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# EXPERIMENTAL FABRICATION OF ECONOMICAL SEGWAY

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**Abstract:**

The difference between a scooter and a segway is the arrangement of wheels. The wheels are arranged in side by side manner for a segway where as it is back to back in a scooter. The wheels were attached to a frame which looks like a simply supported beam. Since the rollers/wheels are used as supports, it become critical to balance a body on the segway. For this balancing, a technology was developed by using electronic circuits and motors by Dean Kamen. The gyro sensor defines the orientation of the vehicle with respect to vertical axis in the form of a signal and this signal will be sent to the electrical actuators or motors with the help of Arduino microcontroller to bring back the vehicle to stand straight vertical. The forward motion is caused by leaning forward and backward motion is by leaning back. The right and left directions were controlled by the program dumped in the microcontroller. The batteries are used to drive the motor. The intial vehicle cost is very high in the market and a normal middle class people cannot afford. The parts used in the fabrication of segway are readily available in the market with low price. This is the reason for developing a low cost segway suitable for all classes of people with all the features present in the high cost segway.

**Key Words:** ArduinoUNO, Gyro Sensor, Accelerometer, Citron Motor Driver & Self-balancing Vehicle

## 1. Introduction:

The human transporter vehicle which is presently termed as Segway uses battery power for self balancing and was designed and developed by Dean Kamen. Because of its ease of operation and simple in structure it became popular for human transportation in most of the automotive industries and robotic applications. The most important and amazing thing about segway is its ability to balance on its own. It turns the wheel at right speed to balance the vehicle to move forward and backward or right and left. It contains the control system which are connected by sensors and motors along with motor drivers. The leaning of the person on the vehicle defines the respective motion of the vehicle. The balancing and controlling of the vehicle will be controlled by the program given to microcontroller. To reduce the fatigue created by walking this segway was designed and this will not cause any inconvenient to the operator once the operation or working of the segway is clearly understood. The segway can move at 12.5kmph and it has a disadvantage of unpredicting the correct operating time for varying masses. To make it simple and availability to all the classes of the people many experiments and research was still going on the development of the segway.

## 2. Components of the Segway:

The fabrication of the segway includes the following components:

- ✓ 24V 250W DC Electric Scooter motors
- ✓ 12V 7ah Lead Acid batteries
- ✓ Seg Wheels
- ✓ MPU 650 GY521
- ✓ Arduino UNOR3
- ✓ Cytron Single channel motor drivers
- ✓ Switches
- ✓ Chassis (Plywood)
- ✓ Brackets (Inner: 2 and Outer: 2)
- ✓ Sprockets and chains
- ✓ Handle
- ✓ Breadboard

## 3. Fabrication of Segway:

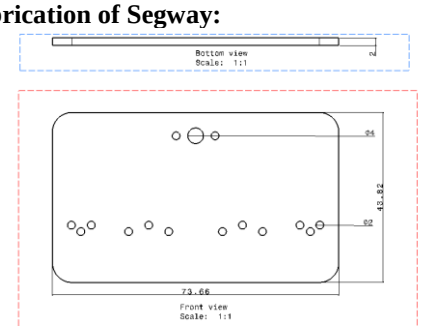


Figure 1: Dimensions of the chassis

Cut the plywood chassis and corner the edges into smooth curves as shown in the figure -1. The plywood considered as base and it should the weight of the person operating the segway. The average weight considered for the design of the segway is 80Kgs. The holes were drilled for the arrangement of other components on the frame. They are located in a conveniently and should not reduce the strength of the chassis.

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Use 2 mild steel brackets for inner as shown in the figure – 2 and another 2 brackets of same material for outer and of different size as shown in the figure - 3. Drill 10mm diameter holes into brackets. Fix these brackets using bolts and nuts to the chassis in such a way that wheels can be fitted in between them.

