Computer Controlled Forces

by

Nizar Diab

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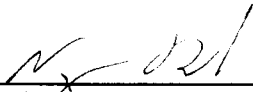Electrical Engineering

Program

YOUNGSTOWN STATE UNIVERSITY

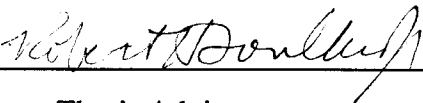August 28, 1997

Computer Controlled Forces

Nizar Diab

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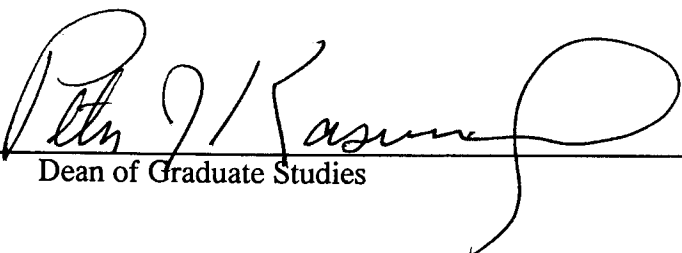
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Abstract

Computer Controlled Forces

Youngstown State University
August 28, 1997

Computer Controlled Forces is the concept of controlling the magnitude, direction, and duration of a force. A force is the application of pressure on a certain area. Forces are used in everyday applications and the need to control and use them is essential. The concept uses Newton's second law (the sum of forces is equal to the mass times the acceleration) and Lorentz Force Law (the interaction of a current carrying conductor with a magnetic field) to apply a force. Since the force is a vector, the magnitude and direction of that vector can easily be defined. From the equations of motion - the duration and the distance in which the force is applied – and Newton's second law, we can mathematically derive a force vector. The concept, which this paper presents, is a general and purely mathematical derivation and simulation of a real concept. Some applications that use this concept are described in chapter 6 of this thesis.

I would like to dedicate this thesis to my best friend. She helped me out when I was feeling down, opened my eyes to the world, and stood by me through whatever was happening. She gave me strength to do what I need to do, wisdom to know what I am doing, and clarity to see through my actions. She gave me a different line of thought and a well of information from which to build my thesis as well as my life. Thank you for being my best friend Hana.

Nizar Diab,

Thursday, August 28, 1997

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Thursday, August 28, 1997
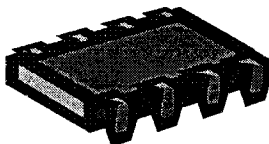
Preface

Ever since the invention of computers and the advancement of automation, people have been subjected to the possibility of machines replacing humans in all aspects of life. When automation began, it was made possible to help the laboring human forces in their work. Unfortunately, the industrial companies grew greedy and replaced the "more expensive human labor" with the "cheaper, easier to control automated machines". This action caused an alarm in the laboring forces to preach against the advancement of automation and new technology.

As my best friend says, "no invention or breakthrough starts out as an evil or harmful object, but as something to help achieve a goal." The human mind accompanied by the human experiences set the use for all inventions and breakthroughs. New objects or ideas are either dedicated for the good of the whole, or against the good of the whole for the material benefit of a few. The good of the few, which control the material possessions of this world, *does not* outweigh the good of the many.

The physical realm that we are living in is but a very small part of the cosmos. We are here to learn from our experiences and from the experiences of the whole. Science and engineering are some methods to help facilitate this learning experience. The human mind has been evolving exponentially, and our awareness of our role in the

universe is also increasing. We can learn from any invention or breakthrough that our minds can come up with, some of which may make our lives a bit simpler.

The concept that I am studying can be directed towards the good of the all, and the applications associated with it can make our lives simpler. As any other concept that came up through history, it may be turned into a concept that could set our learning experiences back. I would really like to see the concept associated with this paper to develop into a useful application that will enhance our learning and make us closer to understanding ourselves and the universe.

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List of Symbols and Terms

PLC	Programmable Logic Controller
A/D	Analog to Digital Conversion
D/A	Digital to Analog Conversion
I/O	Input and Output Ports
DMA	Direct Memory Access
IRQ	Interrupt Request
KBPS	Kilo Bits Per Second
MHz	Megahertz
OLE	Object Linking and Embedding

Chapter 1 Introduction

What are Computer Controlled Forces? Computer controlled forces is a concept in which a computer controls the magnitude, direction and duration of a mechanical or electrical force. The thesis is designed to explain this concept and to give examples of mathematical models that simulate the physical forces and the computer control of these forces. The system will be divided into three different parts: the motor, the data acquisition, and the computer program. Each part will be studied separately in different chapters. A few applications that could use the concept of computer controlled forces will be discussed further in chapter 6.

1.1   Background

The idea of computer controlled forces started from the age of automation and the invention of computers. Automation started with the industrial revolution and with the advancement of science. Since then, different fields of studies required automation in their products and ideas. The military uses automation to control their guns and artilleries. Industry uses automation for mass production. Medicine uses automation for better examination and understanding of the human body. Science uses automation for further research and development of new concepts and ideas.

The word "automation" means the automatic control of a unit. The unit does not have to be a big industry machine. The unit can be as small as a thermostat in your home

or smaller. Automatic control does not imply that a computer processor is doing the automation. The controller can be a simple summer or integrator. Therefore, automation is a simple concept of controlling the performance of the unit without an operator.

1.2 Today's Technology

After the concept of automation was incorporated in all aspects of science and industry, researchers aimed to improve the processes of automation. The automation process started out as a mechanical control for a mechanical machine. As technology improved, the control began to switch to electrical control of mechanical machines. Then the machines started to convert to electrical machines with electrical control. Today's control utilizes PLCs and EPROMs to do logical decision making as well as timing and counter functions.

A computer processor includes EPROMs as one of the hardware components. Therefore, the PLCs and EPROMs can be a subset of the computer processor. The industry uses the PLC processor because of its cost effectiveness as well as its excellent control and decision making ability. Since computer processors are being updated and upgraded constantly, the price of processors is dropping tremendously.

Let us consider the functions of a PLC compared to a computer processor. The PLC capabilities include:

- Digital inputs and outputs

- Decision making capabilities

- Counter and timer capabilities

- Comparative capabilities

The computer processor capabilities include:

- All of the PLC capabilities

- Graphical interface

- Instantaneous user control

- User friendly and hardware friendly

In most PLC automation systems, the warning and error signals are represented by flashing lights or beeping sounds as well as machine safety precautions. The detailed information of what went wrong is not immediately available. The output signal is sent immediately to the controlled machines with little to no user consideration. The process is fully automated, but the user who initiated the process is left completely out of the process. The computer automation system puts the user as the first priority while still keeping the process fully automated. The output signals are displayed on a monitor with detailed graphs and real time data. In case of an error, the user can trace the signal and the time the error occurred.

The standard of industry and large businesses is growing higher and the demand for more efficient and a more user-friendly systems is increasing. Some companies are already switching from PLC control to a computer processor control. Honeywell Inc. is a leading manufacturer of computer based control units and micro switches electric sensor

units. Their sales record for industry is increasing and their product market is gaining more popularity. This indicates that the industry is moving away from the standard PLC and heading more towards the computer processor control.

1.3   Computer Controlled Units

In today's technology, the concept of automatic control is hardware to hardware control system. The PLC control unit introduces the beginning of software to hardware control units. In a hardware control unit, the feedback signal can be either analog or digital. The signal is physically compared with the reference signal and the error signal is calculated. In a PLC control unit, the feedback signal and the reference signal are physically compared to each other but the programming of the comparison is done on a software basis.

In a computer controlled unit, the comparison between the reference signal, and the feedback signal is done on the software basis. This means that the reference signal either is generated by software, or is fed to the computer. The instantaneous reference signal is a mathematical number stored in the software as a variable. The feedback signal is also fed to the computer and transferred to an instantaneous mathematical feedback variable. The two variables are then mathematically compared and a mathematical error signal is then generated. This will allow the user to see the reference signal, the feedback signal, and the error signal in real time data.

To reinforce the idea of a software control over hardware control, let us look at Microsoft® Company. Before the launch of Microsoft Windows 95, all hardware had to be set by DIP switches to be assigned an I/O address. Furthermore, the IRQ and the DMA settings had to be manually configured. Microsoft® realized that the software control is more efficient than hardware control, so Plug and Play concept was designed with the cooperation of Intel®. The I/O addresses, the IRQ, and the DMA settings are all assigned by the software. The CMOS detection and setting is also controlled by the operating system.

1.4   Force Control

What exactly is a force control? In an automatic control unit, the output product is some form of energy. Different units and machines produce different forms of energy. Work is another form of energy. The work is equal to the product of the force by the distance. Therefore, a force control unit is a machine that produces a physical force as its energy output.

What are some of the machines that have a force component as an output? There are hundreds of machine types that produce force. Motors, pulleys, drills, and cranks, are some examples of force producing machines.

1.5   Why Computer Control Forces?

Why do we need to control a force-producing machine through a computer? Well we saw that a computer control is a more efficient and more advanced method of control.

Forces are used in almost every application and their use is not as efficient without a controlling system. Therefore, a force-producing machine with a computer control is the most efficient and advanced form of control.

We have talked about the industry standard of the shift to a computer-controlled unit, but what about the small businesses and household products? We can see automation in homes and in small businesses in different products. Such products include temperature control, home security systems, and simple production equipment. If we were to raise the standard for the industry and large businesses, why can't we attempt to raise the standard of the household products and services, and small businesses equipment?

There have been many books on how the computer can control an industrial robot or machine, but this thesis will attempt to create a concept so general that the idea will also apply for home usage as well as small businesses usage. Some applications will be studied in chapter 6.

Chapter 2 Overview

The computer controlled forces concept is a system that is made up of different parts each serving its own purpose. These units alone can not perform the duties of the whole and neither can the whole perform its duty without these units. The system is dependent upon the integration of its parts. These parts will be discussed in details in the following chapters.

2.1   The Complete System

The complete system of the computer controlled forces concept is made up of a computer, a data acquisition card, and a force-producing machine (Figure 2-1). The user will enter the required information, such as the magnitude, the direction, and the duration of the force, through the computer terminal, and the force-producing machine will generate the output force. The input information can be as versatile as "click and drag" on graphical interfaces representing the actual machine output to very specific as entering the exact information as numbers. The output can be a mechanical force, such as a crank or a torque motor, or an electrical force, such as a magnetic field generated force. The type of input and output will vary depending on the application being used. The type of machine used to produce the forces will also depend on the application and the magnitudes and directions of forces used. The data acquisition card will depend on the accuracy and control speed required from the application.

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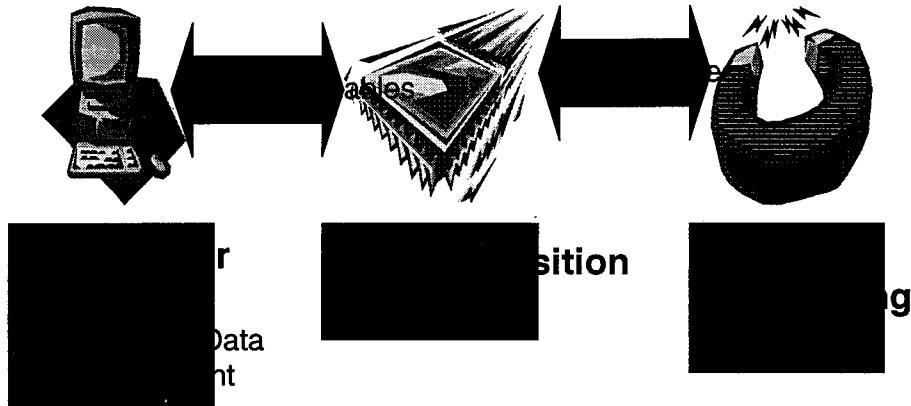
Figure 2-1. Flow Chart of the Complete System.

To put this in a practical point of view, let us model a simple example. Assume that the motor is a simple wire in a magnetic field, and that the data acquisition card is a simple amplifier and a digital to analog converter (and analog to digital). If we want to create a force equal to 5 Newton in the positive[1] direction for 5 seconds, the following procedure is done.

From the field equations:

2-8

$$\vec{F} = L(\vec{I}x\vec{B})$$

where F is the Force vector,

L is the length of the wire in the magnetic field,

B is the magnetic flux density vector,

I is the current vector.

Therefore, the force vector, i.e. magnitude and direction, are directly proportional to the current vector, if the field strength and the length of the wire are constants. If we control the direction and the amplitude of the current sent to the linear motor, we can control the direction and magnitude of the force produced. The current is generated from the data acquisition card, which is being fed from the computer, and supplies the motor to create the desired force. The duration of the force is directly proportional to the duration of the controlling current. If the current is a pulse that has a period of 5 seconds, the force will be generated for 5 seconds. The computer program will then determine the calculations necessary for the amplitude, direction, and duration of the current and send this information to the card. The card will convert the digital information to the corresponding current signal which in turn will generate the required force.

