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Mechanical Engineering Department

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

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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

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إهداء

الى من ارضعني الحب و الحنان

الى رمز الحب و بلسم اشفاء

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 و قتي و ملاذي بعد الله

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...

و قبل 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 the electrical system, computer system and mechanical system of the overall prototype in mechatronics system approach.

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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 tied to 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).

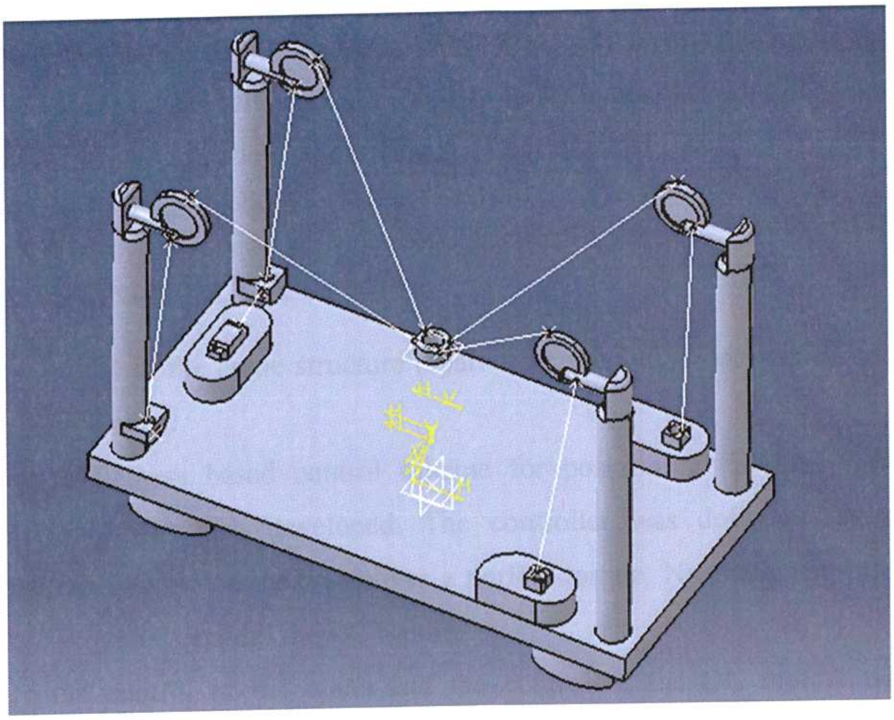


Fig (1.1) general view of DCMOCS

1.4 The 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 Conceptual Design

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.

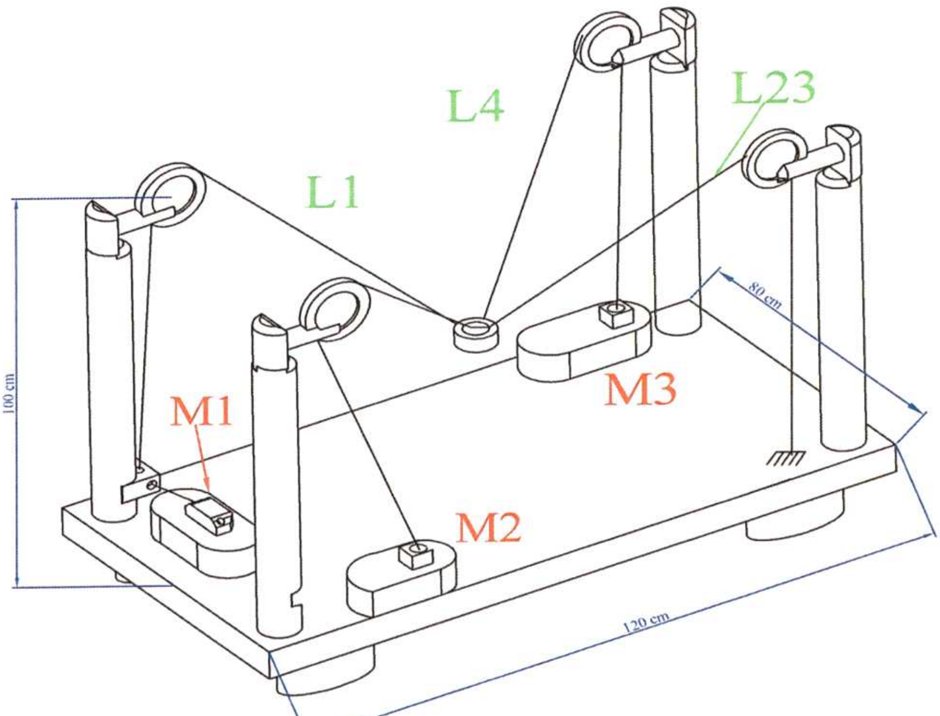
1.4.2 Mathematical Model

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:

1.5.2 Mechanical part

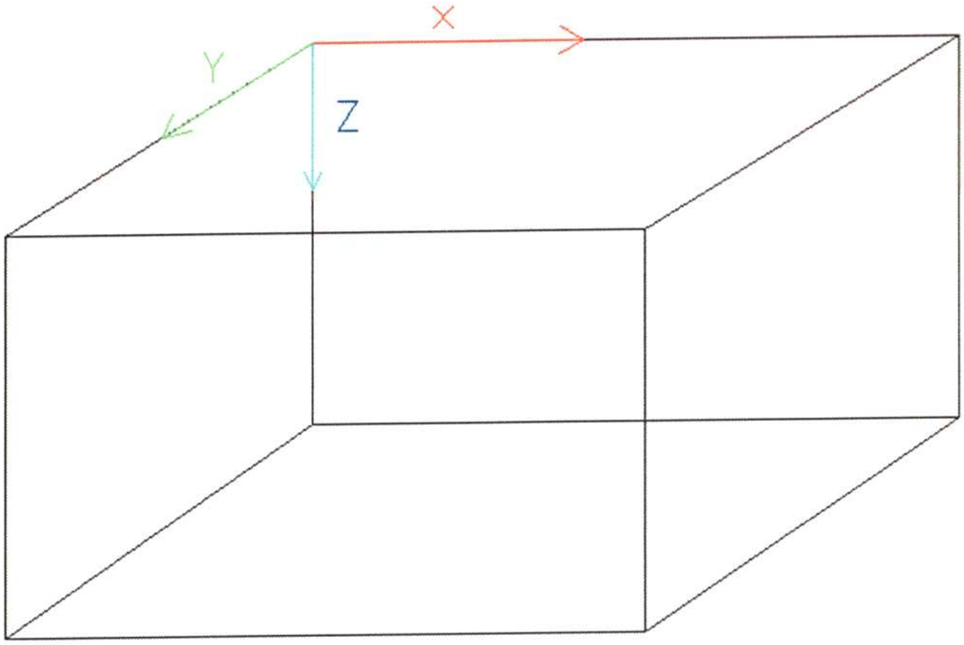
The mechanical components are:

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

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
$\ddot{L_1}$	The acceleration profiles of cable 1	m/s^2
$\dot{L_2}$	The velocity profiles of cable 2	m/s
$\ddot{L_2}$	The acceleration profiles of cable 2	m/s^2
$\dot{L_4}$	The velocity profiles of cable 4	m/s
$\ddot{L_4}$	The acceleration profiles of cable 4	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 profile of the object in x direction	m/s
$\dot{y}(t)$	The velocity profile of the object in y direction	m/s
$\dot{z}(t)$	The velocity profile of the object in z direction	m/s
$\ddot{x}(t)$	The acceleration profile of the object in x direction	m/s^2
$\ddot{y}(t)$	The acceleration profile of the object in y direction	m/s^2
$\ddot{z}(t)$	The acceleration profile 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 length density 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 turns effective of cable		Turn
N_{safty}	Around pulley for safety Maximum number of turns		Turn
L_{effmax}	Maximum number of turns effective 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.