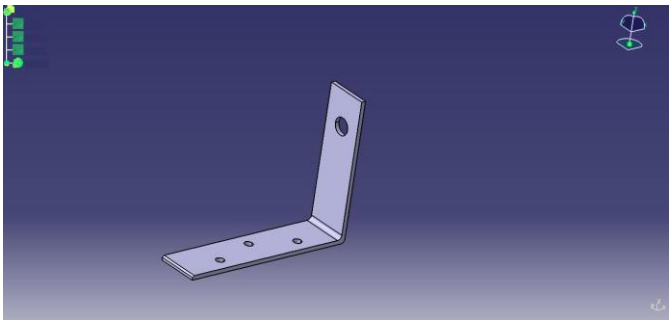

Figure 2: Inner Brackets

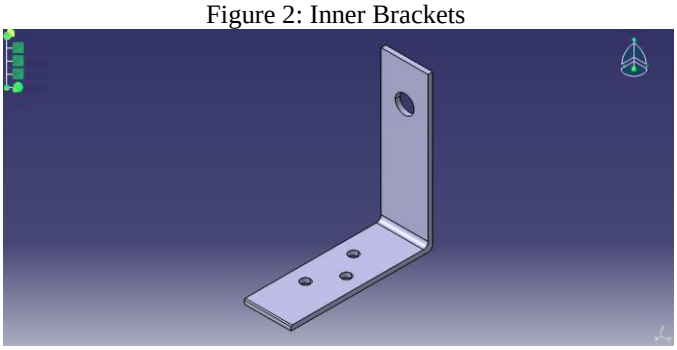

Figure 3: Outer Brackets

Two wheels are fitted in between these brackets using a stepped bar and bearings as shown in figure - 4. Note that chain is also arranged with sprocket which is attached to wheel.

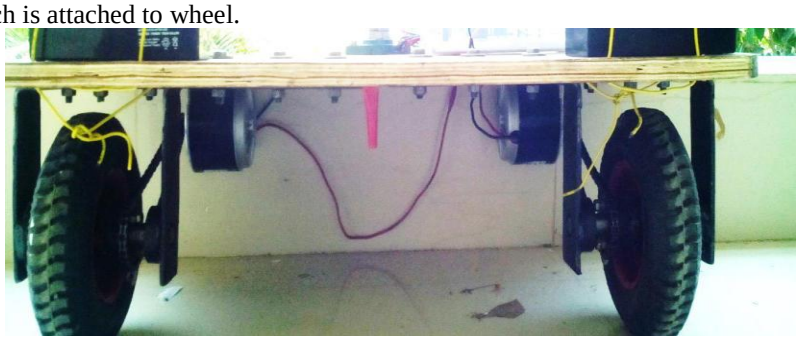

Figure 4: Wheels fixed between brackets

The motor has a bracket and that is fastened with screws to the chassis so that chain is straight and motor gear is perpendicular to the wheel brackets. Pull the motor gently from the wheels and mark the 4 holes. Repeat for the other motor. Punch 8 holes and insert a washer and a bolt of required dimensions into each hole and tighten it as shown in the figure – 5.

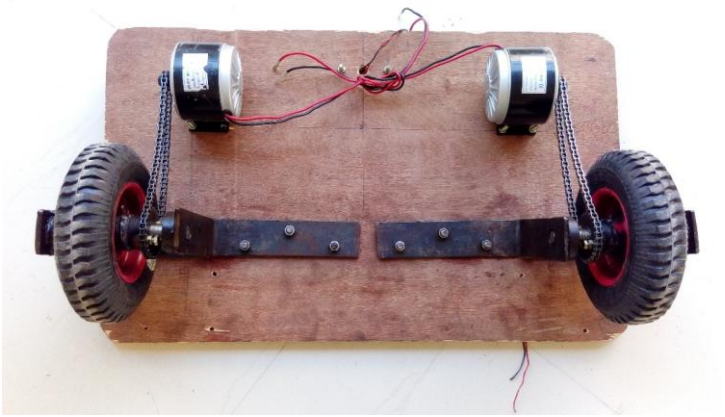

Figure 5: Rear View of Segway

Two batteries of 12V are connected in series and are used to drive the motor and they are arranged on the chassis as shown in the figure - 6.

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Figure 6: Batteries incorporated on chassis

Mark the center line of 53.34cm on the long side of the board. Drill holes on front side so that it exactly fits the flange. Attach flange using nuts and bolts. Cut the PVC pipe and Drill holes on each pipe so that switches can be fixed into them. Cut the steel pipe of length 80cm.Connect these three pipes using a Tee joint. Another end of steel pipe is attached to chassis using flange. Fix each switch to each PVC pipe as shown in the figure -7. The pipes considered should not bend or deform on application of force or during the operation of the segway. The steel pipe acts as a support to the rider. The location of the switches in the PVC should be convenient and near to the grip. A segway can be operated without the application of the switches, since there is a gyro sensor in the panel board. The two switches are used to control the directions of the segway. One switch is used for forward and backward and the other for moving right and left sides. A box is fitted to the right side corner of the chassis using glue. Trace rectangle around each battery. Mark 4 holes outside battery rectangle for wire tacks to go through.

