College of Engineering and Technology

Mechanical Engineering Department

Graduation Project

Designing and Controlling the Movement of an Object via Cables at Space

Project Team

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Jan, 2014

PPU College Of Engineering and Technology
The Home of Competent Engineers and Researchers

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According to the directions of the project supervisor and by the agreement of all examination committee members, this project is presented to the Departments of Mechanical, for partial fulfillment of Bachelor of engineering degree requirements

Project supervisor

Dr. Yousef AI-Switey

……………………………..

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Jan, 2014

إهداء

الى من ارضعني الحب و الحنان

الى رمز الحب و بلسم الشفاء

الى حكمتي...و علمي

الى ادبي...و حلمي

الى ينبوع الصبر و التفائلو الامل

امي

الى من جرع كاس فارغا ليسقيني قطرة الحب

الى من كلت انامله ليقدم لنا لحظة سعادة

الى من حصد الاشواك عن دربي ليمهد لي طريق العلم

الى القلب الكبير والدي

والدي

الى كل من في الوجود بعد الله و رسوله صلى الله عليه و سلم

الى سندي وقتي و ملاذي بعد ا

الى من آثر على نفسهم

الى من اثروني على نفسهم

الى من علموني علم الحياة

اخوتي

الى الروح التي سكنت روحي

الان تفتح الاشرعة و ترفع المرساة لتنطلق السفينة في عرض بحر واسع مظلم هو بحر الحياة و في هذه الظلمة لا يضيء

الا قنديل الذكريات ذكريات الاخوة البعيدة الى الذين احببتهم و احبوني

شكر

بدا لنا و نحن نخطو خطواتنا الاخيرة في الحياة الجامعية من وقفة نعود الى اعوام قضيناها
في رحاب الجامعة مع اساتذتنا الكرام

الذين قدموا لنا باذلين جهودا كبيرة في بناء جيل الغد لتبعث الامة من جديد...

وقبل ان نمضي نقدم اسمي ايات الشكر و الامتنان و التقدير و المحبة الى الذين حملوا اقدس رسالة في الحياة

الى الذين مهدوا لنا طريق العلم و المعرفة...

الى جميع اساتذتنا الافاضل...

و اخص بالتقدير و الشكر

الدكتور يوسف سويطي

الذي تفضل باشرافه على هذا البحث فجزاه الله عنا كل خير فله منا كل التقدير

Abstract

The aim of this project is to design and implement a control system for controlling the three dimensional movement of an object within a selected working space. The trajectory of motion is guaranteed by three cables connected to the object, the length of these cables are controlled by three independent DC motor that receive their commands from a PC-computer, the user gives only the target position through the keyboard, the computer will compute the trajectory and controls the cables' lengths as function of time to achieve the desired target position with the planned trajectory. The length of the three cables is measured by three absolute rotary encoders attached to the driving pulleys at the motor.

Knowing the lengths of three cables leads to computing the (x,y,z) coordinate of the controlled object this is done by utilizing the forward kinematics equation of the system. The proposed controller for each degree of freedom is PID controller, in order to achieve the transient and steady state performance of the controlled system.In addition to the control algorithm design, the synergistic system integrates theelectrical system, computer system and mechanicalsystem of the overall prototype in mechatronics system approach.

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Appendix A

Designing and Controlling the Movement of an Object viaCables at Space

m-file

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                  Matlab has to be used in many calculation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Forsection(2.2.3.2) The Forces Analysis in 3D
First step in calculation find geometer analysis and  The analysis forces in x,y,z direction to get the length of every cable
through Newton law f=ma  and with law matrix to get the value of forces A*F=Q


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Date : 3/18/2013
% writer : Ahmad Bardawill

symsx% The postion of the mass in  x direction
symsy% The postion of the mass in  y direction
symsz% The postion of the mass in  z direction

symsa%The length of the frame in y direction
symsb%The length of the frame in x direction
symsm%The mass of the object (kg)
symsg%The acceleration of gravity (m/s2)

symsxb% The velocity of the mass in  x  direction
symsyb% The velocity of the mass in  y  direction
symszb% The velocity of the mass in  z  direction
```

```
symsxs% The acceleration of the mass in  x  direction
symsys% The acceleration of the mass in  y  direction
symszs% The acceleration of the mass in  z direction

L1 = ((x^2 + y^2 + z^2 ))^0.5;%L1   The length of cable 1 from origin to object
L2 = ( x^2+((a-y)^2 )+ z^2 )^0.5 ;%L2   The length of cable 2 from origin to object
L3 =(((b-x)^2)+ ((a-y)^2 ) + z^2)^0.5 ;%L3  The length of cable 3 from origin to object
L4 = ( ((b-x)^2)   + y^2 + z^2 )^0.5 ;%L4   The length of cable 4 from origin to object



A=[-x/L1   (((b-x)*L2)-(x*L3))/(L2*L3)    (b-x)/L4 ;
   -y/L1    ((a-y)*(L2+L3))/(L2*L3)    -y/L4 ;
   -z/L1             (-z*(L2+L3))/(L2*L3)     -z/L4]

 Q=[m*xb  ; m*yb   ;  m*(zb-g)     ]


D=inv(A)

F=D*Q
```

A*F=Q

```
A =
[ -x/(x^2 + y^2 + z^2)^(1/2), -(x*(z^2 + (a - y)^2 + (b - x)^2)^(1/2) - (b - x)*(x^2 + z^2 + (a - y)^2)^(1/2))/((x^2
+ z^2 + (a - y)^2)^(1/2)*(z^2 + (a - y)^2 + (b - x)^2)^(1/2)), (b - x)/(y^2 + z^2 + (b - x)^2)^(1/2)]
[ -y/(x^2 + y^2 + z^2)^(1/2),  (((x^2 + z^2 + (a - y)^2)^(1/2) + (z^2 + (a - y)^2 + (b - x)^2)^(1/2))*(a - y))/((x^2
+ z^2 + (a - y)^2)^(1/2)*(z^2 + (a - y)^2 + (b - x)^2)^(1/2)),      -y/(y^2 + z^2 + (b - x)^2)^(1/2)]
[ -z/(x^2 + y^2 + z^2)^(1/2),       -(z*((x^2 + z^2 + (a - y)^2)^(1/2) + (z^2 + (a - y)^2 + (b - x)^2)^(1/2)))/((x^2
+ z^2 + (a - y)^2)^(1/2)*(z^2 + (a - y)^2 + (b - x)^2)^(1/2)),      -z/(y^2 + z^2 + (b - x)^2)^(1/2)]
```

```
Q =
[ m*xb
m*yb
 -m*(g - zb)]
```

D=inv(A)

```
[               -(((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))*(x^2
+ y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 +
z^2)^(1/2)),              -((x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 -
2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)), ((x^2 + y^2 +
z^2)^(1/2)*(a*x*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) -
a*b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + b*y*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) +
a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*b*z*(a^2
- 2*a*y + x^2 + y^2 + z^2)^(1/2))]
[
0, ((a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2
+ y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)),
-(y*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*z*(a^2 - 2*a*y +
b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))]
[ (((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))*(b^2 - 2*b*x + x^2
+ y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 +
z^2)^(1/2)),              -((a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 -
2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)),
-((a*x*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - b*y*(a^2 -
2*a*y + x^2 + y^2 + z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2
+ z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))]
```

%%%%%%%%%%%%%%%%%%the result three forces with this value %%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%force cable 1

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

F1=- (m*xb*((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))*(x^2 + y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*yb*(x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*(g - zb)*(x^2 + y^2 + z^2)^(1/2)*(a*x*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + b*y*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%force cable 2

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

F2=(m*yb*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) + (m*y*(g - zb)*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%force cable 3

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

F3= (m*xb*((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*yb*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) + (m*(g - zb)*(a*x*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - b*y*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))

%%
Forsection(2.3) Torque equation analysis

%find torque

After analyzing the forces and action test
the second step to find the forces that affect the mass of the mass of the cord itself, which carries and opposite forces according to physics laws ,to find torque Required from the engine to play for the move mass from the position to position , that all beside calculation the mass inertia of drum on motor
%%
% Date :4/9/2013
% writer : Ahmad Bardawill

```
%first
symsxbybzb
%second
symsxsyszs
symsxyzabm1mg  ;
symsrJ0Tm1
```

%L1b The velocity of cable number 1
%L1s The acceleration of cable number 1

%L2b The velocity of cable number 2
%L2s The acceleration of cable number 2

%L3b The velocity of cable number 3
%L3s The acceleration of cable number 3

% F1b the force acting on motor one along the cable between mass and pulley on motor
% F2b the force acting on motor two along the cable between mass and pulley on motor
% F3b the force acting on motor three along the cable between mass and pulley on motor

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque for cable 1
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

L1 = ((x^2 + y^2 + z^2 ))^0.5
L1b = ((x*xb + y*yb + z*zb ))/L1
L1s ={{ (x*xs+ xb^2) + (y*ys + yb^2)+ (z*zs+ zb^2) } - (L1b^2 ) }/(L1)

 F1=- (m*xb*((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 +
z^2)^(1/2))*(x^2 + y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + b*(a^2 - 2*a*y +
b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*yb*(x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x
+ x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 -
2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*(g - zb)*(x^2 + y^2 + z^2)^(1/2)*(a*x*(a^2 - 2*a*y + b^2 -
2*b*x + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y +
b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + b*y*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) +
a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 +
z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))
F1b = F1+  ((m1*g*z)/L1) -m1*L1s
Tm1 = J0*(L1s/r)+F1b*r
simplify(Tm1)
Tm1= (J0*(x*xs + y*ys + z*zs - (x*xb + y*yb + z*zb)^2/(x^2 + y^2 + z^2) + xb^2 + yb^2 +
zb^2))/(r*(x^2 + y^2 + z^2)^(1/2)) - r*((m1*(x*xs + y*ys + z*zs - (x*xb + y*yb + z*zb)^2/(x^2 +
y^2 + z^2) + xb^2 + yb^2 + zb^2))/(x^2 + y^2 + z^2)^(1/2) - (g*m1*z)/(x^2 + y^2 + z^2)^(1/2) +
(m*xb*((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 +
z^2)^(1/2))*(x^2 + y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + b*(a^2 - 2*a*y +
b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) + (m*yb*(x^2 + y^2 + z^2)^(1/2)*(a^2 - 2*a*y + b^2 - 2*b*x
+ x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) + a*(a^2 - 2*a*y + b^2 -
2*b*x + x^2 + y^2 + z^2)^(1/2)) + (m*(g - zb)*(x^2 + y^2 + z^2)^(1/2)*(a*x*(a^2 - 2*a*y + b^2 -
2*b*x + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - a*b*(a^2 - 2*a*y +
b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + b*y*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) +
a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 +
z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque for cable 2
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

L2 = ( x^2   +   ((a-y)^2 )   + z^2 )^0.5
L2b = ((   (x*xb)    + ((y-a)*yb) + z*zb ))/L2
L2s ={{   (x*xs+ xb^2)     + ((y-a)*ys + yb^2)+ (z*zs+ zb^2) } - (L2b^2) }/(L2)
F2=(m*yb*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(2/2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 +
z^2)^(2/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(2/2) + a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2
+ z^2)^(2/2)) + (m*y*(g - zb)*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(2/2)*(a^2 - 2*a*y + b^2 - 2*b*x +
x^2 + y^2 + z^2)^(2/2))/(a*z*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(2/2) + a*z*(a^2 -
2*a*y + x^2 + y^2 + z^2)^(2/2))
F2b = F2+  ((m2*g*z)/L2) -m2*L2s
Tm2 = J0*(L2s/r)+F2b*r
simplify(Tm2)
Tm2 = r*((g*m2*z)/(x^2 + z^2 + (a - y)^2)^(1/2) - (m2*(x*xs + z*zs - ys*(a - y) - (x*xb + z*zb -
yb*(a - y))^2/(x^2 + z^2 + (a - y)^2) + xb^2 + yb^2 + zb^2))/(x^2 + z^2 + (a - y)^2)^(1/2) +
(m*yb*(a^2 - 2*a*y + x^2 + y^2 + z^2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2))/(a*(a^2 -
2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2) + a*(a^2 - 2*a*y + x^2 + y^2 + z^2)) + (m*y*(g - zb)*(a^2
- 2*a*y + x^2 + y^2 + z^2)*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2))/(a*z*(a^2 - 2*a*y +
b^2 - 2*b*x + x^2 + y^2 + z^2) + a*z*(a^2 - 2*a*y + x^2 + y^2 + z^2))) + (J0*(x*xs + z*zs -
ys*(a - y) - (x*xb + z*zb - yb*(a - y))^2/(x^2 + z^2 + (a - y)^2) + xb^2 + yb^2 + zb^2))/(r*(x^2
+ z^2 + (a - y)^2)^(1/2))
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque for cable 3
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

L4 = ( ((b-x)^2)   + y^2 + z^2 )^0.5
L4b = ( (   (x-b)*xb    + y*yb + z*zb ))/L4
L4s ={{   ((x-b)*xs + xb^2)     + (y*ys + yb^2)+ (z*zs+ zb^2) } - (L4b^2 ) }/(L4)
F3=  (m*xb*((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 +
z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) +
b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*yb*(a^2 - 2*a*y + x^2 + y^2 +
z^2)^(1/2)*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) +
a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) + (m*(g - zb)*(a*x*(a^2 - 2*a*y + b^2 -
2*b*x + x^2 + y^2 + z^2)^(1/2) + a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - b*y*(a^2 - 2*a*y +
x^2 + y^2 + z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x
+ x^2 + y^2 + z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))
F3b = F3+  ((m3*g*z)/L4) -m3*L4s
Tm3 = J0*(L4s/r)+F3b*r
simplify(Tm3)
Tm3 =
r*((g*m3*z)/(y^2 + z^2 + (b - x)^2)^(1/2) - (m3*(y*ys + z*zs - xs*(b - x) - (y*yb + z*zb - xb*(b
- x))^2/(y^2 + z^2 + (b - x)^2) + xb^2 + yb^2 + zb^2))/(y^2 + z^2 + (b - x)^2)^(1/2) +
(m*xb*((a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2) + (a^2 - 2*a*y + x^2 + y^2 +
z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(b*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) +
b*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) - (m*yb*(a^2 - 2*a*y + x^2 + y^2 +
z^2)^(1/2)*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) +
a*(a^2 - 2*a*y + b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2)) + (m*(g - zb)*(a*x*(a^2 - 2*a*y + b^2 -
2*b*x + x^2 + y^2 + z^2)^(1/2) + a*x*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2) - b*y*(a^2 - 2*a*y +
x^2 + y^2 + z^2)^(1/2))*(b^2 - 2*b*x + x^2 + y^2 + z^2)^(1/2))/(a*b*z*(a^2 - 2*a*y + b^2 - 2*b*x
+ x^2 + y^2 + z^2)^(1/2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2))) + (J0*(y*ys + z*zs -
xs*(b - x) - (y*yb + z*zb - xb*(b - x))^2/(y^2 + z^2 + (b - x)^2) + xb^2 + yb^2 + zb^2))/(r*(y^2
+ z^2 + (b - x)^2)^(1/2))
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section (2.4.2) Designing of prototype specifications
              %Maximum torque on cables system through general Cubic Profile

The third step is to find the maximum values of the motor in order to search for the right motor, which can lead to work
correctly , and find the value of two-way carrying a mass of the smallest position to a larger position and vice versa

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Date :5/1/2013
% writer : Ahmad Bardawill

symsTm1% torque of motor one
symsTm2% torque of motor two
symsTm3% torque of motor three
symsm1%The mass of cable one
symsm2%The mass of cable two
symsm3%The mass of cable four
symsJ0%mass moment of inertia of pulley on each motor
symsr%radius of pulley on each motor

symsxoxfyoyfzozf ;
symstftD ;
m=0.5;
g=9.81;
m1=0.005;
m2=0.005;
m3=0.005;
r=0.03;
J0=0.00026325;
```

```
%geometre
b=1.2;
a=.8;
%intial
xf=0.1;
yf=0.1;
zf=0.1;


%final
xo=1.1;
yo=.7;
zo =.9;
D=((xf-xo)^2 +(yf-yo)^2 +(zf-zo)^2)^0.5

tf=(1+(2*D))%% Vavg=0.5m/sec
```

```
%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%
%For  Cubic Profile:
%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%

%x-axis
x= xo + 3*(xf-xo)*t^2 /(tf^2) + 2*(xo -xf)*t^3 /(tf^3)  ;
xb = diff(x,t);
xs = diff(xb,t);

%y-axis

y= yo + 3*(yf-yo)*t^2 /(tf^2) + 2*(yo -yf)*t^3 /(tf^3)  ;
yb = diff(y,t);
ys = diff(yb,t);



%z-axis
z= zo + 3*(zf-zo)*t^2 /(tf^2) + 2*(zo -zf)*t^3 /(tf^3) ;
zb = diff(z,t);
zs = diff(zb,t);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Tm1 = (J0*(x*xs + y*ys + z*zs - (x*xb + y*yb + z*zb)^2/(x^2 + y^2 + ……………………………………………………..2) + a*b*z*(a^2 - 2*a*y + x^2 + y^2 + z^2)^(1/2)))

Tm2 = r*((g*m2*z)/(x^2 + z^2 + (a - y)^2)^(1/2) - (……………………………………………………………a - y)^2) + xb^2 + yb^2 + zb^2))/(r*(x^2 + z^2 + (a - y)^2)^(1/2))

Tm3 = r*((g*m3*z)/(y^2 + z^2 + (b - x)^2)^(1/2) - (m3*(y*ys……………………………………………………………………..+ yb^2 + zb^2))/(r*(y^2 + z^2 + (b - x)^2)^(1/2))
```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%forwarded bath

D =1.4142tf = 3.8284

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque on cable 1 forwarded

Tm1=

t)/19742900584361675 - 3377699720527872/13751792361757825)*((422212465065984*t^3)/19742900584361675 - *٢٥٣٣٢٧٤٧٩٠٣٩٥٩٠٤))*٤٨٥٦١٠٥٣٧٧٤٠٤٠٣٩))*١٠٠)
(1688849860263936*t^2)/13751792361757825 + 7/10))/18446744073709551616 + (4856105377404039*((3377699720527872*t)/19742900584361675 -
4503599627370496/13751792361757825)*((562949953421312*t^3)/19742900584361675 - (2251799813685248*t^2)/
……………………………………………………………………………………………………422212465065984*t^3)/19742900584361675 - (1688849860263936*t^2)/13751792361757825 + 7/10)^2 +
((562949953421312*t^3)/19742900584361675 - (2251799813685248*t^2)/13751792361757825 + 9/10)^2 + ((140737488355328*t^3)/3948580116872335 -
(562949953421312*t^2)/2750358472351565 + 11/10)^2 + (47287796087390208*t^2)/68758961808789125 - (1688849860263936*t^3)/14102071845972625 -
(((42/25)^(1/2

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque on cable 2 forwarded

Tm2 =

t)/19742900584361675 - 4503599627370496/13751792361757825)*((562949953421312*t^3)/19742900584361675 - *٣٣٧٧٦٩٩٧٢٠٥٢٧٨٧٢))*٤٨٥٦١٠٥٣٧٧٤٠٤٠٣٩))*١٠٠)
(2251799813685248*t^2)/13751792361757825 + 9/10))/18446744073709551616 - (4856105377404039*((2533274790395904*t)/19742900584361675 -
3377699720527872/13751792361757825)*(- (422212465065984*t^3)/19742900584361675 +
(1688849860263936*t^2)/………………………………………………………………………………19742900584361675 - (2251799813685248*t^2)/13751792361757825 + 9/10)^2 +
((140737488355328*t^3)/3948580116872335 - (562949953421312*t^2)/2750358472351565 + 11/10)^2 + (47287796087390208*t^2)/68758961808789125 -
((((1688849860263936*t^3)/14102071845972625 - 42/25

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%torque on cable 3 forwarded

Tm3=

*٢٥٣٣٢٧٤٧٩٠٣٩٥٩٠٤))*٤٨٥٦١٠٥٣٧٧٤٠٤٠٣٩))*١٠٠)t………………………………………………………………………………/25)^(1/2) + ((13510798882111488*t^3)/493572514609041875 -
(54043195528445952*t^2)/343794809043945625 + 108/125)*(((422212465065984*t^3)/19742900584361675 - (1688849860263936*t^2)/13751792361757825 +
7/10)^2 + ((562949953421312*t^3)/19742900584361675 - (2251799813685248*t^2)/13751792361757825 + 9/10)^2 + ((140737488355328*t^3)/3948580116872335 -
(562949953421312*t^2)/2750358472351565 + 11/10)^2 + (47287796087390208*t^2)/68758961808789125 - (1688849860263936*t^3)/14102071845972625 -
42/25)^(1/2(((

%%

%backward

D =1.4142tf =3.8284

%%

%torque on cable 3 backward

Tm1=

*٢٥٣٣٢٧٤٧٩٠٣٩٥٩٠٤))))*٣) t)/19742900584361675 - 3377699720527872/13751792361757825)*(- (422212465065984*t^3)/19742900584361675 +
(1688849860263936*t^2)/13751792361757825 + 1/10))/200 + (((3377699720527872*t)/19742900584361675 -
.... + (1688849860263936*t^2)/13751792361757825 + 1/10)^2 + (-
(562949953421312*t^3)/19742900584361675 + (2251799813685248*t^2)/13751792361757825 + 1/10)^2 + (- (140737488355328*t^3)/3948580116872335 +
(562949953421312*t^2)/2750358472351565 + 1/10)^2 - (47287796087390208*t^2)/68758961808789125 + (1688849860263936*t^3)/14102071845972625 +
42/25)^(1/2(((

%%

%torque on cable 2 backward

Tm2=

t)/19742900584361675 - 3377699720527872/13751792361757825)*((422212465065984*t^3)/19742900584361675 - *٢٥٣٣٢٧٤٧٩٠٣٩٥٩٠٤))*٤٨٥٦١٠٥٣٧٧٤٠٤٠٣٩))*١٠٠)
(1688849860263936*t^2)/13751792361757825 + 7/10))/18446744073709551616 - (4856105377404039*
.... + (1688849860263936*t^2)/13751792361757825 + 1/10)^2 + (-
(562949953421312*t^3)/19742900584361675 + (2251799813685248*t^2)/13751792361757825 + 1/10)^2 + (- (140737488355328*t^3)/3948580116872335 +
((((562949953421312*t^2)/2750358472351565 + 1/10)^2 - (47287796087390208*t^2)/68758961808789125 + (1688849860263936*t^3)/14102071845972625 + 42/25

%%

%torque on cable 3 backward

Tm3=

t)/13751792361757825 - (1266637395197952*t^2)/19742900584361675)^2)/18446744073709551616 - *٣٣٧٧٦٩٩٧٢٠٥٢٧٨٧٢))*٤٨٥٦١٠٥٣٧٧٤٠٤٠٣٩))*١٠٠)
(4856105377404039*((3377699720527872*t)/19742900584361675 - 4503599627370496/13751792361757825)*(- (562949953421312*t^3)/19742900584361675 +
(2251799813685248*t^2)/ -... + (54043195528445952*t^2)/343794809043945625 + 12/125)*((-
(422212465065984*t^3)/19742900584361675 + (1688849860263936*t^2)/13751792361757825 + 1/10)^2 + (- (562949953421312*t^3)/19742900584361675 +
(2251799813685248*t^2)/13751792361757825 + 1/10)^2 + (- (140737488355328*t^3)/3948580116872335 + (562949953421312*t^2)/2750358472351565 + 1/10)^2 -
((((47287796087390208*t^2)/68758961808789125 + (1688849860263936*t^3)/14102071845972625 + 42/25)^(1/2

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Forsection (2.5) Inspection of mathematical models
                                              %static test in z direction
Testing was conducted for the values of the forces acting on the mass in the three directions make sure the same values
manually and compensation valuesmatlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Date :4/2/2013
% writer : Ahmad Bardawill

symsxyzabmg ;
symsxbybzb

m=1;
b=120;
a=80;
x=b/2;
y=a/2;
z=40;
g=10;
xb = 0;
yb = 0 ;
zb= 0 ;
L1 = ((x^2 + y^2 + z^2 ))^0.5;
L4 = ( ((b-x)^2)   + y^2 + z^2 )^0.5 ;
L3 =(((b-x)^2)+ ((a-y)^2 ) + z^2)^0.5 ;
L2 = ( x^2+((a-y)^2 )+ z^2 )^0.5 ;

A=[-x/L1   (((b-x)*L2)-(x*L3))/(L2*L3)    (b-x)/L4 ;
    -y/L1    ((a-y)*(L2+L3))/(L2*L3)    -y/L4 ;
    -z/L1             (-z*(L2+L3))/(L2*L3)     -z/L4]
```

```
 Q=[m*xb  ; m*yb   ;  m*(zb-g)     ]
D=inv(A)
F=D*Q
A =

  -0.7276         0    0.7276

  -0.4851    0.9701   -0.4851

  -0.4851   -0.9701   -0.4851

Q =

     0

     0

   -10

D =

  -0.6872   -0.5154   -0.5154

        0    0.5154   -0.5154

   0.6872   -0.5154   -0.5154

F =

   5.1539

   5.1539

   5.1539
```

And the result was the same magnitude ,It is here to be manual calculations andmatlab calculations Identical

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% dc motor control simulation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section (4.4) control simulation
% Date :30/12/2013
% writer : Ahmad Bardawill

Ts=0.001;%sampling time
km=100;

symsx% The postion of the mass in  x direction
symsy% The postion of the mass in  y direction
symsz% The postion of the mass in  z direction

symsa%The length of the frame in y direction
symsb%The length of the frame in x direction
symsm%The mass of the object (kg)
symsg%The acceleration of gravity (m/s2)
 r=0.03;% The raduis of  the pully on each  motor
 x=2;
 y=3;
 z=4;
 a=0.03;
 b=0.06;
L1 = ((x^2 + y^2 + z^2 ))^0.5%L1   The length of cable 1 from origin to object
L2 = ( x^2+((a-y)^2 )+ z^2 )^0.5 %L2   The length of cable 2 from origin to object
L4 = ( ((b-x)^2)   + y^2 + z^2 )^0.5 %L4   The length of cable 4 from origin to object

A = L1/r ;%A % The angular  postion of the pully at motor 1
B = L2/r; %B % The angular postionof  thepully at motor 2
C = L4/r; %C % The angular postionof  thepully at motor 3
```

Chapter one

An Over view

1.1 Introduction

Designing and Controlling the Movement of an Object via Cables at Space represent a challenge problem in control study. The system consists of three cables and a mass tiedto the cables which are driven by three DC motors. Whose torque represents the input of the system to control the position of the mass, as seen at Fig (1.1).