2.1.1 Matlab

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

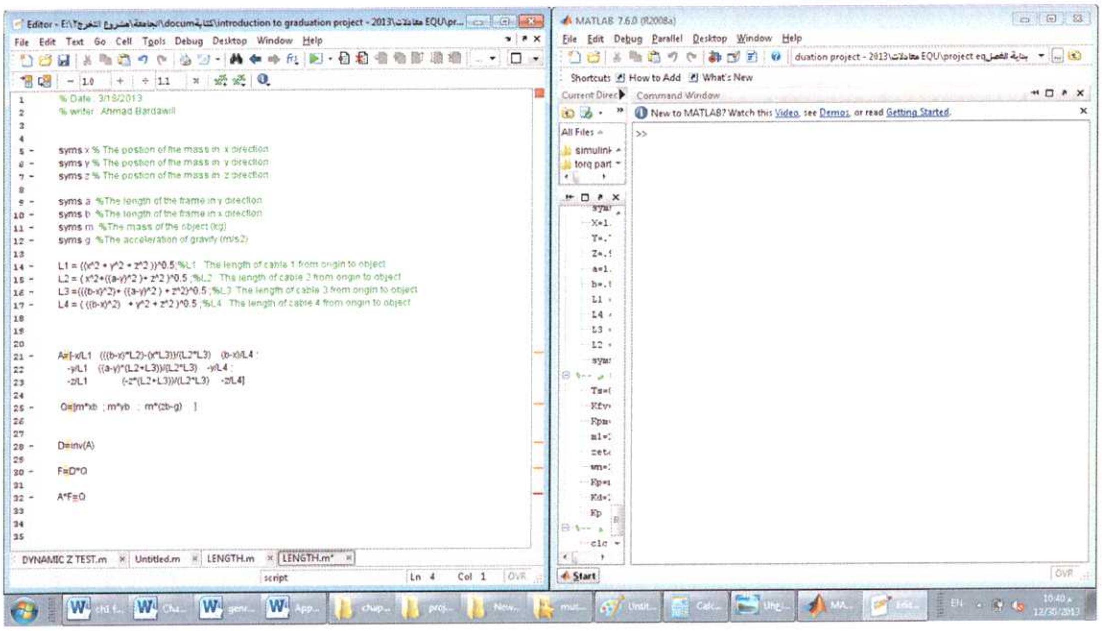


Fig (2.1) matlab window

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 no curvature 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).

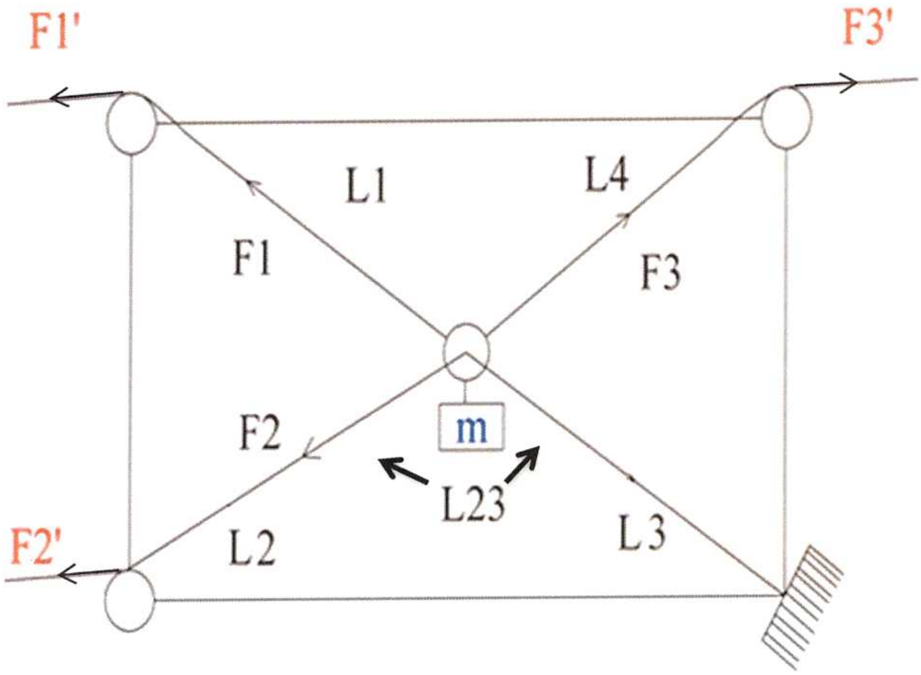


Fig.(2.2) general top view of the structure

$$L_1 = \sqrt{x^2 + y^2 + z^2} \tag{2.1}$$

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

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

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

$$L_{23}=L_2+L_3 \tag{2.5}$$

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.

$$\sum f = ma \qquad (2.6)$$

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

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

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

$$\hat{n}f=\frac{(xn-x)\hat{\imath}}{\sqrt[2]{(xn-x)^2}}+\frac{(yn-y)\hat{\jmath}}{\sqrt[2]{(yn-y)^2}}+\frac{(zn-z)K}{\sqrt[2]{(Zn-Z)^2}} \qquad (2.9)$$

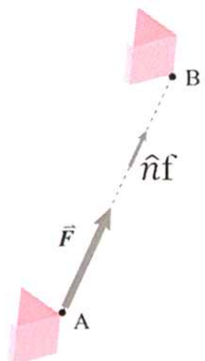


Fig.(2.3) unit vector notation

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

$$\overrightarrow{F1}=F_1*n\widehat{F_1} = \frac{-xF_1\hat{\imath}-yF_1\hat{\jmath}-zF_1\hat{k}}{L_1} \qquad (2.10)$$

$$\overrightarrow{F2}=F_2*n\widehat{F_2}=\frac{-xF_2\hat{\imath}+(a-y)F_2\hat{\jmath}-zF_2\hat{k}}{L_2}\text{, for cable 2} \qquad (2.11)$$

$$\overrightarrow{F2}=F_2*n\widehat{f2}=\frac{F_2(b-x)\hat{\imath}+F_2(a-y)\hat{\jmath}-F_2z\hat{k}}{L_3}\text{, for cable 3} \qquad (2.12)$$

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

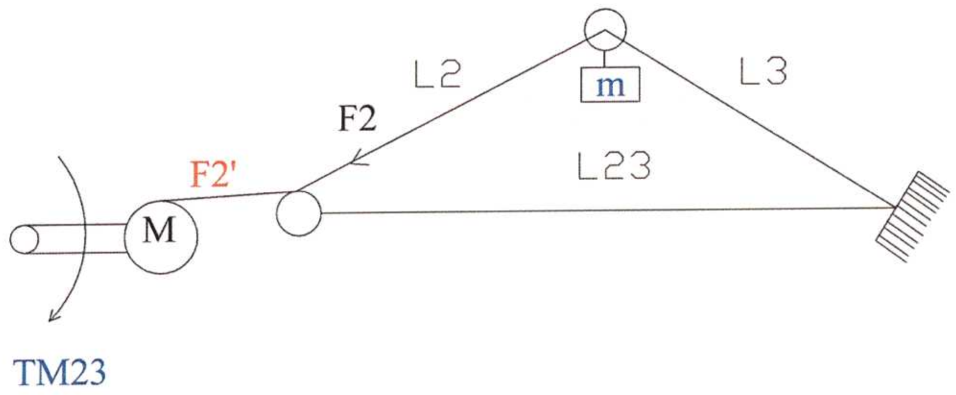


Fig. (2.4) the geometry of cable L_{23}

$$\overrightarrow{F3} = F_3 * \text{n}\ \widehat{F_3} = \frac{F_3(b-x)\hat{\imath} + F_3 y\,\hat{\jmath} - F_3 z\hat{k}}{L_4} \quad (2.13)$$

$$\text{W} = \text{mg} * \text{n}\hat{w} = \text{mg}\ \hat{k} \quad (2.14)$$

$$F_{23} = F_2 * \text{n}\widehat{F_2} + \grave{F}2 * \text{n}\widehat{\grave{f}2} = \left[\frac{(bL_2 - L_{23})}{L_2\ L_3}\right] F_{23}\ \hat{\imath} + \left[\frac{(a-y)}{L_2\ L_3}\right] F_{23}\ \hat{\jmath} - \left[\frac{zL_{23}}{L_2\ L_3}\right] F_{23}\hat{k} \quad (2.15)$$

Where:

- $\hat{n}$f = The unit vector of the force
- $\overrightarrow{F1}$ = force on cable number one, N
- $\overrightarrow{F2}$ = force on cable number two, N
- $\overrightarrow{\grave{F}2}$ = force on cable number three, N
- $\overrightarrow{F3}$ = force on cable number four, N

By MATLAB

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

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

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

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.

2.2.3 Analysis 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 affected from 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.

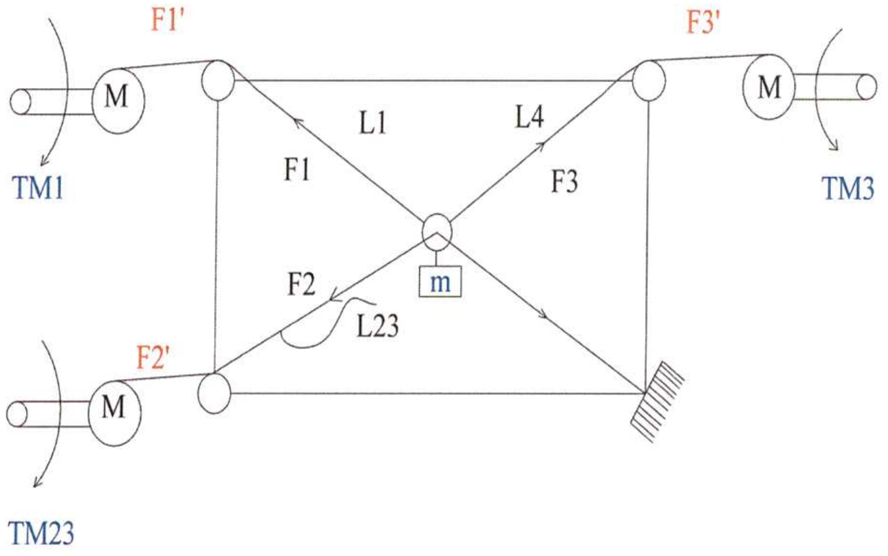


Fig.(2.5) top view of the system structure

- $\ddot{x}(t)$ = 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

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

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).