2.2   Control and Feedback

In order to control a system, you need to find out what the system is doing and decide what you want the system to do, then force the system to do what you instruct it to do. This concept is also defined as feedback control systems. Feedback systems, also

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[1] The positive direction can be determined by the direction of the magnetic field and the direction of the current by using the right hand rule.

known as automatic control systems, have been around since 1790 when James Watt invented the centrifugal governor to control the speed of his steam engine. During the years following Watt, the need to control more applications arose and the advancement of automatic control was in progress.

In the age of the industrial revolution, large-scale machines were developed to produce the desired products. In the early ages, those machines were controlled by a human observer who operated the machine. As the industry prospered, the need for improved machines arose. The human operation and control of those machines was no longer an efficient process. This forced the engineers and scientists to focus their research to automate the control and operation of the large-scale industrial machines. Nowadays the control process of large and even small-scale machines is fully automated.

Control systems are usually divided into two different groups, an open loop control system, and a closed loop control system. The open loop control system is defined by an input signal that is connected to an amplifier or "controller" that feeds the signal to the actual system. This system is described in Figure 2-2.
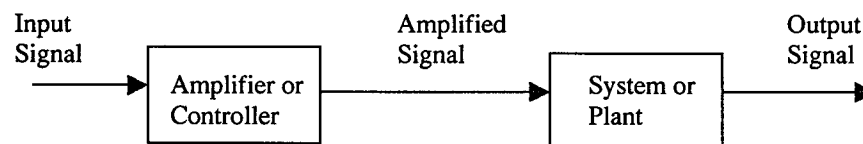
Figure 2-2. Open Loop Control System.

The input signal is usually a reference signal that is used to drive the system. This signal is passed to an amplifier or a controller where it is adjusted to be able to drive the actual system. The amplified or controlled signal is then sent to the system or plant that produce an output signal. The Laplace transform of the above model can be represented as:

2-1

$$a(s) = H(s)r(s)$$

where a(s) is the amplified signal,

r(s) is the reference signal,

H(s) is the transfer function of the controller.

███████████

2-2

where y(s) is the output signal,

G(s) is the plant transfer function.

Therefore,

████████████

2-3

The open loop systems are usually to control a system whose output load is constant and accounted for by the controller. If the load varies or needs to be "started up", the open loop controller will not force the output system to follow the reference

signal. In other words, the open loop control system is not a feedback system but rather just a simple controller.

The second group of control systems is called a closed loop control system. The closed loop system is defined by an input signal, which is compared with the output signal to generate what is known as the "error" signal, the controller, and the plant. Figure 2-3 describes this system.

The error signal is fed to the controller to generate the amplified signal. The amplified signal is then sent to drive the plant. The plant in turn produces the output signal that is used to drive the load and sent back to be compared with the reference
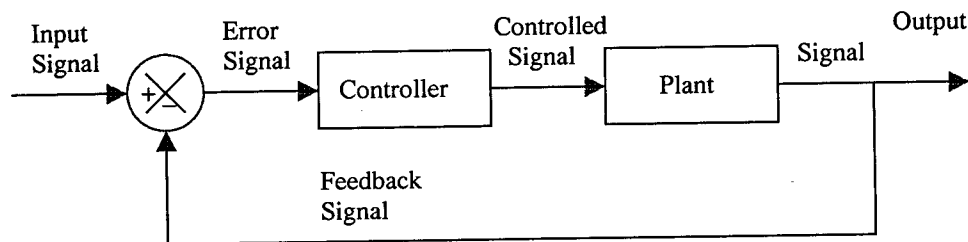
Figure 2-3. A Closed Loop Control System.

signal. The Laplace transform of the above model can be represented as:

$$e(s) = r(s) - y(s)$$ 2-4

where e(s) is the error signal,

r(s) is the reference signal,

y(s) is the output signal.

$$a(s) = H(s)e(s)$$

2-5

where a(s) is the controlled signal,

H(s) is the transfer function of the controller.

$$y(s) = G(s)a(s)$$

2-6

where G(s) is the transfer function of the plant.

Therefore,

$$y(s) = G(s)H(s)e(s)$$
$$y(s) = G(s)H(s)[r(s) - y(s)]$$
$$y(s) = \frac{G(s)H(s)}{1 + G(s)H(s)}r(s)$$

2-7

The closed loop systems are designed to control a variable load where the output tracks the input signal. The error signal is the forcing signal that feeds the controller and directs the output signal to follow the input signal. This type of control system is the most common group of control systems and is used in most feedback applications. This group of controller will be used in the concept defined in this paper.

The feedback system that is used in the computer controlled forces is a closed loop feedback system that has a motor as the plant and the computer program along with the data acquisition circuit as the controller (Figure 2-4). The reference signal is a user-input signal that is obtained from the terminal and the user-interface system. The error

signal is the digital comparison between the input signal and the output signal after being processed through the data acquisition card and the computer program. The controlled signal is the analog signal that is fed to the motor. The output signal is the force produced by the motor.
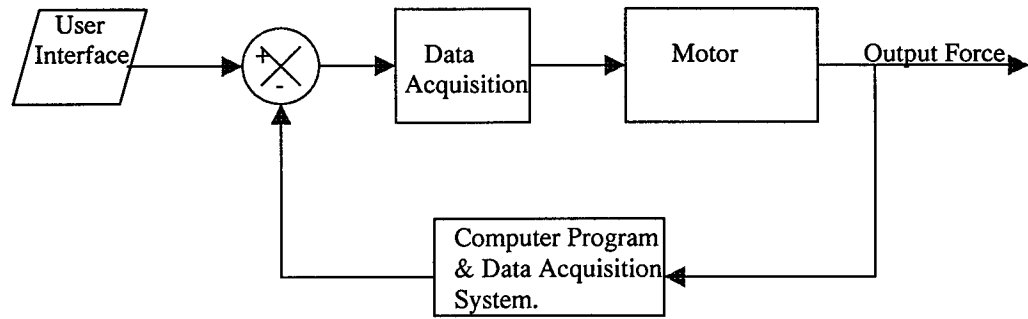
Figure 2-4. Feedback system of the Computer Controlled Forces.

The control of the output force will be in three forms, magnitude, direction, and duration of the force. The magnitude of the force will be controlled by the amplitude of the controlled signal after the signal is amplified and converted to analog. The direction of the force will be controlled by the phase of the amplified signal. The duration of the force will be controlled by the duration of the digital input signal.

Let us consider the example used in section 2.1. The computer requirements were generated to produce a 5 Newton force in a known direction for a period of 5 seconds. The computer can not predetermine the load that the machine has to drive. The computer program generated the information for a no load situation, but when the load is engaged, the force required to drive the load at 5 Newton will be different. Therefore, the computer needs to determine the magnitude and the direction of the force at all times.

The computer has to keep track of the time period when the load is engaged. To measure the magnitude of the force and feed the measurement to the computer, we will need an electric force sensor. The sensor can measure the magnitude and direction of the actual force at all times, and feed the information to the data acquisition card which in turn notifies the computer program of the current status of the output signal. A timer chip can also be installed on the machine that can be triggered as soon as the force is produced, and feed the information back to the computer. The computer program will acquire the information and readjust the amplified signal to track the input signal. This procedure will repeat until the actual force is exactly 5 Newton in the required direction for a duration of 5 seconds.

2.3   Integration of all the Parts

Now that we see how the entire system operates, and how the concept of feedback control works, we can ask the question of how can we use all these parts together as a single unit. The answer is simple yet complex. The system is composed of three main parts but those parts will not interface with each other that easily. Each unit will have to be modified or reprogrammed to be able to produce the most efficient output.

From the previous section, we can determine the direction of flow of information from one unit to the other. From figures 2-1 and 2-4, we know that the computer has a two directional flow with the data acquisition card, and the motor has a two directional flow to the card. This means that the computer and motor do not need to be integrated together, but rather the data acquisition card has to be compatible with both the computer

and the motor. The user, who controls the input signals, communicates with the computer only. The output signal can be displayed to the user since the signal is fed back to the computer. The application needs the output signal only and therefore communicates with the motor only.

The integration of all the parts involves the synchronization of all the units along with each other. Let us look at the concept as a third person (Figure 2-5). The user sits in front of the terminal and sees the user interface program. The user wants to start an application that is connected to the terminal. They program certain parameters for the application and they expect the application to work within those parameters. Those parameters are passed from the user interface, to the variable control part of the program. The program then modifies the parameters and converts them into digital signals that can be passed to the data acquisition card. The card accepts those signals and converts them into analog signals that can drive a motor. The motor uses those analog signals to produce force and start the application. Sensors read the progress of the motor and relay the information back to the data acquisition card. The data acquisition card converts the sensor readings into digital and feeds them back to the variable control part of the program. The computer program then makes the necessary modifications to the digital signals that the card receives and updates the user interface part of the program. The user administers the progress of the application. The controlled signal is then converted back to analog and drives the motor. This process is repeated until the application is working according to the original parameters.
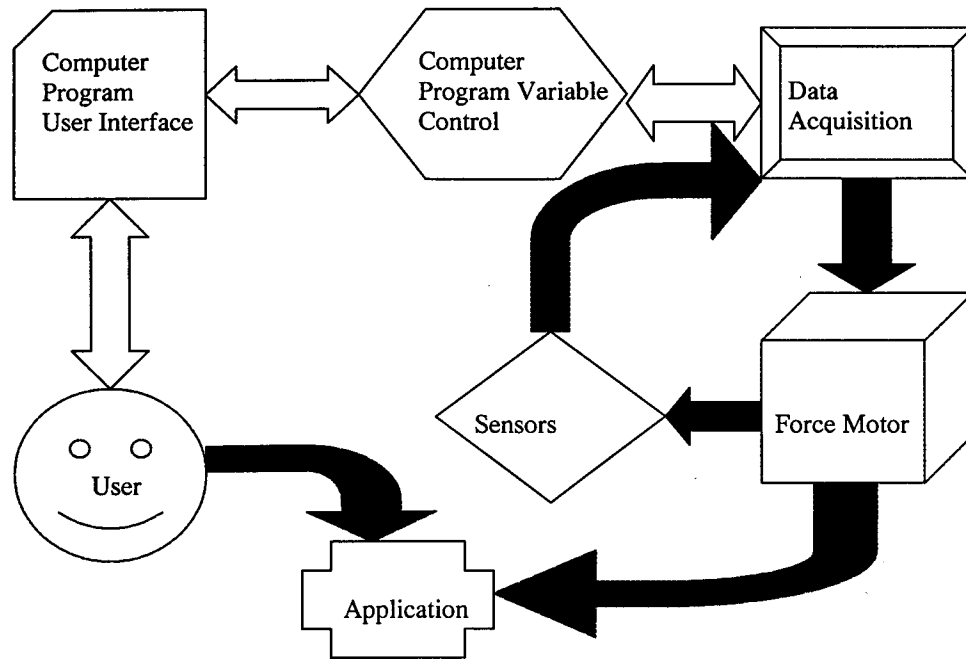
Figure 2-5. Flowchart of Direction of Information.

In such a system, timing is crucial. Certain requirements for the hardware and the software need to be observed. For instance, to have a fast response system, we need to provide the application with a fast processor such as Pentium 133 or faster with enough memory to run the user interface as well as handle the decision making of the variables. The software needs to be very efficient and does not waste needed time. Priority is given to decision making over updating of the user interface. The data acquisition card needs to have a clock that is proportional to the computer clock. Sampling the sensor input and converting the digital signal to analog signal is very important and requires precision. The motor has a slower response time than the other units in the system. A mechanical

motor is slow and is hard to control and drive with electrical signals, while an electrical motor is faster and easier to control.

In the following chapters, we are going to discuss the details of all the units and the exact requirements for each. The discussion will turn into a more technical and advanced analysis of each unit. In chapter 6, we will discuss the applications for such a concept.

Chapter 3 Motors

There is a lot of variety of force producing motors in today's technology. Motors are not limited to mechanical or electrical but also extend to chemical, nuclear, thermal, etc. Every type of motor posses their own pros and cons and each are more likely to be used in their prospective applications. Some motors are easier to control and some other motors produce more energy. In our discussions and applications, control of the behavior of the motor is the focus. The two main types of controlled motors are mechanical and electrical motors. In this chapter we will discuss those two types of motors but will focus the study on the electrical motors.

3.1   Definition

Motors are machines that convert one type of energy into another. Mechanical motors convert mechanical energy, such as heat, momentum, kinetic energy, or potential energy into work done. Electrical motors convert electrical energy, such as magnetic fields, alternating current, direct current, or electric fields into work done. The work done can be due to a rotary machine or a linear machine.

Let us start by examining the general operations of motors and their properties. Motors use and produce energy. The input energy is not necessarily the same as the output energy. The conversion of energy can take place in different forms but the output energy is usually work done. The work done is a function of the force and the distance.