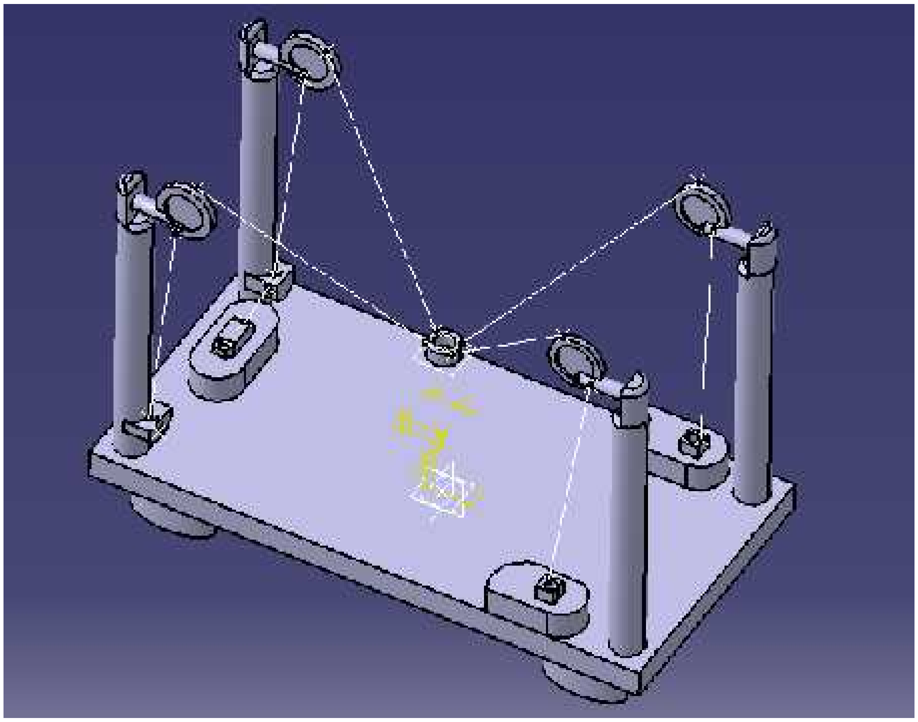


Fig (1.1)general view of DCMOCS

The objective of the **DCMOCS** is to develop our theoretical skills throughout our project in the practical aspects of this idea, so the main aim is to create a complete system which is able to cover a large predetermined area by controlling the object's position. In addition, the second objective is to control and increase the relative stability of the movement of the mass in the space.

Application ofthis projectincludes discovering the space as in the movement of a spider cam robot,and other applications used to discover the position.

1.2 Literature review

The control mass position ofthis projectis always an interesting and challenging field of study, thus there are many researches and paper that take the position control as the core of their studies using a wide variety of designs, and control techniques.

<u>Thomas Johansson, December 9, 2005</u>

Full dynamical model of the cranestructure (apart from the DC motors which controls the cables) was developed.
In that project, a flatness based control scheme for positioning theload (given a reference trajectory) was also developed. The controller wasdesigned under the assumption that the DC motors could deliver a perfecttorque. No particular care was taken in order to accurately model the DCmotor.
In this project the control of the crane and the control of the DC motorswill be separated, as seen at Fig (1.1).

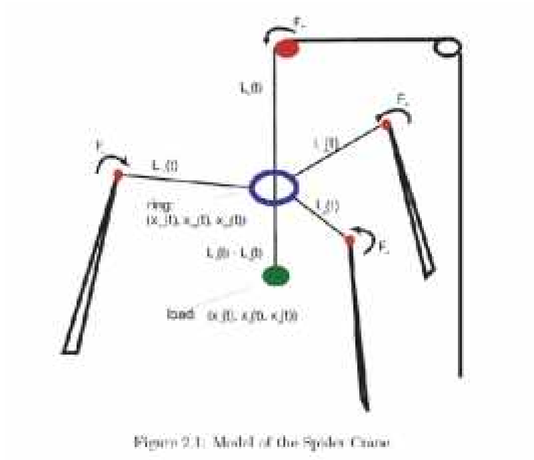


Fig (1.1) Spider Crane

1.3Aims of the project

Many objectives could be achieved throughout thisproject; the working team developstheir theoretical skills in the practical aspects of this idea starting from molding and ending at computer control. So the main aim is to create a complete system which is able to cover a large predetermined area by controlling an object’s position.

It is possible to put a new product that uses applications in several areas including:

- The field of tourism (chairlifts three-dimensional).
- Agricultural field (automatic spray pesticides on crops in large area).
- Field imaging (Flash photography in stadiums).

1.4The process of the Designing and Controlling the Movement of an Object via Cables at Space

As a mechatronics system, the most convenient way to follow during the design and implementation of the Movement of an Object Tied by Cords at Space is the concurrent design approach. This approach consists of a sequence of stages, which are shown in the next subsection.

1.4.1 ConceptualDesign

Designing and Controlling the Movement of an Object via Cables at Space system consists of a mass tide by three cables, which are driven by three DC motors to control the position of the mass .The input of the system is the final target position (x_f,y_f,z_f) coordinates from the computer which will be achieved by three DC motors in a closed loop control. The important thing in the control is to determine the maximum torque for the motors, which are required to perform the task.

The controller is implemented using one of two different kinds of control,first option a proportional integral derivative controller (**PID**), every motor is controlled by one PID Controller,in order to matching the requirement design.

1.4.2 Mathematical Model

The second step in the design process is mathematical modeling, which includes a set of differential equations, and then we find the global matrices for the system that describe the system behavior. The model will not only give a better understanding for the system, but also it will be used for two major purposes, which are:

1. Controller.
2. Simulation process.

After the mathematical model is derived, the controller law can be found, the detailed mathematical model and its derivation procedure will be discussed in chapter two of this report.

1.4.3 Control Design

Based on the mathematical model a closed loop control system will be designed, the controller must be able to control of the position and velocity, as required by the user.

The controller should be able to reject, or to compensate for the unknown disturbances acting on the system.

1.4.4The Actuators

Based on the dynamics of the system and the proposed closed loop control method, the selection criteria of the motors, are based on their inertia, power, speed and torque requirementto specify the dynamics of the DC motors.

1.5Designing and Controlling the Movement of an Object Tied via cables at Space elementary components

1.5.1Methodology

The project will be a mechatronics system, which is integration betweenmultidisciplinary sciences; it can represent by Fig (1.3), which show the synergisticintegration of three engineering fields. This integration within a mechatronics system can be performed through the combination of hardware (components) and software (information processing).

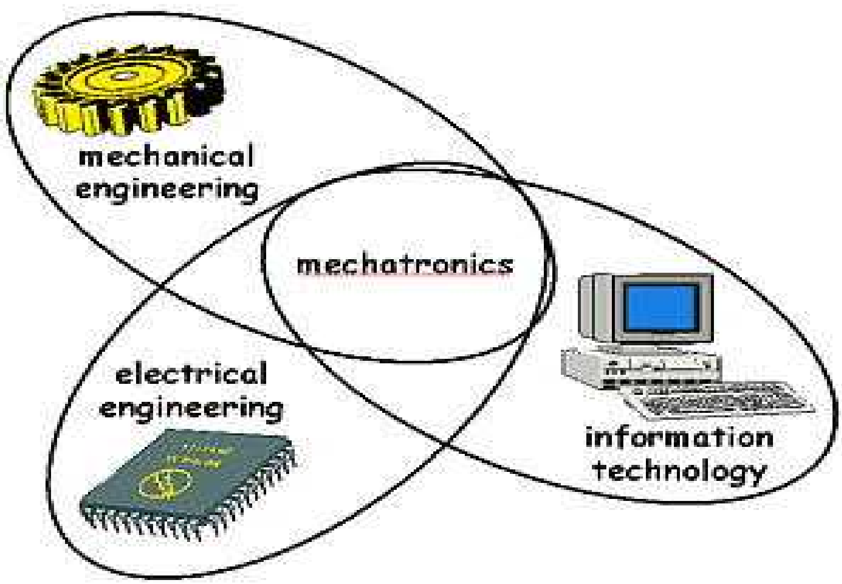
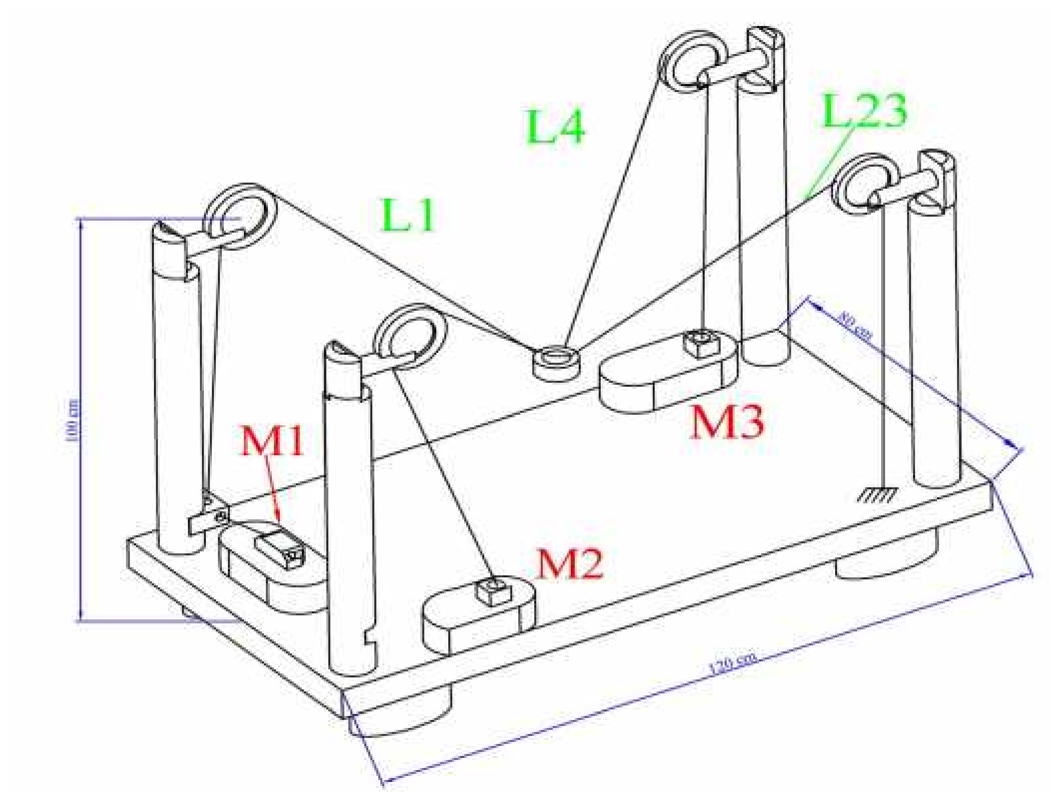


Fig (1.3)Mechatronics basic disciplines

1.5.2Mechanical part

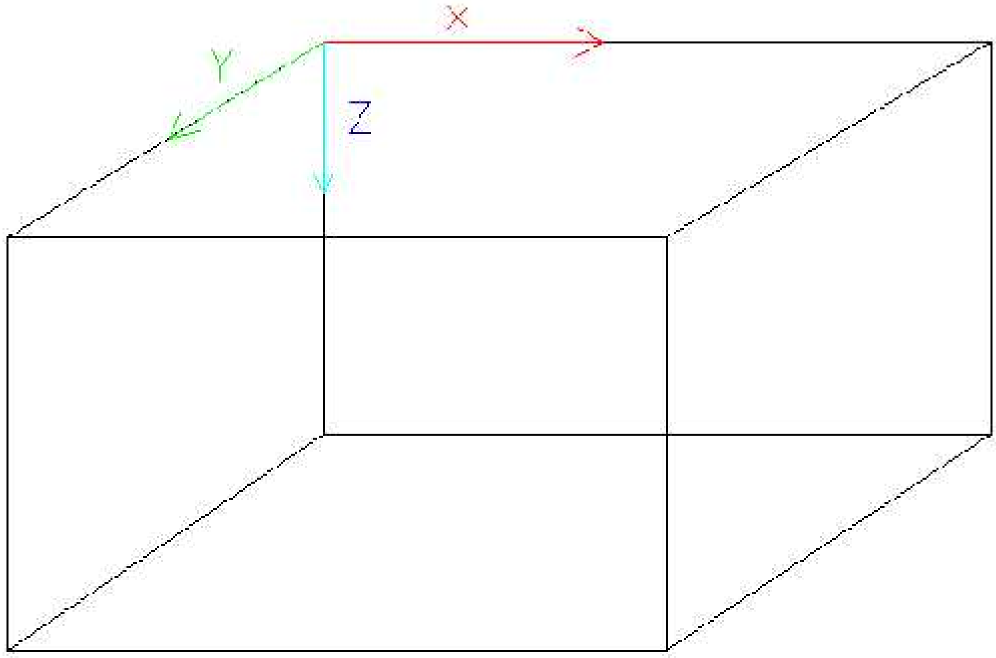
The mechanical components are:

1. The load (mass 1kg)
2. Pulleys (ideal pulleys)
3. Bolts
4. Rods
5. Bearing
6. Welds
7. Frame structure,as seen at Fig (1.4):
    a) x-axis 120cm
    b) y-axis 80cm
    c) z-axis 100cm



Fig(1.4) 3D general view of DCMOCS

The coordinate system,as seen at Fig(1.5)



Fig(1.5)coordinate system

1.5.3 Electrical part

The electrical part in this project includes actuators, **PID** controller circuit, and the interfacing circuit that connect those **PID** controller circuit and actuator with the computer.

1.5.4 Programs

use many programs for drawing, calculation, simulation, tests and circuits; because :

- Shorten time
- The answers are very accurate
- Allows the possibility of experimentation and shortly
- Shorten days in an effort click away
- can simulate the system
- find out what many points before experimentation in fact

The list of programs :

1. Matlab
2. Autocade
3. Catia
4. Proteus
5. Aurdino

Chapter TWO

Mathematical Modeling

Table (2.1) variablesof system

Symbol	Description	Unit
L_1	The length of cable 1 from origin to object	m
L_2	The length of cable 2 from origin to object	m
L_3	The length of cable 3 from origin to object	m
L_4	The length of cable 4 from origin to object	m
L_{23}	The total length of cable 2 & 3	m
X	position of the object in x direction	m
Y	position of the object in y direction	m
Z	position of the object in z direction	m
t	Time	Sec
$\hat{n}$f	The unit vector of the force	m
F1	force on cable number one	N
F2	force on cable number two	N
F2	force on cable number three	N
F3	force on cable number four	N
A	Matrix which describe the differential equation of the system(nxn)	
Q	Acceleration matrix(3x1)	
F	Forces matrix	
A'	MatrixInverse which describe the differential equation of the system(nxn)	

m_1	The mass of cable one	kg
m_2	The mass of cable two	kg
m_3	The mass of cable four	kg
$\dot{L}_1$	The velocity profiles of cable 1	m/s
$\dot{L}_1$	The acceleration profiles of cable 1	m/s^2
$\dot{L}_2$	The velocity profiles of cable 2	m/s
$\dot{L}_2$	The acceleration profiles of cable 2	m/s^2
$\dot{L}_4$	The velocity profiles of cable 4	m/s
$\dot{L}_4$	The acceleration profiles of cable4	m/s^2
D	Distance which object move it in work space	m
t_f	is the time for the desired goal position of object	sec
(x_0, y_0, z_0)	Initial position of the object	m
x_f, y_f, z_f	Final desired position of the object	m
$\dot{x}\ t$	The velocity profileof the object in x direction	m/s
$\dot{y}\ t$	The velocityprofile of the object in y direction	m/s
$\dot{z}\ t$	The velocity profileof the object in z direction	m/s
$\ddot{x}\ t$	The accelerationprofile of the object in x direction	m/s^2
$\ddot{y}\ t$	The accelerationprofile of the object in y direction	m/s^2
$\ddot{z}(t)$	The accelerationprofile of the object in z direction	m/s^2
T_{max}	Is maximum torque applied on pulley motor get from torque curve	**N.m**
w_{max}	Is maximum speed getting from cubic polynomial profile	**rad/sec**

Table (2.2) constant parameters of system

parameter	Description	value	Unit
a	length of the frame in y direction	.8	m
b	length of the frame in x direction	1.2	m
J_0	mass moment of inertia of pulley on each motor		$kg.m^2$
r	radius of drum on each motor		m
m	mass of the object		Kg
g	acceleration of gravity		m/s^2
ρ	the longitudinal lengthdensity of the cables		kg/m
D_{max}	Maximum distance which object move it in work space		m
d_{pully}	Diameter of pulley		m
L_{effmax}	Maximum effective length of cable		m
h	The height of the frame in z direction		m
N_{eff}	Number of turnseffective of cable		Turn
N_{safty}	Around pulley for safety Maximum number of turns		Turn
L_{effmax}	Maximum number of turnseffective of cable		m
H_{eff}	The height of pulley what turns on it		m
H_{total}	The all height of pulley		m
H_{safty}	Distance from right and lift sides of pulley for safety		m
r_{pully}	Radius of pulley		m
m_{pully}	Mass of pulley		kg
J_{pully}	Mass moment of inertia		$kg.m^2$

2.1 Introduction

Mathematical modeling of the **DCMOVCS** system tends to represent all important features of the system and describe its behavior in terms of differential equation.

In general, there are two main purposes for modeling physical system:

- To predict the dynamic behavior of the system as accuracy as possible.
- The first step in building controller is the building of the mathematical model, which can be used to improve the response, stability,…etc.

2.1.1Matlab

Matlab is the program given what need in calculation, as seen at Fig (2.1).

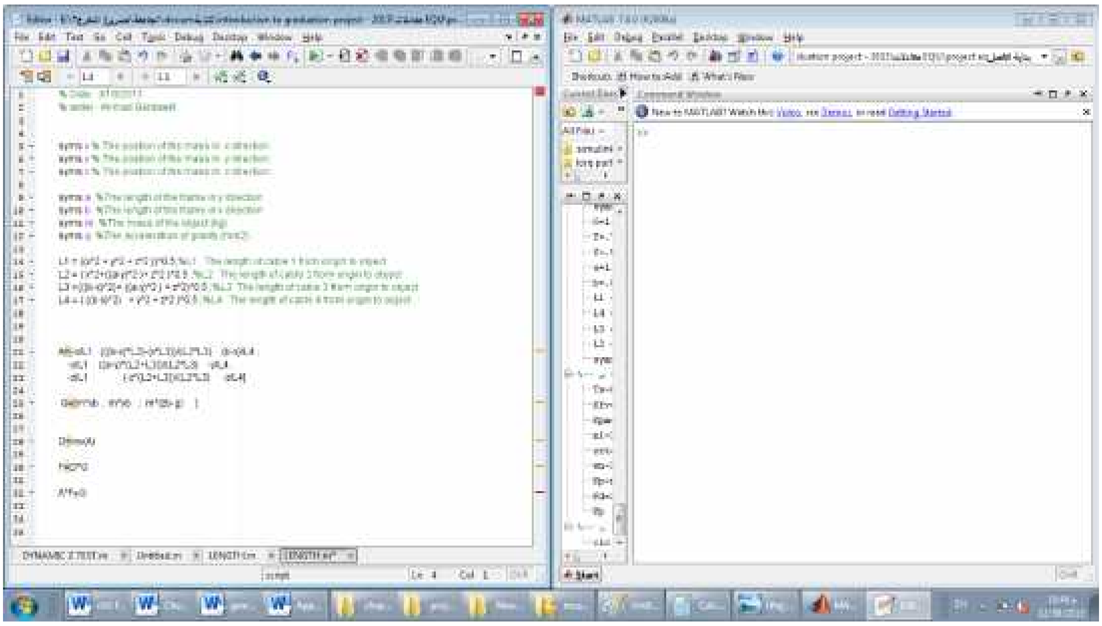


Fig (2.1)matlab window

2.2 Equation of Motion for the Geometry System

- Geometry equation describes the system.
- Geometry equation describes the system includes the length of the cables and the distributed loads on this cables and the weight of the cables.