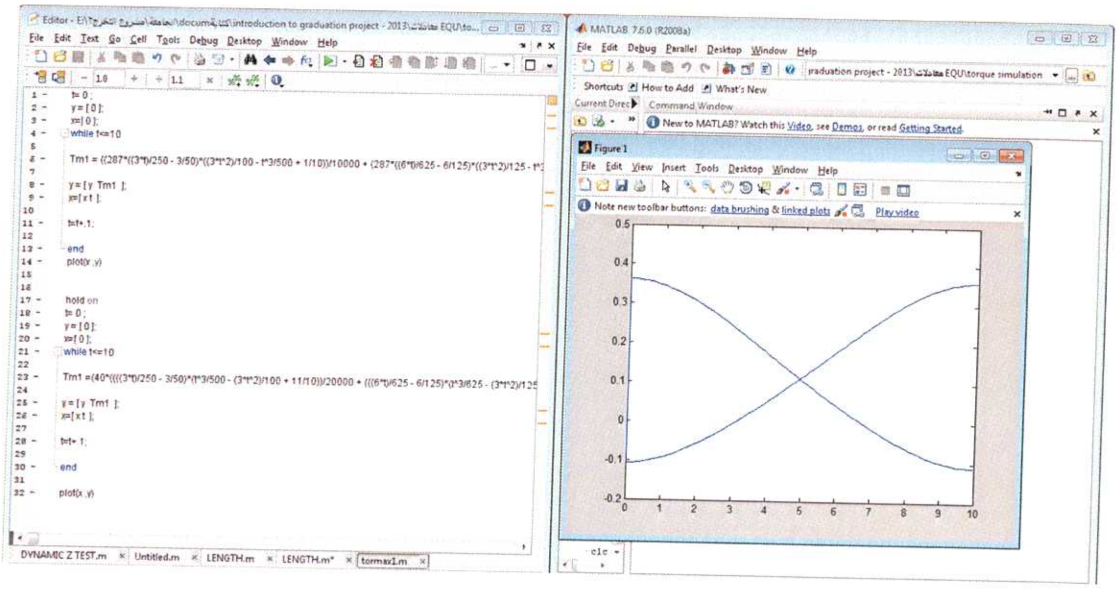


Fig (2.10) plotter matlab

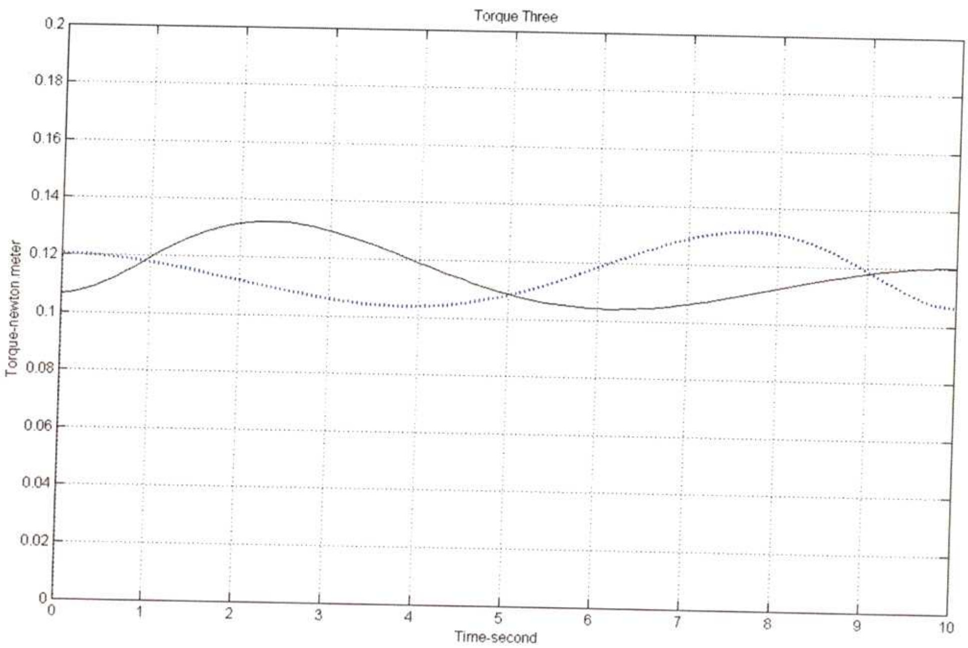


Fig.(2.11) maximum torque applied for motor one

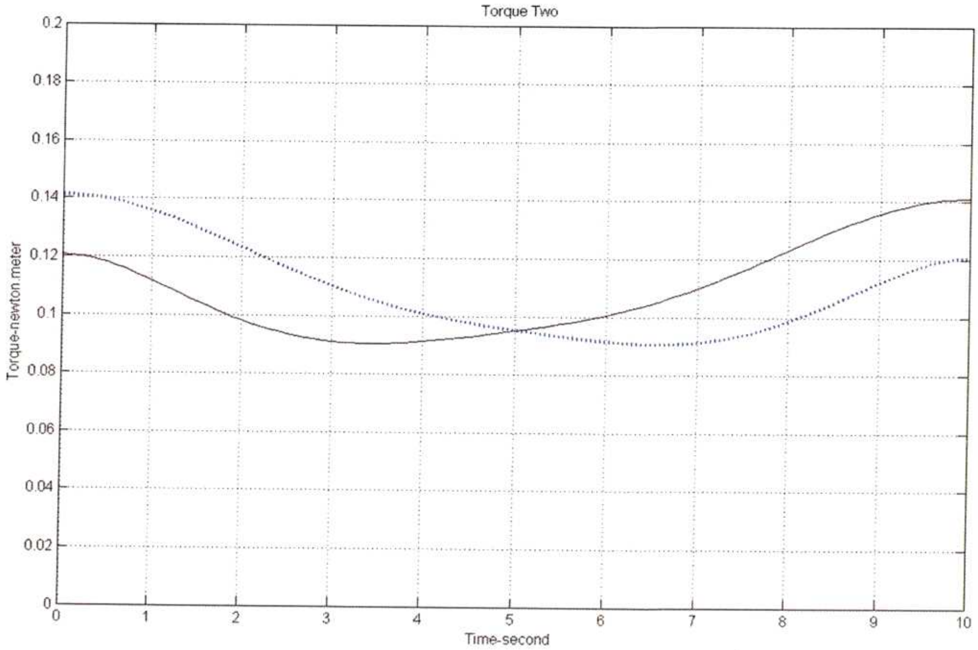


Fig.(2.12) maximum torque applied for motor two

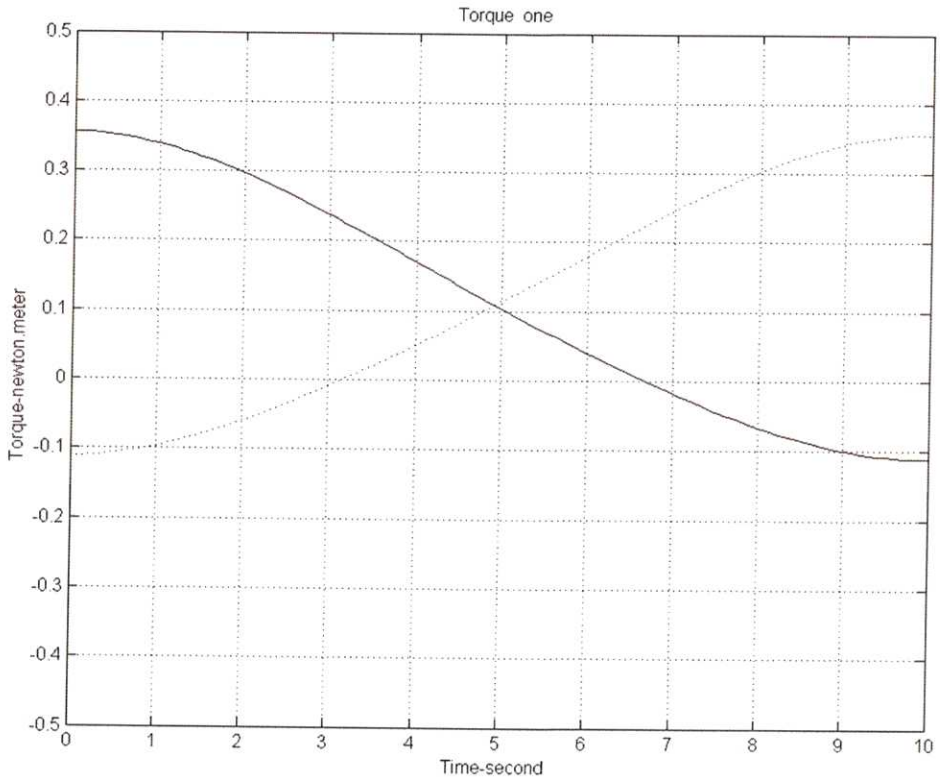


Fig.(2.13) maximum torque applied for motor three

2.5 Inspection 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:

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

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

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

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

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

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

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

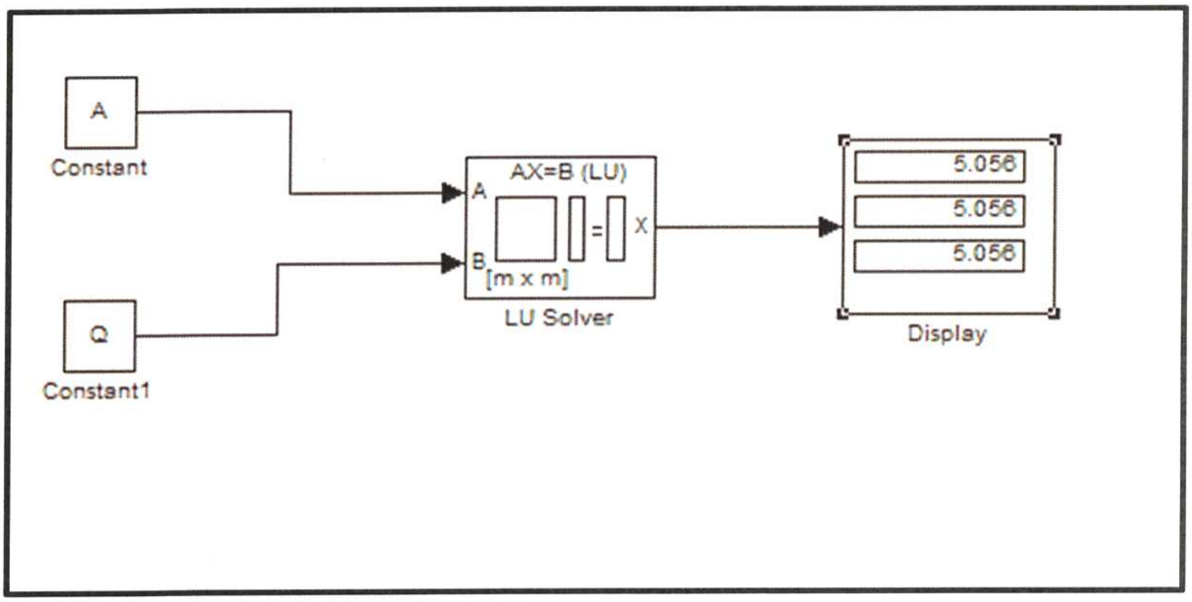


Fig.(2.17)Simulink to obtained the force matrix

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

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

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

Ztest

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

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

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