Since we are interested in harnessing the output force of the motors, we will need to examine the work done as a relation of the output force produced.

$$W = \int F(x)dx$$

<div align="right">3 – 1</div>

where W is the work done,

F is the applied force,

x is the distance the force is applied.

The different forms of energy are directly related to the work done by the motor. Energy is always conserved, and it can never be created nor destroyed. Therefore, any conversion of energy can be monitored and predicted. In any loss-less system, the input energy should equal to the output energy. Theoretically, that could be possible, but there is no such system in today's technology that does not incur any losses. Therefore, the equation for the energy conversion becomes:

Output Energy = Input Energy - Change in Stored Energy - Energy Lost

<div align="right">3-2</div>

Let us start by examining the mechanical motors and their properties. Mechanical motors use different forms of input energy such as heat, gravity, hydraulic, etc. The most common application of a mechanical motor is the conversion of heat energy into work done. Heat is the lowest grade of energy and by far the least efficient. Heat is also the cheapest and the most common source of energy. Therefore, efficiency is not a major problem and can be ignored. Springs are another form of a mechanical motor whose input energy is force and output energy is work done. This process converts one energy

form into the same form while losing energy due to the elasticity of the springs. Hydraulics is a more efficient approach of conversion but they are not as common. The conversion from a hydraulic to a force producing output is a more complex and bulkier process.

To control such motors, we must control the input energy that drives those motors. The ease of energy control depends on the kind of input energy. Thermal energy is an easier form of energy to control. The quantity of heat converted limits the output energy produced. Hydraulics on the other hand, is a much harder energy to control since the input energy is constant. In such cases, the control of the output energy is the control of the conversion process. This form of control will create more losses in the energy conversion.

The electrical motors are of a similar design and requirement using energy comparison. The most common electric motor is the conversion of electric current in a magnetic field to work done. There are different types of electric motors that use the similar method. To control those kinds of machine, we need to control either the magnetic field or the current.

There are two types of output work done. A rotary motor will produce a torque and an angle of rotation and a linear motor will produce a force and a distance.

$$W = Fd$$
$$W = T\theta$$

3-3

Every application uses a specific type of motor. Linear motors are best suited to simulate force components, and rotary motors are best suited to simulate moments. This thesis topic deals more with force components rather than moment components. Therefore, the rest of the discussion will be focused on linear motors and their applications.

3.2   Design

The discussion about the design of a linear motor for a computer controlled force will not be very specific. The reason is that the motor design does depend on the different applications. The idea and the general design parameters are the same for most applications and will be discussed in details.

In an electric motor, force is produced by the interaction between a current carrying conductor, and a magnetic field or electric field. The equation for the force produced is defined by *Lorentz force law*:

$$\vec{F} = q(\vec{E} + \vec{v}x\vec{B}) \qquad\qquad 3-4$$

where q is the charge of a particle,

E is the electric field density,

v is the speed of a particle,

B is the magnetic field density.

For a purely magnetic field, equation 3 – 4 becomes:

$$\vec{F} = NL\left(\vec{I} x \vec{B}\right)$$ 3 − 5

The above equation states that the force is proportional the current, magnetic field intensity, length of the conductor in the magnetic field, and the number of turns of the conductor in the magnetic field. In a physical motor, it is impractical and almost impossible to vary the number of turns and the length of the conductor for control purposes. This implies that equation 3 − 5 has two more parameters to control. A magnetic field can be formed either by the use of permanent magnets or by a field generating current. In a permanent magnet, the field density is not as strong and is subjected to demagnetization due to temperature and time. The permanent magnet motor leaves only one variable to be controlled, which is the current carrying conductor.

In a current generated magnetic field, the density of the magnetic field is much stronger and is not subjected to demagnetization. Heat loss in the coils of the magnetic field is another variable to worry about. The field can be controlled with a current, which leaves one variable to be controlled according to equation 3 − 5. Therefore, the force produced is directly proportional to the current.

Any motor for an application would require the control of the current feeding the motor. The current may feed the field or the current carrying conductor or both. Equation 3 − 5 represents the relationship between the force, the current, and the field in a vector format. Therefore, we can control the direction of the force by either changing the direction of the current or the direction of the field. The magnitude of the force is

proportional to the magnitude of the current that is feeding the motor. In other words, to control the force produced by that motor, we need to control the current feeding that motor.

Each application will have a unique motor design that is dependent on the usage of the motor. An application that requires a large force magnitude with no relevance to speed or time has a different motor design than an application that requires a low force magnitude with speed requirements. Since the computer operates on a digital level, the voltages associated with the computer and the card are DC voltages. Some motors may require an AC input current, but that means the control needs to be set by physical relays which requires a slower reaction time.

3.3 Sensors

In order to control a motor, we need to know some information about it. Different sensors can be installed to measure different parameters on a motor. For example, to measure the magnitude of the force, we need to install a pressure sensor such that the force generated is perpendicular to the surface of the sensor. If we need to measure the distance covered by the motor, we can install LEDs along the path of the motor. To measure the speed, we can measure the distance from point to point and time the measurement. Sensors attached to the motor also vary from application to application.

Let us consider an example for discussion. The user would like to push a box with a magnitude of 5 N for 5 seconds. The user inputs the information to the computer.

The computer then determines the current signal that is necessary to exert such a force for such a period. The force to current conversion is dependent on the type and qualities of the particular motor. When the current signal is determined, the computer sends that signal to the motor via the data acquisition card. The card generates the corresponding analog signal that drives the motor for a period of 5 sec. Since we are interested in controlling the magnitude of the force during this duration, we need to measure the magnitude and feed the information back to the computer. A sensor would be placed on the motor such that the surface of the sensor is subjected to the force being applied to the box. The card samples the data from the sensor and feeds it back to the computer. If the force were different than 5 N, the computer would alter the current signal in order to force the output to follow the input.

Chapter 4 Data Acquisition Card

The difference between the motor and the computer is that the first operates on analog signals while the other on digital signals. In order to bring the two different systems together, we need an interface card that can convert the digital signal to analog signal and vice-versa. These conversions are simple and do not require a complicated card to perform it. However, the conversion from digital to analog is not the only function that the card has to do. This chapter will describe the functions of the card and design a sample card to interface the computer with the motor.

4.1   Definition

A data acquisition card is a circuitry that is designed to acquire analog signals and convert them to digital signals and vice-versa. Such cards are available to the market and can be purchased from companies such as National Instruments, HoneyWell Inc., etc. Each card has different functions that are dependent on the application. A simple data acquisition circuit consists of a clock, a D/A chip, and an A/D chip.

The data acquisition card that is referred to in this thesis has a slightly more application-oriented. The basic concept and design are the same but certain additional features are also included. Since a force vector can be oriented in any direction in our three dimensional view of the world, there needs to be three force components, one in each dimension. Therefore, the card has to be connected to three different motors to represent the three different dimensions. Each motor has a sensor and therefore requires

unique sampling of the individual sensor. The data acquisition card has to interface with the computer as well as the motors. Figure 4-1, shows the flow chart for such a circuitry.
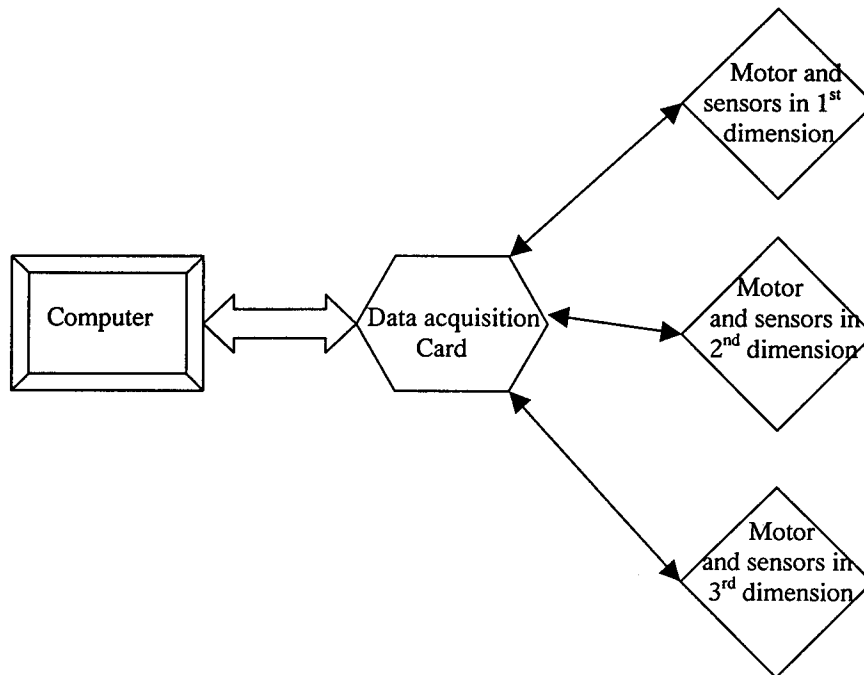
Figure 4-1. Flowchart for the Data Acquisition Card.

4.2   Design

The data acquisition card design can be altered from application to application; however, the design of the card discussed in here is a general design that can accommodate all applications. Before we can design the card, we need to know the exact duties that the card is supposed to perform. The data acquisition card is mainly to interface the computer to the motors. The data will be processed from the computer in a purely digital form, and an analog current signal will be produced to feed the motors. Sensors attached to the motors will be sampled and converted to a digital signal then sent to the computer for further processing. The computer outport has the capability of producing 8 bits of information per unit time. Since there are three motors, the card and

the computer need to know which signal is controlling which motor. The sampling rate of the sensors attached to the computer cannot be faster than the computer clock; otherwise, the information will be lost. The details of the card design are shown in Figure 4-2.
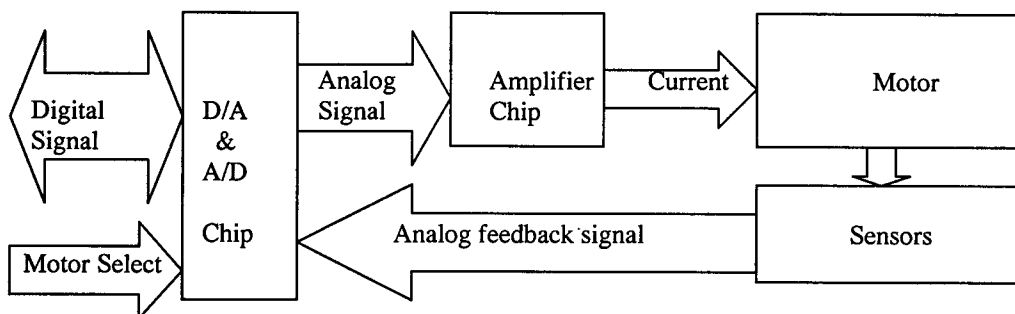
Figure 4-2. Basic Circuit Design.

Let us start by explaining and studying each part of the data acquisition card. The D/A chip is used to accept the data from the computer as an 8-bit digital input signal and convert that to an analog current signal. The circuitry that is explained from here of are found in the National Semiconductors Databooks. A current analog output signal can be produced from a DAC0806 8-bit D/A converter (specifications are found in appendix A). The inputs are the 8-bit signal, the ground, and a voltage reference signal. The fast current settling time and the low power dissipation as well as the accuracy of the output signal make this D/A converter chip the most logical choice. The maximum current output with all the input bits set to high is V_{ref} / Impedance. The maximum current range is 4.2 mA for $V_{EE} = -15V$. The power supply for the chip is a DC voltage of 18V.

The current output generated from the D/A will not be sufficient to drive a motor. Therefore, a current amplifier is required to amplify the output signal. LH0021 1.0 Amp Power Operational Amplifier is an ideal choice of high current output with low power dissipation (specifications are found in appendix B). The amplifier uses the same power supply as the D/A (18V).

Now that the digital signal from the computer is converted to an amplified signal that could drive the motor, the card needs to direct the current to the specified motor. The computer sends a 2-bit information that will inform the card to direct the signal to one of the three motors. Therefore, a digital switch needs to direct the analog current to the specified motor. AH0015 Quad SPST TTL/DTL compatible MOS analog switch is a digital controlled analog switch (specifications are found in appendix C). The input is a 4-bit logic input that controls 4 analog switches. A low signal will turn off the switch and a high signal will turn on the switch. Since the computer provides a 2-bit signal for the address of the motor, the input to the switch has to be connected as shown in Figure 4-3. The switch input signals are connected to the analog current generated from the amplifier. Each motor will be connected to one of the output pins. Figure 4-3 describes the circuit connections using the specified chips.