Figure 7: Handle fixed to flange

A through hole is drilled on the chassis in order to fix the batteries as shown in the figure - 8.

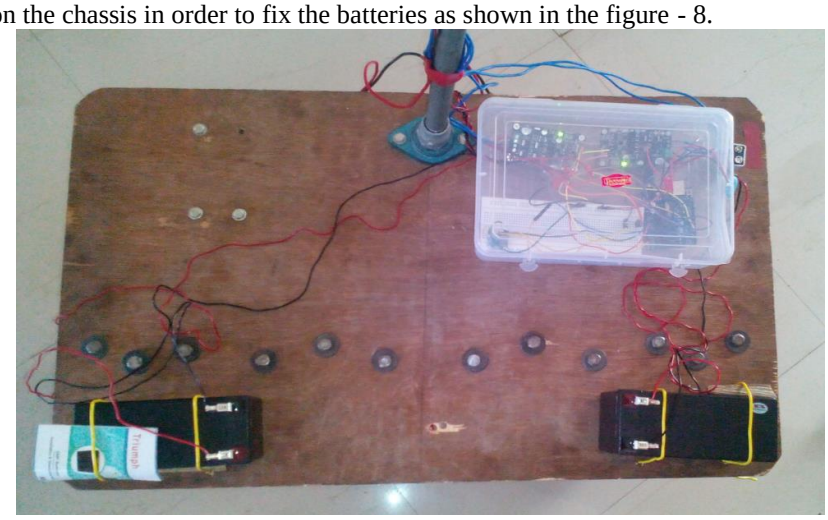

Figure 8: Arrangement of batteries and electronic box

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The motor driver board, the Arduino shield Gyro sensor, Accelerometer motors are connected as shown in the figure. If the + and - are swapped, we may burn out the expensive motor driver board, so proper care is taken in connecting the circuit. Wire up the pull up resistors, Vcc, GND, and I2C lines as shown in the figure – 9. In order to avoid confusion a color coding of cables is followed. The connection of battery to the electronic circuit is only given after confirmation of the connections.