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).

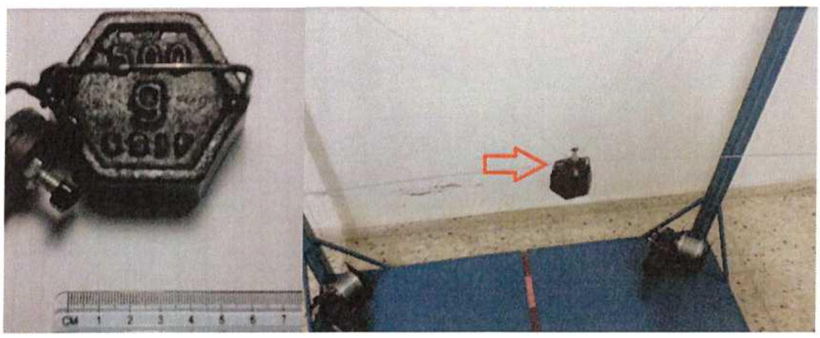


Fig (3.5) the mass

3.1.3 Cable

Many choices of kinds of cable in project with different specification as cable nailon and cable rope ,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).

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 slot which 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).

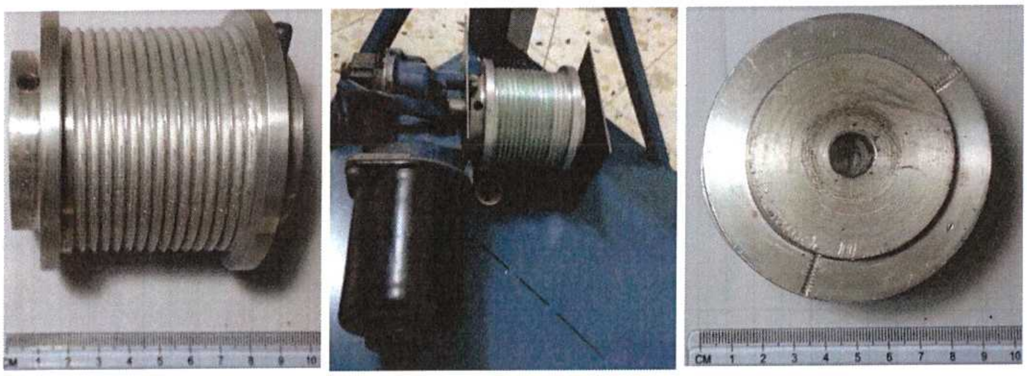


Fig (3.7) Aluminum Pulley

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 cable and smoothly motion in xy-plane , as seen at fig (3.9),the choice of prototype is number two through experimental tests, as seen at fig (3.10).

		
1	2	3

Fig (3.8) Cables pulleys choices

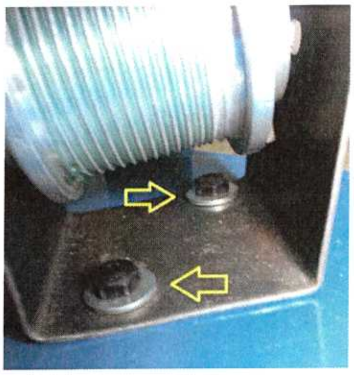


Fig (3.13. b)

Fig (3.13.c)

3.1.6 Bearing

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

3.1.7 The welding

In prototype was used 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).

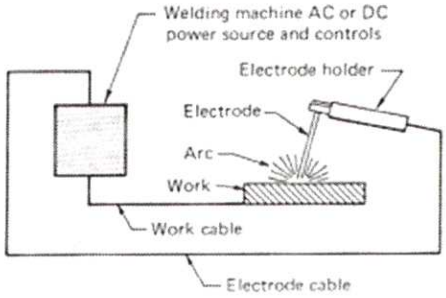


Fig (3.15) The basic arc-welding circuit

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).

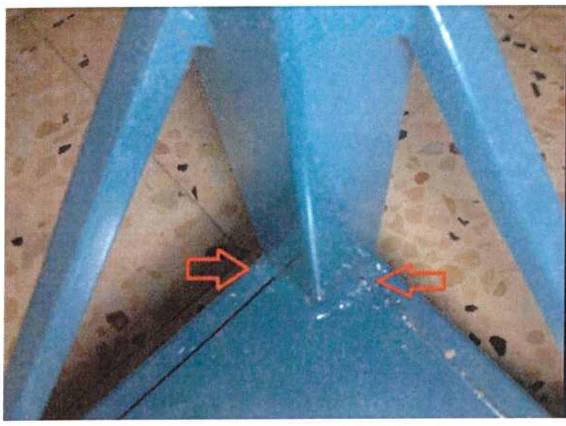


Fig (3.16)

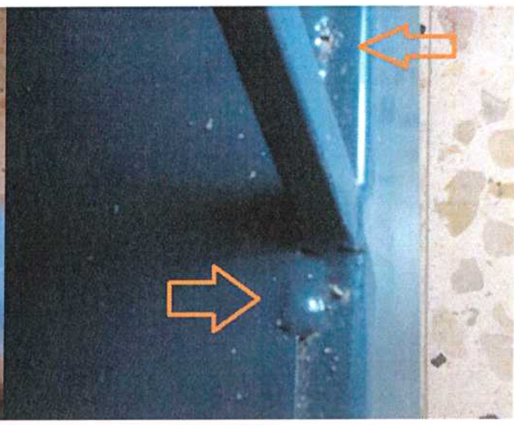


Fig (3.17)

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).