The data bits that are sent in from the computer are connected to a sample bit through an AND gate. If the sample bit is high, the input to the D/A converter is the desired signal to be converted. If the sample bit is low, the input signal to the D/A is low and therefore no conversion takes place. The sample bit is used to control the flow of
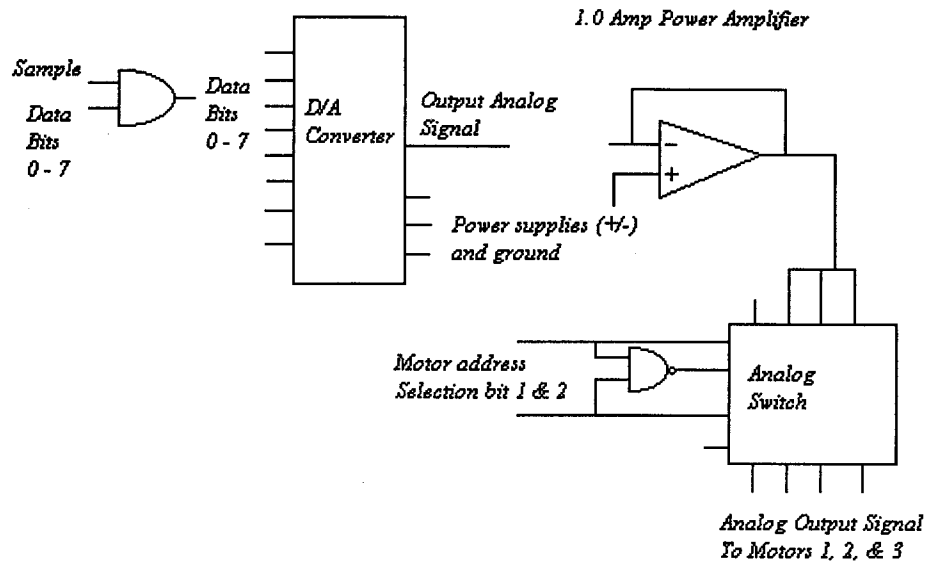
Figure 4-3. Digital to Analog Circuit Design

information to and from the motor. The data bits are then connected to the D/A chip and

an analog output current is generated. The current is passed to the power amplifier chip

to increase the maximum output current. The current is then passed to the input of the

analog switch. The switch is controlled by the motor selection bits. The motor address is

assigned by a 2-bit signal from the computer. Therefore, a low input bit will operate one

switch and a high input bit will operate another switch. The outputs of the analog switch

are passed to the respective motor.

The card will also transmit information from each motor upon the computers

request. The sensors attached to the motors will provide the card with constant analog

signals. This information is untouched until the computer issues a command to sample a

particular motor. The motor address is sent to the card as well as a sample bit. The

sample bit controls the A/D chip-select pin and the direction of flow of information

between the computer and the card. The motor address is a 2-bit signal that allows the card to sample a particular sensor. The ADC08238 8-bit high-speed serial I/O A/D converter is used to sample and digitize the specified analog signal into a digital signal (specifications are found in appendix D). The A/D has a conversion frequency of 4 MHz with a maximum input voltage level of 6.3V. The clock that is associated with the sampling of the sensors has the same frequency as the A/D conversion frequency. Figure 4-4 describes the A/D part of the data acquisition card.

Figure 4 - 4, Analog to Digital Conversion Circuit Design

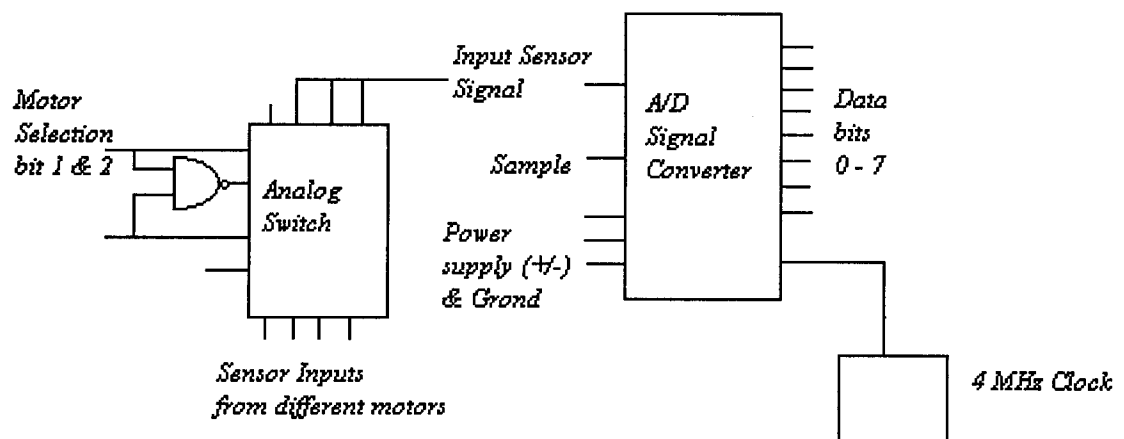Let us take the example of the box described in chapter 3. The user would like to push the box for a period of 5 seconds and exerting a force of 5 N. The use inputs the parameters into the computer that in turn determines the correct current setting to supply the motor. The mathematical signal is sent through the I/O ports as an 8-bit digital signal.

The computer will send a high signal for the sample and the motor address of "01". The digital signal is converted to an analog current (maximum current is approximately 2 mA). This current signal is amplified and sent to the switches were the motor id selection chooses the signal to go to motor 1. In the mean time, the computer times the procedure that should last about 6 μs. After a certain clock cycle, the computer sets the sample bit to low thus turning off the D/A conversion. The A/D chip is activated through the chip-select that is connected to the sample bit. The motor id controls the choice of the sensor signal that represents the motor. This signal is sampled and converted to a digital signal where it is fed back to the computer. The process will be repeated until the computer clock reaches 5 sec from the time the application started.

4.3   Improvement

As stated earlier, the card is application oriented and could vary its design depending on the load and type of control. If a large force magnitude is required and the control of this force involves the duration and magnitude for example, then the signal would not need to produce an output current. The card could control high amplitude current through a digital switch. If very high position accuracy is needed, then a faster A/D chip will be required. The slew rate on all the chips is acceptable and within the limits of the design.

A better card design would be to design an internal computer card with access to more I/O ports. The cables from the computer to the card will be eliminated, but the

cables from the card to the motors would be increased. The accuracy however, lies within the digital information that is passed from the computer.

Chapter 5 Computer Program

As everyone knows, the computer industry has flourished in the recent years. New computer hardware and software are developed every month. The possibilities that opened up from these advancements are endless and are waiting to be forged into applications. As engineers, we have to keep up with those developments and try to develop products and concepts that use the full capacity of new improvements in the computer industry. This chapter will describe the current technology that is available to us and will take the fullest advantage of those developments.

5.1   Definition

Let us start by defining the typical processors and the newest technology. Both hardware and software developments will be defined. The most common processor that is available to the industry is a Pentium® 166 MHz with an Intel® processor. This processor is usually equipped with 16 to 32 Mbytes of memory with a 256 Kbytes of cache. Today's typical computer also includes an 8x speed CD-ROM with at least 1 Gbytes of hard disk space and a 28.8 KBPS fax/modem. Other features that are included in today's typical computer include a 3D-wavetable sound system and a 2 Mbytes of video memory with an IDE hard drive accelerator. The most common operating system in today's technology is Microsoft Windows 95.

Now that the typical personal computer has been defined, let us define the ultimate computer that is equipped with today's newest technology. Even though an

80686 computer is being developed, the Pentium processor is still the dominant CPU available. Pentium® 300 MHz with MMX Intel® technology is the newest processor on the market. Memory requirement for a PC can go as high as 128 Mbytes of DRAM memory with 512 Kbytes of pipeline burst cache. Additional features include a 16x CD-ROM with surround sound and up to 8 Mbytes of video memory with windows accelerator. The hard drive space is increasing by the week and can reach up to 6 Gbytes of physical space with a SCSI accelerator that has up to 10 nano seconds of access time. Fax/modem capabilities are also increasing with the launch of satellite receiving modem (up to 400 KBPS), and fiber optics cable connection for modems. The operating systems are also advancing and developing more features. Microsoft Windows 98 is soon to be released and the Internet access is increasing.

Now since the typical and the most advanced system are defined, let us define the system that the thesis model uses. For a typical application, we need a fast response time and an accurate interpretation of the data. The previous chapter described the time clock for the data acquisition but the rate of transfer of information between the card and the computer depends on the computer clock. The computer on-board clock has to be at least 3 times faster than the clock that is onboard the data acquisition card. The reason is that the graphics part of the software requires 3 times the amount of time to perform a command than an I/O operation[1]. The clock of the card is rated at 66 MHz, which means the clock of the computer has to be greater than 198 MHz. The transfer of information from the card to memory depends on the cache size. The cache is the amount of

---

[1] Experimental analysis was done in Windows 95 using Borland C++. The experiment involved creating a window and an object inside that window versus a simple I/O port operation.

information that the computer processes per time. To process the most amount of information, we need to select a 512 Kbytes pipeline burst cache. The processor chip has to be able to handle high mathematical calculations as well as graphical interfaces in real time. The best chip to handle such demands is an Intel Pentium® chip with MMX technology. Since the computer program will also handle the user interface and the progress display of the application, a video card with its own memory is recommended. The computer will need to keep track of several variables as well as record all the information that the application is experiencing, so the memory requirement is high preferably 32 Mbytes or more. The application program occupies about 100 Mbytes including the operating system. Sound and a CD-ROM are optional peripherals that are not required for this model. Fax/modem functions are also optional and may help if sending the results of the application via network or LAN. Therefore, the system that this model will use is a Pentium 200 MHz with MMX technology, 512 Kbytes pipeline burst cache with 32 Mbytes memory, a 2 Mbytes video card, and 256 Mbytes of hard drive space.

Microsoft Windows 95 is an object-oriented operating system. The system is designed to accelerate graphic displays and enhance user-interface programs. File sharing and OLE applications are very useful parts that will allow the application to share the results between different applications. The Plug-and-Play feature of Windows 95 also enhances the performance of the CMOS and the PC. The operating system that the thesis will use is Microsoft Windows 95.

5.2   Design of the Computer Program

The applications that require computer controls are getting more sophisticated. Different forms of user input and interface make the operation of such applications easier and more efficient. Turning switches or pulling knobs are dated to the Stone Age of technical revolution. Monitoring the performance of a machine is not limited to blinking lights or a small screen with a bunch of numbers. The technology is available to animate the machine and its application and to virtually create the work environment.

5.3   User Interface Part

The computer program is divided into three main parts, the user interface, the controlling part, and the hardware interface (figure 5-1). Let us start by examining the user interface part of the computer program. The user interface is divided into two parts,

Computer Program

User Interface		Controlling Procedure		Hardware Interface	
Input Display	Output Display	Input Signal	Error Signal	Reading Signals	Writing Signals

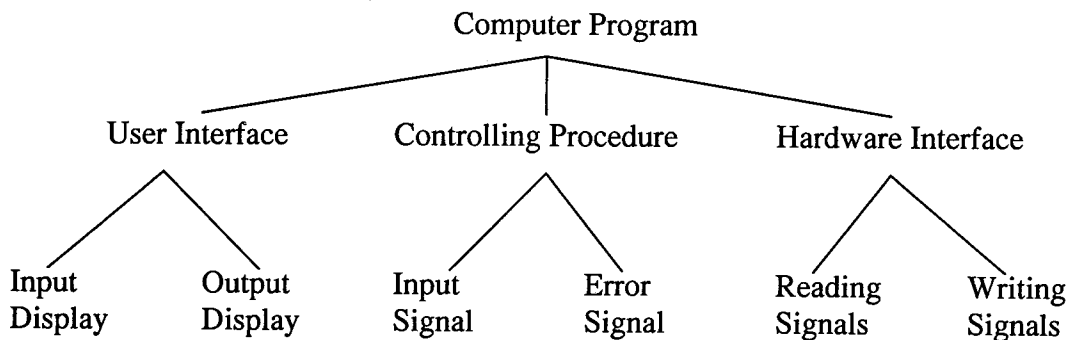Figure 5-1. Division of the Computer Program Parts.

the input display, and the output display. The input display is the part that accepts the parameters and variables associated with the application. With the advancement of the software available to all applications, "point and click" method is an increasing tool that most Windows 95 programs are incorporating. The "point and click" method is a user

interface concept that is associated with most applications. The application will be virtually displayed on the terminal screen with all the parameters represented as objects on the screen. The user moves the mouse pointer, selects the desired object, and moves the mouse again to drag the object to another location on the screen. A second user interface concept is the simple "question and answer" method. This method is when the computer asks the user a set of questions that includes the parameters for the application, or gives the user a choice to select from a list. Another user interface concept is the hardware-input interface. This method involves the use of other peripherals such as a data-glove, a pressure sensor, thermal sensors, etc. The terminal in this case acts only to display the input and output signals. The input signal is processed from the peripheral and sent to the controller part of the program. These are the most common methods of input user-interface.

Irrelevant of the method of the user-interface, the computer program requires certain parameters to operate the motor and produce a force. A force vector is defined by its magnitude and direction. To produce a force vector then, the computer needs to acquire a magnitude and a direction for that force. The next parameters that the computer requires are the distance that the force will move, and the time in which to complete the actions. From the distance and the time required, the average velocity and acceleration can be determined.