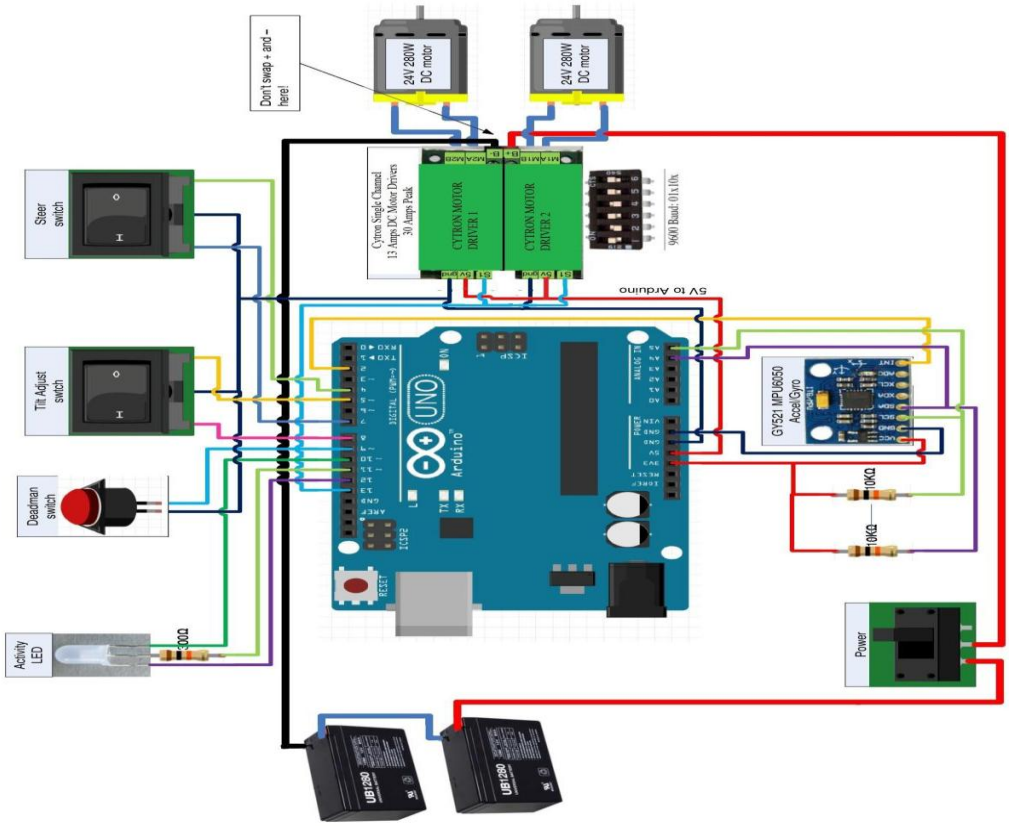


Figure 9: Schematic layout of electronic circui

**4. Arduino Programming:**

After fabricating the components, the following program is dumped into the Arduino board.

```
#include <Wire.h>
#include "I2Cdev.h"
#include "MPU6050_6Axis_MotionApps20.h"
#include <SoftwareSerial.h>
#define ACCEL_GAIN 18.0
#define ACCEL_GAIN 17.
#define GYRO_GAIN 6.0
#define GYRO_GAIN 5.0
floatti_constant = 3;
const float ANGLE_GAIN = 1.20;
const float ANGLE_GAIN = 1.15; float aa_constant = 0.005;
#define DEBUG_FORCE_DEADMAN_SWITCH 0
#define DEBUG_ENABLE_PRINTING 0
#define DEBUG_DISABLE_MOTORS 0
#define SABER_TX_PIN  13
#define SABER_RX_PIN  12
#define SABER_BAUDRATE  9600
#define SABER_MOTOR1_FULL_FORWARD 1
#define SABER_MOTOR1_FULL_REVERSE 127
#define SABER_MOTOR2_FULL_FORWARD 128
#define SABER_MOTOR2_FULL_REVERSE 255
#define SABER_ALL_STOP  0
SoftwareSerialSaberSerial=SoftwareSerial  (SABER_RX_PIN,
SABER_TX_PIN );
voidinitSabertooth (void)  {
pinMode ( SABER_TX_PIN, OUTPUT );
SaberSerial.begin( SABER_BAUDRATE );
SaberSerial.write((byte) 0);   }
#define MPU_INT 0 //is on pin 2
MPU6050 mpu;   // AD0 low = 0x68
booldmpReady = false;
uint8_tdevStatus;
uint16_tpacketSize;
uint16_tfifoCount;
uint8_tfifoBuffer[64]; // FIFO storage buffer
Quaternion q; // [w, x, y, z] quaternion container
VectorFloat gravity;
int16_t gyro[3];
floatypr[3];
floatangle_Y, angular_rate_Y, angular_rate_X;
floatangle_X, angle_Z, angular_rate_Z;
boolblinkState = false;
volatile bool mpuInterrupt = false;
voiddmpDataReady()
{
mpuInterrupt = true;
}
intoscopePin= 3;
floatcur_speed;
floatcycle_time = 0.01;
int STD_LOOP_TIME = 9;
intlastLoopTime = STD_LOOP_TIME;
```