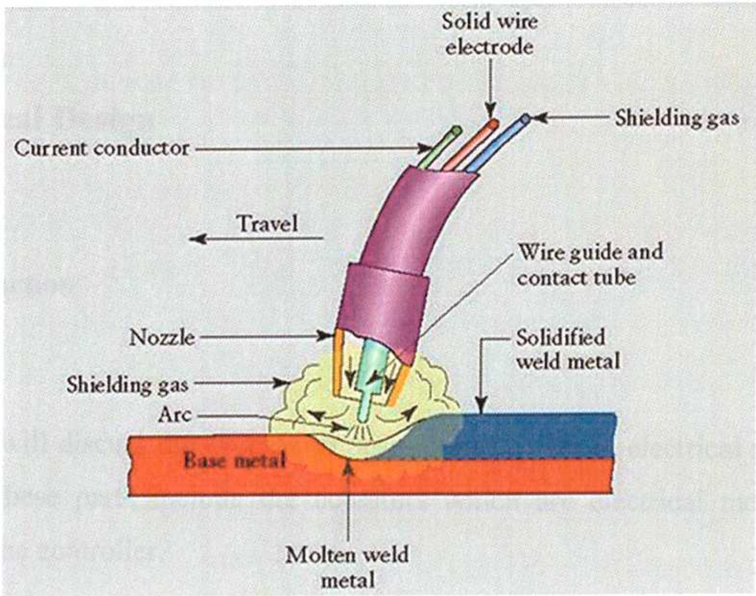


Fig (3.18) MIG welding

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

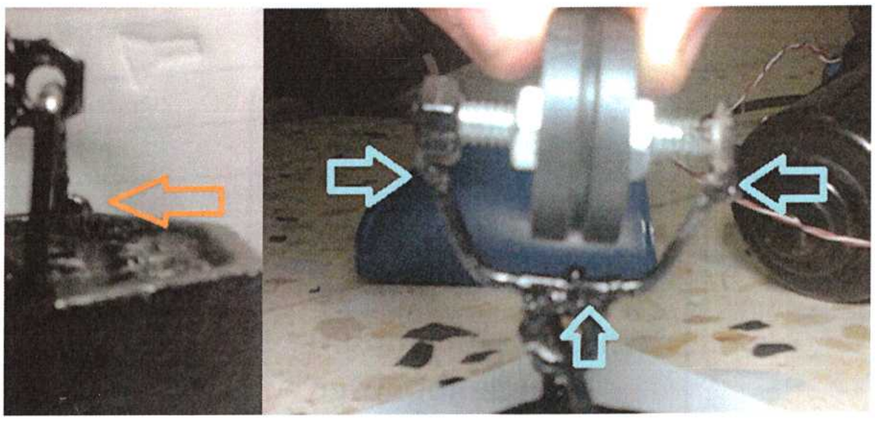


Fig (3.19) MIG welding on pulley

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 .

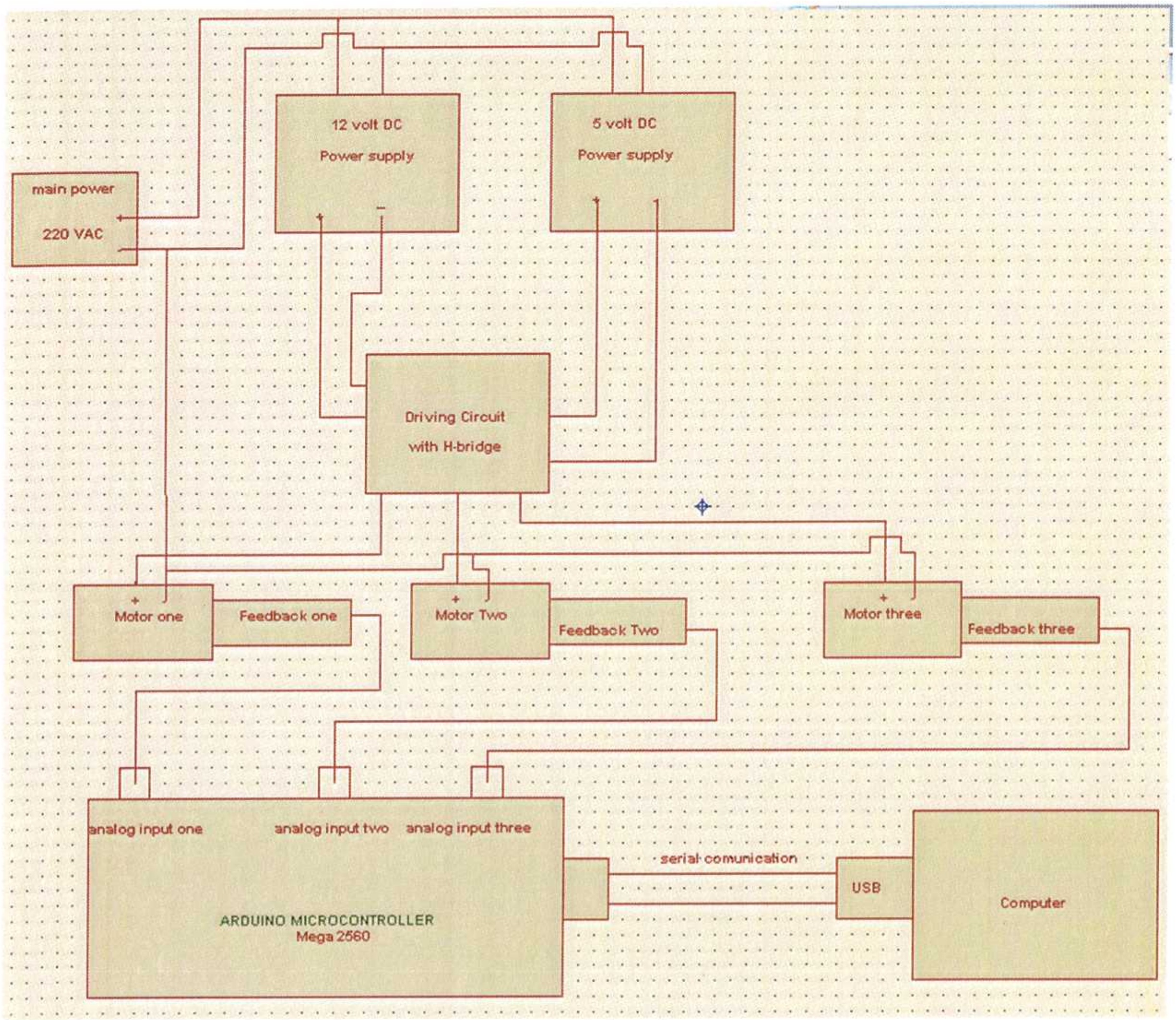


Fig (3.25) electrical wiring diagram

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 .

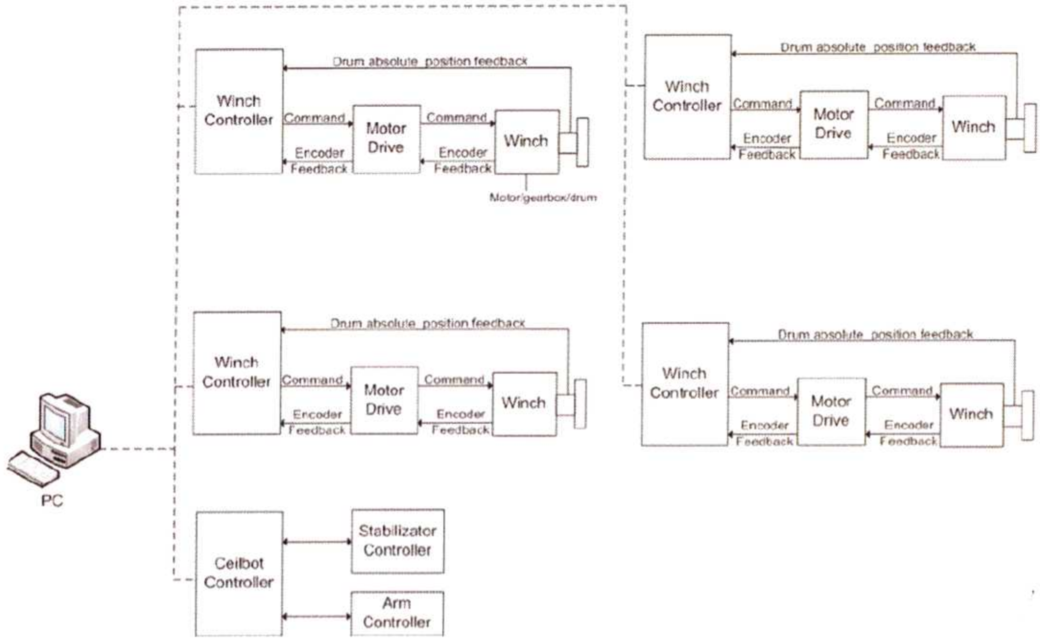


Fig (3.26) Interface diagram

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

Arduino Target:

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

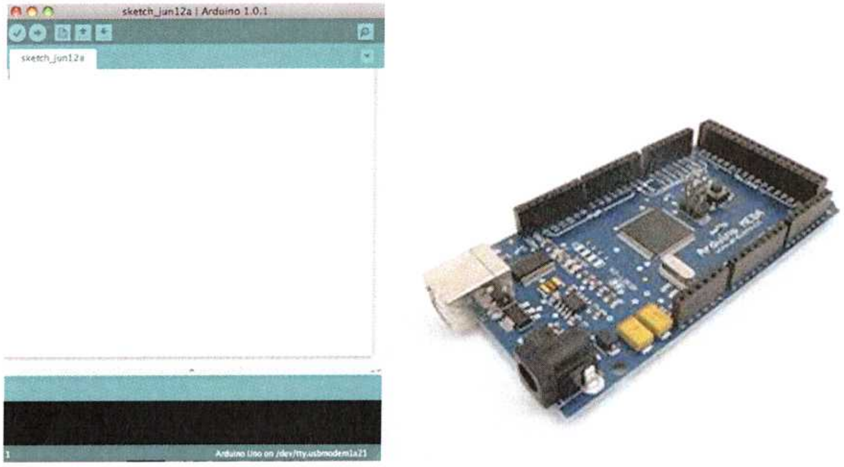


Fig (3.27). Arduino Target

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] .