Let us consider a force vector F in a two dimensional system that travels for a distance d in a time period t (figure 5-2). The force vector can be divide into its Cartesian

components F_x and F_y. The input parameters can be the represented by any coordinate system as long as the user understands the input requirements. The distance that the force is applied for is specified for any direction and can be represented by any coordinate system. Other input requirements will depend on the application that the motor is operating. The main input requirements are in Table 5-1:

Table 5-1, Input Requirements

$|F|$	Magnitude of the force
$\angle F$	Direction of the force
$|d|$	Magnitude of the movement
$\angle d$	Direction of the movement
T	Time of applied work
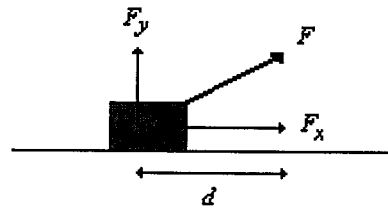
Figure 5-2. A Force Vector in a Two Dimensional System.

Any other variable that an application might use can be derived from the parameters stated above. Let us consider any other parameter that an application might use. The mass of the object on which the force is applied on can be determined from the Potential energy or Newton's second law. The acceleration or the velocity of the object on which the force is applied on can be derived through the equations of motion and Newton's second law.

$$Work = PotentialEnergy$$
$$Fd = Mgd$$
$$F = Mg$$
$$M = \frac{F}{g}$$

5-1

Equation 5-1 is valid only if the object is suspended freely and supported only by a force in the direction of gravity.

$$\vec{F} = M\vec{a}$$

$$\vec{a} = \frac{\vec{F}}{M}$$

$$\Rightarrow \left\{ \begin{array}{l} a_x = \dfrac{F_x}{M} \\[2mm] a_y = \dfrac{F_y}{M} \\[2mm] a_z = \dfrac{F_z}{M} \end{array} \right\} \qquad\qquad 5\text{-}2$$

$$v = at$$

The distance is not included in the above equation although it could be derived from the equations of energy, but it is needed for control purposes, as we will see in the next section.

In a "question and answer" method of user interface, the parameters are clearly defined, but in other more advanced interfaces, the parameters are not as clear. The "point and click" method displays the application and the objects associated with the application on a two dimensional screen. A geometrical transformation to convert the 3D-world into a 2D-screen takes place in the user-interface part. When you point at an object, the computer already knows the (x, y) coordinates of the mouse location. The arm of the motor moves in the 3D-world to correspond to the movement of the 2D-mouse. A click and drag on a specified object will subject that object to a force that is sufficient to move the object to the specified location.

Let us study the user-interface affect on the box example. The box is located on a smooth surface inside a room where the motor is located. The user sees the box on a surface and the mouse pointer. They wish to move the box from position 1, to position 2 inside that room (figure 5-3). The user points the mouse on the object, clicks on it, and moves the object to the desired location. The information that are obtained from those actions are the initial
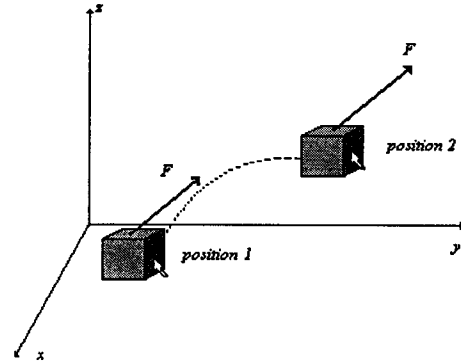
Figure 5-3. A User-Interface Input Sample.

position of the box and the final position of the box. This will determine the distance vector as well as the direction of the force vector. The time from the when the user clicked on the box, to when the user drops the box is the time that is required for the input variables. The mass of the box will determine the magnitude of the force vector. The movement of the mouse in real time may not necessarily represent the real time movement of the motor arm. The motor will first measure the mass of the box, then apply the necessary force in the direction specified for the period that the user specified.

Let us write a sample flow-chart program in Borland C++®:

```
SetUpApplication ();
SetUpWindow ();
While (ProcessEventMsg ())
        {
        Period = 0;
        GetMousePos (&Point);
        TranslatePos_3D (Point, &Point3D);
        MoveMotorArm (Point3D);
        if (GetEvent () == WM_LEFTBUTTONDOWN)
                {
```

```
If (Point3D == BoxLocation)
        {
        Period = timer ();
        GrabObject (Point3D);
        WeighObject (Point3D);
        Position1 = Point3D;
        }
}
if (GetEvent () == WM_LEFTBUTTONUP && Period != 0)
        {
        DropObject ();
        }
```

The output part of the user interface can be expressed in different forms as well. A standard display involves the usage of charts or graph to relay the information that is gathered from the application. A more advanced and user-friendlier approach is the animation of the application as well as certain graphs and charts. The output can be displayed on a terminal screen or a plotter/printer port.

5.4   Control Part

The controlling part of the software is the main decision making part of the program. This part also organizes the flow of information from the user interface to the hardware output. The Control part also processes the input parameters and the feedback signal and determine the control signal.

The hardware interface is a bi-directional communication interface with the card, which means that the error signal and the feedback signal cannot be processed simultaneously. The CPU of a PC does not operate as a parallel processor but as a step by step instruction processor. A lot of software manufactures boost the ability of their

software to perform multitasking an preprocessing of commands, but ultimately the CPU must handle certain instructions in a step by step method. The software that operates the instructional and decision making part of the program has to be optimized so as to perform the most amount of work in the least amount of instructions.

Let us break down the controlling part of the software and analyze its flow chart (figure 5-4). Since the communication with the hardware interface can only be done in one direction for each statement, the reading and writing of the control signals has to be organized. The control part of the software reads the user-interface preparation of the input signal and determines if there are other parameters to be calculated. The parameters are sorted out and assigned to global variables that are called the input signal. If the application has just started, the feedback signal is zero and therefore the computer program needs only to send the data to the hardware-interface. However, if the application has already started, the program needs to read the feedback signal and compare that to the input signal. The output user-interface is updated on where the feedback signal is compared to the input signal. The error signal is calculated from the input signal and the feedback signal and then mathematically amplified to as to form a mathematical signal that is ready to feed the motor. This signal is sent to the hardware-interface to be transferred to a digital signal. If the error signal is zero, i.e. the feedback signal is exactly the same as the input signal, or the input parameters are met, then the controlling part of the software is completed and the program awaits new instructions. The program keeps monitoring the application constantly for any changes in the feedback signal.
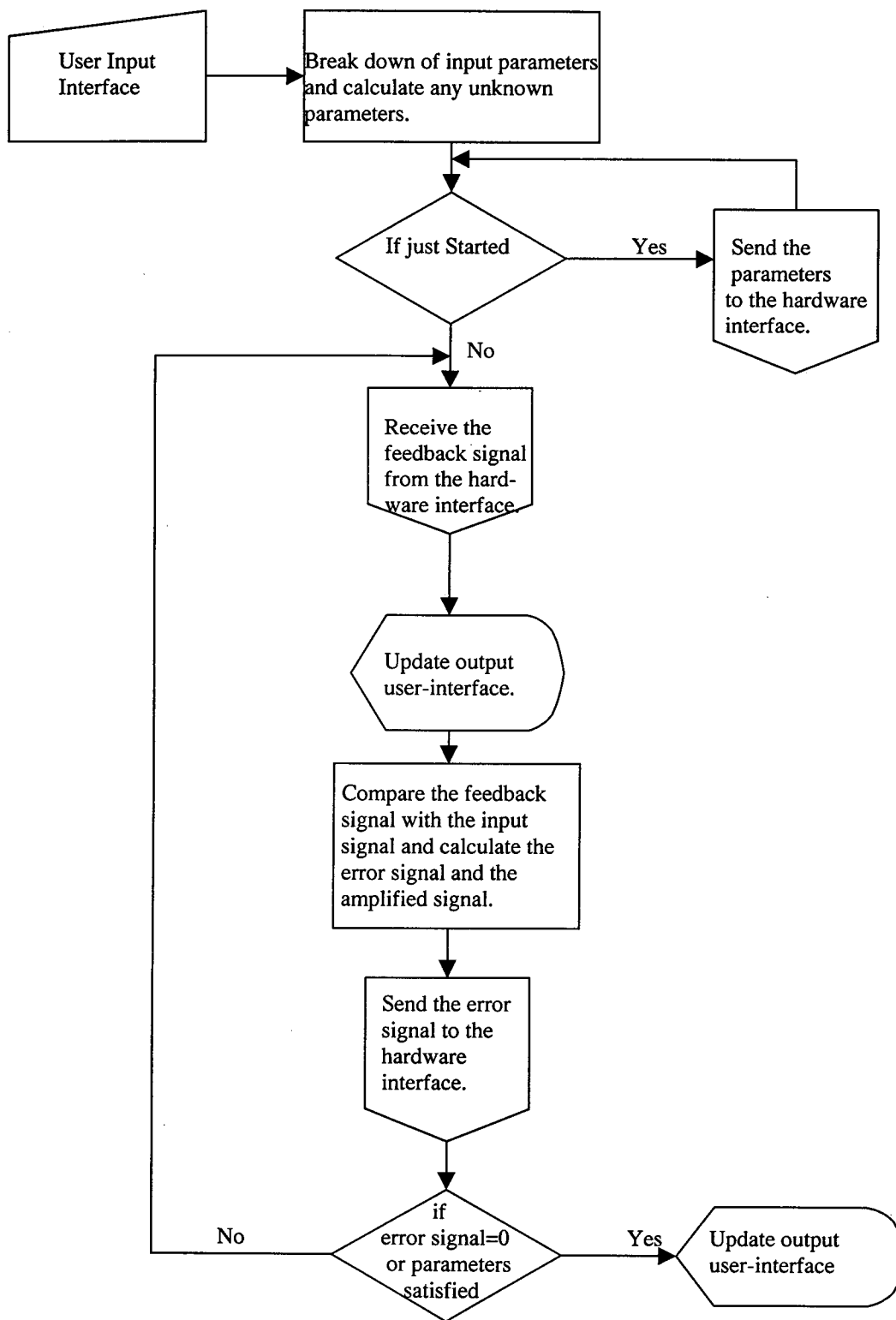
Figure 5-4. Flow Chart of the Control Part of the Program.

Let us examine the mathematical evaluation and comparison of the input signal and the feedback signal. The signal that drives the actual motor is a DC current with an amplitude and a direction. Since the force vector is a three-dimensional vector, we need to divide it into its Cartesian components. Each force component has a relative current component to drive the motor in a single direction. In order to simulate the work done on an object, we need to create a force that for a finite distance. The motor has a mass, and when it applies a force to move an object, it acquires kinetic energy. This energy needs to be transferred to the object completely so that the motor is at rest when the distance is covered. The motor has to accelerate to a point where the motor acquires the highest velocity component then decelerate back to another point to bring the velocity back to zero. The acceleration of the motor is not constant and therefore, the force that the motor applies is not constant. The current signal is directly proportional to the force curve and will have the same basic shape.