2.2.1 Assumption used of this project

The following assumptions are considered in deriving the mathematical model of the system:

1-The extension in the cables is neglected.

2-The driving pulleys are assumed to be frictionless.

3-The air resistance on the moving object is neglected.

4-The motors are strong enough and fast dynamic characteristic than the system to be controlled.

5-The position of the object is measured indirectly by measuring the lengths of the driving cables.

6- The weight suspended to the cables ensure that there is nocurvature at the cables.

2.2.2 The Length of the Cables

Since the system has three degree of freedom, only three cables are sufficient to control the position of the object; L1 which connect the suspended object to the upper left right corner of the frame, its length is controlled by the motor M1, is responsible for moving the object toward the upper left corner of the working space.L23 connect the object to the lower right corner and lower left corner .The cable passes the object through ideal small pulley attached to the suspension point of the object. The length of the cable is controlled by the motor M2. The cable L4 connects the object to the upper right corner and is controlled by the motor M4 .The cable is responsible for forcing the object to move toward the upper right corner of the working space, as seen at Fig (2.2).

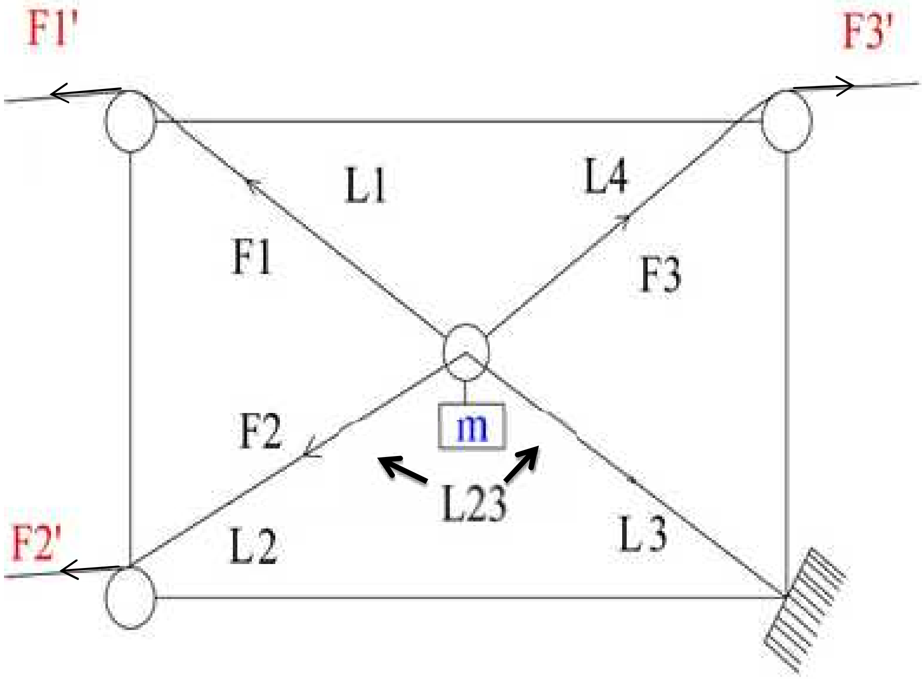


Fig.(2.2) general top view of the structure

$$L_1 = \sqrt{x^2 + y^2 + z^2} \quad (2.1)$$

$$L_2 = \sqrt{x^2 + (a-y)^2 + z^2} \quad (2.2)$$

$$L_3 = \sqrt{(b-x)^2 + (a-y)^2 + z^2} \quad (2.3)$$

$$L_4 = \sqrt{(b-x)^2 + y^2 + z^2} \quad (2.4)$$

$$L_{23} = L_2 + L_3 \quad (2.5)$$

Where:

- L_1 = The length of cable 1 from origin to object, m
- L_2 = The length of cable 2 from origin to object, m
- L_3 = The length of cable 3 from origin to object, m
- L_4 = The length of cable 4 from origin to object, m
- L_{23} = The total length of cable 2 & 3, m

- a = The length of the frame in y direction, m
- b = The length of the frame in x direction, m

2.2.3 Force Analysis of System

2.2.3.1 Components of Forces in 3D Space

From newton second law $\sum f = ma$ we can determine the total force acting on the object in three dimensions.

$$\sum \boldsymbol{f} = \boldsymbol{ma} \quad (2.6)$$

$$\vec{F1} + \vec{F2} + \vec{F2} + \vec{F3} + W = m\vec{a} \qquad (2.7)$$

Through vector notation [1] of force,as seen at Fig.(2.3)

$$\vec{F} = F * \hat{n}f \qquad (2.8)$$

$$\hat{n}f = \frac{(xn-x)\hat{i}}{{}_2\overline{(xn-x)^2}} + \frac{(yn-y)\hat{j}}{{}_2\overline{(yn-y)^2}} + \frac{(zn-z)K}{{}_2\overline{(Zn-Z)^2}} \qquad (2.9)$$

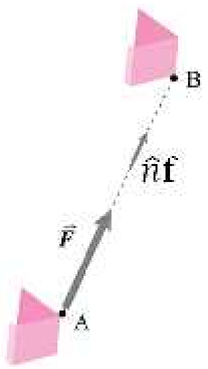


Fig.(2.3) unit vector notation

Force on cable number twoand three are same force because they are driven by one motor

$$\vec{F1} = F_1 * n\vec{F}_1 = \frac{-xF_1\hat{i} - yF_1\hat{j} - zF_1\hat{k}}{L_1} \quad (2.10)$$

$$\vec{F2} = F_2 * n\vec{F}_2 = \frac{-xF_2\hat{i} + \ a-y \ F_2\hat{j} - zF_2\hat{k}}{L_2}, \text{ for cable 2} \qquad (2.11)$$

$\grave{F}2 = F_2 * n\grave{f}2 = \frac{F_2(b-x)\hat{i} + F_2\ a-y\ \hat{j} - F_2 z\hat{k}}{L_3}$, **for cable 3** **(2.12)**

Because force on cable 2 and cable 3 same force,as seen at Fig.(2.4)

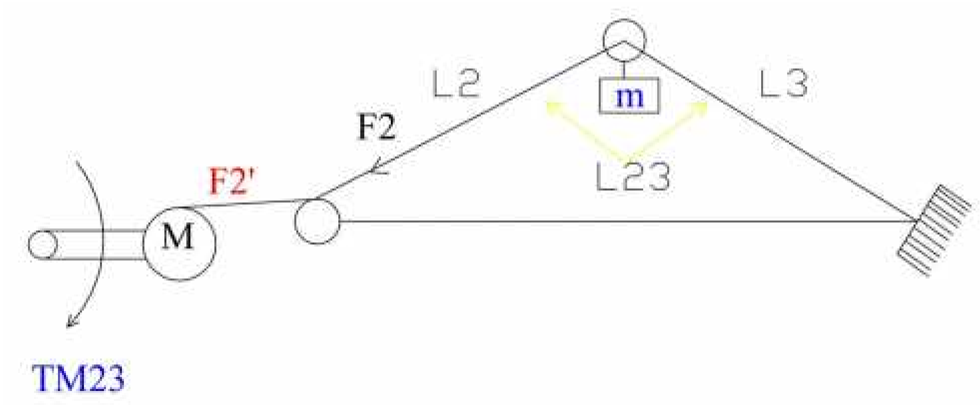


Fig. (2.4) the geometry of cable L_{23}

$\overline{F3} = F_3 * \text{ n } \bar{F}_3 = \frac{F_3(b-x)\hat{i} + F_3 y\hat{j} - F_3 z\hat{k}}{L_4}$ **(2.13)**

$\mathbf{W} = \mathbf{mg} * \mathbf{n}\widehat{w} = \mathbf{mg}\ \bar{k}$ **(2.14)**

$F_{23} = F_2 * n\bar{F}_2 + \grave{F}2 * n\grave{f}2 = \frac{bL_2 - L_{23}}{L_2 L_3}\ F_{23}\hat{\imath} + \frac{a-y}{L_2 L_3}\ F_{23}\hat{\jmath} - \frac{zL_{23}}{L_2 L_3}\ F_{23}\bar{k}$ **(2.15)**

Where:

- $\hat{n}$f = The unit vector of the force
- $\bar{F}1$ = force on cable number one, N
- $\bar{F}2$ = force on cable number two, N
- $\dot{F}2$ = force on cable number three, N
- $\bar{F}3$ = force on cable number four, N

2.2.3.2The Forces Analysis in 3D

Introducing (2.10),(2.11) and (2.13) in (2.16) to get the equations of motions

$$\sum \boldsymbol{f} = m\ddot{x} + m\ddot{y} + m\ddot{z} \qquad \textbf{(2.16)}$$

$$\frac{-XF_1}{L_1} + \frac{bL_2 - L_{23}\ \ F_2}{L_2 L_3} + \frac{-XF_3}{L_4} = m\ddot{x}$$ **in x direction(2.17)**

$$\frac{-yF_1}{L_1} + \frac{[\ a - y\ \ L_{23}]F_2}{L_2 L_3} + \frac{-yF_3}{L_4} = m\ddot{y}$$ **iny direction(2.18)**

$$\frac{-zF_1}{L_1} + \frac{-[zL_{23}]F_2}{L_2 L_3} + \frac{-zF_3}{L_4} + mg = m\ddot{z}$$ **in z direction(2.19)**

$$\boldsymbol{A}\ \ \boldsymbol{F} = \boldsymbol{Q}$$ [4] **(2.20)**

Equations (2.17),(2.18),(2.19)and (2.20) are combined to get

$$
\begin{matrix} \frac{-X}{L_1} & \frac{[\ b-x\ \ L_2-xL_3]}{L_2L_3} & \frac{-X}{L_4} \\ \frac{-y}{L_1} & \frac{[\ a-y\ \ \ L_{23}\ ]}{L_2L_3} & \frac{-y}{L_4} \\ \frac{-z}{L_1} & \frac{[-z\ L_{23}\ ]}{L_2L_3} & \frac{-z}{L_4} \end{matrix} \begin{matrix} F_1 \\ F_2 \\ F_3 \end{matrix} + mg \begin{matrix} 0 \\ 0 \\ 1 \end{matrix} = \begin{matrix} m\ddot{x} \\ m\ddot{y} \\ m\ddot{z} \end{matrix}
$$

$$[F] = A' \ \ Q$$

Where:

$A =$ Matrix which describethe differential equation of the system (nxn)

Q = Acceleration matrix(3x1)

$F =$Forces matrix

$A' =$ Inverse of A matrix

By MATLAB

F1= $-\frac{m\dot{x}L_1L_3+L_2}{b\ L_2+L_3} - \frac{m\ \dot{y}L_1L_3}{a\ L_2+L_3} - \frac{m(g-\ddot{z})L_1\ \ axL_3+bL_3\ \ y-a\ +aL_2\ \ x-b}{abz\ L_3+\ L_2}$ **(2.21)**

F2= $\frac{m\dot{y}\ \ L_2L_3}{a\ L_2+\ L_3} + \frac{my\ (g-\ddot{z})L_2L_3}{az\ L_2+\ L_3}$ **(2.22)**

F3= $\frac{m\dot{x}L_4\ \ L_3+L_2}{b\ L_2+L_3} - \frac{m\ \dot{y}L_2L_4}{a\ L_2+L_3} + \frac{m(g-\ddot{z})L_1\ \ ax\ \ L_3+\ L_2\ \ -byL_3+\ L_4}{abz\ L_2+\ L_3}$ **(2.23)**

Where:

- **F1 is** the external force applied to the cable of length L1 by the motor.
- **F2 is** the external force applied to the cable of length L2 by the motor.
- **F3 is** the external force applied to the cable of length L4 by the motor.

2.2.3Analysis of forces in every cable in a system include weight of cable

The resultant of the forces on the cables, including the weight of the cable itself,In addition to the force that affectedfrom body weight on the cable and the force generated from the motor on the cable, where assume that acceleration have the same direction of the cable.

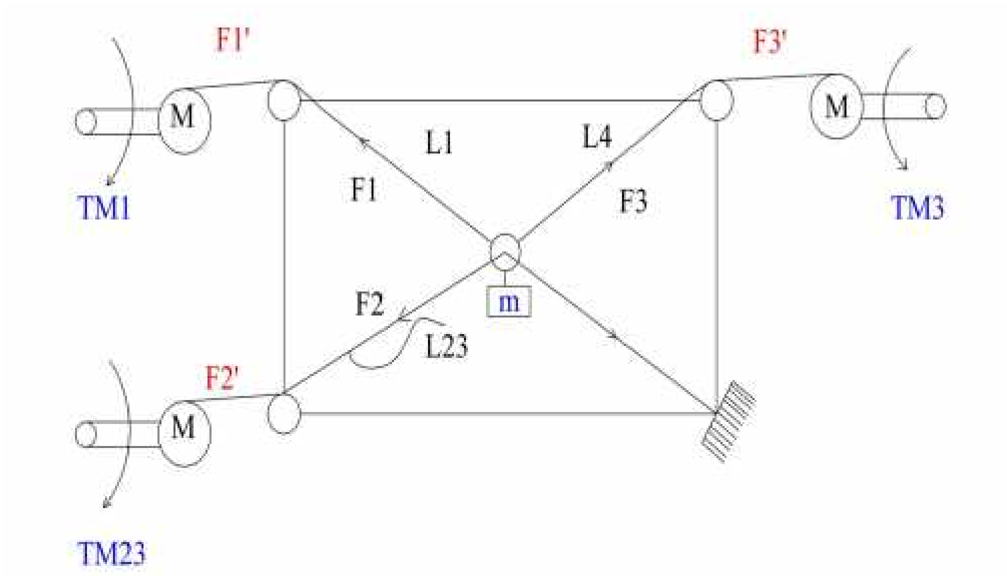


Fig.(2.5) top view of the system structure

Mass of cables:

$$\boldsymbol{m_{cable} = \rho L_{cable}} \qquad \textbf{(2.24)}$$

$m_1 = \rho L_1$, $m_2 = \rho L_2$, $m_3 = \rho L_4$

Where:

- m_1 =The mass of cable one, kg
- m_2 =The mass of cable two, kg
- m_3 =The mass of cable four, kg
- $\rho =$ longitudinal density of cable, kg/m

Note: weight of the cable number three is neglected with the fixed attach to the column number three, as seen at Fig.(2.2).

- Weight of cable number one, as seen at Fig. (2.6):

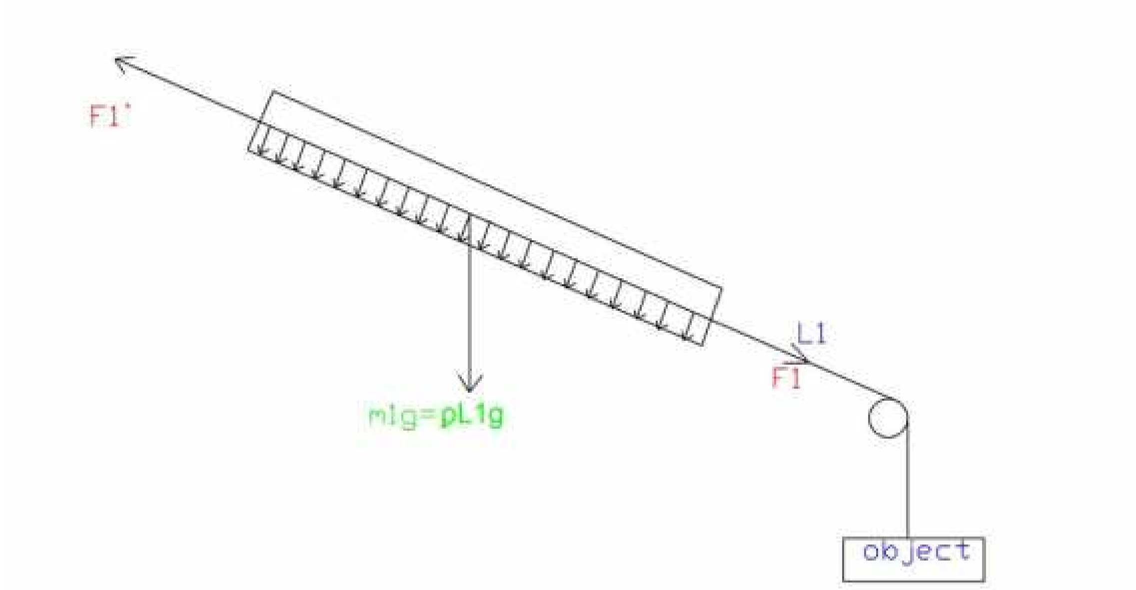


Fig.(2.6) distributed load on cable number one

$$\sum F = \mathrm{m}_1 \dot{L_1}$$

$$F_1 - F_1' + \mathrm{m}_1\,\mathrm{g}\,\bar{k}.\hat{n}_{L_1} = \mathrm{m}_1 \dot{L_1}$$

$$F_1 - F_1' + \mathrm{m}_1\,\mathrm{g}\,\bar{k}\ \frac{x\hat{\imath} + y\hat{\jmath} + z\bar{k}}{\sqrt{x^2 + y^2 + z^2}} = \mathrm{m}_1 \dot{L_1}$$

$$F_1 - F_1' + \frac{\mathrm{m}_1\,\mathrm{g}\,z}{L_1} = \mathrm{m}_1 \dot{L_1}$$

$$\therefore \boldsymbol{F_1'} = \boldsymbol{F_1} + \frac{\mathbf{m_1 g z}}{\boldsymbol{L_1}} - \mathbf{m_1}\dot{\boldsymbol{L_1}} \qquad \textbf{(2.25)}$$

Where:

- $L_1 = \sqrt{x^2 + y^2 + z^2})$ **(2.25.1)**
- $\dot{L_1} = \frac{x\dot{x} + y\dot{y} + z\dot{z}}{L_1}$ **(2.25.2)**
- $\dot{L_1} = \frac{x\ddot{x} + \dot{x}^2 + y\ddot{y} + \dot{y}^2 + z\ddot{z} + \dot{z}^2 \ - \dot{L_1}^2}{L_1}$ **(2.25.3)**

- Weight of cable number two, as seen at Fig.(2.7)

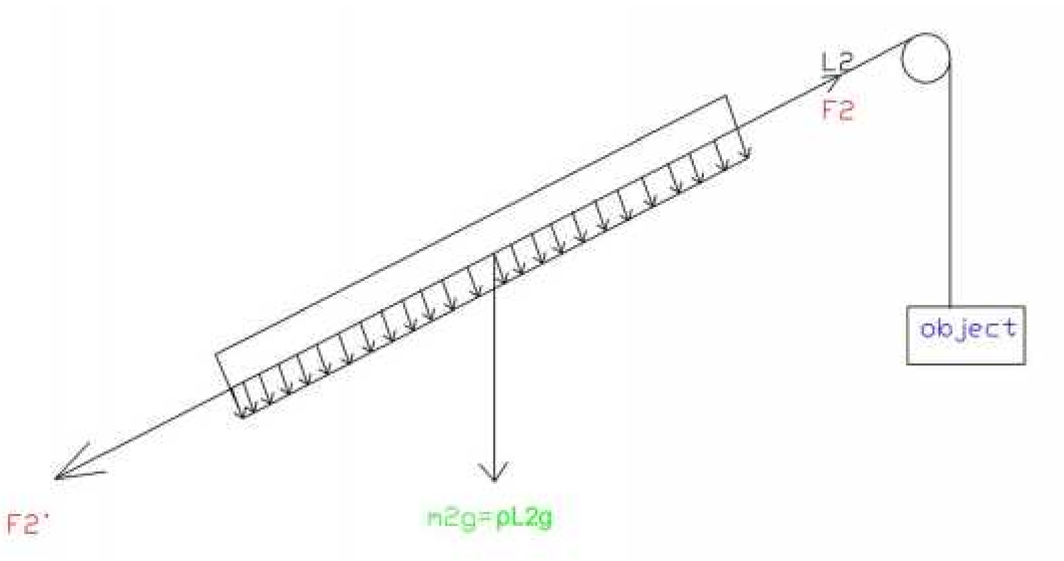


Fig.(2.7)distributed load on cable number two

$$F'_2 = F_2 + \frac{m_2 g z}{L_2} - m_2 \ddot{L}_2 \tag{2.26}$$

Where:

- $L_2 = \sqrt{x^2 + (a-y)^2 + z^2}$
- $\dot{L}_2 = \frac{x\dot{x} + (y-a)\dot{y} + z\dot{z}}{L_2}$
- $\ddot{L}_2 = \frac{x\ddot{x} + \dot{x}^2 + (y-a)\ddot{y} + \dot{y}^2 + z\ddot{z} + \dot{z}^2 - \dot{L}_2^{\,2}}{L_2}$

- Weight of cable number four, as seen at Fig.(2.8)

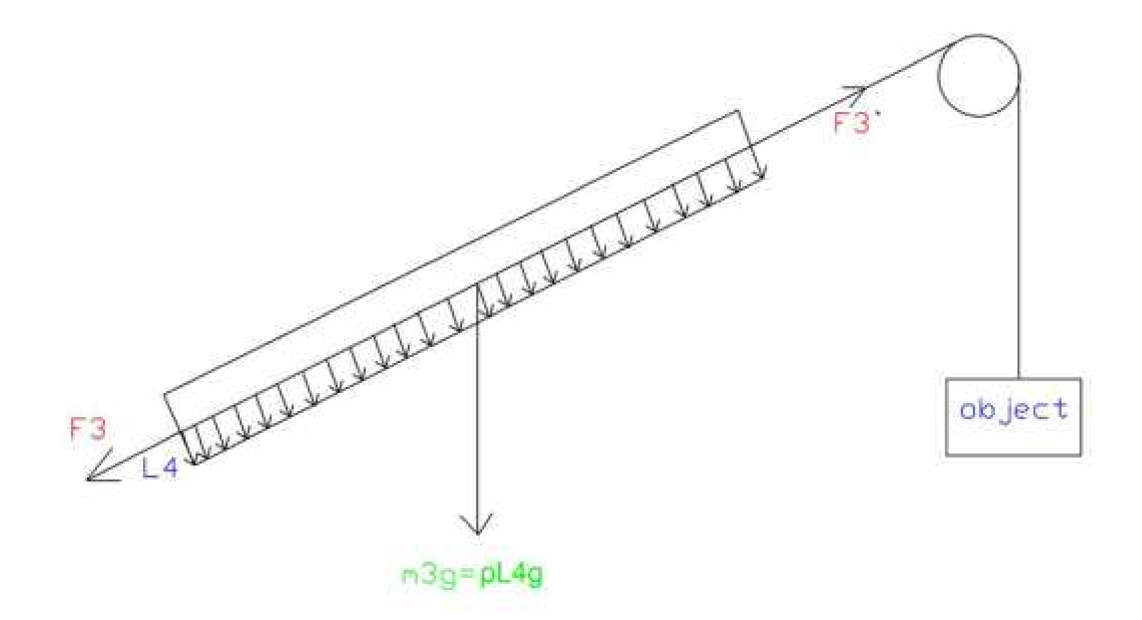


Fig.(2.8)distributed load on cable number three

$$F'_3 = F_3 + \frac{m_3 g z}{L_4} - m_3 \dot{L}_4 \qquad \textbf{(2.27)}$$

Where:

- $L_4 = \sqrt{(b-x)^2 + y^2 + z^2}$
- $\dot{L}_4 = \frac{(x-b)\dot{x} + y\dot{y} + z\dot{z}}{L_4}$
- $\ddot{L}_4 = \frac{(x-b)\ddot{x} + \dot{x}^2 + y\ddot{y} + \dot{y}^2 + z\ddot{z} + \dot{z}^2 - \dot{L}_4^2}{L_4}$

2.3 Torque equation analysis

Torque equation is calculate as a function of time for eachthree motorin the system to know how the mechanical torque and electrical torque is required to drive of each three motors.