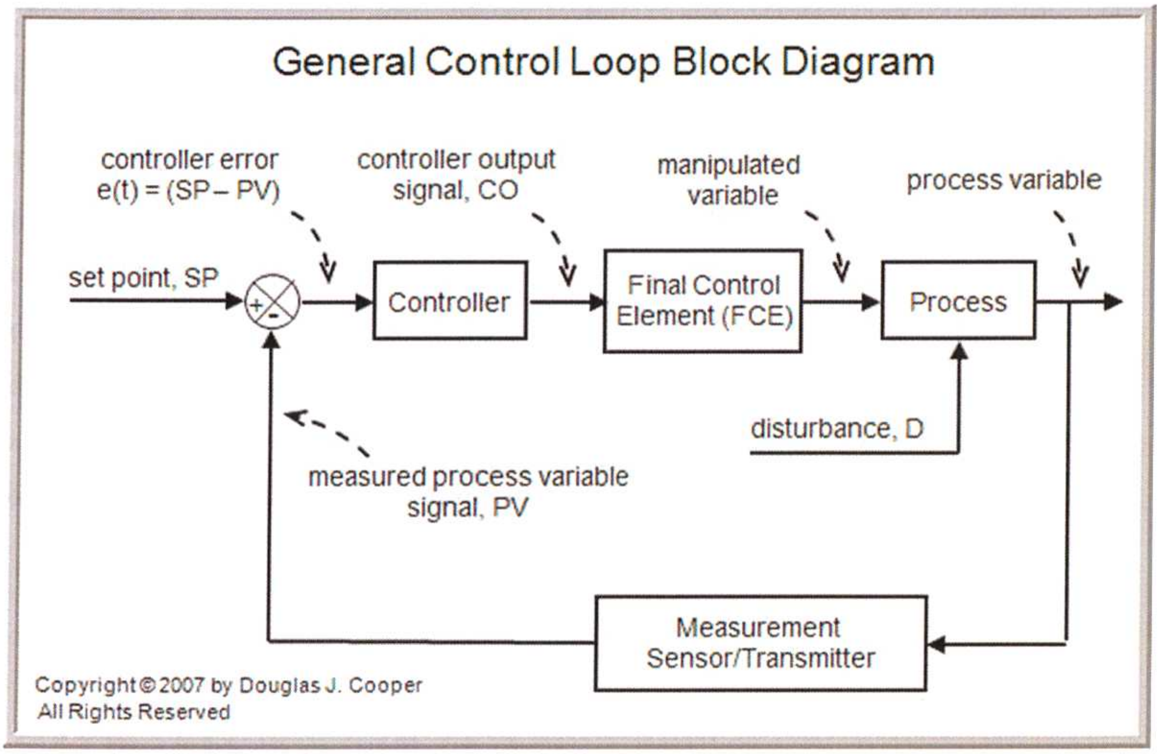


Figure (4.1) General control loop

4.3.2.2 Experimental Results

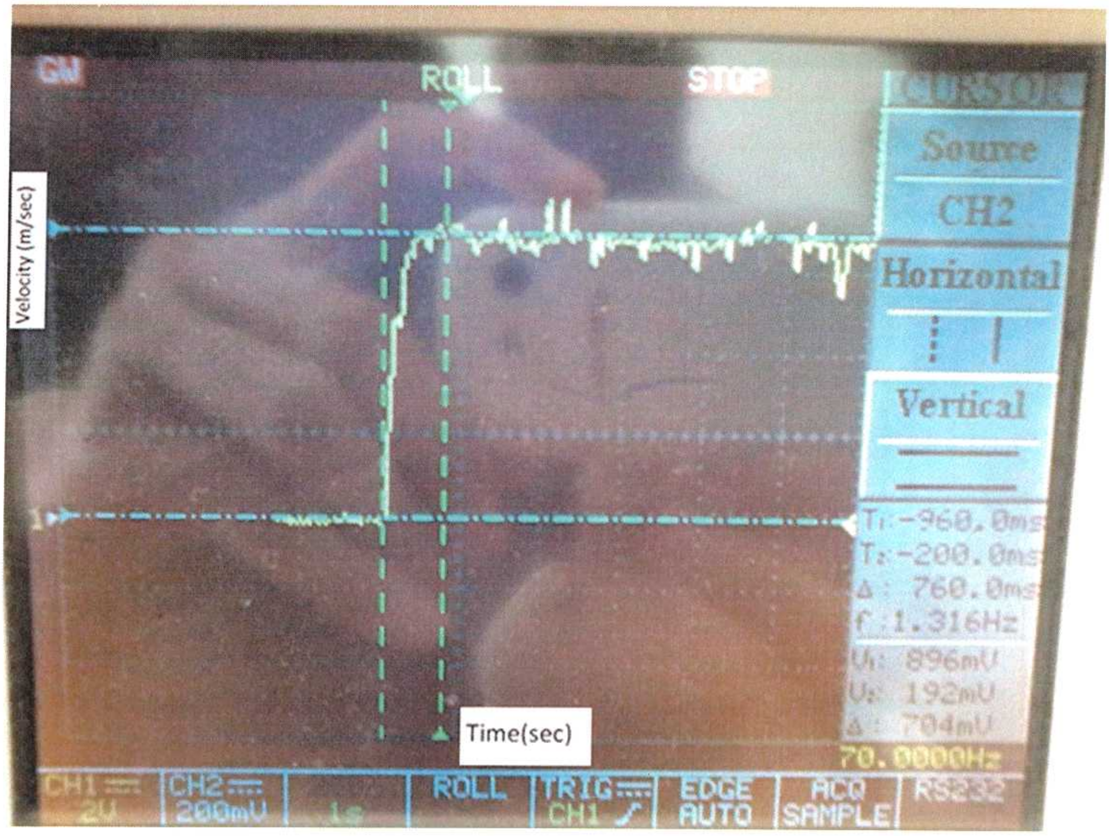


Figure (4.4) Step response for estimated DC motor model

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

$$G(s) = \frac{3.8}{s+5.7} \quad \textbf{(4.14)}$$

Note that the electrical pole is neglected.