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```
intlastLoopUsefulTime = STD_LOOP_TIME;
unsigned long loopStartTime = 0;
float level=0;
float Steering;
floatSteerValue;
floatSteerCorrect;
int   Steer = 0;
floatx_acc;
floatSG_filter_result;
floatx_accdeg;
floatinitial_angular_rate_Y = 0;
floatinitial_angular_rate_Y_sum = 0;
floatinitial_angular_rate_X = 0;
floatinitial_angular_rate_X_sum = 0;
floatgangleratedeg;
float gangleratedeg2;
floatgangleraterads;
intSteerLeftPin;
intSteerRightPin;
intDeadManPin;
intDeadManPin_temp = 1;
intDeadManPin_temp_old = 1;
longlastDebounceTime = 0;
longdebounceDelay = 50;
floatgyroangle_dt;
float angle;
floatanglerads;
floatbalance_torque;
floatsoftstart;
floatBalance_point;
floatbalancetrim = 0;
intbalancelForward;
intbalancelBackward;
float gv0, gv1, gv2, gv3, gv4, gv5, gv6;
int j;
inttipstart;
signed char Motor1percent;
signed char Motor2percent;
intdeadman_occured_flag;
int skip = 0;//for debug
initSabertooth(); //initialzesaber motor controller
SaberSerial.write((byte) 0);
Wire.begin();
TWBR = 24; // 400kHz I2C clock (200kHz if CPU is 8MHz)
Serial.begin(115200);
Serial.println(F("Initializing I2C devices..."));
mpu.initialize();
Serial.println(F("Testing device connections..."));
Serial.println(mpu.testConnection() ? F("MPU6050 connection
successful") : F("MPU6050 connection failed"));
delay(2);
Serial.println(F("Initializing DMP..."));
devStatus = mpu.dmpInitialize();
mpu.setXGyroOffset(10);
mpu.setYGyroOffset(7);
mpu.setZGyroOffset(14);
mpu.setZAccelOffset(900); // 1688 factory default for  test chip
if (devStatus == 0)
   {
Serial.println(F("Enabling DMP..."));
mpu.setDMPEnabled(true);
Serial.println(F("Enabling interrupt detection (Arduino external
interrupt 0)..."));
attachInterrupt(MPU_INT, dmpDataReady, RISING);
mpuIntStatus = mpu.getIntStatus();
Serial.println(F("DMP ready! Waiting for first interrupt..."));
dmpReady = true;
packetSize = mpu.dmpGetFIFOPacketSize();
   }
void loop ()   {
tipstart = 0;
overallgain = 0;
cur_speed = 0;
level = 0;
  Steer = 0;
angle = 0;
  Steering = 512;
SteerValue = 512;
overallgain = 0.3;  while (1) {
read_accel_gyro(); // read accel/gyro
do_calculations(); //do math
set_motor(); //set motors up
lastLoopUsefulTime = millis() - loopStartTime;
if (lastLoopUsefulTime< STD_LOOP_TIME) {
delay(STD_LOOP_TIME - lastLoopUsefulTime);
   }
lastLoopTime = millis() - loopStartTime;
loopStartTime = millis();
serialOut_timing();
if (overallgain< 0.5) {
overallgain = (float)overallgain + 0.005;
   }
if (overallgain> 0.5) {
overallgain = 0.5;
   }
}  //end of while(1)
} //end of main LOOP
voidread_accel_gyro()  {     //digital accel/gyro is read here
if (!dmpReady) return; // if programming failed, don't try to do
anything
while (!mpuInterrupt&&fifoCount<packetSize) {
  }
mpuInterrupt = false;
mpuIntStatus = mpu.getIntStatus();
fifoCount = mpu.getFIFOCount();
if ((mpuIntStatus& 0x10) || fifoCount == 1024)
   {
mpu.resetFIFO();
Serial.print(" fifoCount: ");
Serial.print(fifoCount);
Serial.print(" mpuIntStatus: ");
Serial.print(mpuIntStatus);
Serial.println(F("FIFO overflow!"));
   }
}
voiddo_calculations()  {
SteerLeftPin = digitalRead(steeringLeftPin);
SteerRightPin = digitalRead(steeringRightPin);
DeadManPin_temp = digitalRead(deadmanButtonPin);
if (DeadManPin_temp != DeadManPin_temp_old) {
lastDebounceTime = millis();
  }
DeadManPin_temp_old = DeadManPin_temp;
```

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```
if ( (millis() - lastDebounceTime) >debounceDelay){
if (DeadManPin_temp == HIGH) {
DeadManPin = 1;
   }
else {   //if (DeadManPin_temp == LOW)
DeadManPin = 0;
   }//close if/else
  }//close if(time buffer)
balancelForward = digitalRead(balanceForwardPin);
balancelBackward = digitalRead(balanceBackwardPin);
if (balancelForward == 0) balancetrim = balancetrim - 0.04;
if (balancelBackward == 0) balancetrim = balancetrim + 0.04;
if (balancetrim< -30) balancetrim = -30;
if (balancetrim> 30) balancetrim = 30;
  gv0 = gv1;
  gv1 = gv2;
  gv2 = gv3;
  gv3 = gv4;
  gv4 = gv5;
  gv5 = gv6;
  gv6 = (float) angle_Y;
SG_filter_result = (float) ((-2*gv0) + (3*gv1) + (6*gv2) +
(7*gv3) + (6*gv4) + (3*gv5) + (-2*gv6))/21;
  gangleratedeg2 = angular_rate_X - initial_angular_rate_X;
if (SteerLeftPin == 1 &&SteerRightPin == 1){
SteerCorrect = 0;
if (gangleratedeg2 > 10 || gangleratedeg2 < -10) {
SteerCorrect = (float) 0.4 * gangleratedeg2;