2.3.1Analysis of torque on each cable

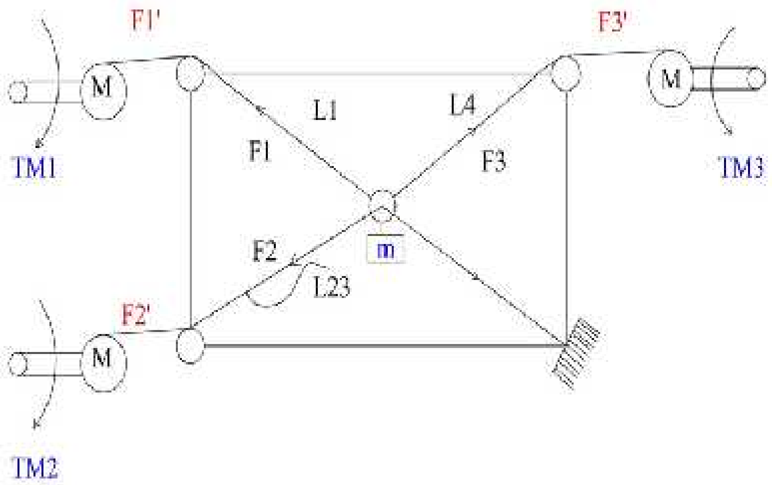


Figure (2.9)Torque of system

- The driven torque for motor one:

Introducing (2.25) and (2.25.3) in (2.28) to get the equations of driven torque for motor one

$$\boldsymbol{Tm_1 = J_0\ \frac{\ddot{L}_1}{r}\ + F'_1 r}, \textbf{N.m} \qquad \textbf{(2.28)}$$

$$Tm_1 = J_0\ \frac{\dfrac{x\ddot{x}+\dot{x}^2+y\ddot{y}+\dot{y}^2+z\ddot{z}+\dot{z}^2\ \ -\dot{L}_1^{\,2}}{L_1}}{r}$$

$$+r \quad - m_1 \frac{x\ddot{x} + \cdots}{\cdots}$$

- The driven torque for motor two:

$$\boldsymbol{Tm_2 = J_0 \left(\frac{\ddot{L}_2}{r}\right) + F'_2 r}, \textbf{ N.m} \qquad \textbf{(2.29)}$$

$$Tm_2 = J_0 \left(\frac{\frac{x\ddot{x}+\dot{x}^2+(y-a)\ddot{y}+\dot{y}^2+z\ddot{z}+\dot{z}^2-\dot{L}_2^{\,2}}{L_2}}{r}\right)$$

$$+r\left(F_2 + \frac{m_2\, g\, z}{\sqrt{x^2+(a-y)^2+z^2}} - m_2 \frac{x\ddot{x}+\dot{x}^2+(y-a)\,y+\dot{y}^2+zz+\dot{z}^2-\left(\frac{x\dot{x}+(y-a)\dot{y}+z\dot{z}}{\sqrt{x^2+(a-y)^2+z^2}}\right)^2}{\sqrt{x^2+(a-y)^2+z^2}}\right)$$

- The driven torque for motor three:

$$\boldsymbol{Tm_3 = J_0 \left(\frac{\ddot{L}_4}{r}\right) + F'_3 r}, \textbf{ N.m} \qquad \textbf{(2.30)}$$

$$Tm_3 = J_0 \left(\frac{\frac{(x-b)\ddot{x}+\dot{x}^2+y\ddot{y}+\dot{y}^2+z\ddot{z}+\dot{z}^2-\dot{L}_4^{\,2}}{L_4}}{r}\right)$$

$$F_3 + \frac{m_3 g z}{\sqrt{(b-x)^2 + y^2 + z^2}}$$

$$+r \quad - m_3 \frac{(x-b)\ddot{x} + \dot{x}^2 + y\ddot{y} + \dot{y}^2 + z\ddot{z} + \dot{z}^2 - \left(\frac{(x-b)\dot{x} + y\dot{y} + z\dot{z}}{\sqrt{(b-x)^2 + y^2 + z^2}}\right)^2}{\sqrt{(b-x)^2 + y^2 + z^2}}$$

2.4Maximum torque on cables system through general Cubic Profile

Consider the problem of moving the tool from its initial position to a goalposition in a certain amount of time

2.4.1The Cubic Polynomialstrajectory [2] method

ln making a single smooth motion, at least four constraints on s(t)are evident. Two constraints on the function's value come from the selection of initial and final values:

$$s(0) = s_0$$
$$s(t_f) = s_f \, 0 \qquad \textbf{(2.31)}$$

The Cubic Polynomials trajectory method is used to generate the trajectory path of the object along the coordinate axis (x,y,z).

An additional two constraints are that the function is continuous in velocity, which in this case means the initial and final velocity is zero:

$$\dot{s}(0) = 0$$
$$\dot{s}(t_f) = 0 \qquad \textbf{(2.32)}$$

These four constraints can be satisfied by a polynomial of at least third degree. Since a cubic polynomial has four coefficients, it can be made to satisfy the four constraints given by (2.31)and(2.32). Theseconstraints uniquely specify a particular cubic. A cubic has the form:

$$s(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \textbf{(2.33)}$$

And so the joint velocity and acceleration along this path are clearly:

$$\dot{s}(t) = a_1 + 2a_2 t + 3a_3 t^2 \qquad \textbf{(2.34)}$$

$$\ddot{s}(t) = 2a_2 + 6a_3 t \qquad \textbf{(2.35)}$$

Where:

- s(t)=The position profiles of the object in cubic form ,m
- s (t)=The velocity profiles of the object in cubic form ,m/s
- s (t)=The acceleration profiles of the object in cubic form ,m/s^2

Combining (2.33),(2.34) and (2.35) with the four desired constraints yields four equations in four unknowns:

$s_0 = a_0$
$s_0 = a_0 + a_1 t + a_2 t^2 + a_3 t^3$

$0 = a_1$ **(2.36)**

$0 = a_1 + 2a_2 t + 3a_3 t^2$

Solving these equations for the a_i we obtain:

After calculation:

$a_0 = 0$,

$a_1 = x_0$,

$a_2 = 3\ \frac{s_f - s_0}{t_f^2}$, **(2.37)**

$$a_3 = 2\ \frac{s_0 - s_f}{t_f^3}$$

.

$t_f = 1 + 2D$, V_{avg} = 0.5 m/sec

$$D = \sqrt{(x_f - x_0)^2 + (y_f - y_0)^2 + (z_f - z_0)^2} \quad \textbf{(2.38)}$$

Where:

- D =Distance between previous position and desired position in the work space, m
- t_f = Is the time for the desired goal position of object, sec
- (x_0, y_0, z_0) Initial position of the object, m
- x_f, y_f, z_f Final desired position of the object, m

- Cubic formin the x-direction:

$$x(t) = x_0\, t + 3t^2\ \frac{x_f - x_0}{t_f^{\,2}} + 2t^3\ \frac{x_0 - x_f}{t_f^{\,3}} \qquad \textbf{(2.36)}$$

$$\dot{x}(t) = 6t\ \frac{x_f - x_0}{t_f^{\,2}} + 6t^2\ \frac{x_0 - x_f}{t_f^{\,3}} \qquad \textbf{(2.37)}$$

$$\ddot{x}(t) = 6\ \frac{x_f - x_0}{t_f^{\,2}} + 12t\ \frac{x_0 - x_f}{t_f^{\,3}} \qquad \textbf{(2.38)}$$

- Cubic form in the y-direction:

$$y(t) = y_0\, t + 3t^2\ \frac{y_f - y_0}{t_f^{\,2}} + 2t^3\ \frac{y_0 - y_f}{t_f^{\,3}} \qquad \textbf{(2.39)}$$

$$\dot{y}(t) = 6t\ \frac{y_f - y_0}{t_f^{\,2}} + 6t^2\ \frac{y_0 - y_f}{t_f^{\,3}} \qquad \textbf{(2.40)}$$

$$\ddot{y}(t) = 6\ \frac{y_f - y_0}{t_f^{\,2}} + 12t\ \frac{y_0 - y_f}{t_f^{\,3}} \qquad \textbf{(2.41)}$$

- Cubic form in the z-direction

$$z(t) = z_0\, t + 3t^2\ \frac{z_f - z_0}{t_f^{\,2}} + 2t^3\ \frac{z_0 - z_f}{t_f^{\,3}} \qquad \textbf{(2.42)}$$

$$\dot{z}(t) = 6t\ \frac{z_f - z_0}{t_f^{\,2}} + 6t^2\ \frac{z_0 - z_f}{t_f^{\,3}} \qquad \textbf{(2.43)}$$

$$\ddot{z}(t) = 6\ \frac{z_f - z_0}{t_f^{\,2}} + 12t\ \frac{z_0 - z_f}{t_f^{\,3}} \qquad \textbf{(2.44)}$$

Where:

- $x(t) =$ Position of the object in x direction
- $y\ t$ = Position of the object in y direction
- $z\ t$ = Position of the object in z direction

- $\dot{x}\ t\ =$The velocity of the object in x direction
- $\dot{y}\ t\ =$The velocity of the object in y direction
- $\dot{z}\ t\ =$The velocity of the object in z direction

- $\ddot{x}\ t\ =$ The acceleration of the object in x direction
- $\ddot{y}\ t\ =$ The acceleration of the object in y direction
- $\ddot{z}(t) =$ The acceleration of the object in z direction

2.4.2 Designing of prototype specifications

- r=0.03m
- m=0.5 kg
- J_0=0.00026325 $kg.m^2$.
- m_1, m_2, m_3=0.005 kg

$$D_{max} = \sqrt{x_f - x_0\ ^2 + \ y_f - y_0\ ^2 + \ z_f - z_0\ ^2} \qquad (2.50)$$

Where:

- $D_{max} =$ Maximum distance which object move it in work space, m
- x_0, y_0, z_0 The origin position 0.1,0.1,0.1 , m
- x_f, y_f, z_f Max distance of work space is .1,.6,.8 , m

Table (2.2) profile path for prototype:

		Forward bath	Backward bath	unit
Initial position	x_0	0.1	1.1	m
	y_0	0.1	0.7	m

	z_0	0.1	0.9	m
Final position	x_f	1.1	0.1	m
	y_f	0.7	0.1	m
	z_f	0.9	0.1	m
Needed time	t_f	3.8284	3.8284	sec
Max distance	D	1.4142	1.4142	m

Use Matlab to show the torque curve of each motor,as seen at Fig (2.10).

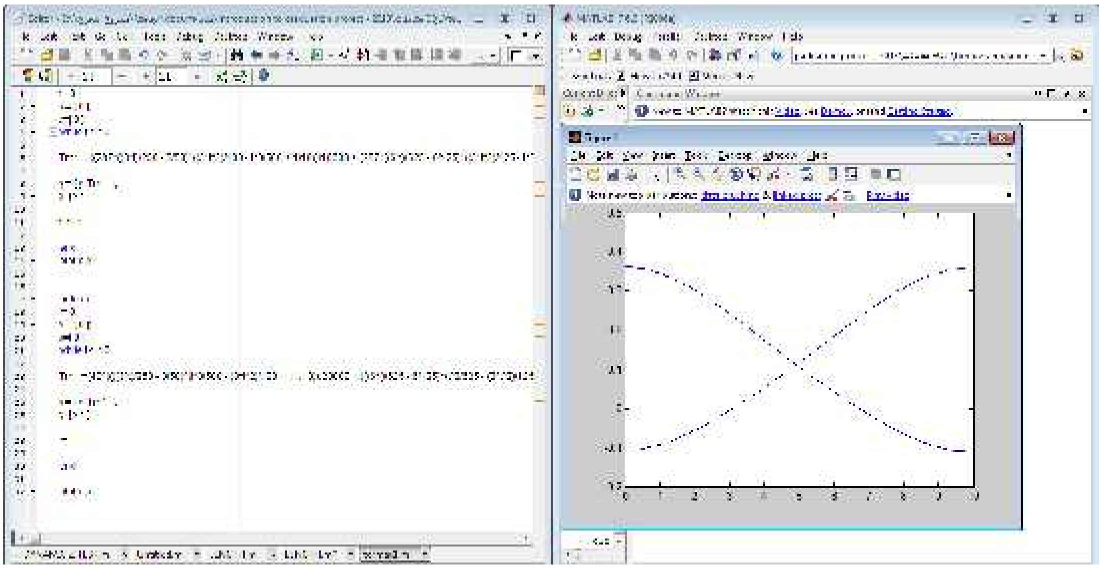


Fig (2.10) plotter matlab

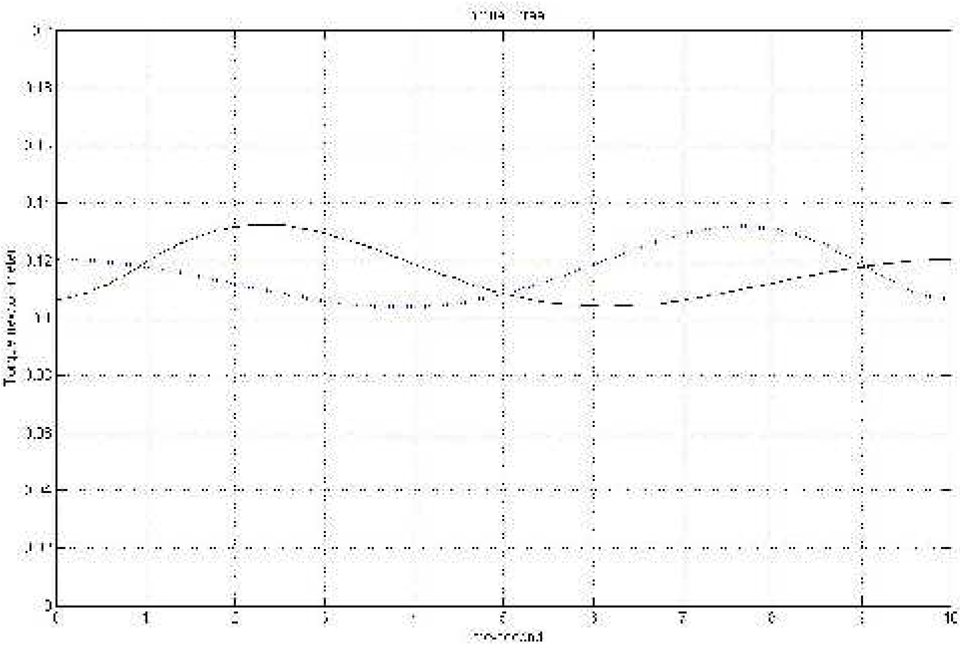


Fig.(2.11) maximum torque applied for motor one

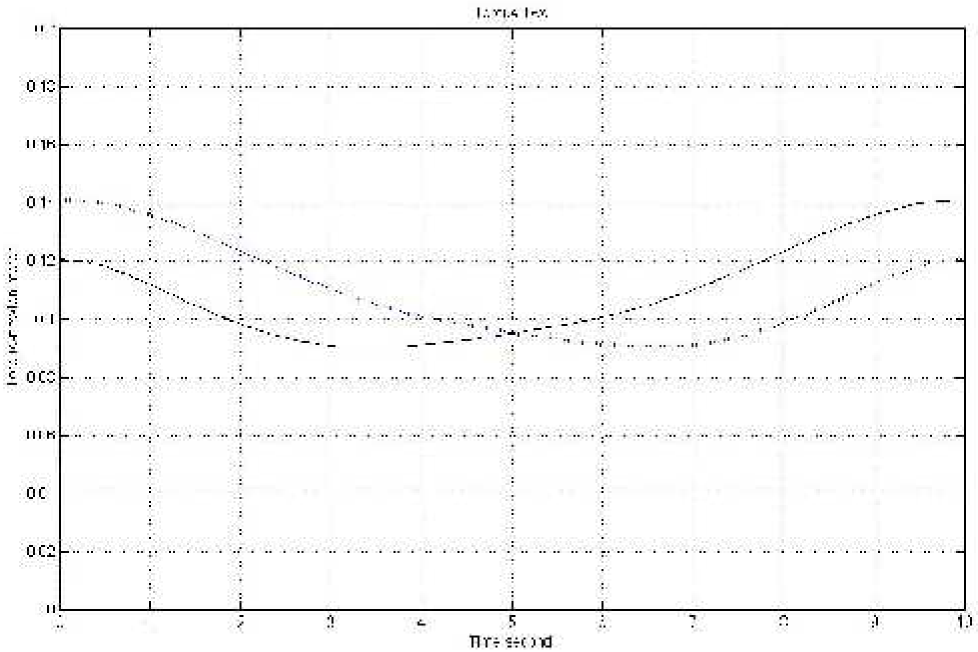


Fig.(2.12) maximum torque applied for motor two

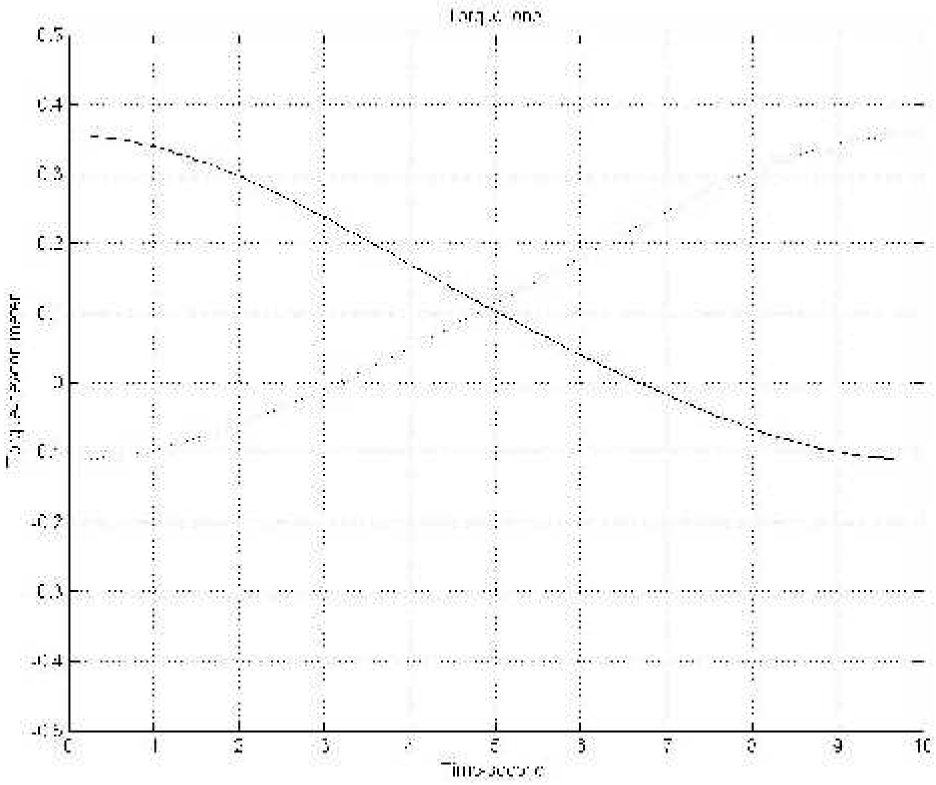


Fig.(2.13) maximum torque applied for motor three

A result was observed when we compute the torque that is required for motors to transport an object between two points in the work space .The torque was obtained as a function of time .The torque function is obtained using cubic polynomial trajectory path. The torque function of the forward motion was the same of torque function of backward motion .

This test was mad when the distance between the actual position and desired position was maximum, the maximum distance was used to calculate the torque function in order to select the motor using its required power.

$$Power_{max} = w_{max} T_{max} \quad \textbf{(2.51)}$$

Where:

- T_{max} =Is maximum torque applied on pulley motor get from torque curve, **N.m**
- w_{max} = Is maximum speed getting from cubic polynomial profile, **rad/sec**

2.4.3 The length of all cables used in prototype:

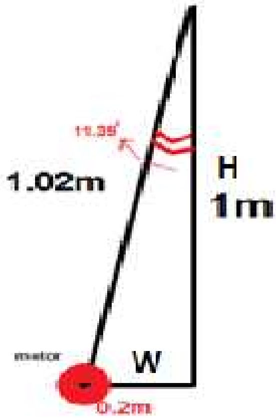


Fig.(2.14)distance from the shaft's pulley to the upper

h = $\sqrt{H^2 + W^2} = 1.02\ m$

h = $\sqrt{0.2^2 + 1^2} = 1.02\ m$

where:

- h= the distance from the shaft's pulley to the upper fixed pulleys on the frame, m.
- H = the height from the upper pulley to the shafts pulley in z direction.
- W = the distance from each motor to the column of the fame.

The equations which describe the total length of each cable used in the system.

$$\boldsymbol{L_{cable} = 3\ \pi\ d_{pulley} + h + L_{eff_{max}}} \quad \textbf{(2.52)}$$

Where:

- $L_{eff_{max}}$= Maximum effective length of cable(the maximum distance which object moving), m
- d_{pulley} = Diameter of motor's pulley,m

For cable number 1 the length subs in eq. (2.52):

$L_1 = 3\ \pi\ d_{pully} + h + L_{1eff_{max}}$

$= 3 \ \pi * 0.05 \ + 1.1 + \sqrt{1.1^2 + 0.7 + 0.9^2}$ = 1.491+1.585

$\therefore L_1$= 3.075 m , the total length of cable number one.

For cable number four same calculation and same result.

$$\therefore L_4 = 3.075 \ m$$

For the cable which include the cable number two and three:

L_{23}=3 $\pi \ d_{pully} \ + h + L_{2eff max} + L_{3eff max}$

$$= 0.47 + 1.1 + \sqrt{1.1^2 + 0.7 + 0.9^2} + \sqrt{0.1^2 + 0.7 + 0.9^2}$$

$\therefore L_{23} =$ 4.2195 m, the total length of cable number (two, three).

The total lengthof all cables used to cover the area of work space:

$$\therefore L_{total} = L_1 + L_{23} + L_4 = 10.369 \ m$$

2.4.4 Pulley connected to shaft motor characteristics

Pulley's motor design

To meet the desired specifications which give the project the perfect performance and to consider the length of the cable which will be turn on the shaft's pulley, so the distance of these cable will be known from the number of cable's turns on the shaft's pulley for each motor.