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

$$G(s) = \frac{3.8}{s^2+5.7s} \quad \textbf{(4.15)}$$

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

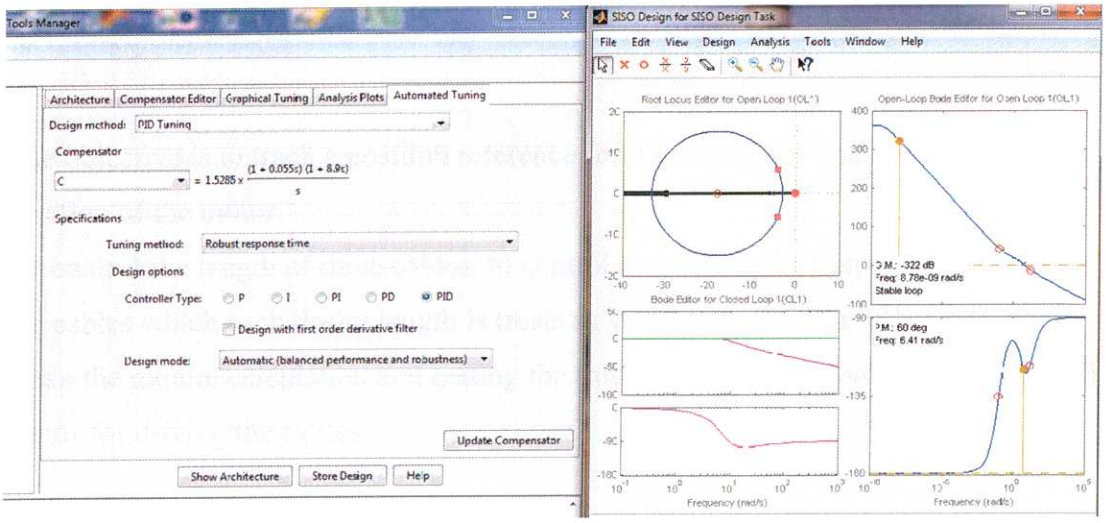
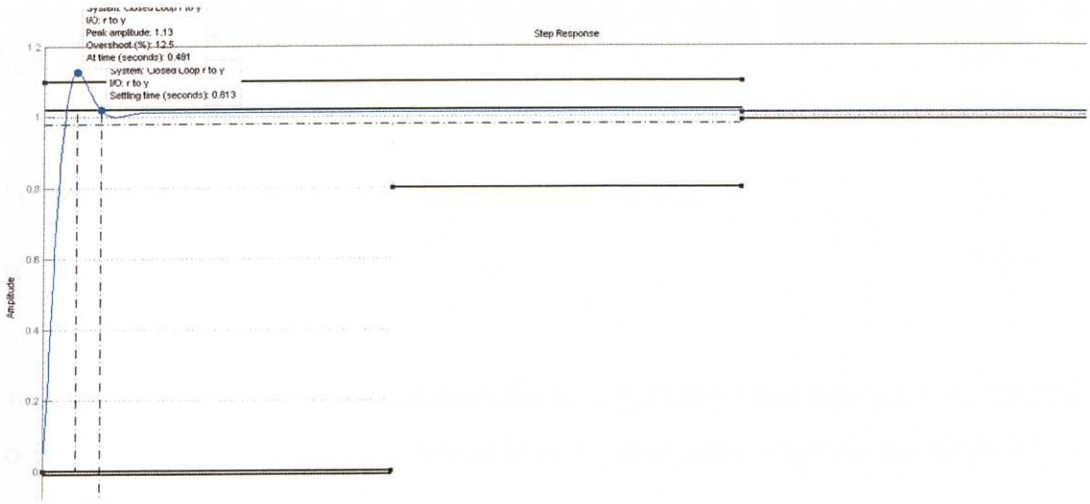


Fig (4.5)The designed PID controller for motor control position



Fig(4.6) The simulated response of the motor control position with sisotool

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:

$$\mathbf{G(S) = P + I\,\frac{1}{s} + D\,\frac{Ns}{s+N}} \qquad \textbf{(4.19)}$$

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

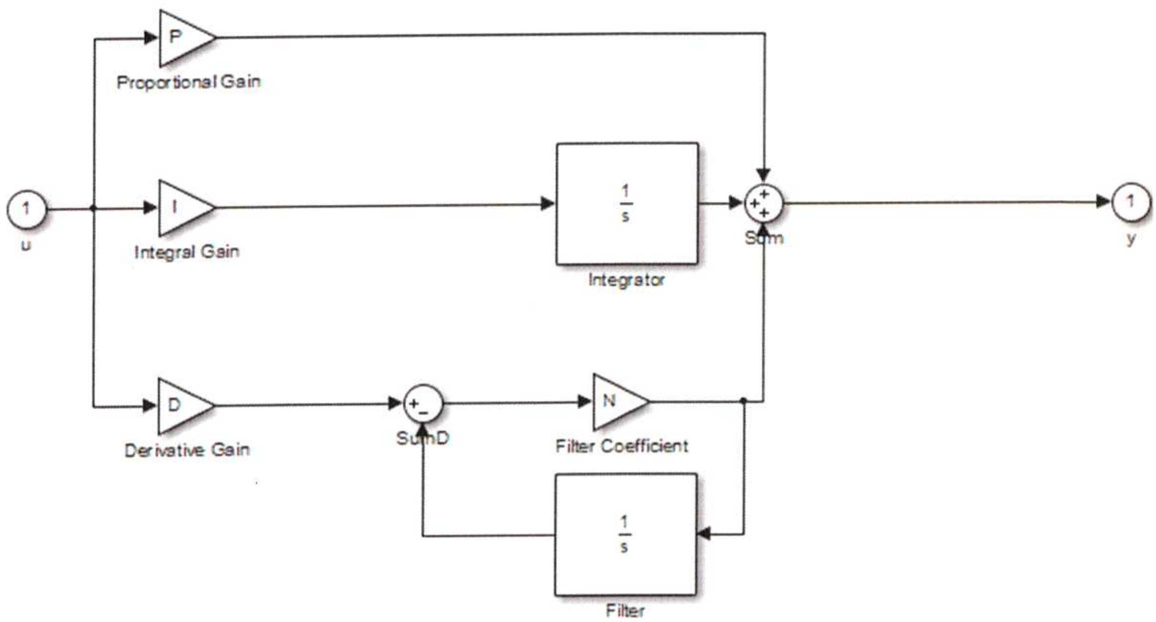


Figure (4.7) Parallel PID Controller

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.

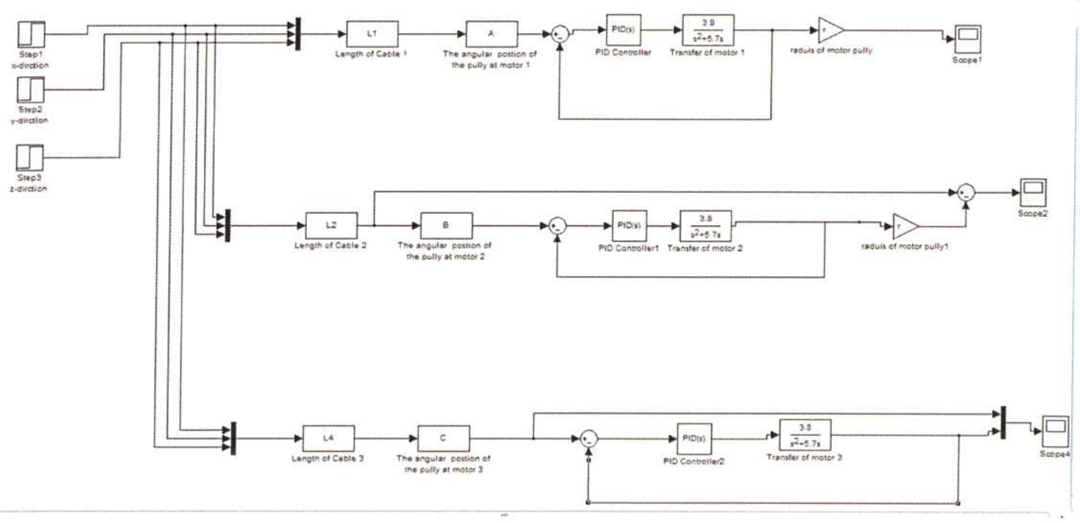


Figure (5.1) Simulation control for all over process

Appendix A

Appendix A

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

m-file

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                                   Matlab has to be used in many calculation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section(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

syms x % The postion of the mass in  x direction
syms y % The postion of the mass in  y direction
syms z % The postion of the mass in  z direction

syms a  %The length of the frame in y direction
syms b  %The length of the frame in x direction
syms m  %The mass of the object (kg)
syms g  %The acceleration of gravity (m/s2)

syms xb % The velocity of the mass in  x  direction
syms yb % The velocity of the mass in  y  direction
syms zb % The velocity of the mass in  z  direction
```

```
syms xs % The acceleration of the mass in  x  direction
syms ys % The acceleration of the mass in  y  direction
syms zs % 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)]
```

```
%%%%%%%%%%%%%%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))
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
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

syms Tm1% torque of motor one
syms Tm2% torque of motor two
syms Tm3% torque of motor three
syms m1 %The mass of cable one
syms m2  %The mass of cable two
syms m3 %The mass of cable four
syms J0  %mass moment of inertia of pulley on each motor
syms r  %radius of pulley on each motor

syms xo xf yo yf  zo zf ;
syms tf t D ;
 m=0.5;
g=9.81;
m1=0.005;
m2=0.005;
m3=0.005;
r=0.03;
J0=0.00026325;
```

Appendix A

Appendix A

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

m-file

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                    Matlab has to be used in many calculation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section(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

syms x % The postion of the mass in  x direction
syms y % The postion of the mass in  y direction
syms z % The postion of the mass in  z direction

syms a  %The length of the frame in y direction
syms b  %The length of the frame in x direction
syms m  %The mass of the object (kg)
syms g  %The acceleration of gravity (m/s2)

syms xb % The velocity of the mass in  x  direction
syms yb % The velocity of the mass in  y  direction
syms zb % The velocity of the mass in  z  direction
```

```
syms xs % The acceleration of the mass in  x  direction
syms ys % The acceleration of the mass in  y  direction
syms zs % 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)]
```

```
%%%%%%%%%%%%%%%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))
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section(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
syms xb yb zb
%second
syms xs ys zs
syms x y z a b m1 m g ;
syms r J0 Tm1

%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))
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
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

syms Tm1% torque of motor one
syms Tm2% torque of motor two
syms Tm3% torque of motor three
syms m1 %The mass of cable one
syms m2  %The mass of cable two
syms m3 %The mass of cable four
syms J0  %mass moment of inertia of pulley on each motor
syms r  %radius of pulley on each motor

syms xo xf yo yf  zo zf ;
syms tf t D ;
 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
```

```
%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 =1.4142 tf = 3.8284

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

Tm1=