Let us consider the example of the box. Let us assume that the user wants to move the box in one direction for a distance of 16 cm in 5 milli-seconds. The user also wants the maximum speed of the box to reach 8.5 m/sec. The computer program accepts those parameters and then determines the rest of the parameters in order to run the application. The program first initializes the data and locates the box in the room. The program weighs the box to determine its mass. From the distance, time, and max velocity, the computer program can plot an acceleration curve based on a few default-programmed parameters. Note that the acceleration curve is not a unique curve to satisfy the input parameters.
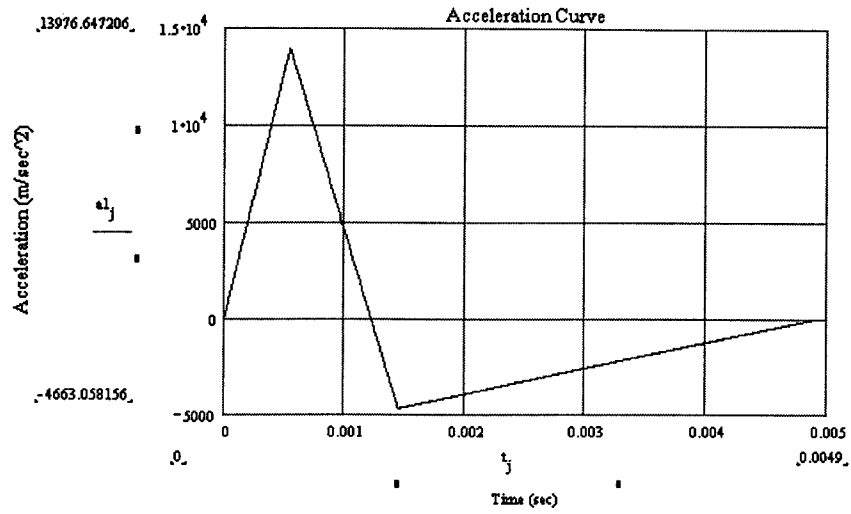
Figure 5-5. Acceleration Curve of the Motor in a Single Direction.
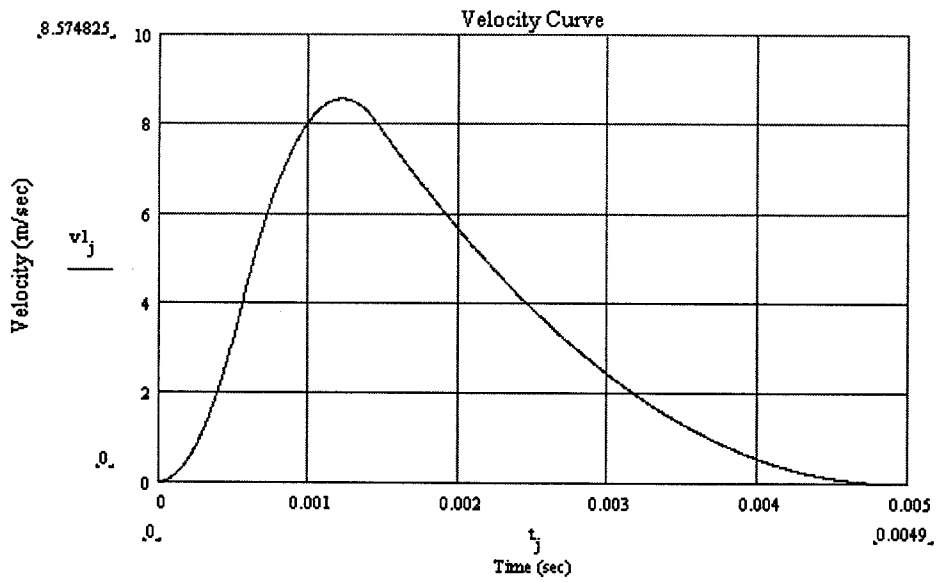
Figure 5-6. Velocity Curve for the Motor in a Single Directional.
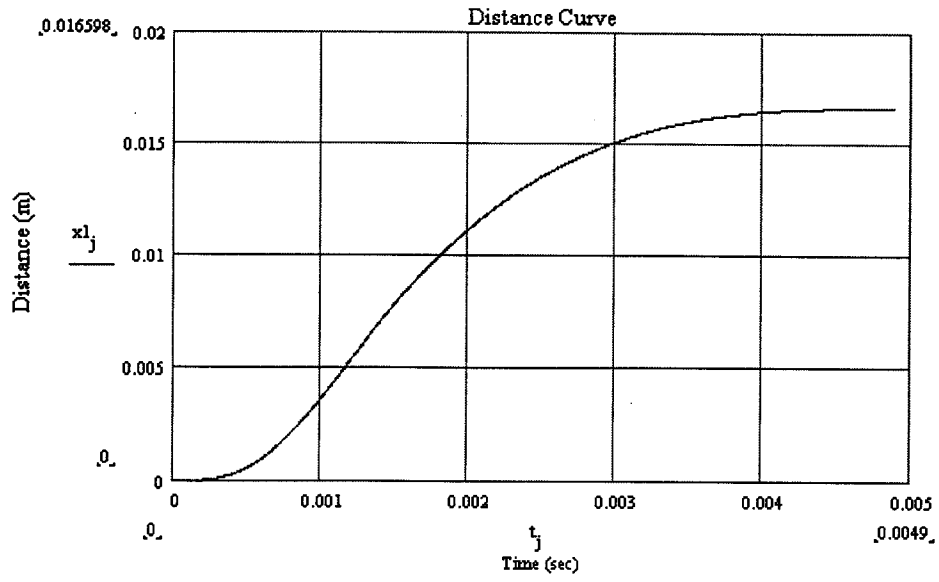
Figure 5-7. Distance Curve for the Motor in a Single Direction.
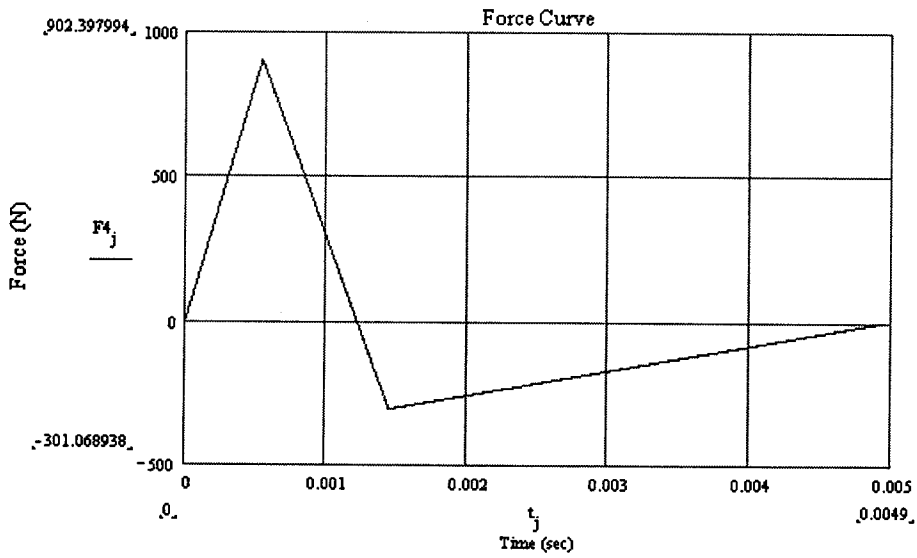
Figure 5-8. Force Curve for the Motor in a Single Direction.

Figures 5-5 to 5-8 represent a computer simulation of the input parameters to generate a force curve. This force component curve is for a single direction, and the procedure can be repeated for the other two components.

If we refer back to the flow-chart of figure 5-4, the procedure that was done above represents the first block after the user input interface. The force curve is now called the input signal. This signal now has to be mathematically transferred to a current signal to feed the motor. The current signal will be the amplified signal that feeds the plant. The mathematical transformation from a force signal to a current signal was described in chapter 3. From the sensors that are attached to the application, the instantaneous force in any direction can be measured. This measured signal is called the feedback signal. The feedback signal is then compared to the input signal. The error signal is the result of the feedback signal subtracted from the input signal. The error signal is still a force signal and has to be transformed to a current signal. This method is repeated until the error signal is zero or the distance is reached.

5.5 The Hardware Interface part

The computer can generate a perfect mathematical solution to a control problem. The program can generate a mathematical force curve that can perform "miracles". However, can these signals be transferred to reality? The computer needs to transfer the mathematical signal to a digital signal that the data acquisition card can handle. The computer can communicate with any hardware through its I/O ports. These ports are

either serial (COM), or parallel (LPT) ports.   Other I/O communication means are

through internal boards and cards.

The serial port can handle bi-directional communication with an external port and

can transmit and receive data.   Table 5-2 represents the pin out for a serial port and the

Table 5-2. Pin Out Designation for a Parallel I/O Port. Courtesy of
Gateway 2000®.

Pin Number	Description	Hardware-Interface Usage
1	Strobe	Sample
2	Data bit 0	Data bit 0
3	Data bit 1	Data bit 1
4	Data bit 2	Data bit 2
5	Data bit 3	Data bit 3
6	Data bit 4	Data bit 4
7	Data bit 5	Data bit 5
8	Data bit 6	Data bit 6
9	Data bit 7	Data bit 7
10	ACK (Acknowledge)	Acknowledge
11	Busy	Not Used
12	Paper End	Motor Selection Bit In
13	SLCT (Select Out)	Motor Selection Bit Out
14	Auto Feed	Motor Selection Bit Out
15	ERROR	Error
16	INIT (Initialize)	Reset
17	SLCT IN (Select In)	Motor Selection Bit In
18	GND (Ground)	Ground
19	GND (Ground)	Not Used
20	GND (Ground)	Not Used
21	GND (Ground)	Not Used
22	GND (Ground)	Not Used
23	GND (Ground)	Not Used
24	GND (Ground)	Not Used
25	GND (Ground)	Not Used

hardware-interface usage. The pin outs are digital signals that are either high (1), or low

(0). The data bits 0 – 7 are used to transmit data back and forth. The computer on board

clock is three times faster than the data acquisition clock. This allows the computer to

transmit the data bits to the card and allows it to convert the digital bits to an analog

signal. Since there are three different motors for all three dimensions, the computer needs to prepare the data for each motor and convert it to a digital signal. In Borland C++, the variables are stored either as a short, a float, a double, or a long double. Each variable type occupies a different amount of bytes. A short variable occupies 4 bits, or one half of a byte. A float occupies 8 bits or one byte. A double occupies 2 bytes, and a long double occupies 4 bytes. The parallel port supports up to 8 bits, so that limits the variable types to short or floats. As a rule, the more bits you assign to store a variable, the better the accuracy and representation of that variable. Hence, the float type is the ideal type to use in this situation. The eight bits assigned from pin 2 to pin 9 will then transmit one variable at a time. Every pin out on the motherboard has an I/O address that allows access to read or write to that pin. Since there are three different motors to drive, motor selection is another important pin out. Pin 13 and 14 allow the computer to transmit to the card the motor selection, i.e. motor 1, 2, or 3. Pin 12 and 17 allows the card to transmit to the computer the identification of the motor selection, i.e. the computer will know that this information is from motor 1, 2, or 3. Pin 1 sends a command to the data acquisition card to sample the selected motor and transmit the information back through the data bits. Pin 16 allows the computer to reset all the functions on the data acquisition card. Pin 10 informs the computer program that the card is operational. Pin 15 informs the computer that an error occurred in the card or the sensors. Pin 18 is the ground pin.

The computer program accepts the amplified signal from the control part of the program and the direction of this signal, i.e. the x-direction. Before the computer starts

the application, the hardware-interface will send an INIT signal through pin 16 to initialize the card. If the ERROR pin 15 returns high, then the card or one of the attached components is non-functional. The hardware interface will inform the control part and the user of the error. If the card and all of its components are functional, the interface will then send the following signals to the out ports:

- Pin 2 to Pin 9 is the instantaneous amplified signal,
- Pin 13 and Pin 14 is the motor Id (the direction of the force),
- Pin 10 to acknowledge that the card is functional,
- Pin 18 as the ground.

After the three instantaneous force components are sent to the card and the motor, the computer informs the card to start sampling the output force vectors. The resultant information along with the motor Id are sent back to the computer through pins 2 – 9 and pins 12 and 17. When all three motors are sampled, the sample pin 1 is low again and the computer transmits the processed information all over again.

5.6   Improvements

As we mentioned earlier, the speed of the advancements of computer technology allows for constant improvements on both the hardware and the software parts of the program. The user-interface is what makes this concept unique and any advancement to simplify the operation of any application is always a positive improvement.

Chapter 6 Applications

The concept of a computer controlled forces may be a wonderful and general idea, but what are its benefits? Is the whole discussion just an idea and a collection of thought, or can it be put to practical use? This chapter will discuss several applications that utilize the concept of computer controlled forces. Most automation machines imply an industrial use with no small business or home applications. The use of personal computers for small businesses and home use are increasing everyday. Since automation is not available to these markets, such concept that utilizes an item that is already available to them is a practical idea.

6.1   Home Use

In the recent years, automation began finding its way to into the homes of millions of people. These automated items are now a part of every new home and are an integral part of living, yet we are unaware of the concept in our homes. Temperature control units are the most common of these systems. Home security is yet another example of automation. But, is that the limit of today's technology? Can we use this technology in simple duties that are just time consuming yet so necessary? If you ever saw the Jetson's house (cartoon comedy series), you will laugh at the idea of ever having a similar house. The house of the future is not so far fetched idea.

Most house duties require the movement of something, the pressing of an item, the lifting of objects, etc. In other words, most duties require the usage of a force applied

to an object. In the homes of physically impaired people, such units do exist and are an integral part of their life. However, those units require a manual signal to be activated, i.e. remote control or sensors.

Before I start to discuss the actual applications, I would like to point out that these applications are designed to help people in their daily life and protect children from harming themselves. Let us discuss the possibilities of computer controlled forces in a typical home. To begin the discussion, we will assume that the home is equipped with a PC. The PC is equipped with the data acquisition card and the software to control the different motors. The motors are placed in locations where the physical control of objects is desired.

The first purpose of such an application in a house is home security. Main locations of motors for security purposes are windows and doors. The computer can be programmed to close all the windows and doors (that are controlled) at a certain time and open them (if desired) at another time. The computer can detect an attempt to force open a window or a door and can initiate a preprogrammed action. In case of a fire or other emergencies, the computer can open all emergency exits and inform the house residents of such an emergency. The computer can also log in all entries through any controlled door.

In detail explanation, the user interface part of the program can be set to display the details of the fore-mentioned house. The controlled windows and doors can be

presented as items with which the user can interact. Zoom functions in the software part can show a more detailed area of the house. The user can, for example, click and drag a window open or shut. The distance the window opens or closes depend on the user's choice. Since the computer is so versatile, it can use its modem capability to dial certain numbers and relay a message. This feature along with the physical computer control of all entries and exists make a much safer and reliable home security system.

