_Buff = 0.0;
double pitch = 0.00;

//ranging sensor variables
float time1,dist1,range1,time2, dist2, range2;

//radio variables
char *controller;

void setup(){
```

```
  Serial.begin(9600);

  //ranging sensor
  pinMode(trigpin1, OUTPUT);
  pinMode(echopin1, INPUT);
  pinMode(trigpin2, OUTPUT);
  pinMode(echopin2, INPUT);
  pinMode(ledpin, OUTPUT);
  pinMode(2, OUTPUT);
  digitalWrite(2, HIGH);
  pinMode(3, OUTPUT);
  digitalWrite(3, HIGH);

  //accelerometer
  analogReference(EXTERNAL); //3.3v is the maximum output so the analog
                             // values have to be calibrated
  //radio
  vw_set_tx_pin(12);
  vw_setup(2000);// speed of data transfer Kbps
}

void loop(){

  range1=range_1();
  range2=range_2();

  x_Buff = float(analogRead(ap1)-512); //512 implies zero gravity
  delay(2);
  y_Buff = float(analogRead(ap2)-512);
  delay(2);
  z_Buff = float(analogRead(ap3)-512);

  pitch = atan2((- x_Buff) , sqrt(y_Buff * y_Buff + z_Buff * z_Buff)) *
57.3;

   if(range1<5.0 || range2<5.0) {
```

```
    digitalWrite(ledpin, HIGH);
    controller="1"  ;
    vw_send((uint8_t *)controller, strlen(controller));//transmit string
    vw_wait_tx(); // Wait until the whole message is gone
  }
  else{
    digitalWrite(ledpin, LOW);
    controller="0"  ;
    vw_send((uint8_t *)controller, strlen(controller));
    vw_wait_tx(); // Wait until the whole message is gone
  }
  delayMicroseconds(20);
  //loop END

}



float range_1(){

  digitalWrite(trigpin1 ,LOW);
  delayMicroseconds(2);
  digitalWrite(trigpin1, HIGH);
  delayMicroseconds(15);
  digitalWrite(trigpin1, LOW);

  time1=pulseIn(echopin1, HIGH); //returns time taken for echo to hit
                                //back
  dist1=(time1/2)*0.0330;   //half time * speed of sound in cm/s
  return dist1;
}

float range_2(){

  digitalWrite(trigpin2 ,LOW);
  delayMicroseconds(2);
  digitalWrite(trigpin2, HIGH);
```

```
  delayMicroseconds(15);
  digitalWrite(trigpin2, LOW);