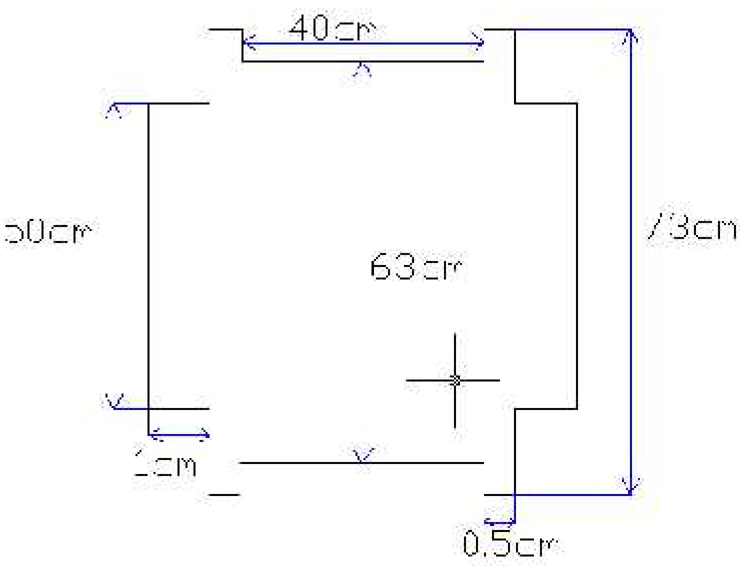


Fig.(2.15)

Let :

- $d_{pully} = 0.06m$ for all motors
- $\rho_{Al} = 2700\ kg/m^3$ (aluminum density)[3]
- H_{safty} =0.05m .

$\boldsymbol{m_{pully} = \rho * v}$

Where :

- m = mass of pulley, kg
- ρ = density of aluminum, kg/m^3
- v =The volume of aluminum, m^3

$$\boldsymbol{m_{pully} = \pi\, r_{pully}{}^2 H_{total}\, \rho_{Al}} \qquad \textbf{(2.53)}$$

$$\boldsymbol{J_{pully} = \frac{1}{2} m_{pully} r_{pully}{}^2} \qquad \textbf{(2.54)}$$

$$\boldsymbol{N_{eff} = \frac{L_{eff\,max}}{\pi\, d}} \qquad \textbf{(2.55)}$$

Where :

- J_{pully}=Mass moment of inertia of pulley, $kg.m^2$.

- m_{pully} = Mass of pulley,kg.
- r_{pully} = Radius of pulley m,turn.
- N_{eff} = Number of turns effective of cable, turn.
- L_{effmax} = Maximum number of turns effective of cable,m.
- d = diameter of motors pulley,m

Number of turns effective of cable from eq(2.55):

$$N_{eff} = \frac{1.414}{\pi * 0.05} = 9turn$$

The length of the shaft the cable that are turned on the pulley can be calculated using the number of turns the diameter of the pulley:

$$H_{eff} = 2 \quad N_{safty} + N_{eff} \ r_{cable} \ = \ 3turn + 9turn \ * 0.03 * 2 = 7.2cm$$

$$\therefore H_{eff} = 7.2cm$$

Then the all height of pulley

$$H_{total} = H_{eff} + H_{safty} = 7.2 + 0.5 * 2 = 8.2m$$

J_{pully}=Mass moment of inertia for the pulley, $kg.m^2$.

$$m_{pully} = 0.585 \ kg$$

Sub in eq (2.53) to find Mass moment of inertia of pulley

$$J_{pully} = \frac{1}{2} m_{pully} {r_{pully}}^2 \tag{2.56}$$

$$J_{pully} = \frac{1}{2} * 0.585 * 0.03^2 = 0.00026325 \ kg.m^2.$$

2.5Inspection of mathematical models

2.5.1 The static test in z direction:

Let:

M= 1 kg,mass object .

$\ddot{z} = \ddot{y} = \ddot{x} = 0$, the acceleration in x,y,z direction

The static test of the force in z direction which applied in the systems

From matlab:

$$F_z = \begin{matrix} \frac{\ddot{z} - 9.81\ \sqrt{17}}{8} \\ \frac{\ddot{z} - 9.81\ \sqrt{17}}{8} \\ \frac{\ddot{z} - 9.81\ \sqrt{17}}{8} \end{matrix}$$

$$8F_z = \sqrt{3}\ \ddot{z} - g\ m$$

$$8F_z = \ddot{z}\sqrt{3}m - \sqrt{3}m\, g$$

$$\ddot{z} = \frac{-\sqrt{17}m\, g - 4F_z}{-\sqrt{17}m}$$

$$F_z = \frac{-\sqrt{17}\ \ddot{z} - 9.81}{8} \qquad \text{Let } \ddot{z} = 0$$

$$F_z = \frac{-\sqrt{17}*-9.81}{8} = 5.05$$

From matlab:

```
syms x y z a b m g ;
syms xb yb zb

m=1;
b=120;
a=80;
x=b/2;
y=a/2;
z=40;
g=9.81;
xb = 0;
yb = 0 ;
zb= 0 ;

L1 = ((x^2 + y^2 + z^2 ))^0.5;
L4 = ( ((b-x)^2)   + y^2 + z^2 )^0.5 ;
L3 =(((b-x)^2)+ ((a-y)^2 ) + z^2)^0.5 ;
L2 = ( x^2+((a-y)^2 )+ z^2 )^0.5 ;

A=[-x/L1    (((b-x)*L2)-(x*L3))/(L2*L3)     (b-x)/L4 ;
    -y/L1     ((a-y)*(L2+L3))/(L2*L3)     -y/L4 ;
     z/L1                  ( z*(L2+L3))/(L2*L3)       z/L4]

 Q=[m*xb  ; m*yb   ;  m*(zb-g)      ]


D=inv(A)

F=D*Q
```

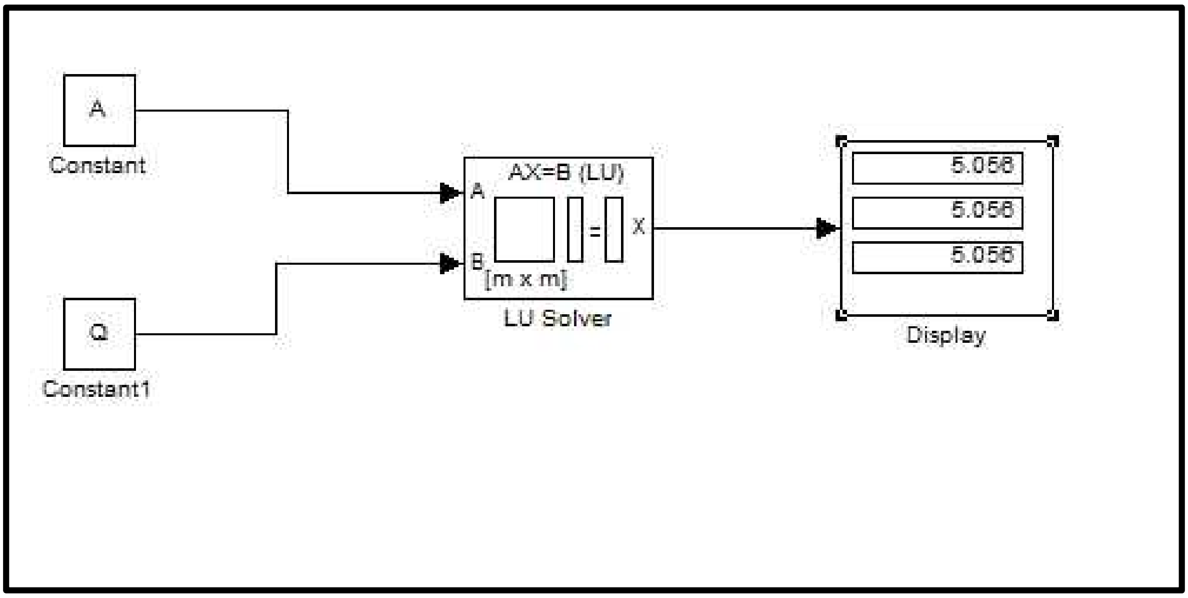
Fig.(2.16) the code to find force matrix

Fig.(2.17)Simulink to obtained the force matrix

$$A = \begin{matrix} -0.7276 & 0 & 0.7276 \\ -0.4851 & 0.9701 & -0.4851 \\ -0.4851 & -0.9701 & -0.4851 \end{matrix}$$

$$Q = \begin{matrix} 0 \\ 0 \\ -9.8100 \end{matrix}$$

$$D = \begin{matrix} -0.6872 & -0.5154 & -0.5154 \\ 0 & 0.5154 & 0.5154 \\ 0.6872 & -0.5154 & -0.5154 \end{matrix}$$



Ztest

$$A = \begin{matrix} -0.7276 & 0 & 0.7276 \\ -0.4851 & 0.9701 & -0.4851 \\ -0.4851 & -0.9701 & -0.4851 \end{matrix}$$

$$Q = \begin{matrix} 0 \\ 0 \\ z - 9.81 \end{matrix}$$

$$D = \begin{matrix} -0.6872 & -0.5154 & -0.5154 \\ 0 & 0.5154 & -0.5154 \\ 0.6872 & -0.5154 & -0.5154 \end{matrix}$$

Chapter Three
Mechanical and Electrical Design for Prototype

3.1 The mechanical components:

Design is an iterative process with many interactive phases. Many resources exist to support the designer, including many sources of information and an abundance of computational design tools [7].

The mechanical design of any mechanical machine means the description of physical parts of the system; know any how much the forces acting on each part of the system in addition to knowing the pressure and tension caused by these forces, it is also necessary to know the geometry of each part of the machine is mechanical.

CATIA V5 program and AutoCAD2007 is used for designing and simulation of the mechanical structure for the system,as seen at Fig (3.1) and Fig (3.2).

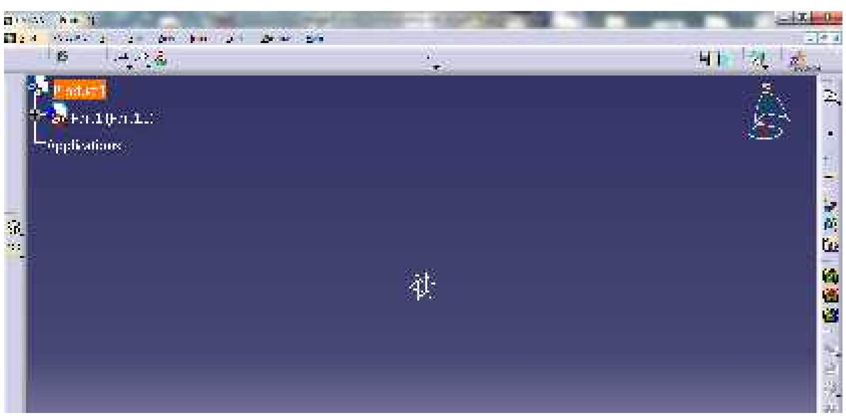


Fig (3.1) CATIA V5window

Fig (3.2) AutoCAD2007 window

The system has to be designed for different mechanical components, will be shown and discussed according to their functions.

The dimensions of frame, as seen at Fig (3.3)is :

a) x-axis 120cm
b) y-axis 80cm
c) z-axis 100cm

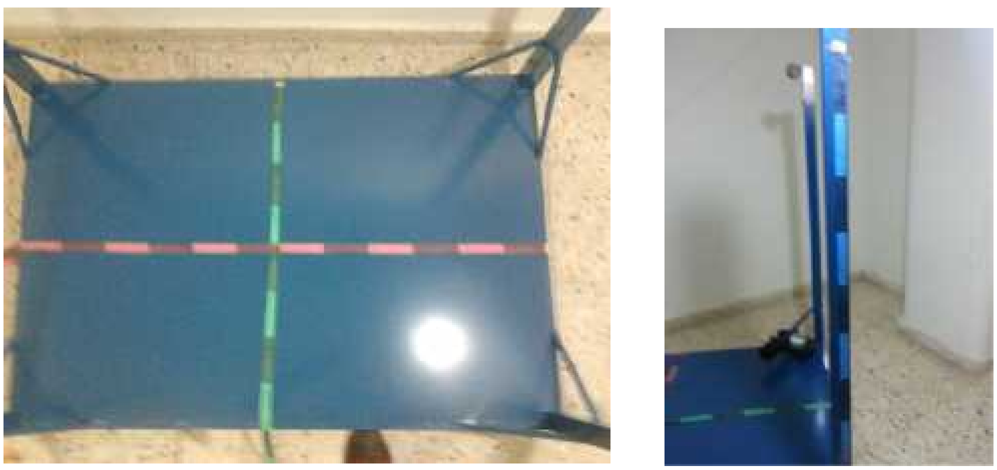


Fig (3.3) geometer of DCMOCS

3.1.1 Frame

The material of frame is cast iron with 4*4 cm with plate of 4 mm cast iron, the prototype has 4 wheel ,as seen at Fig (3.4).

Fig (3.4) frame prototype

3.1.2 The load (mass 0.5 kg)

In first design the choice is 1 kg but after some experimental tests with rapid prototype the 1kg has big weight that cause a big load on motor which that cause high current , that is danger effect for circuits and some mechanical problem as big inertia moment in begging move to desired position, as seen at Fig (3.5).

Fig (3.5)the mass

3.1.3 Cable

Many choices of kinds of cable in project with different specification as cablenailonand cablerope,then the specification of prototype need the best cable which has :

a) no elongation without string from the mass weight with long time
b) less friction with pulleys
c) small mass density , because it don’t cause a big difference in calculation

The choices, as seen at Fig (3.6).

	
1	2
	
3	4

Fig (3.6) kinds of cable

The best choice is number one for project specification.

3.1.4 Pulleys

The system has to be designed for different pulleys with different tasks , namely:

1. Aluminum Drums

Prototype Has two screw for fixed with shaft motor to avoid any back lash with internal slotwhich has same cable's diameter with helical shape for smoothly motion and transit the desired length of cable that the cable need it to receive the next position and all of that repeat for another two motor, as seen at Fig (3.7).

Fig (3.7)Aluminum Pulley

2. Cable pulley

Many choices of pulley, as seen at fig (3.8) , can get the rational motion for cable but the best choice with less friction with cableand smoothly motion in xy-plane , as seen at fig (3.9),the choice of prototype is numbertwo through experimental tests, as seen at fig (3.10).

		
1	2	3

Fig (3.8)Cables pulleys choices

Fig (3.9)Cable pulley

Fig (3.10)motion of pulley cable

3. Mass pulley

The choice of pulley is limitation with dimension of system, that would to find a small pulley with small bearing, that can carry mass inside the whole space of prototype.

Fig (3.11)pulley mass

This pulley has one rotational degree of freedom in zy-plane. , as seen at Fig (3.12).

Fig (3.12) pulley massmotion

3.1.5 Bolts

Blots in mechanical systemis way to connect two part or more, in prototype use bolts, nuts and washer, as seen at Fig (3.13.a),with difference dimensions for :

- Fixed motor with frame of prototype, as seen at Fig (3.13.b)
- Fixed pulleys cable with frame of prototype, as seen at Fig (3.13.c)

Fig (3.13.a)Bolts, Nuts and Washer

Fig (3.13. b)Fig (3.13.c)

3.1.6Bearing

The choice of bearing pulley is limitation with dimension of system as talked in pulley mass, then the best choice with pulley dimension, as seen at Fig (3.14).

Fig (3.14) bearing of mass pulley

3.1.7The welding

In prototype wasused in order to fixed the various parts of mechanics, especially the overall structure that holds most of the parts and the pieces connect with each other in different systems mechanics simple.

3.1.7.1 Arc welding

is a type of welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metals at the welding point.[7] , as seen at Fig (3. 15).

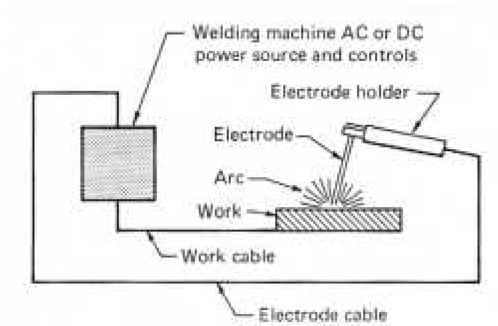


Fig (3.15)The basic arc-welding circuit

Arc welding use for fixed the frame of prototype, as seen at fig (3.16.a), and struts in order to avoid any possible Moment to get in the long run , as seen at Fig (3.16.b).

Fig (3.16)

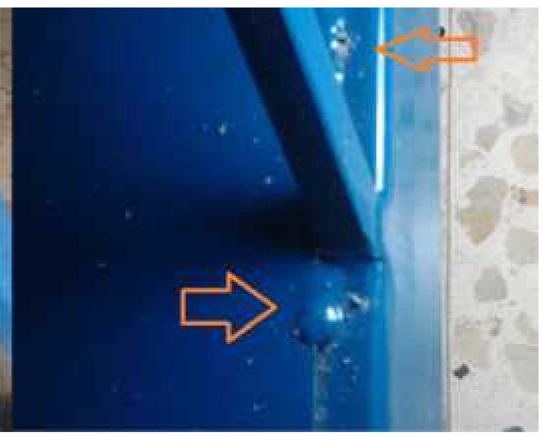


Fig (3.17)

3.1.7.2 Metal inert gas (MIG)welding:

is a welding process in which an electric arc forms between a consumable wire electrode and the work piece metal(s), which heats the work piece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air.[8], as seen at Fig (3.18).

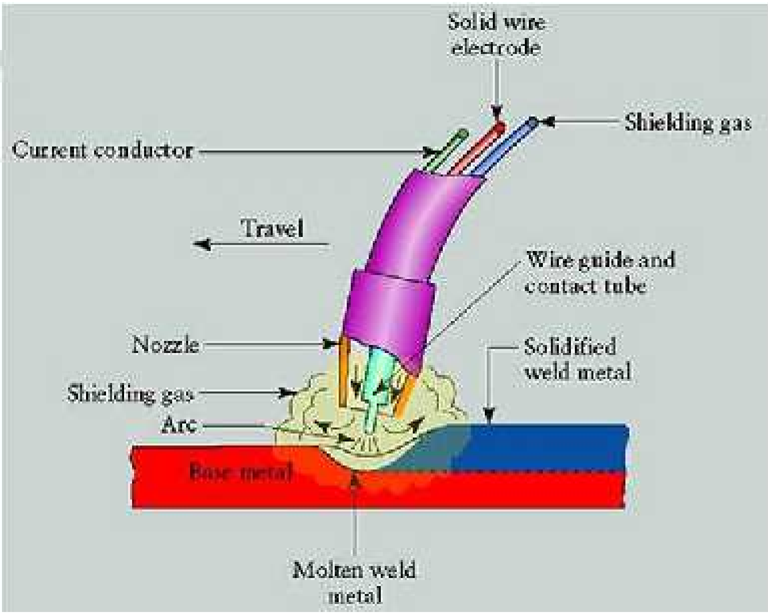


Fig (3.18)MIG welding

Mig weld use for fixed the pulley mass with mass, as seen at Fig (3.19).

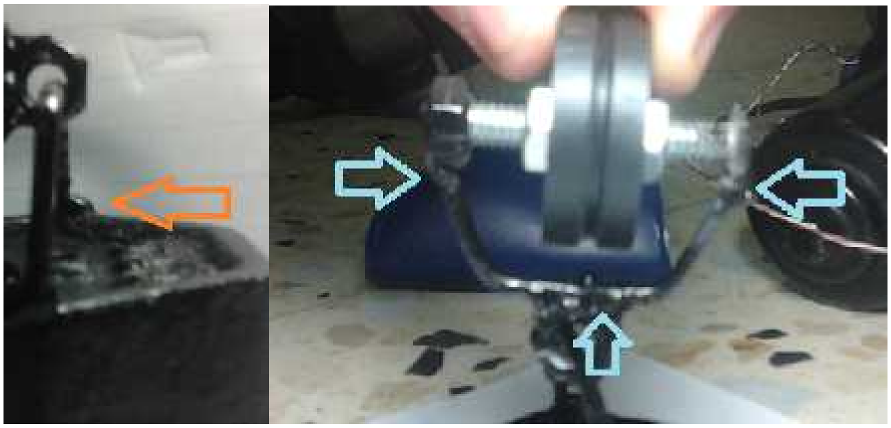


Fig (3.19)MIG welding on pulley

3.2 Electrical Design

3.2.1 Introduction

This chapter will discuss the process of designing the needed electrical parts to operate the system; these parts include the actuators which are electrical motors, the drive circuits ,and the controller.

The block diagram shown in Figure (3.20) describes the elements that form the entire system generally.

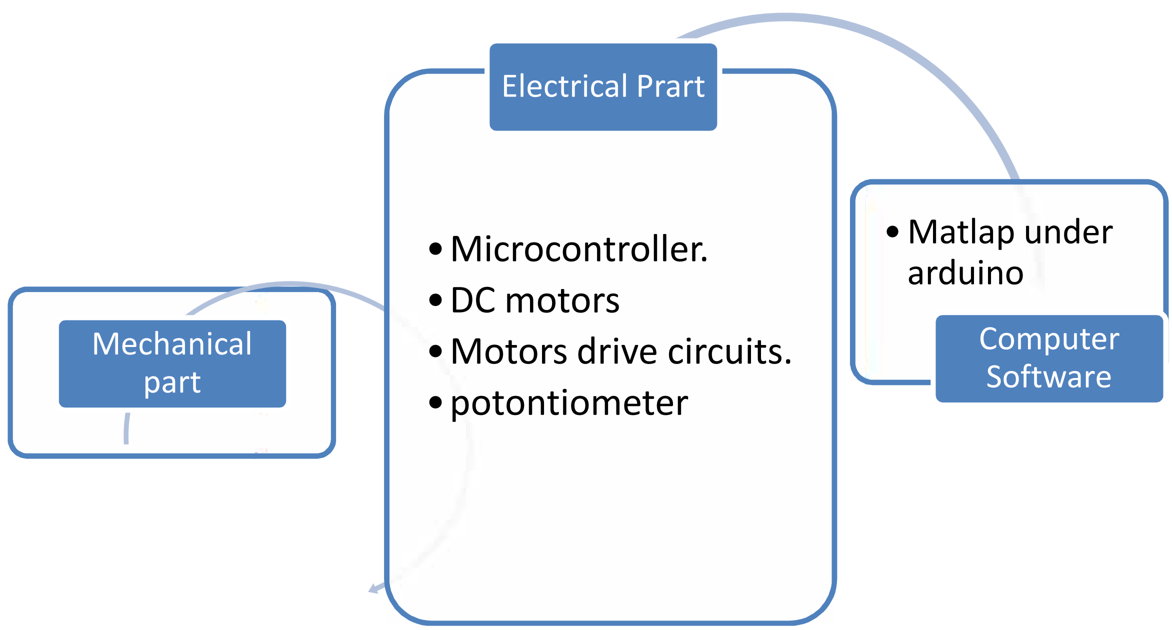


Figure (3.20) Basic Elements in the System

The electrical system includes DC of electrical motors, this motors are controlled by digital sequence generated by microcontroller and supplied to the motors throw drive circuits.

3.2.2 MOTORS

in the first we were used some kind of motors such stepper motor and dc motor ,but in the end

we use the DC motors depend on the characteristics of the motors and which is more suitable for control .so The system includes three DC motor to provide the needed motion.

3.2.2.1 Stepper motor

Unipolar stepping motors are composed of two windings, each with a center tap as shown in Figure (3.21). The center taps are brought outside the motor as two separate wires. As a result, unipolar motors have 6 wires, and driven by tied the 4 coils to power supply and the center tap wire(s) are alternately grounded[9].