Another home use item is a child safety and adult comfort utility that utilizes a rotary torque motor. This feature protects children from extreme temperature variation while bathing. It also adjusts the temperature and the pressure setting for an adult comfort in a shower. The idea uses the computer to monitor the current temperature and pressure of the water flow, and control the hot and cold water valve opening. The user can turn on the shower and set the desired temperature and pressure before entering the shower. The computer then handles the temperature and pressure regulating.

6.2   Exercise Machine

This application is a more detailed application and can be used for either medical monitoring or physical exercise. This application is a computer controlled exercise machine. A simple model would be to portray the human body according to sex, height, weight, and age. The concept of this application is to simulate the lifting of weights and muscle exercise. The user pushes against the motor as if lifting a heavy weight. The computer senses the opposing force, and reacts to it with an equal amount of force. The user interface part could be designed to monitor the target muscle groups depending on

the direction of the user force, and the location of the user compared to the motor. The user interface can also be set to display certain information such as target heart rate, calories burned and a timer. The computer setting could be adjusted to different mode settings such as high magnitude resistance, normal opposing force, or low resistance.

Traditional weight lifting is still much more economical and easier to operate. However, safety of the user is better when using a controlled force as a weight lifting method. The weight could be removed completely if you do not apply any resistive force against the motor. In addition, the information about the muscle group operation is more informative and will help the exercise routine. The user interface can also demonstrate different exercise methods in order to use different muscle groups.

The motor in this application consists of two motors in single directions that are placed in a symmetrical manner to exert an equilibrium force on an ergonometric rod. The input signal in this case is the user-applied force on the rod. Magnetic sensors can be applied to the rod to sense the pressure exerted on the rod. The computer program will then control the output force so that it is of the same magnitude of the input force but of opposing direction.

Very few people have their own personal trainer with them to demonstrate and show them how to exercise and what muscle groups to use. Such an application requires a motor resistance supplied with force sensors, a data acquisition card, and software to be

installed on a PC. The economic aspect of such an application is extremely sensible. This computer-controlled trainer could replace the traditional weight lifting methods.

6.3   Sculptures and Art

Artistic ability is something that is within every being. Some posses the ability to express the arts more than others. Some people say that not everyone was born to be an artist. It is a gift! If people can appreciate art, then they can be artists. The most difficult form of art is creating a piece of art from a solid dull object. To be an artist in the old days was to be poor and unappreciated. Sculpting takes a long time to produce one piece of art. In addition, physically impaired people that have those tendencies to express their artistic abilities are denied an opportunity that they could have used if they were able.

Now since the advancement of technology, carving and sculpting are a less time consuming process but still a very hard and detailed artistic ability. Very little technological advancement was dedicated to art and the enhancement of one's artistic ability. With the concept of computer controlled forces, an application could be devised to "bring up" the artist in the user

The drawing capabilities of today's software are advancing and growing in detail and reality. If a computer can draw a three-dimensional model on a two dimensional screen, why can't it "draw" or carve this model in a three dimensional world. Let us consider an application for a computer controlled forces concept. The software is a drawing aid that creates three-dimensional objects of the user's creation on a computer

terminal. After the drawing is complete and the three-dimensional model is ready to be created from physical matter, the user can choose to render the object and start the carving procedure. The software will analyze the three-dimensional image that is created and compare it to the original shape of the material. The original shape of the material, and the designed object are overlapped and the difference between the two is the controlled signal. Sensors can measure the distance of movement of the carving motor arm and update the computer program on the process of the sculpting. The magnitude of the force is determined by the material density and the distance to the desired shape. The feedback signal will inform the user on the progress of the sculpture and update the user display. The computer processes the feedback signal. The program increases or decreases the magnitude of the force in relation to the distance from the current position to the surface of the object. The direction of the force vector is best simulated as perpendicular to the three surface of the desired object. The motor arm will be equipped with a sharp solid stone cutter and will be free to move around as the sculpting begins. The best coordinate system for such an application is a cylindrical coordinate system.

This application is a practical solution for the busy artist who can spare a few hours to draw their creation on the "drawing board" (computer screen) then let the program render the object and bring it to physical existence.

6.4   Cooking and Catering

The kitchen and the dining room are places where many people spend their time. Preparing or serving food is a process that requires time and dedication. It also requires

help if any are offered! There are many gadgets in today's kitchen to slice and dice, chop and cut, but those devices are manually operated and that is not a major help. What is really needed is an extra hand or two to help in the kitchen. Most cooks enjoy cooking their meals and catering them, but they do not enjoy much the tiresome job of slicing tomatoes or cutting cucumbers.

An excellent application for such people using the computer controlled forces can be installed. The computer can perform the duty of another hand or two. In fact, the computer can add much more than two helping hands in the kitchen. The program will display a large database of fruits and vegetables for the user to select. The user will also select the cutting style and thickness of the slices. The motor is equipped with a very sharp knife and is free to travel in all three dimensions. The best dimension system for such an application is the Cartesian system. The vegetables are placed on a pressure sensing plate so that the program can determine the exact dimensions and locations of the vegetables. The motor will then move over a vegetable and apply a pressure to stabilize the vegetable. The knife will then apply the force necessary to slice the vegetable. The magnitude of the force applied can be determined by the type of vegetable. After all, slicing a tomato is different than slicing a cucumber.

The user interface will display the type of vegetable being cut. The position of the knife relative to the vegetable is also displayed. The sensors will detect the position of the vegetable on the plate and will detect the size of the vegetable. The computer program will determine the optimal cut size and the force applied to it.

Such an application could save a cook lots of unpleasant chopping or cutting time. This application is automated and does not need an operator to control it or use it. The application is not an expensive alternative to the kitchen knife, but rather a cheap alternative to a professional cook. The program can also hold thousands of recipes and cooking demonstrations.

6.5   Small Businesses

We have described several application examples that are home related. Generally, the industry and large business corporations are the first to acquire technology and incorporate it into their regular production. Small businesses usually wait to see the outcome of such technology and their effect on sales or production. To introduce such a concept to small businesses we must first prove their efficiency and effect on sales and production.

If we consider the industry standard, automation and control are an integral part of their manufacturing system. The sales and profit from the automation principles have exceeded any nominal profit margin. So the efficiency and sales capability of automation can be proven without a doubt. The next step is to develop applications that are designed especially for small businesses. The wide variety of businesses makes it impossible to quote an application for every type of business.

Let us consider an example of a carpenter shop. Power tools are a common and necessary part of any carpenter shop. However, the power tools require an operator to

use them. Let us assume that the carpenter needs to make cuts in a 4x8 piece of plywood. The carpenter needs to measure the distances, mark the cuts on the board, and cut the marked pieces. This can slow production down and decrease the efficiency of the business.

Let us devise a computer controlled forces to assist the carpenter in their application. The computer software will have sketching capabilities to allow the carpenter to sketch their design on the computer. If they like the design and are satisfied with it, they can issue a command to the software to handle the rest. The computer will then determine the magnitude of the force needed to drive the power saw and the direction of the force in which to make the cut. Sensors are placed to read the position of all direction components from a reference point. The mass of the saw is taken into consideration and the feedback signal needs to account for the resistance of the wood.

The user interface will display the original 4x8 plywood and the marks on which the cuts are to be made. The user interface will also display the cuts made and the current location of the saw. The motor arm is attached to the power saw and is free to travel in all three Cartesian components. Since the saw is a separate unit that is attached to the motor, the user can attach other units such as a drill, or a power screwdriver. The principal is the same, and the output force is driving the power tools.

Chapter 7 Ethics

In an age where technology is thriving and communications set the learning curve of the world, we tend to forget about our most basic philosophy. Before the industrial revolution and the scientific advancement of our society, there were basic rules that governed our role in society. Laws were different for each civilization, but there were a few laws shared by all civilizations. Laws like do not kill another being based on your emotions, do not steal from others based on your needs, etc. These laws and others became more like moral laws that all civilizations followed. Morality and human behavior in society were studied by a lot of philosophers and sociologists over time. As the communications between the different cultures grew, the moral laws of our society grew stronger and helped us interact amongst each other. Laws are still different from country to country, but the moral laws are universal laws that help us break the barriers of different cultures and civilizations. In other words, moral laws help us as a whole function in harmony. Ethics is the definition of the moral laws that govern our behavior in society. Ethics is not a law that would necessarily send you to jail, but would put you down in the eyes of society. The ethical laws advance with the same rate that our society advances.

This age is called the age of communications because of the simple fact that our small physical world is connected together. Any human being on this planet can now share experiences that other human beings shared or are sharing. A person in Australia can know about an experience that happened to another person in the U.S.A. and learn

from that experience. Therefore, the person in Australia shared the same experience that a person in the U.S.A. shared. With the advancement of communication, the sharing of our experiences have defied the space-time continuum. Our combined experience and knowledge of humanity are accessible to us and that raises our awareness. Ethical standards are shared over the world through the sharing of our experiences. World War II gave us the shared experience of the horrors that man can do and how it could be done. With the shared knowledge of these experiences, our ethical standards were raised.

Science and technology are two fields of studies that depend on communications and ethics. When scientists discovers new concepts, they need to share those concepts with other scientists in order to validate those concepts. The scientific community depends on the ethical standards that were set to govern the way experiments are run. Without those ethical standards, scientists could easily manipulate their concepts and experiments for personal gain. Many experiments and ideas will not have the solid proof that can convince the rest of the scientific society. Without ethics, the scientific community will spend its time trying to validate if experiments are true and do give the intended results. No scientist will honor another scientists' proof of the validity of an experiment. Without ethics, there won't be any more advancement to raise our knowledge to another level.

Ethics is not limited to the scientific community but rather applies to all aspects of life. Every field of study depends on the ethical standards of others that are in the same field of study. Every human being depends on the ethical behavior of other beings in

order to go through life with ease. If there were no ethical standards in our daily life, we would not trust any other person or service that was provided to us. If we go out to eat in a restaurant, we will need to test the food and watch them cook it. We would not be able to trust our own doctors to take care of us. If another person greeted us, we would wonder about the reasons behind that greeting. Therefore, ethical standards are a crucial part of all of society and not just limited to field of studies.

So far, we have discussed the ethical standards between human beings, but we are not alone on this planet. Other life forms share this planet with us has the right to be subjected to the same ethical standards that we subject ourselves to. Human beings throughout time and space have disrespected the other beings that live on this planet. We chain dogs to the side of the house to protect our properties. If that dog were a chained human being, the ethical - as well as federal - laws would be violated. Human beings also cut down trees and destroy forests to build more possessions. If another being were to destroy our house to build a property of their own, the ethical – as well as federal – laws would also be violated. So why do we subject ourselves to ethical standards when we don't really apply them on other beings?

Ever since the industrial revolution, other beings on this earth have been abused in so many unspeakable ways. The holocaust during World War II happens on a daily basis in a cow or chicken-raising farm. Millions of animals die every day so we can eat food that we really don't need to survive. This act of slaughter, however, is not called unethical because it is a different species. Before the advancement of communications,

the same actions were done between cultures. The stronger culture would slaughter and rape the weaker culture, but that was not unethical. Later, the different cultures were merged and those actions were considered extremely unethical. Those same actions were repeated when another human race was discovered, but again the actions were ethical at the time. We are fighting for equal rights among all races and sexes, and we are approaching an ethical standard that could make humanity function in harmony with each other. The fight for equality however, should include all the other species that occupy our planet. We are a part of nature and we live on this planet, so why can't we protect it and live in harmony with all other beings?

The discussion that was raised above is not just for the sake of argument but does apply towards this thesis. In the age of computers and advanced technology, human beings are faced less and less with the actual world. The world is being limited to a computer screen that can simulate nature. Children do not need to go and experience the planet that we live on but can see the experience from a digital point of view. The sharing of experiences is becoming the only way we do experience the world. In order for us to advance our knowledge and experiences, we need to experience new situations and deal with new events. Sharing the experiences that were accumulated over time and space has raised our awareness to the point we are in right now. This point can only be pushed further and further into a higher level of knowledge if and only if we encounter new experiences. If we ignore the planet we live in and the other beings that share the planet, we will miss such experiences.

The computer has facilitated the sharing of the experiences between all human beings. The Internet has connected billions of people together and enabled us to pass our knowledge without regards to time and space. This function of the computer does help us advance our knowledge. However, the computer does have a side effect of representing the real word in a digital form. Virtual reality is a new concept that is gaining popularity in this era. This concept was devised to replace reality with a computer version of reality. Nature and all the species living in nature are being replaced with a reality that exists only in the computer screen and the mind of the person that is operating that specific computer. One can argue the existence of the physical realm that we all live in, but our current reality took over 2 billion years to be defined and understood by all the beings living in it. In other words, our reality has reached a level of harmony so that all of us do experience the same thing. A computer reality on the other hand is limited between the computer and the user. Its vision is controlled by the people who wrote the software to produce the reality. Therefore, the computer reality is very limited and represents certain visions of the creators of the software that produces the reality.