  time2=pulseIn(echopin2, HIGH);
  dist2=(time2/2)*0.0330;
  return dist2;
}
```

5 Results

A motor of torque 1kg-cm with a 1000rpm was found suitable to run inside the sphere. The ranging sensors were found to be accurate to +-3mm. The mounting of ranging sensors at an angle caused the sound to reflect off from the ground but the sensor received partially reflected sound most of the times. The faulty data received had to be filtered off. The magnets caused the sensor unit to create resisting torque for the internal drive unit given the rough surface and the sliding friction. The sphere rolls as expected but gets stuck at the separation line between the two halves.

5.1 Scope for future work.

The sensor unit can be actively controlled using a sensor mounted radially so as to eliminate the need to evaluate the range every instant with changing angle.

Whole robot can be made with light weight materials and can me made to run on water. With fluid dynamics evaluated properly, this will prove to be an extremely useful solution in extra terrestrial and military applications.

6. Conclusion

Though the robot cannot reach very high speeds, it has its own advantages to trade off for the speed. Charging is a problem but wireless charging can be adopted. The magnetic coupling needs to optimised since it cannot be too strong or too weak. The advantages and disadvantages of a spherical robot are given and discussed. Several different designs are introduced and also, a simple dynamic analysis, applications, and future prospects are presented in order to give a better understanding of the field of spherical rolling robots. As expected, the heading control is the most sensitive one and the robot is difficult to drive on a strait line manually. Instead, the longitudinal velocity control is easy to maintain. With the quite low speeds used the ball is relatively easy to handle with moderate accuracy. In this mechanical construction Internal Drive unit must be, however, well balanced.

7 References

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[11] www.rotundus.se

Appendix

Carbon Fiber

Standard Fiber Properties

	US Units	SI Units
Tensile Strength	600 Ksi	4137 MPa
Tensile Modulus	35 Msi	242 GPa
Elongation	1.5%	
Density	0.065 lb/in^3	1.81 g/cc
Fiber Diameter	0.283 mils	7.2 microns
Carbon Content	95%	
Yield	400 ft/lb	270 m/kg

Glass Fiber

Glass Fiber Mechanical Properties

	E-glass	R-glass	HS2,HS4	T-glass	S-1	S-2
Tensile Strength GPa	1.9-2.5	3.1-3.4	3.1-4.0	4.0-4.2	3.8-4.1	4.3-4.6
Tensile Modulus GPa	69-80	86-89	82-90	84	85-87	88-91

Virtual-Wire Library

Configuration Functions

vw_set_tx_pin(transmit_pin)

Configure the transmit pin. Default is pin 12. Blah

vw_set_rx_pin(receive_pin)

Configure the receive pin, Default is pin 11. On Teensy 2.0, pin 11 should not be used because most receiver modules can not work correctly with the orange LED on that pin.

vw_set_ptt_pin(transmit_en_pin)

Configure the transmit enable pin, or "push to talk". Default is pin 10.