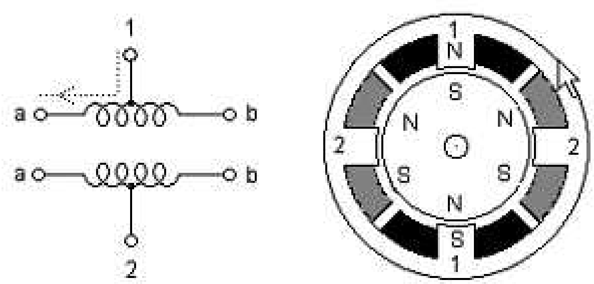


Figure (3.21) Unipolar stepper motor windings

3.2.2.2 Dc motors

A DC motor is a mechanically commutated electric motor powered from direct current (DC). The stator is stationary in space by definition and therefore the current in the rotor is switched by the commentator to also be stationary in space. This is how the relative angle between the stator and rotor magnetic flux is maintained near 90 degrees, which generates the maximum torque.

DC motors have a rotating armature winding (winding in which a voltage is induced) but non-rotating armature magnetic field and a static field winding (winding that produce the main magnetic flux) or permanent magnet. Different connections of the field and armature winding provide different inherent speed/torque regulation characteristics. The speed of a DC motor can be controlled by changing the voltage applied to the armature or by changing the field current. The introduction of variable resistance in the armature circuit or field circuit allowed speed control. Modern DC motors are often controlled by power electronics systems called DC drivesas seen at Fig (3.22)[10].

Fig(3.22) DC drives

3.2.3 Sensor

Linear Potentiometer linear potentiometers is sufficient.
A potentiometeras seen at Fig (3.23), is a three-terminal resistor with a sliding contact that forms an adjustable voltage divider.

Fig(3.23) potentiometers

Potentiometers are also very widely used as a part of displacement transducers because of the simplicity of construction and because they can give a large output signal [11].

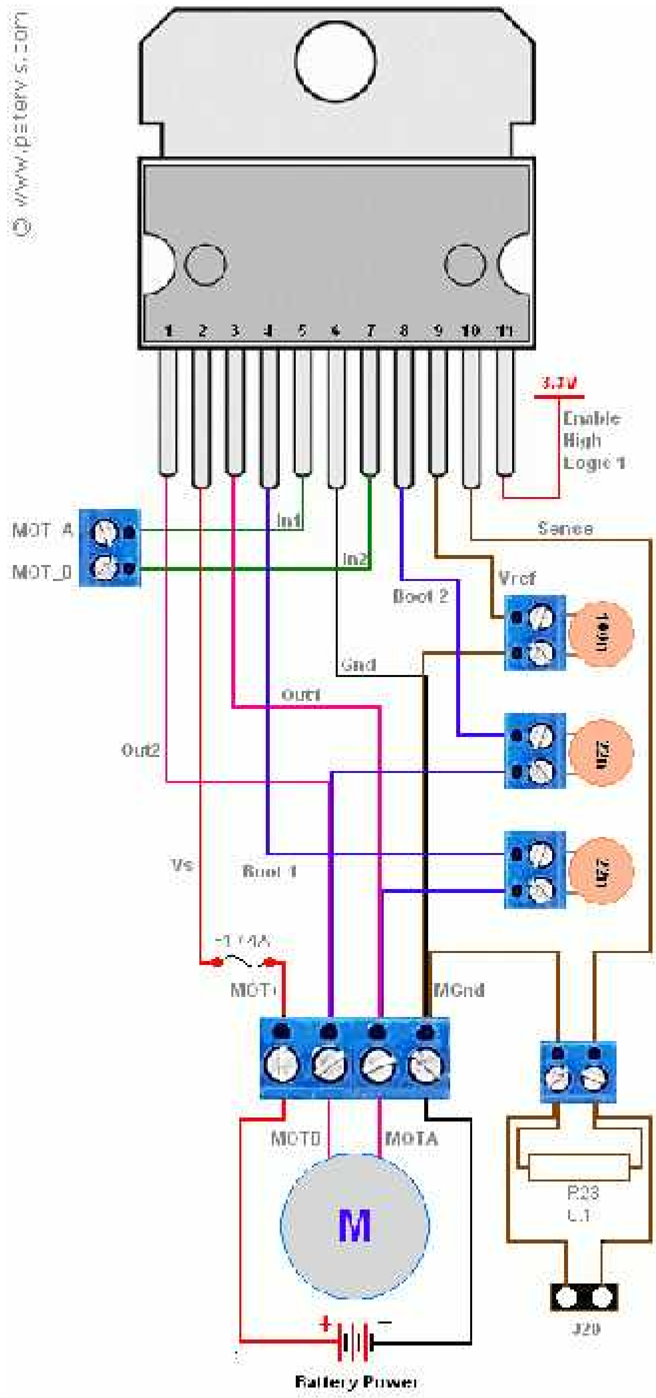
A potentiometer measuring instrument is essentially a voltage divider used for measuring electric potential (voltage).

Potentiometers can be used as position feedback devices in order to create "closed loop" control, such as in a servomechanism. This method of motion control used in the DC Motor is the simplest method of measuring the distance or speed.

- Using linear potentiometer instead of encoder
- Noted a potentiometer will give an absolute position within a limited range of motion regardless of its starting location. And it is also inexpensive and practical In contrast to the encoder.

3.2.4 MOTORS DRIVE CIRCUIT

The drive circuit is transfer the digital signal produced by the Microcontroller and supplies the motor with the required power as it donated in the motors datasheets ,as show Fig(3.24).



Fig(3.24)The Electrical wiring diagram of the system

There are two power supply and Arduino microcontroller and computer and three DC motors contact with three potentiometer (feedback) ,so the figure (3.25) below show the wiring between this component .

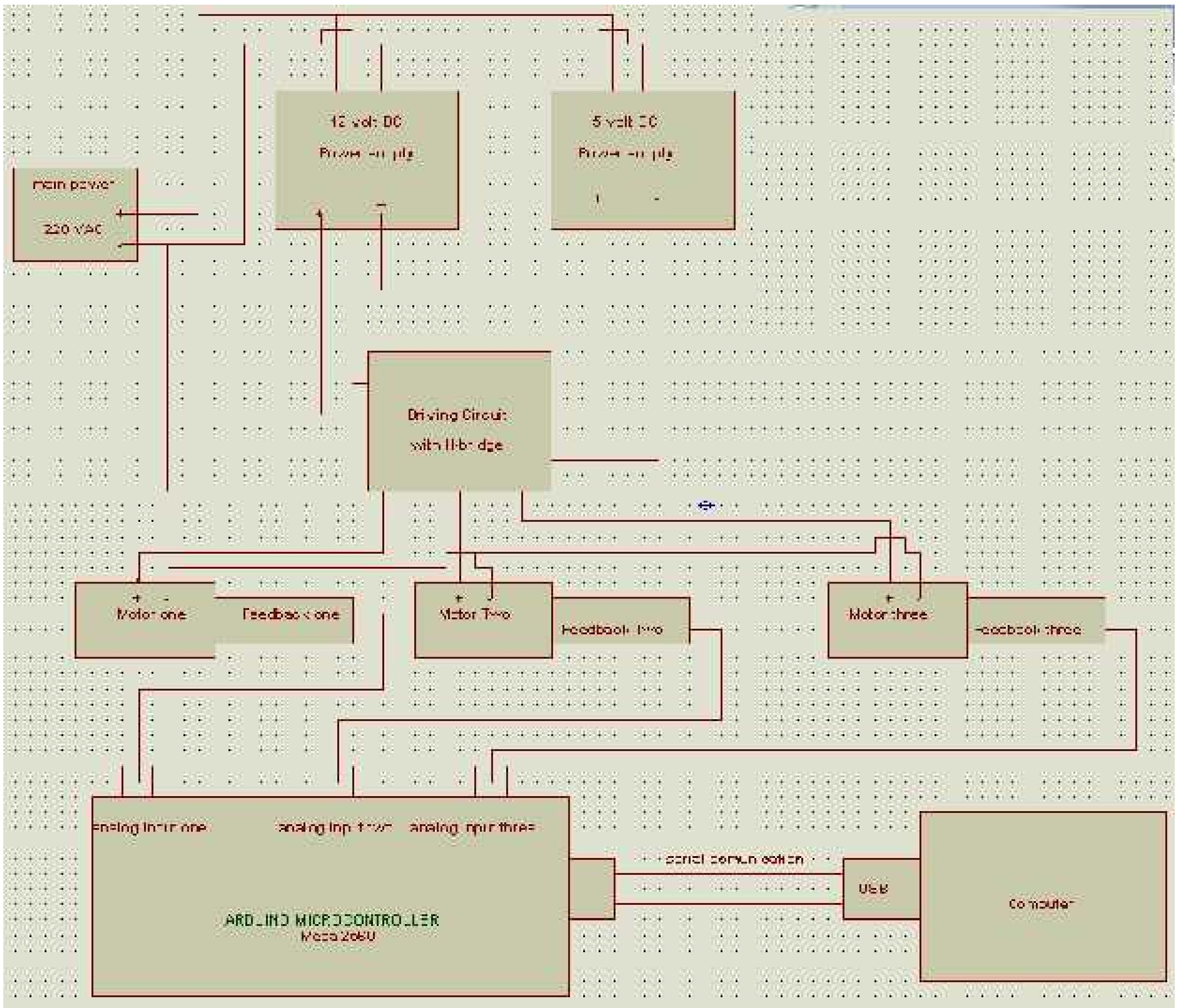


Fig (3.25) electrical wiring diagram

3.2.5 Interface programming

We used two type of the Interface programming such(matlap2013a,arduino microcontroller) ,in the next chapter we take about this in details .

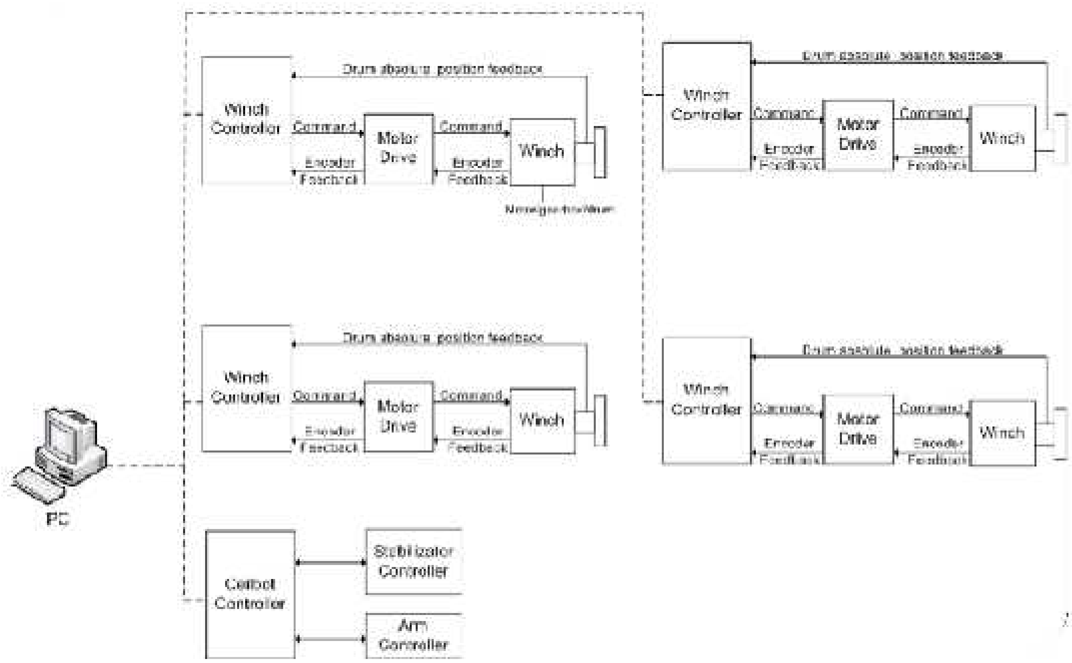
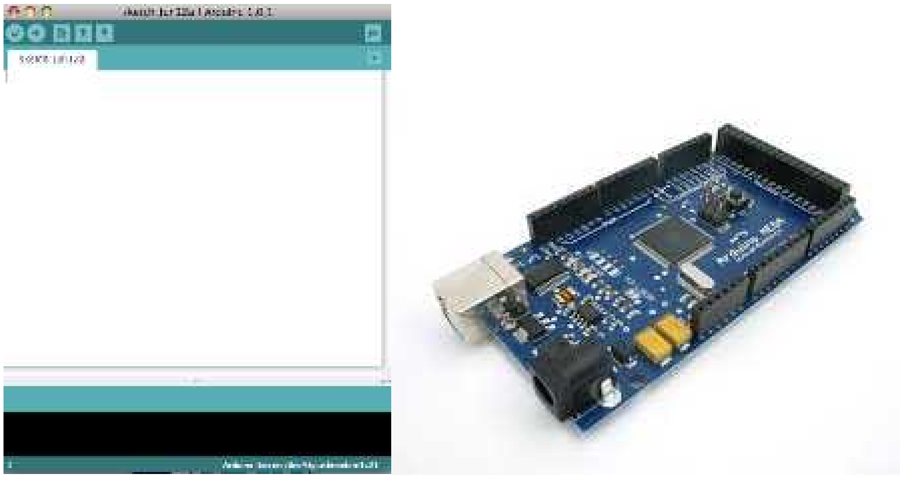


Fig (3.26) Interface diagram

1- Matlap2013a is used to make a control Simulink model
2- Arduino microcontroller program

Arduino Target:

Used to compile and download Simulink code directly tothe Arduino board, ,as show Fig(3.27).



Fig(3.27).Arduino Target

Chapter four

Control Design

4.1 Introduction

Why control system?

Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems with inputs. The external input of a system is called the reference. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system. The usual objective of a control theory is to calculate solutions for the proper corrective action from the controller that result in system stability [12] .

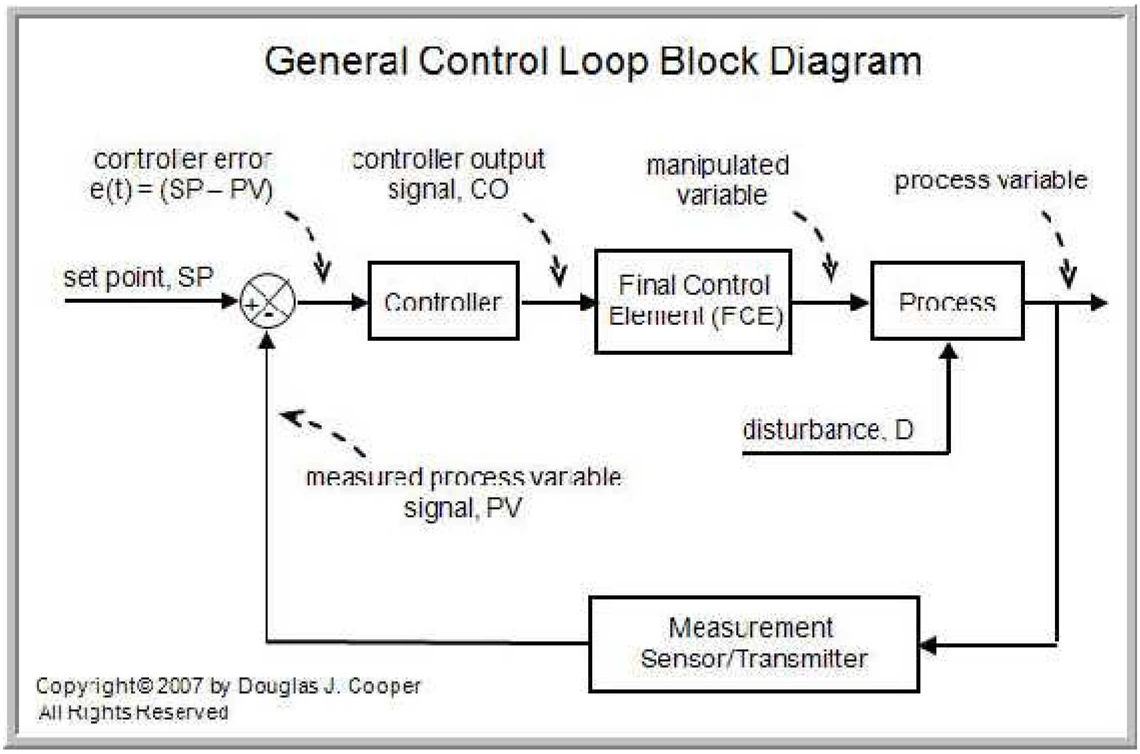


Figure (4.1)General control loop

A control system consist of subsystems and processes (or plants) assembled for the purpose of controlling the outputs of the process. There are two common classes of control systems, open loop control systems and closed loop control systems. In open loop control systems output is generated based on inputs. In closed loop control systems current output is taken into consideration and corrections are made based on feedback, so control system can automatically changes the output based on the difference between the feedback signals to the input signal.

4.2 Recognitionof the Need

This project aims to design and implement a prototype of a control system to control a position of an object to transportit from a specified position to another specified position in three-dimensional space. The strategy that is used to control the position of an object usesthree cables, these cables are hold with the object and each end of cable is connected to a DC motor.

This strategy needs a closed loop control system to make the required calculations to obtain the torque foreach motor to get the required length of eachcable. Moreover, the computer will compute the trajectory and control the cables lengths as function of time to achieve the desired target position with the planned trajectory.

The proposed controller for each degree of freedom is a PID controller to control of three independent DC motors in order to Determination the cables lengths. The current (actual) position is usually obtained from the previous command, and the desired position will be given by the user .The actual position of the object can be determined using encoders that are placed at pulleys of motors. The controller makes a comparison between the actual and desired position in order to get the true position of the object and matching the requiring design.

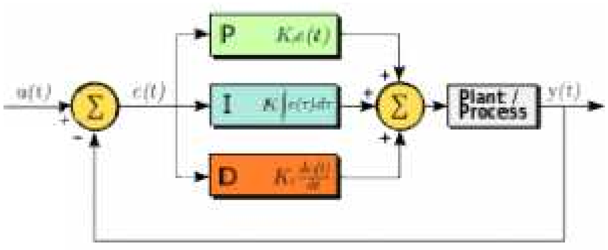


Figure (4.2) General PID Controller close loop

4.3 DC motor

4.3.1Theoretical model

The model that describes the system does not take the dynamics of the DCmotors into account. A way to improve the control of the hole system isto take these dynamics into account. The model of the DC motor, whichis identified, consists of a DC motor gear box with a pulley connected to the shaft.

This is due to the fact that one would like to control the length and velocityof the cables, which is the same as the position and velocity of a point onthe Suspended object. By the way, it is desirable to have a simple model that describes the DC .

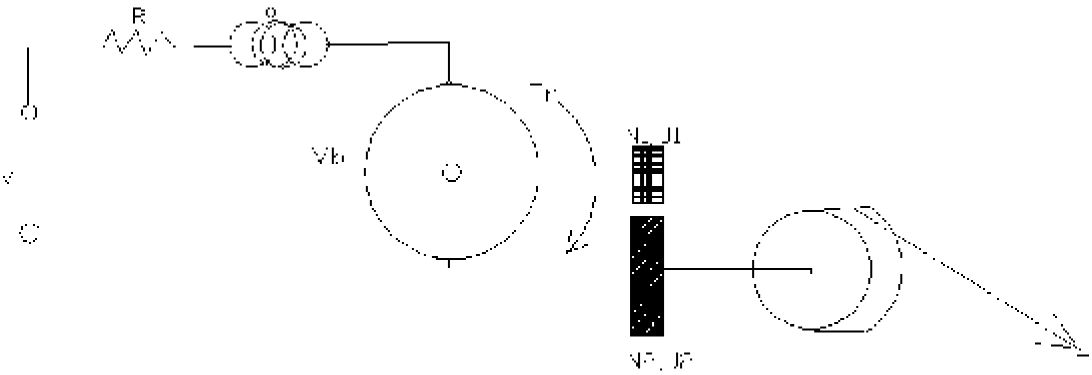


Figure (4.3): A simple model of a DC motor.

- This system is described by the following differential equations :

From fig(4.3) and Ohm's law the input current to te motor

$$\mathbf{i} = \frac{V_i - V_b}{R_a} \quad \textbf{(4.1)}$$

The input voltage of motor is:

$$\mathbf{V_b = K_b * W} \quad \textbf{(4.2)}$$

The input voltage of motor in frequancy domainis:

$$\mathbf{V_b \; s \; = K_b * s * \Theta_m} \quad \textbf{(4.3)}$$

The electrical torqueof motor in frequancy domainis:

$$\mathbf{Tm_{elec} = K_m * i(s) = K_m * \frac{V_i - K_b \, S \, \Theta}{R_a}} \qquad \textbf{(4.4)}$$

The mechanical torqueof motor in frequancy domainis:

$$\mathbf{Tm_{mech} = J_{eq}\ddot{\Theta}_m + C_{eq}\dot{\Theta}_m + T\ r}$$

$$\mathbf{K_m * \frac{V_i - K_b \, s \, \Theta}{Ra} = s^2 \; J_{eq}\Theta_m + C_{eq} s \, \Theta_m} \qquad \textbf{(4.5)}$$

Tabel (4.1) Dc motor pameters

Symbol	Description
R_a	resistance
L	inductance
$K_b$and$K_m$are	motor gains
W	the velocity of the pulley
i	current
V_i	applied voltage
r	pulley radius
Tm_{mech}	mechanical torque
Tm_{elec}	Electricaltorque
Θ	angular position of the motor

The differential equations above correspond to a first order transfer function assuming that the electrical pole is neglected.

$$\mathbf{W\ s} = \frac{K_m}{(\tau_m * S+1)} * \mathbf{v(s)} \qquad \textbf{(4.6)}$$

Which is the transfer function from applied voltage to velocity of the pulley cable?

Where:

- $\mathbf{K}_m$ is related to the dc-gain,
- τ_m is the mechanical time constant
- v(s) = applied voltage

Assuming that:

The motor is strong enough, and is the mechanical time constant is very small ($\tau_m \approx 0$).

$$\mathbf{W(s) = K_m * v(s)} \qquad \textbf{(4.7)}$$

$$\boldsymbol{\theta}\mathbf{(s)} = \frac{K_m}{s} * \mathbf{v(s)} \qquad \textbf{(4.8)}$$

Where:

- $\mathbf{K}_m$ is related to the dc-gain
- v(s) = applied voltage
- W(s)= velocity of the motor
- θ(s)=angular position of the motor

4.3.2Experiment and Estimation

The inertial load on the DC motors will change when the load is moved.This is due to the fact that the forces in the cables are dependent on theposition of the load. The two extreme cases for the inertial load on the DCmotor are:

• Weight of load is not connected to the DC motor

• The whole weight of the load is connected to one DC motor.