   }
SteerValue = 512;
  }
else {
if (SteerLeftPin == 0) {
SteerValue = 612;
   }
if (SteerRightPin == 0) {
SteerValue = 412;
   }
SteerCorrect = 0;
  }
SG_filter_result = (float) SG_filter_result * ANGLE_GAIN;

x_accdeg = (float)((SG_filter_result - (80 + balancetrim)) *
(1.0));
if (x_accdeg< -72) x_accdeg = -72; //put in range.
if (x_accdeg> 72) x_accdeg = 72;
gangleratedeg = (float)(angular_rate_Y -
initial_angular_rate_Y); // IDH
if (gangleratedeg< -110) gangleratedeg = -110;
if (gangleratedeg> 110) gangleratedeg = 110;
gyroangle_dt = (float) ti_constant * cycle_time * gangleratedeg;
//e.g  = 3*0.01*gyro_reading
gangleraterads = (float) gangleratedeg * 0.017453; //convert to
radians - just a scaling issue from history
angle = (float) ((1-aa_constant) * (angle + gyroangle_dt)) +
(aa_constant * x_accdeg);//aa=(0.005) allows us to feed a bit
(0.5%) of the accelerometer data into the angle calculation
anglerads = (float) angle * 0.017453; //converting to radians
again a historic scaling issue from past software
balance_torque = (float) (ACCEL_GAIN * anglerads) +  //from
accelerometer
   (GYRO_GAIN * gangleraterads); //from Gyro
cur_speed = (float) (cur_speed + (anglerads * 6 * cycle_time)) *
0.999;
level = (float)(balance_torque + cur_speed) * overallgain;
//final overall gain = 0.5
} //end do_calculations
voidset_motor()  {
unsigned char cSpeedVal_Motor1 = 0;
unsigned char cSpeedVal_Motor2 = 0;
level = level * 20;
if (level < -100) {level = -100;}
if (level > 100) {level = 100;}
  Steer = (float) SteerValue - SteerCorrect  Steer = (Steer - 512)
* 0.09;
  Motor1percent = (signed char) level + Steer;
  Motor2percent = (signed char) level - Steer;
if (Motor1percent > 100) Motor1percent = 100;
if (Motor1percent < -100) Motor1percent = -100;
if (Motor2percent > 100) Motor2percent = 100;
if (Motor2percent < -100) Motor2percent = -100;
if (DEBUG_FORCE_DEADMAN_SWITCH == 1) {
DeadManPin = 0; }
if (DeadManPin> 0){
level = 0;
   Steer = 0;
   Motor1percent = 0;
   Motor2percent = 0;
digitalWrite(redLedPin, LOW);
digitalWrite(greenLedPin, HIGH);
deadman_occured_flag = 1;
  }
 cSpeedVal_Motor1 = map (Motor1percent,-
100,100,SABER_MOTOR1_FULL_REVERSE,
SABER_MOTOR1_FULL_FORWARD);
  cSpeedVal_Motor2 = map ( Motor2percent,
-100,  100,  SABER_MOTOR2_FULL_REVERSE,
SABER_MOTOR2_FULL_FORWARD);
SaberSerial.write ((byte) cSpeedVal_Motor1);
SaberSerial.write ((byte) cSpeedVal_Motor2);
}
voidserialOut_timing(){ //print out to serial port when enabled.
if (DEBUG_ENABLE_PRINTING == 1 &&
DeadManPin == 0 && //deadman is pushed
skip++==10) { //display every 200ms (at 5Hz)
skip = 0;
  }
}//end void serialOut_timing()
```

**5. Testing of Segway:**

The segway is tested by placing on a separate platform in such a way that the wheels of the segway should be free from all the contact surfaces. Turn on the power switch. Wait 8 seconds. Hold the Deadman switch down and move the board forward and backwards. We will see the wheels spin in each direction. If we see the red Error LED on the Cytron flashing and the motors start to shake, we have low battery voltage and we either need to charge batteries OR replace them because they can't hold a full charge anymore. When this works we must try out the board on the ground. If forward and backward tilt were reversed, The pins should be flipped in the Arduino code. Try out the steering and tilt. Pop out and flip the steering and tilt switches if they are reversed.

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**6. Conclusion and Future Scope:**

The direction control was achieved in both forward and backward directions as well as in turning the vehicle in right and left directions. Some of the working features of barriers are: The speed of the segway was reduced by directly connecting batteries to individual motors. The response time of arduino is slow due to large size of the program. By connecting batteries in series, the exact potential for the motors is achieved to drive a man of weight upto 70kgs. The complexity of the program can be reduced by using a single sabertooth dual channel motor driver instead of two citron single channel motor drivers. The response time can be reduced by selecting an arduino of high memory. Segway is often refered to as future of mechanical and it can improved further to achieve high speed and quick response.

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