vw_set_ptt_inverted(true)

Configure the "push to talk" polarity.

vw_setup(2000)

Begin using all settings and initialize the library. This is similar to the "begin" function of other libraries. All pins should be configured before calling this function.

Transmission Functions

vw_send(message, length)

Transmit a message. "message" is an array of the bytes to send, and "length" is the number of bytes stored in the array. This function returns immediately and the message is sent slowly by an interrupt-based background process.

vw_tx_active()

Returns true if the message is being sent, or false if the transmitter is not active. You can use this after sending a message to test when it has finished being transmitted.

vw_wait_tx()

Wait for a message to be fully transmitted. Often the simplest approach is to call this after vw_send.

Reception Functions

vw_rx_start()

Activate the receiver process. You must call this function before any reception can occur. An interrupt-based background process is started which monitors the reception of data.

vw_have_message()

Returns true if message has been received. This is similar to the "available" function of most other libraries.

vw_wait_rx()

Wait for a message to be received. This will only return when a message has been received, otherwise it will wait forever.

vw_wait_rx_max(timeout_ms)

Wait for a message, but give up after "timeout_ms". Returns true if a message was received, or false if the timeout period elapsed.

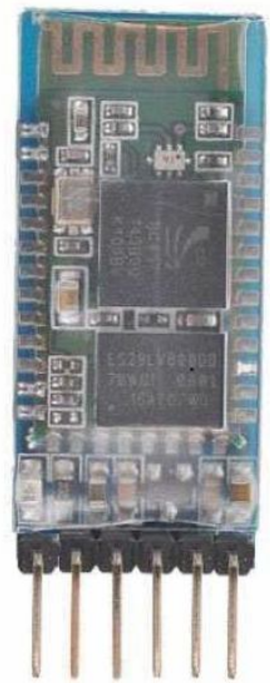
vw_get_message(buf, &buflen))

Read the last received message. This should be called only when a message is known to be received with any of the 3 functions above. "buf" is an array where the message is copied. "buflen" should have the array's maximum size upon input, and upon return the number of bytes actually copied is retured. The function itself returns true if the message was verified correct, or false if a message was received but appears to have been corrupted.

vw_rx_stop()

Disable the receiver process.

DATASHEET
BLUETOOTH TO SERIAL PORT MODULE
HC05



Overview

HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup.

Serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). It has the

footprint as small as 12.7mmx27mm. Hope it will simplify your overall design/development cycle.

www.electronica60norte.com
electronica60norte@hotmail.com

Specifications

Hardware features

- Typical -80dBm sensitivity.
- Up to +4dBm RF transmit power.
- Low Power 1.8V Operation, 3.3 to 5 V I/O.
- PIO control.
- UART interface with programmable baud rate.
- With integrated antenna.
- With edge connector.

Software features

- Slave default Baud rate: 9600, Data bits:8, Stop bit:1,Parity:No parity.
- PIO9 and PIO8 can be connected to red and blue led separately. When master and slave are paired, red and blue led blinks 1time/2s in interval, while disconnected only blue led blinks 2times/s.