4.3.2.1 Estimation Results

W(s)= Km*v(s) **(4.9)**

θ(s) = km/S * v(s) **(4.10)**

It is desirable to have a simple model that describes the DC motor.The estimated first order transfer function model is

$$G(s) = \frac{\beta}{s+\alpha} \qquad \textbf{(4.11)}$$

System Identification method is used to estimate the coefficients (α , β) of the first order model by Appling open loop velocity feedback :

$\alpha=4/T_S$ **(4.12)**

$\beta= V_f \times\alpha$ **(4.13)**

Where:

- T_S = the settling time ,ms
- β= related to the dc-gain
- V_f= final value ,mv

4.3.2.2Experimental Results

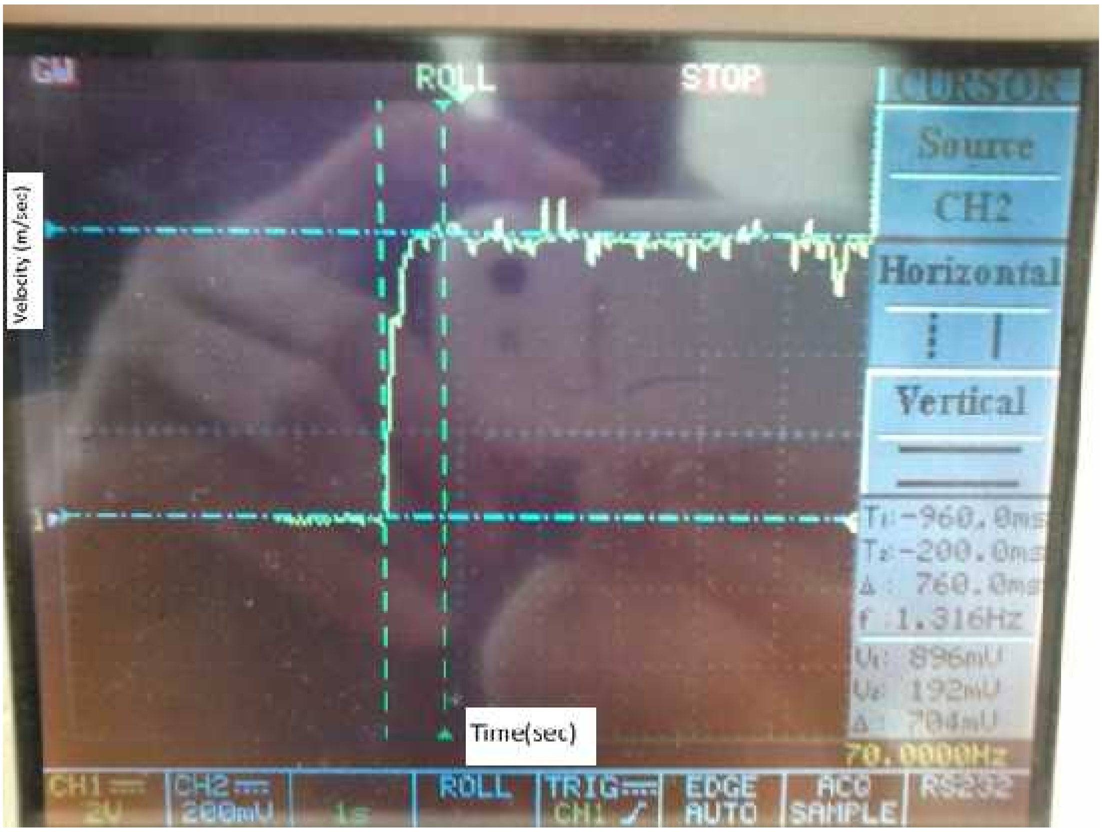


Figure (4.4) Step response for estimated DC motor model

Introducing (4.12) and (4.13) in (4.11) to get the estimated first order transfer function for motor control velocity:

$$G\ s\ = \frac{3.8}{s+5.7}$$ **(4.1٤)**

Note that the electrical pole is neglected.

The estimated transfer function for motor control position by ingrate eq(4.13)

$$G\ s\ = \frac{3.8}{s^2+5.7s}$$ **(4.1٥)**

- Designing a pid controller by sisotool in matlab to matching requirements :

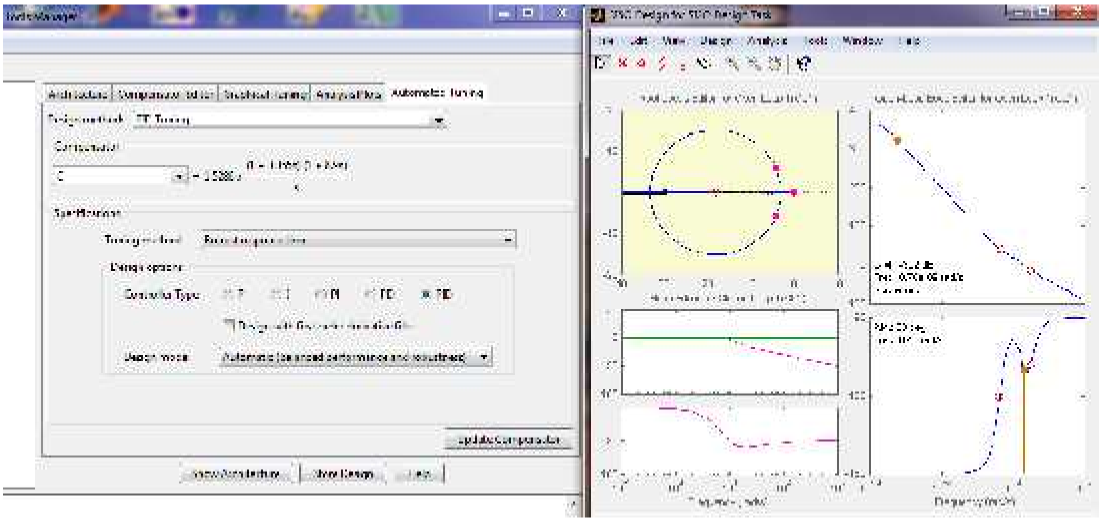
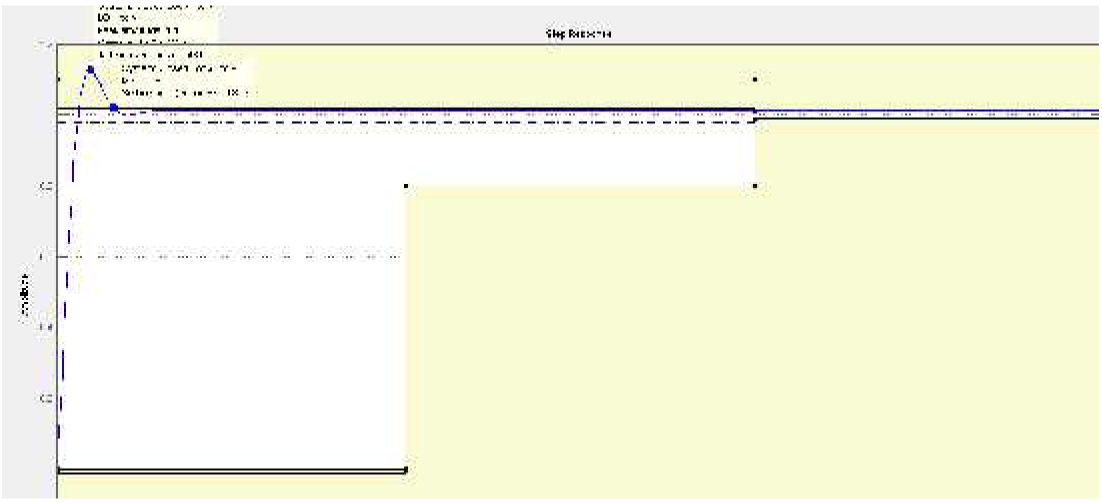


Fig (4.٥)The designed PIDcontroller for motor control position



Fig(4.٦) The simulated response of the motor control position with sisotool

4.4 controlsimulation

The objective is to track a position reference for the cable, which is the same as the position of the motor.

By control the length of three cables, to control position of the suspended object to the cables which each desire length is treats as voltage input to the PID controller to make the require calculation and getting the true position and velocity needed to each motor for driving the cables.

The length of cable which treat with motor number four

$$L_4 = \sqrt{(b-x)^2 + y^2 + z^2} \qquad (4.1٦)$$

The length of cable which treat with motor number two

$$L_2 = \sqrt{x^2 + (a-y)^2 + z^2} \qquad (4.1٧)$$

The length of cable which treat with motor number one

$$L_1 = \sqrt{x^2 + y^2 + z^2} \qquad (4.1٨)$$

There are three variable in the equation above (x,y,z) this value represent the desired position of the object which is obtained from the user ,after calculate the length of each cable they converted to the angular position to driveeach motor's drum.

The suggested control structure is simulated in Matlab :

Where:

- A = L1/r ;%A % The angular position of the pulley at motor 1
- B = L2/r; %B % The angular positionof thepulley at motor 2
- C = L4/r; %C % The angular positionof thepulley at motor 3
- $r =$ radius of drum on each motor,m

Selects a controller form in which the output is the sum of the proportional, integral, and derivative actions, weighted according to the independent gain parameters **P**, **I**, and **D**. The filter coefficient **N** sets the location of the pole in the derivative filter. For a continuous-time parallel PID controller, the transfer function is:

$$G\ S\ = P + I\,\frac{1}{s} + D\,\frac{Ns}{s+N} \qquad \textbf{(4.1٩)}$$

The controller transfer function for the current settings is displayed,as seen at Fig (4.7).

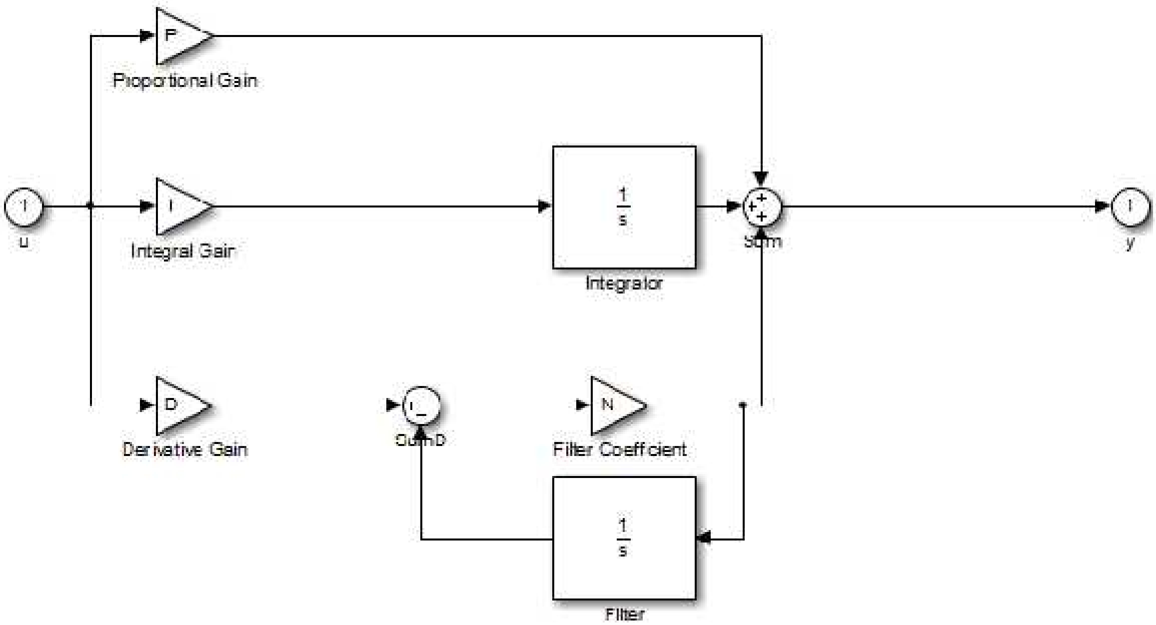


Figure (4.7) Parallel PID Controller

The designing PID controller bytuning on matlabto get the gains (P, I, D) which match the requirement of desiredresponse design, as seen at Fig (4.8).

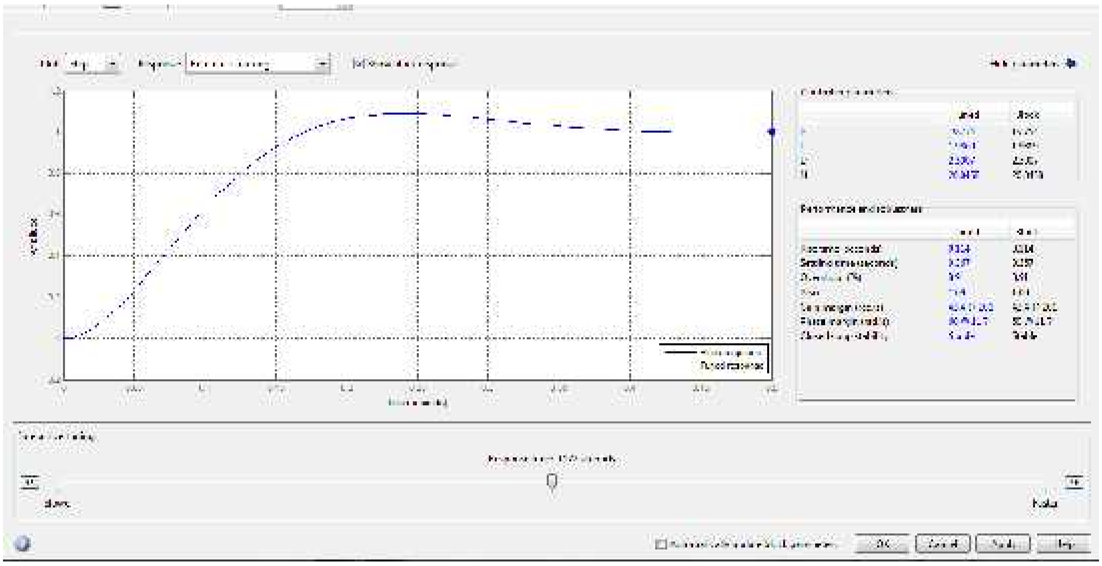


Figure (4.8) desiredPID response

Chapter five

Results

5.1 Result Simulation

The suggested control structure is set up with ”Simulink” in Matlab ,the output of the PID controller is representing the actual angular position which is desired.

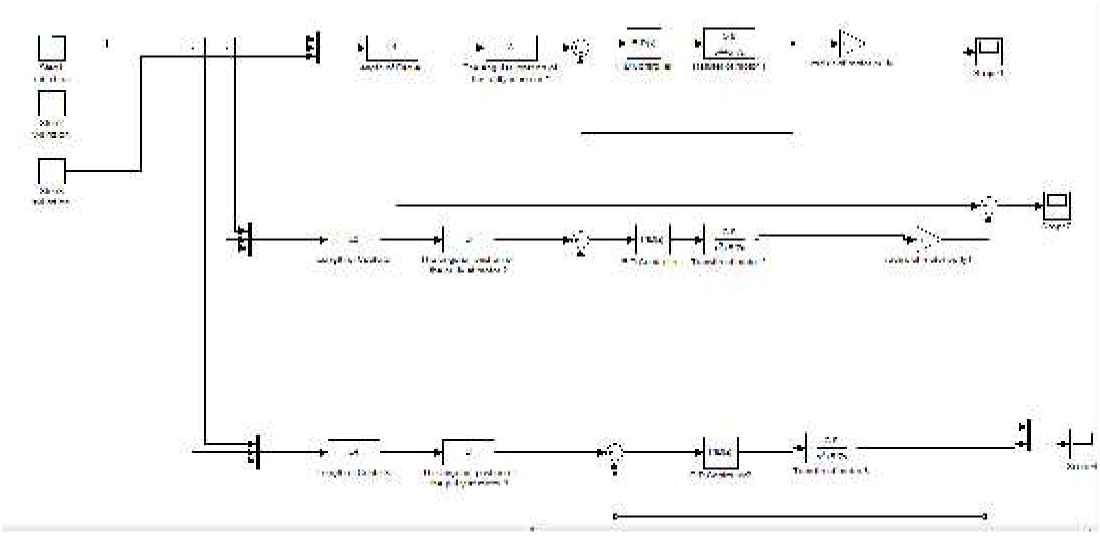


Figure (5.1) Simulation control for all over process

The first test stage is to check the response of the motor after the feedback process

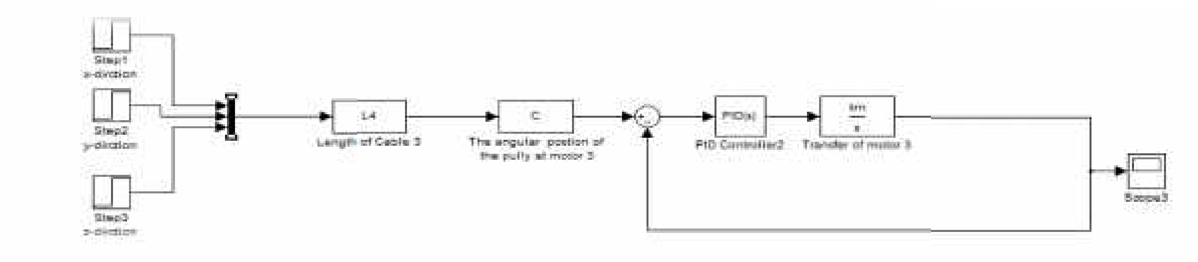


Figure (5.2) Control Simulation by Simulink model for the angular position of the motor's drum

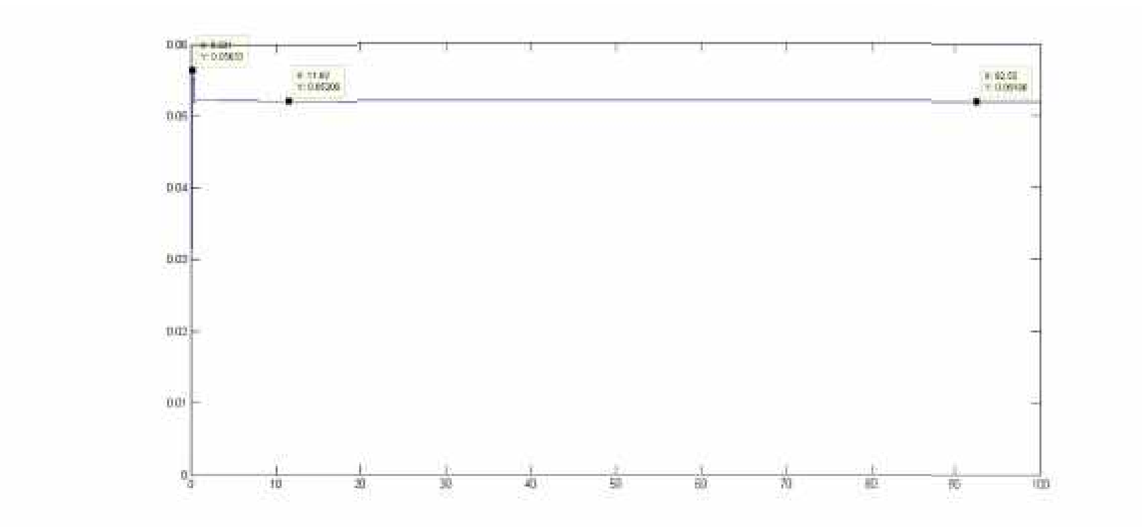


Figure (5.3)thestep response of theangular position for motor's drum

The response in the figure(5.3) is match the requirement of the PID controller design and achieves the true position which user interest.

The second test stage is to check the response oflength before and after the controller

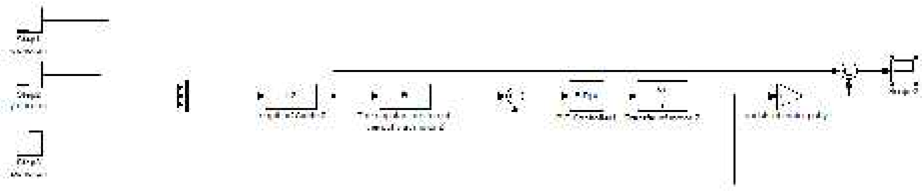


Figure (5.4) Control Simulation by Simulink model for thelength of cable in close loop strategies

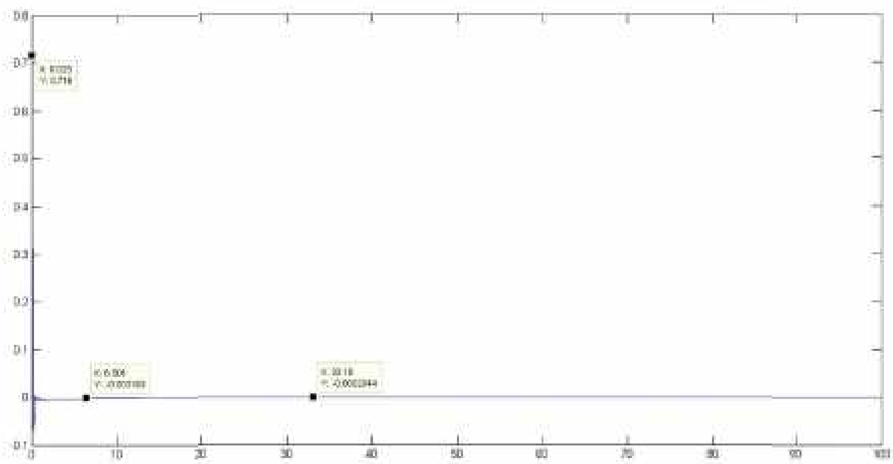


Figure (5.5) cable’s length step response before and after controller

The result ensure that there is no error in actual and desired length of the cableas seen in figure (5.5) ,therefore the input position from the user by terms of (x,y,z) is the same to the actualposition .

The third test stage is to check the response of the angular position of motor’s drum

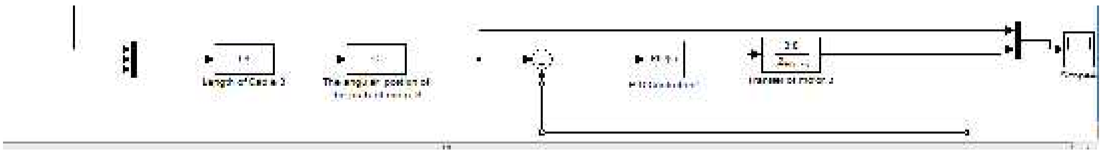


Figure (5.6) Control Simulation by Simulink model for the angular position of the motor’s drum

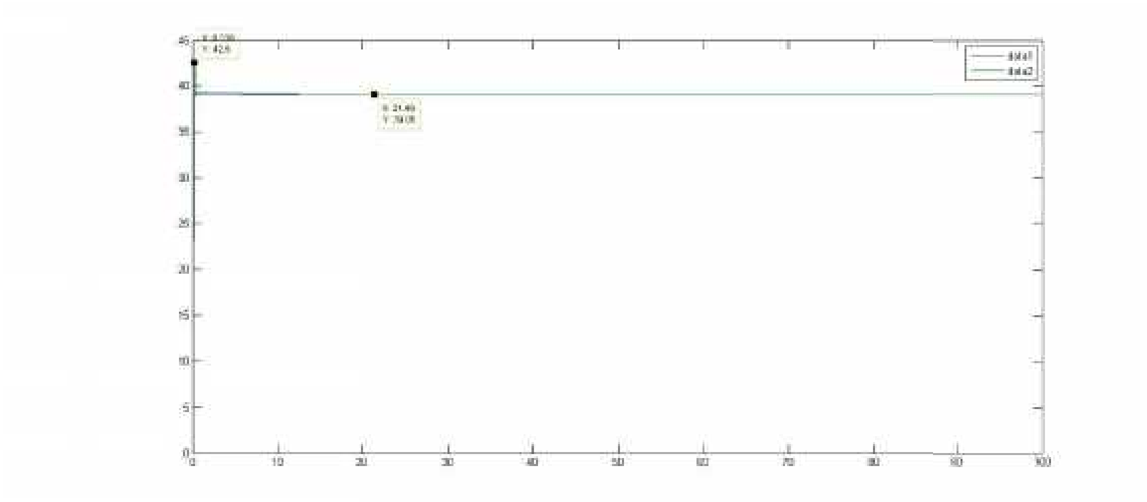


Figure (5.7)thestep response of the angular position for motor’s drum

The responses in the figure(5.7) are matching the requirement design of the PID controller and seen the same response result between the reference position and the actual true position which user interest.