```
t)/19742900584361675 - 3377699720527872/13751792361757825)*((422212465065984*t^3)/19742900584361675 - *٢٥٣٣٢٧٤٧٩.٣٩٥٩.٤))*٤٨٥٦١.٥٣٧٧٤.٤.٣٩))*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 - *٣٣٧٧٦٩٩٧٢.٥٢٧٨٧٢))*٤٨٥٦١.٥٣٧٧٤.٤.٣٩))*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=

```
*٢٥٣٣٢٧٤٧٩.٣٩٥٩.٤))*٤٨٥٦١.٥٣٧٧٤.٤.٣٩))*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 =1.4142 tf =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

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section (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 values matlab
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Date : 4/2/2013
% writer : Ahmad Bardawill

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=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 and matlab calculations Identical

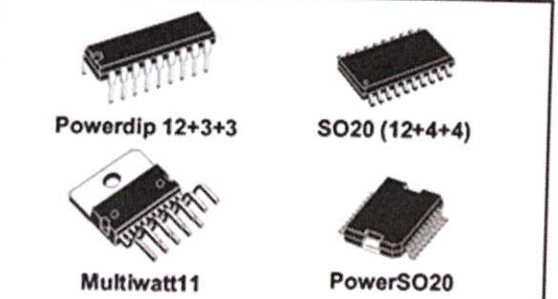
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                    % dc motor control simulation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
For section (4.4) control simulation
% Date : 30/12/2013
% writer : Ahmad Bardawill

Ts=0.001;%sampling time
km=100;

syms x % The postion of the mass in  x direction
syms y % The postion of the mass in  y direction
syms z % The postion of the mass in  z direction

syms a  %The length of the frame in y direction
syms b  %The length of the frame in x direction
syms m  %The mass of the object (kg)
syms g  %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 postion of  the pully at motor 2
C = L4/r; %C % The angular postion of  the pully at motor 3
```

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

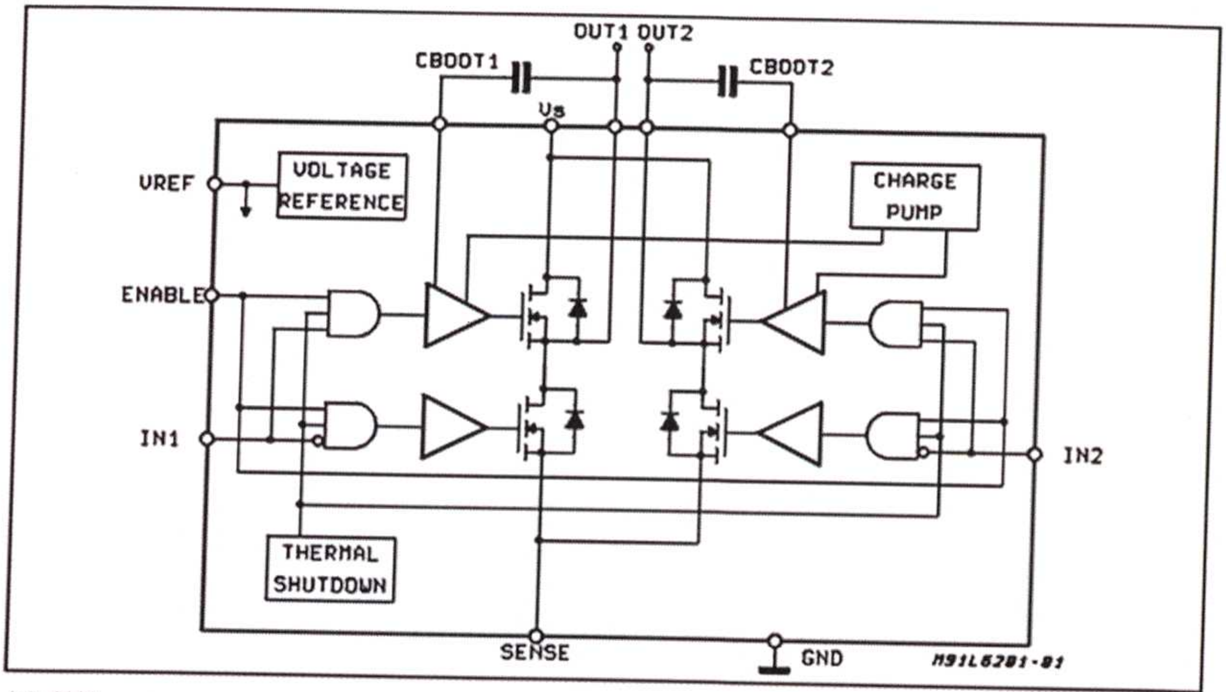


ORDERING NUMBERS:
L6201 (SO20)
L6201PS (PowerSO20)
L6202 (Powerdip18)
L6203 (Multiwatt)

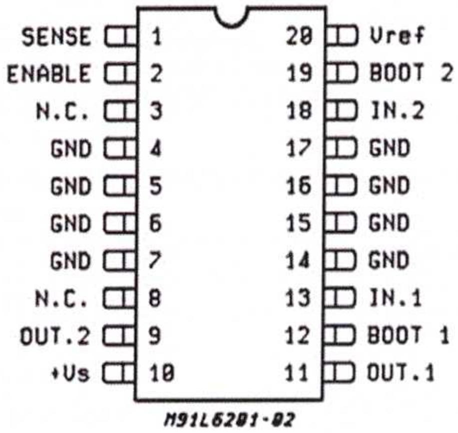
DESCRIPTION

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.

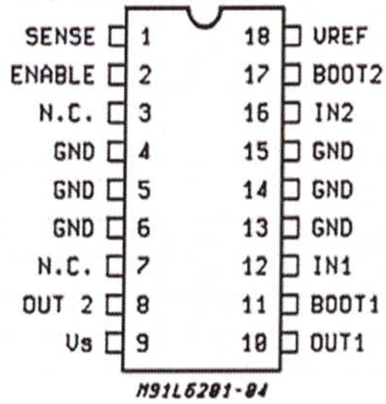
BLOCK DIAGRAM



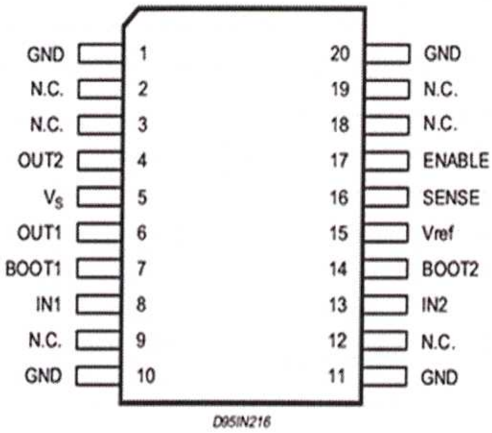
PIN CONNECTIONS (Top view)



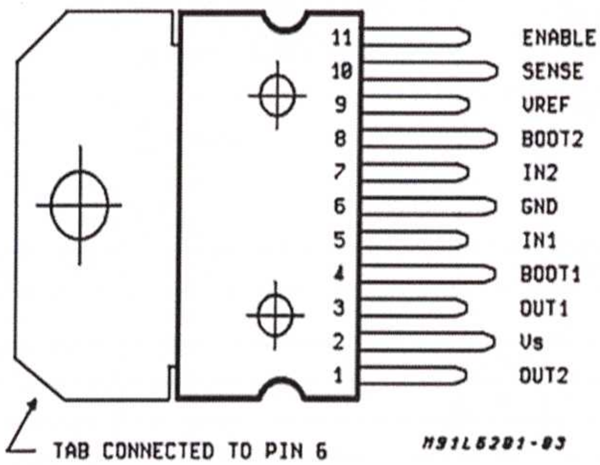
SO20



POWERDIP



PowerSO20



MULTIWATT11

THERMAL DATA

Symbol	Parameter		Value				Unit
			L6201	L6201PS	L6202	L6203	
$Rt_{h\ j\text{-}pins}$	Thermal Resistance Junction-pins	max	15	–	12	–	°C/W
$Rt_{h\ j\text{-}case}$	Thermal Resistance Junction Case	max.	–	–	–	3	°C/W
$Rt_{h\ j\text{-}amb}$	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