- Auto-connect to the last device on power as default.
- Permit pairing device to connect as default.
- Auto-pairing **PINCODE:"1234"** as default.
- Auto-reconnect in 30 min when disconnected as a result of beyond the range of connection.

www.electronica60norte.com
electronica60norte@hotmail.com

Accelerometer (ACC)
Sensor Data Sheet

ACC 080115

SPECIFICATIONS
> **Range:** ±3G
> **Bandwidth:** 0-50Hz
> **Consumption:** ~0.35mA

FEATURES
> 3-axis sensing
> MEMS technology
> Pre-conditioned analog output
> Small form factor
> Raw data output
> Easy-to-use

APPLICATIONS
> Activity monitoring
> Tilt detection
> Vibration measurement
> Human-Computer Interaction
> Robotics & Cybernetics
> Biomechanics
> Biomedical devices prototyping

GENERAL DESCRIPTION
Motion produces accelerations that can be translated into numerical values. Our Accelerometer (ACC) has a limited bandwidth, especially designed to acquire data from kinematic and biomechanical events. The analog output of each axis can be accessed individually, extending its potential use. Typical applications include posture detection, range of motion estimation, step counting, actigraphy, fall detection, vibration analysis, and shock detection. By default only the Z-axis is connected, however the sensor has 3 axis, and the user can choose to connect the X- and Y-axis as well, by following these steps:
https://www.youtube.com/watch?v=RaJQ3hcdJqUh
https://www.youtube.com/watch?v=rh8y_NsVLI4h

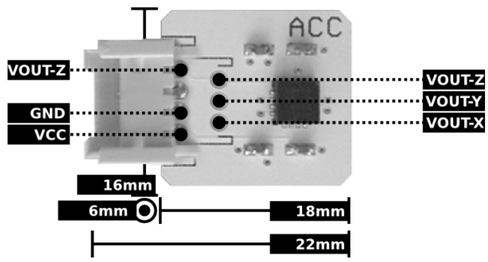


Fig. 1. Pin-out and physical dimensions.

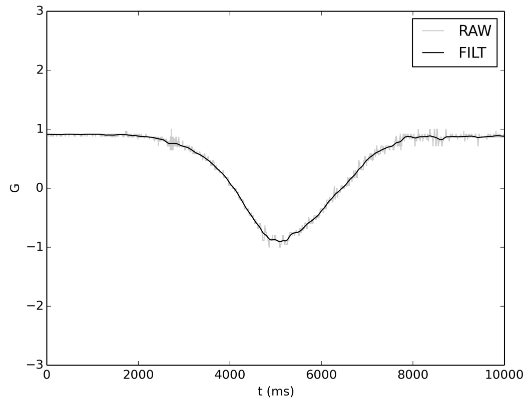


Fig. 2. Raw and filtered ACC data (acquired with BITalino) for a full rotation around the Z-axis.

PLUX – Wireless Biosignals, S.A.
Av. 5 de Outubro, n. 70 – 8.
1050-059 Lisbon, Portugal
bitalino@plux.info
http://bitalino.com/

REV A

BEWARE: DIRECT OR INDIRECT COUPLING TO THE MAINS MAY RESULT IN SHOCKING HAZARD

TRANSFER FUNCTION

[-3g, 3g]

$$ACC(g) = \frac{ADC - C_{min}}{C_{max} - C_{min}} . 2 - 1$$

$ACC(g)$ – ACC value in g-force (g)
ADC – Value sampled from the channel
C_{min} – Minimum calibration value[1] (typically $C_{min} \approx 208$)
C_{max} – Maximum calibration value[1] (typically $C_{max} \approx 312$)

[1] Calibration values are determined by performing a very slow 360° rotation of the sensor board to force the accelerometer to cross the gravity-imposed $-1g$ and $1g$.

Ultrasonic Ranging Module HC - SR04

Product features:

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:

(1) Using IO trigger for at least 10us high level signal,

(2) The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back.

(3) IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning.

Test distance = (high level time×velocity of sound (340M/S) / 2,

Wire connecting direct as following:

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

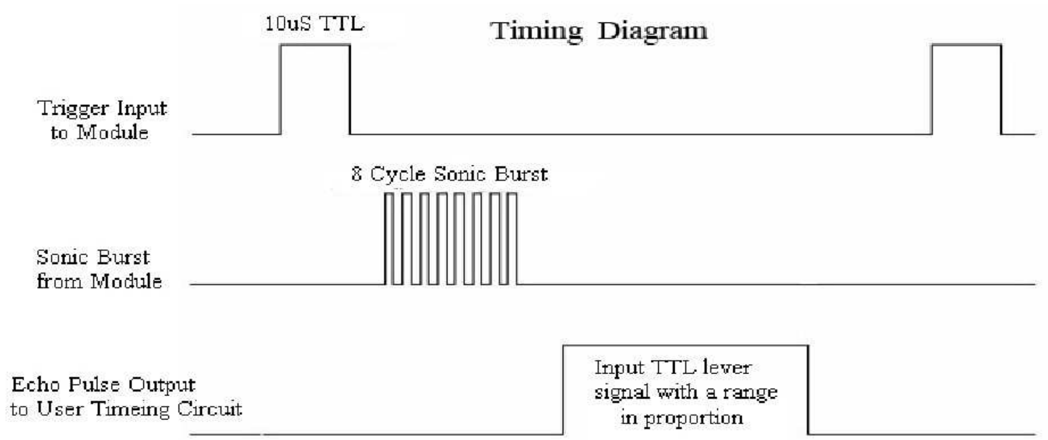
Electric Parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Vcc Trig Echo GND

Timing diagram