5.2 Implementation result

5.2.1Communicating with Arduino Mega 2560

5.2.1.1Introduction

Arduino is an open-source microcontroller board, with an associated development environment.

What is Arduino good for?

- Basically any Mechatronics project requiring sensing and acting, provided that computational requirements are not too high (e.g. can't do image processing with it)
- Ideal for undergraduate/graduate Mechatronics Labs and Projects
- There is a very large community of people using it for all kind of projects, and a very lively forum where it is possible to get timely support

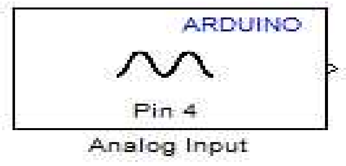
to Communicating Arduino Mega 2560 with matlab (2013a) we need Simulink Support Package for Arduino Hardware enables you to monitor and tune algorithms running on Arduino Mega 2560 board from the same Simulink models from which you developed the algorithms.

Arduino IO Package: Used to perform analog and digital input and output as well as motor control from the MATLAB command line.

Arduino Target: Used to compile and download Simulink code directly to
The Arduino board

5.2.1.2Analog & Digital IO that use in model control

Analog input block



Measure the voltage of an analog pin relative to the analog input reference voltage on the Arduino hardware Output the measurement as a 10-bit value that ranges from 0 to 1023.If the measured voltage equals the ground voltage,the block outputs 0.If the measured voltage equals the analog referencevoltage, the block outputs 1023.The default value of the analog input reference voltage is 0to 5 V

Pulse width modulation plock

Use pulse-width modulation (PWM) to change the duty-cycle of square-wave pulses output by a PWM pin on the Arduino hardware. PWM enables a digital output to provide a range of different power levels, similar to that of an analog output.The value sent to the block input determines the width of thesquare wave, called duty-cycle, that the target hardware outputs on the specified PWM pin. The range of valid outputs is 0 to 255.

Digital input block

Get the logical value of a digital pin on the Arduinohardware:If the logical value of the digital pin is LOW, the block outputs 0.If the logical value of the digital pin is HIGH, the block outputs

Digital output block

Set the logical value of a digital pin on the Arduino hardware:

- Sending 1 to the block input sets the logical value of the digital pin HIGH to 5 V or 3.3 V, depending on the board voltage.
- Sending 0 to the block input sets the logical value of the digital pin LOW to 0 V.The block input inherits the data type of the upstream block, and internally converts it to boolean.

5.2.2Model control implementation for one unit of DC motor

This model consist from a PID controller and some of gains and Arduino input output blocks and step input ,so when apply a step input for this model this value of the step go to the PID controller and after that to the arduino input/output pins and to the motor to drive it, as seen in figure(5.8).

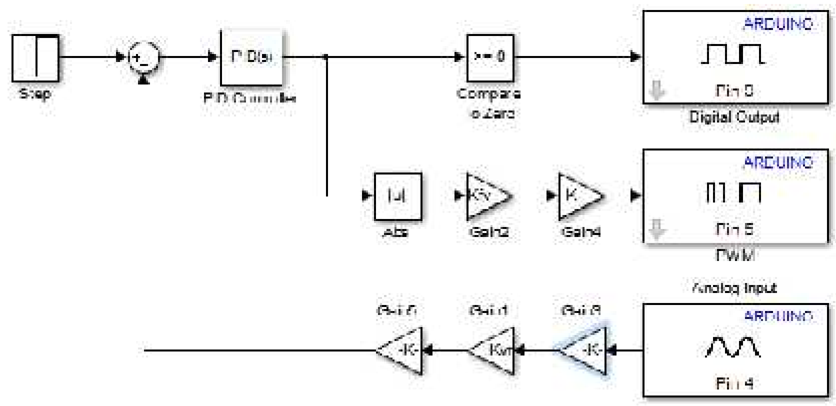


Figure (5.8) DC control model with aurdion

Description of the gains

- Gain3: Knv=5/1024; %To convert from 10bit number to voltage
- Gain1: Kvr=(5/10)*(2*pi); %To convert from voltage to radian
- Gain5: Krm=1; %To convert from radian to meter
- Gain4: Kvd=256/5; %To convert from voltage to duty cycle
- Gain2: Kfv=1; %To convert from force to voltage

The final real control model

The final control model is describe the kind of control is used and the input of the system and the output of the system and the number of bins of microcontroller which is used and the gains that convert the data, so when we apply three step input (x,y,z)is come from the user of the system and this value is substitute in the length of the cables equation (L1,L2,L3),so the value of the length cables is substract and the value of the sensor is the input for the three PID controller for three motors , as seen in figure(5.9).

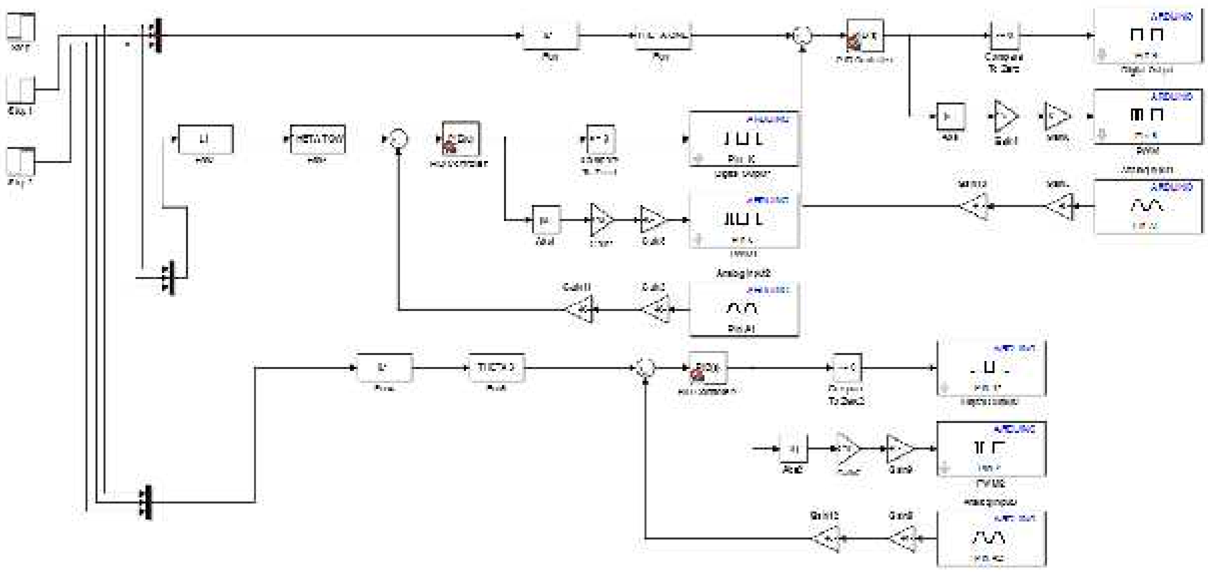
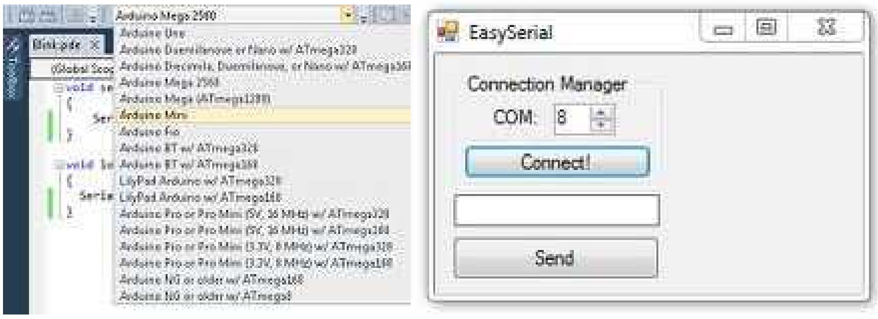


Figure (5.9) final real control model

5.2.3Interface Result

The software interface which is used to control the model is a combination of a C Sharpe interface with visual studio 2010 which runs a real-time interfacing. In the current setup of the visual studio interface.The experimental setup of the system was done according the simplified model. All parameters and the reference trajectory were the same as in the simulation part



Chapter six

Conclusion

The main problem with the identification of the model for the motors was that the motors were very fast. This meant that the software interfaced connected to to motors could not sample fast enough, without inducing aliasing of the measurement data. This meant that the identified models were not totally reliable, and also that it would be hard to control the motors. In the software algorithm of the controller there is limitation to sample the small values of voltage because of consider that the sampling time is treat with the derivative controller which mean having a big value of derivative gain, therefore there is some reading error from the feedback sensor on the motor.So, Due to the characteristics of the model of the motor, the controller needed to amplify high frequencies a lot.

Recommendation

It is possible for anyone who wants to project developmentAvoid the following problemswhich mention in conclusion and work to improve the mechanical and electrical systems in the overallstricter.While taking into account the stretch in the cables and may be addingGPS system to Suspended object to facilitate locate object in workspace.

The simulations of the motor showed that the control structure was a bit sensitive to noise, this might be something one can improve upon A better approach would have been to identify one model for the motor with only the pulley connected, since theeffect of the load is canceled by the feed forward term in the controller for the reduced bandwidth design.

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http://en.wikipedia.org/wiki/Gas_metal_arc_welding[8]

[9] http://en.wikipedia.org/wiki/stepper_motor

[10] http://en.wikipedia.org/wiki/Dc_motors

[11]http://en.wikipedia.org/wiki/poteniometer

[12]http://en.wikipedia.org/wiki/Control theory

1.6 The Schedule Time

Table(1.1) the schedule time

Tasks / #of weeks	Simulation & testing	Building the apparatus	Mechanical design	Electrical design	Control design & programming	Mathematical model	proposal	Collection data	Selection the idea of project
1									
2									
3									
4									
5									
6									
7									
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Appendix A

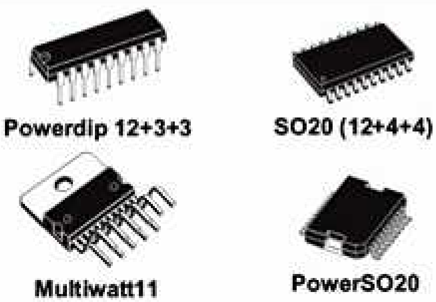
Appendix B

L6201
L6202 - L6203

DMOS FULL BRIDGE DRIVER

- SUPPLY VOLTAGE UP TO 48V
- 5A MAX PEAK CURRENT (2A max. for L6201)
- TOTAL RMS CURRENT UP TO L6201: 1A; L6202: 1.5A; L6203/L6201PS: 4A
- $R_{DS\,(ON)}$ 0.3 Ω (typical value at 25 °C)
- CROSS CONDUCTION PROTECTION
- TTL COMPATIBLE DRIVE
- OPERATING FREQUENCY UP TO 100 KHz
- THERMAL SHUTDOWN
- INTERNAL LOGIC SUPPLY
- HIGH EFFICIENCY

MULTIPOWER BCD TECHNOLOGY

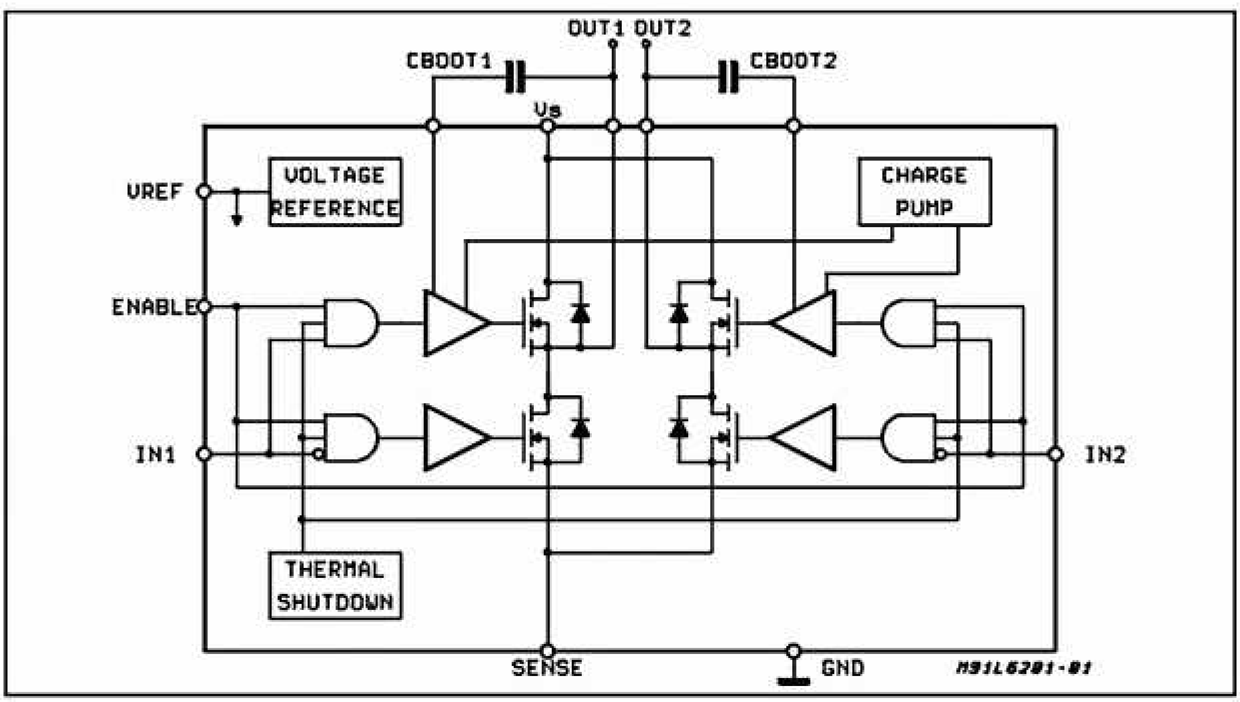


ORDERING NUMBERS:
L6201 (SO20)
L6201PS (PowerSO20)
L6202 (Powerdip18)
L6203 (Multiwatt)

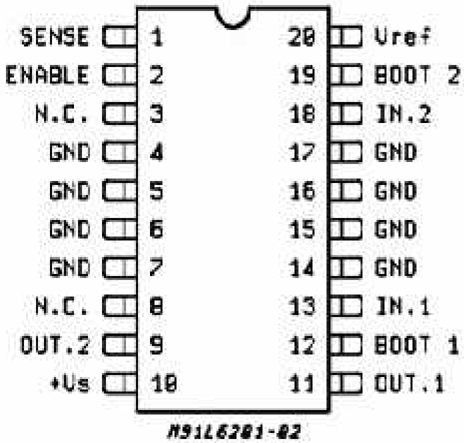
DESCRIPTION

The I.C. is a full bridge driver for motor control applications realized in Multipower-BCD technology which combines isolated DMOS power transistors with CMOS and Bipolar circuits on the same chip. By using mixed technology it has been possible to optimize the logic circuitry and the power stage to achieve the best possible performance. The DMOS output transistors can operate at supply voltages up to 42V and efficiently at high switching speeds. All the logic inputs are TTL, CMOS and μC compatible. Each channel (half-bridge) of the device is controlled by a separate logic input, while a common enable controls both channels. The I.C. is mounted in three different packages.

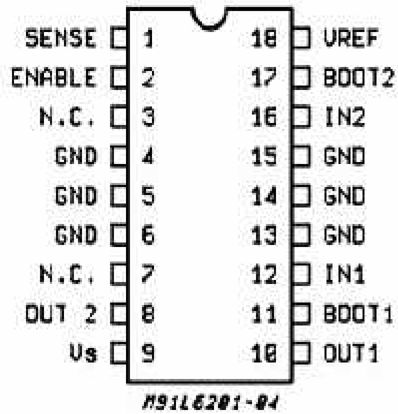
BLOCK DIAGRAM



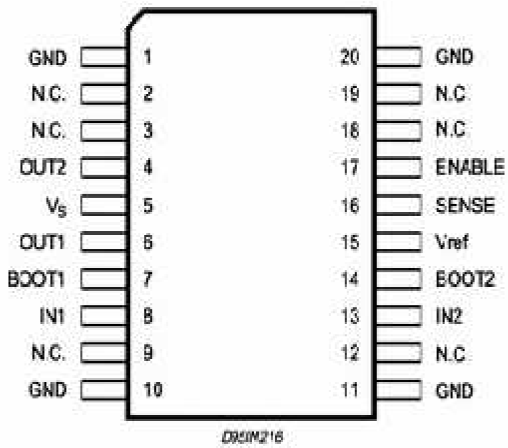
PIN CONNECTIONS (Top view)



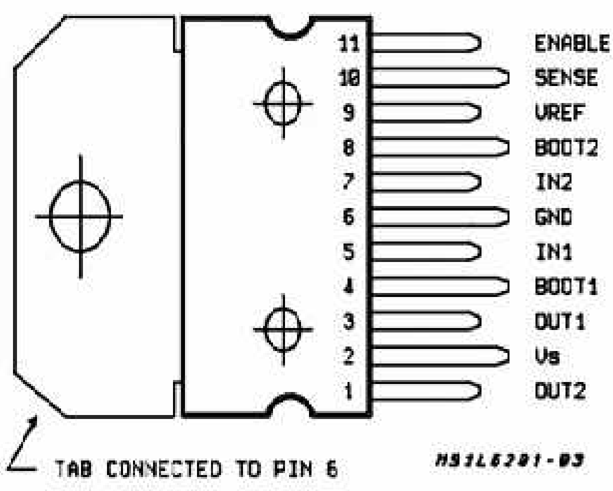
SO20



POWERDIP



PowerSO20



MULTIWATT11

THERMAL DATA

Symbol	Parameter		Value				Unit
			L6201	L6201PS	L6202	L6203	
$Rth_{j\text{-}pins}$	Thermal Resistance Junction-pins	max	15	–	12	–	°C/W
$Rth_{j\text{-}case}$	Thermal Resistance Junction Case	max.	–	–	–	3	°C/W
$Rth_{j\text{-}amb}$	Thermal Resistance Junction-ambient	max.	85	13 (*)	60	35	°C/W

(*) Mounted on aluminium substrate.

ELECTRICAL CHARACTERISTICS (Refer to the Test Circuits; T_j = 25°C, V_S = 42V, V_{sens} = 0, unless otherwise specified).

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_s	Supply Voltage		12	36	48	V
V_{ref}	Reference Voltage	I_{REF} = 2mA		13.5		V
I_{REF}	Output Current				2	mA
I_s	Quiescent Supply Current	EN = H V_{IN} = L EN = H V_{IN} = H I_L = 0 EN = L (Fig. 1,2,3)		10 10 8	15 15 15	mA mA mA
f_c	Commutation Frequency (*)			30	100	KHz
T_j	Thermal Shutdown			150		°C
T_d	Dead Time Protection			100		ns

TRANSISTORS

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
OFF						
I_{DSS}	Leakage Current	Fig. 11 V_s = 52 V			1	mA
ON						
R_{DS}	On Resistance	Fig. 4,5		0.3	0.55	Ω
$V_{DS(ON)}$	Drain Source Voltage	Fig. 9 I_{DS} = 1A **L6201** I_{DS} = 1.2A **L6202** I_{DS} = 3A **L6201PS/03**		0.3 0.36 0.9		V V V
V_{sens}	Sensing Voltage		– 1		4	V

SOURCE DRAIN DIODE

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_{sd}	Forward ON Voltage	Fig. 6a and b I_{SD} = 1A **L6201** EN = L I_{SD} = 1.2A **L6202** EN = L I_{SD} = 3A **L6201PS/03** EN = L		0.9 (**) 0.9 (**) 1.35(**)		V V V
t_{rr}	Reverse Recovery Time	$\frac{dif}{dt}$ = 25 A/µs I_F = 1A L6201 I_F = 1.2A L6202 I_F = 3A L6203		300		ns
t_{fr}	Forward Recovery Time			200		ns

LOGIC LEVELS

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$V_{IN\,L}$, $V_{EN\,L}$	Input Low Voltage		– 0.3		0.8	V
$V_{IN\,H}$, $V_{EN\,H}$	Input High Voltage		2		7	V
$I_{IN\,L}$, $I_{EN\,L}$	Input Low Current	V_{IN}, V_{EN} = L			–10	µA
$I_{IN\,H}$, $I_{EN\,H}$	Input High Current	V_{IN}, V_{EN} = H		30		µA

THERMAL DATA

Symbol	Parameter		Value				Unit
			L6201	L6201PS	L6202	L6203	
$Rth_{j\text{-}pins}$	Thermal Resistance Junction-pins	max	15	–	12	–	°C/W
$Rth_{j\text{-}case}$	Thermal Resistance Junction Case	max.	–	–	–	3	°C/W
$Rth_{j\text{-}amb}$	Thermal Resistance Junction-ambient	max.	85	13 (*)	60	35	°C/W

(*) Mounted on aluminium substrate.

ELECTRICAL CHARACTERISTICS (Refer to the Test Circuits; T_j = 25°C, V_S = 42V, V_{sens} = 0, unless otherwise specified).

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_s	Supply Voltage		12	36	48	V
V_{ref}	Reference Voltage	I_{REF} = 2mA		13.5		V
I_{REF}	Output Current				2	mA
I_s	Quiescent Supply Current	EN = H V_{IN} = L EN = H V_{IN} = H I_L = 0 EN = L (Fig. 1,2,3)		10 10 8	15 15 15	mA mA mA
f_c	Commutation Frequency (*)			30	100	KHz
T_j	Thermal Shutdown			150		°C
T_d	Dead Time Protection			100		ns

TRANSISTORS

OFF						
I_{DSS}	Leakage Current	Fig. 11 V_s = 52 V			1	mA
ON						
R_{DS}	On Resistance	Fig. 4,5		0.3	0.55	Ω
$V_{DS(ON)}$	Drain Source Voltage	Fig. 9 I_{DS} = 1A **L6201** I_{DS} = 1.2A **L6202** I_{DS} = 3A **L6201PS/03**		0.3 0.36 0.9		V V V
V_{sens}	Sensing Voltage		– 1		4	V

SOURCE DRAIN DIODE

V_{sd}	Forward ON Voltage	Fig. 6a and b I_{SD} = 1A **L6201** EN = L I_{SD} = 1.2A **L6202** EN = L I_{SD} = 3A **L6201PS/03** EN = L		0.9 (**) 0.9 (**) 1.35(**)		V V V
t_{rr}	Reverse Recovery Time	$\frac{dif}{dt}$ = 25 A/µs I_F = 1A L6201 I_F = 1.2A L6202 I_F = 3A L6203		300		ns
t_{fr}	Forward Recovery Time			200		ns

LOGIC LEVELS

$V_{IN\,L}$, $V_{EN\,L}$	Input Low Voltage		– 0.3		0.8	V
$V_{IN\,H}$, $V_{EN\,H}$	Input High Voltage		2		7	V
$I_{IN\,L}$, $I_{EN\,L}$	Input Low Current	V_{IN}, V_{EN} = L			–10	µA
$I_{IN\,H}$, $I_{EN\,H}$	Input High Current	V_{IN}, V_{EN} = H		30		µA