The Timing diagram is shown below. You only need to supply a short 10uS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion .You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: uS / 58 = centimeters or uS / 148 =inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.



Attention:

- The module is not suggested to connect directly to electric, if connected electric, the GND terminal should be connected the module first, otherwise, it will affect the normal work of the module.
- When tested objects, the range of area is not less than 0.5 square meters and the plane requests as smooth as possible, otherwise ,it will affect the results of measuring.

www.Elecfreaks.com

433Mhz RF Transmitter With Receiver Kit For Arduino ARM MCU Wireless

Description:

This is 433Mhz RF transmitter with receiver kit for Arduino ARM MCU wireless
Application environment:

Remote control switch, receiver module, motorcycles, automobile anti-theft products, home security products, electric doors, shutter doors, windows, remote control socket, remote control LED, remote audio remote control electric doors, garage door remote control, remote control retractable doors, remote volume gate, pan doors, remote control door opener, door closing device control system, remote control curtains, alarm host, alarm, remote control motorcycle remote control electric cars, remote control MP3.

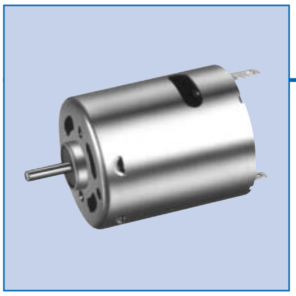
Specification:

Receiver module:
Product Model: XD-RF-5V
Operating voltage: DC5V
Quiescent Current: 4MA
Receiving frequency: 433.92MHZ
Receiver sensitivity: -105DB
Size:30x14x7mm

Transmitter:

Product Model: XD-FST
Launch distance :20-200 meters (different voltage, different results)
Operating voltage :3.5-12V
Dimensions: 19 * 19mm
Operating mode: AM
Transfer rate: 4KB / S
Transmitting power: 10mW
Transmitting frequency: 433M
Pinout from left → right: (DATA; VCC; GND)

See for how to: http://electronics-diy.com/arduino-rf-link-using-433mhz-transmitter-receiver-modules.php



RS-360SH

MABUCHI MOTOR

Carbon-brush motors

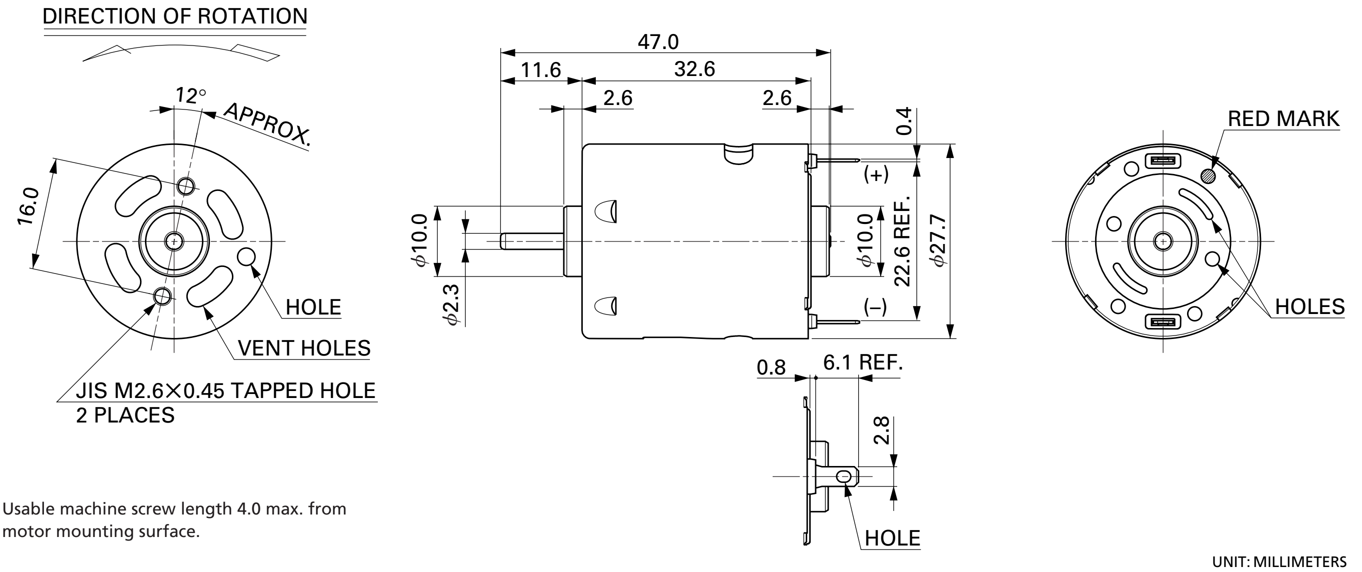
OUTPUT : 0.7W~40W (APPROX)

WEIGHT : 55g (APPROX)

Typical Applications

Home Appliances : Massager / Vibrator
Office Automation Equipment : Copy Machine / Laser Printer
Precision Instruments : Vending Machine

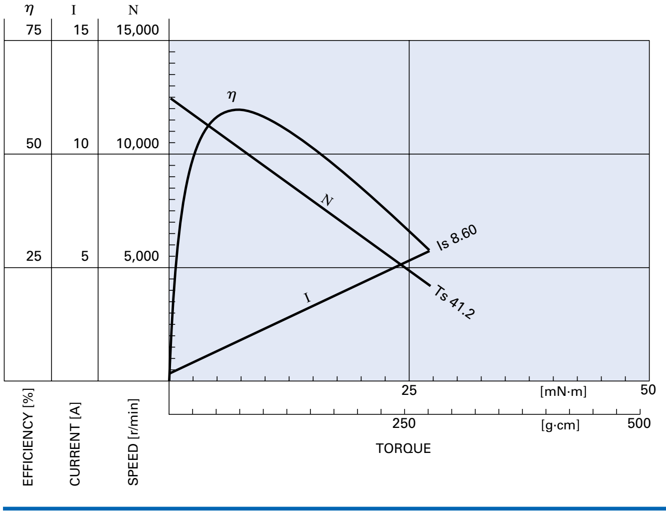
MODEL	VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
	OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
			r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RS-360SH-2885	3~9	7.2V CONSTANT	12500	0.36	10380	1.76	7.00	71.3	7.59	41.2	420	8.60
RS-360SH-10500	12~25	12V CONSTANT	3500	0.050	2590	0.14	2.74	28.0	0.74	10.6	108	0.41



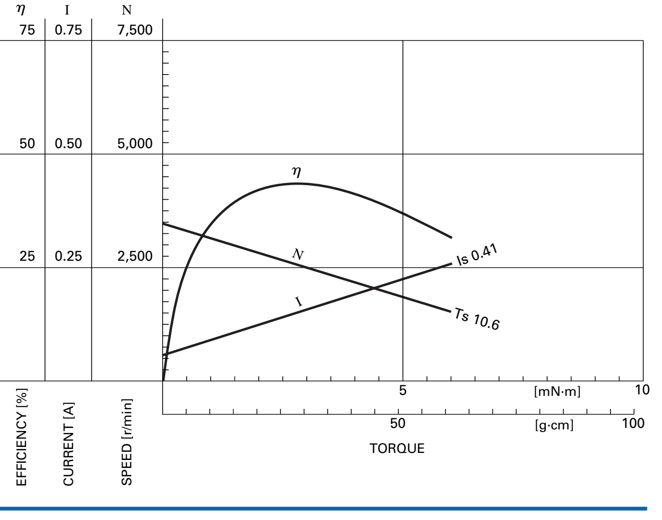
Usable machine screw length 4.0 max. from motor mounting surface.

UNIT: MILLIMETERS

RS-360SH-2885 7.2V



RS-360SH-10500 12.0V



MABUCHI MOTOR CO., LTD. **Headquarters** 430 Matsuhidai, Matsudo City, Chiba, 270-2280 Japan. Tel:81-47-710-1177 Fax:81-47-710-1132 (Sales Dept.)