In a computer-controlled world, the applications can be used to create a more diversified realty. However, this reality is still not the reality that was developed over 2 billion years. The applications can also facilitate and enhance our knowledge to advance to our next plateau of wisdom. In a world that is still struggling for equal rights among the human species, computer applications can help us advance to a standard that will allow this equality to happen. The computer applications can also help us reach an equality that all beings would share.

It is easy to develop a concept or idea that would ease our lives and lower our workload. It is also easy to invent products that will limit our interactions with other beings. We can also limit ourselves to a reality that only each individual experiences. Does this "ease of lifestyle" help us advance as a society? Every concept and idea can be used for different purposes. The hard part of sharing a new concept is making sure that the idea helps our society as a whole and not as an individual. When we learn how to implement ideas and concepts to raise the harmony between all beings on this earth, then those concepts are good and ethical concepts.

The applications as well as the idea presented in this thesis are intended to be used to help the society as a whole. The concept is also intended to help the other beings fight for their independence. No longer would we need a "watchdog" to protect our material possessions from other beings. We would no longer need to kill animals to test our products, or create art for our pleasure.

I would hope that in the future, these applications would not be needed and would not be used. After all, Einstein said the most complex systems are the simplest systems. Our bodies are considered the most complex design, but it is the work of all the cells working in harmony. Until we get to a stage that we would not depend on material possessions, we should develop concepts and ideas that would lead us there.

Chapter 8 Conclusion

In this chapter, I will attempt to summarize the thesis and conclude the discussion. I will suggest some future recommendation and further applications. In this summary, I will cite an application and the use of the thesis on that application.

8.1   Summary

What is a computer controlled force? A computer controlled force is a general concept that sets the precedence in certain feedback applications. Control systems have been around for a number of years, and have been advancing in design and practicality. The feedback applications started with design of mechanical machines that would control the input energy (steam) of a motor. Feedback applications evolved to analog electrical signals that were physically summed together through an operational amplifier. The next era of feedback applications started with the PLC control. In today's technology, feedback applications can be pushed to a higher plateau by using a computer to control the signals.

Feedback applications are defined as any application whose output signal is subtracted from the input signal to drive the application. The output signal tracks the input signal and adjusts itself when the input changes. Feedback applications are also called closed loop control systems.

A computer is defined by a central processing unit, memory, storage space, and an operating system. A computer can be found on the desks of many businesses and homes. A force is defined as the pressure being applied to (or removed from) a surface. A more fundamental definition of a force would be the work done on an object divided by the distance the object moved. A force is a vector that has a magnitude and a direction. Therefore, a computer controlled force could then be defined as a processing unit / operating system that can apply a pressure to the surface of an object.

The computer controlled force can be physically realized by obtaining a personal computer and creating a force. Personal computers can easily be purchased from any electronic shop. A force can be created with the help of a motor. Since the force is a vector in the three-dimensional point of view of space, we require three different motors to create such a force vector. Electric motors can produce a force through the interaction of a current carrying conductor in a magnetic field. Therefore, the force vector can be created with three different current signals.

The personal computer can not interface directly with a motor. The computer can produce low power digital signals, while the motor requires medium – high power analog signals. A data acquisition card is needed to interface the computer with the motor. The data acquisition card is a circuit that has, at least, a digital to analog converter and visa versa, and an amplifying circuitry.

The applications that use such a concept are infinite in numbers. Certain applications were discussed in chapter 6, and the concept behind choosing any application is discussed in chapter 7. To summarize the thesis, let us pick an application, and follow the concept of computer controlled forces in that application.

In chapter 6, the home security application was discussed and analyzed. Let us reexamine to better understand the concept. A home security application involves the computerized control of home security features. Typical home security applications sound an alarm and notify the local police of a possible breach of security. Those applications would react in the same manner in case of an emergency such as a fire. This unit would be controlled with a small box that has flashing light emitting diodes (LEDs) to inform the user of any change in security parameters. We now posses the technology to perform more features to the home security system.

A computerized home security system, which utilizes the computer control forces concept, is more efficient and user oriented system. The computer software will display a three-dimensional view of the home it is installed in. Secured entry points can be displayed on the monitor. Instead of the typical magnetic sensor that could detect the opening and closing of a door or a window, the system would install a small motor with a sensor attached to the motor. The motor would be controlled from the computer. The motor will exert force on a door or a window (entry points) to either open or close the entry point. The typical features can easily be included and enhanced. In an emergency,

the entry points will open to provide easier exits from the house. Such a security system is much more advanced than the typical analog circuitry.

8.2 Future Recommendations

The concept defined in this thesis is general enough to include several applications that could be discussed in further details. The work done in this paper is a stepping stone for the future of control systems. No longer are we limited to control circuitry but to move physical objects in a desired manner. The concept is not yet fully applied in the scientific world, and the future recommendation is to incorporate the computer as the basic controller unit for future applications.

Appendix A

N *National Semiconductor*
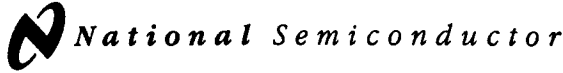
DAC0808/DAC0807/DAC0806 8-Bit D/A Converters

General Description

The DAC0808 series is an 8-bit monolithic digital-to-analog converter (DAC) featuring a full scale output current settling time of 150 ns while dissipating only 33 mW with ±5V supplies. No reference current (I_REF) trimming is required for most applications since the full scale output current is typically ±1 LSB of 255 I_REF/256. Relative accuracies of better than ±0.19% assure 8-bit monotonicity and linearity while zero level output current of less than 4 μA provides 8-bit zero accuracy for I_REF ≥ 2 mA. The power supply currents of the DAC0808 series are independent of bit codes, and exhibits essentially constant device characteristics over the entire supply voltage range.

The DAC0808 will interface directly with popular TTL, DTL or CMOS logic levels, and is a direct replacement for the MC1508/MC1408. For higher speed applications, see DAC0800 data sheet.

Features

- Relative accuracy: ±0.19% error maximum (DAC0808)
- Full scale current match: ±1 LSB typ
- 7 and 6-bit accuracy available (DAC0807, DAC0806)
- Fast settling time: 150 ns typ
- Noninverting digital inputs are TTL and CMOS compatible
- High speed multiplying input slew rate: 8 mA/μs
- Power supply voltage range: ±4.5V to ±18V
- Low power consumption: 33 mW @ ±5V

Block and Connection Diagrams
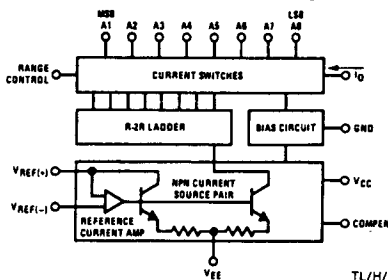
Order Number
DAC0808, DAC0807,
or DAC0806
See NS Package
Number J16A,
M16A or N16A

TL/H/5687-1

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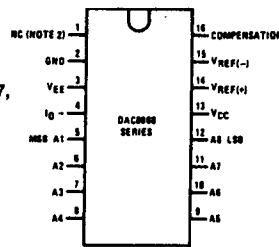
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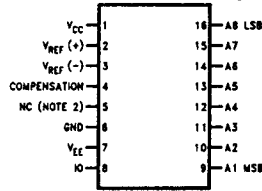
TL/H/5687-13

Top View

Ordering Information

ACCURACY	OPERATING TEMPERATURE RANGE	ORDER NUMBERS				
		J PACKAGE (J16A)*		N PACKAGE (N16A)*		SO PACKAGE (M16A)
				DAC0808LCN	MC1408P8	DAC0808LCM
7-bit	0°C ≤ T_A ≤ +75°C	DAC0807LCJ	MC1408L7	DAC0807LCN	MC1408P7	DAC0807LCM
6-bit	0°C ≤ T_A ≤ +75°C	DAC0806LCJ	MC1408L6	DAC0806LCN	MC1408P6	DAC0806LCM

*Note. Devices may be ordered by using either order number.

Electrical Characteristics (Continued)

(V_{CC} = 5V, V_{EE} = -15 V_{DC}, V_{REF}/R14 = 2 mA, DAC0808: T_A = $-55°C$ to $+125°C$, DAC0808C, DAC0807C, DAC0806C, T_A = 0°C to $+75°C$, and all digital inputs at high logic level unless otherwise noted.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
SRI$_{REF}$	Reference Current Slew Rate	*(Figure 6)*	4	8		mA/μs
	Output Current Power Supply Sensitivity	$-5V \leq V_{EE} \leq -16.5V$		0.05	2.7	μA/V
	Power Supply Current (All Bits Low)	*(Figure 3)*				
I_{CC}				2.3	22	mA
I_{EE}				-4.3	-13	mA
	Power Supply Voltage Range	T_A = 25°C, *(Figure 3)*				
V_{CC}			4.5	5.0	5.5	V_{DC}
V_{EE}			-4.5	-15	-16.5	V_{DC}
	Power Dissipation All Bits Low	V_{CC} = 5V, V_{EE} = $-5V$		33	170	mW
		V_{CC} = 5V, V_{EE} = $-15V$		106	305	mW
	All Bits High	V_{CC} = 15V, V_{EE} = $-5V$		90		mW
		V_{CC} = 15V, V_{EE} = $-15V$		160		mW

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its specified operating conditions.

Note 2: Range control is not required.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{JMAX}, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any temperature is P_D = (T_{JMAX} − T_A)/θ_{JA} or the number given in the Absolute Maixmum Ratings, whichever is lower. For this device, T_{JMAX} = 125°C, and the typical junction-to-ambient thermal resistance of the dual-in-line J package when the board mounted is 100°C/W. For the dual-in-line N package, this number increases to 175°C/W and for the small outline M package this number is 100°C/W.

Note 4: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 5: All current switches are tested to guarantee at least 50% of rated current.

Note 6: All bits switched.

Note 7: Pin-out numbers for the DAL080X represent the dual-in-line package. The small outline package pinout differs from the dual-in-line package.
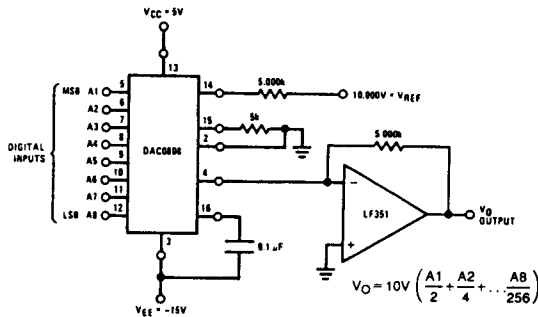
Typical Application

$$V_O = 10V \left(\frac{A1}{2} + \frac{A2}{4} + \ldots \frac{A8}{256} \right)$$

FIGURE 1. + 10V Output Digital to Analog Converter (Note 7)

TL/H/5687-3

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Supply Voltage	
V_{CC}	$+18\ V_{DC}$
V_{EE}	$-18\ V_{DC}$
Digital Input Voltage, V5–V12	$-10\ V_{DC}$ to $+18\ V_{DC}$
Applied Output Voltage, V_O	$-11\ V_{DC}$ to $+18\ V_{DC}$
Reference Current, I_{14}	5 mA
Reference Amplifier Inputs, V14, V15	V_{CC}, V_{EE}
Power Dissipation (Note 3)	1000 mW
ESD Susceptibility (Note 4)	TBD

Storage Temperature Range	$-65°C$ to $+150°C$
Lead Temp. (Soldering, 10 seconds)	
Dual-In-Line Package (Plastic)	260°C
Dual-In-Line Package (Ceramic)	300°C
Surface Mount Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C

Operating Ratings

Temperature Range	$T_{MIN} \le T_A \le T_{MAX}$
DAC0808LC Series	$0 \le T_A \le +75°C$

Electrical Characteristics

(V_{CC} = 5V, V_{EE} = $-15\ V_{DC}$, V_{REF}/R14 = 2 mA, DAC0808: T_A = $-55°C$ to $+125°C$, DAC0808C, DAC0807C, DAC0806C, T_A = 0°C to $+75°C$, and all digital inputs at high logic level unless otherwise noted.)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
E_r	Relative Accuracy (Error Relative to Full Scale I_O)	*(Figure 4)*				%
	DAC0808LC (LM1408-8)				± 0.19	%
	DAC0807LC (LM1408-7), (Note 5)				± 0.39	%
	DAC0806LC (LM1408-6), (Note 5)				± 0.78	%
	Settling Time to Within ½ LSB (Includes t_{PLH})	T_A=25°C (Note 6), *(Figure 5)*		150		ns
t_{PLH}, t_{PHL}	Propagation Delay Time	T_A = 25°C, *(Figure 5)*		30	100	ns
TCI_O	Output Full Scale Current Drift			± 20		ppm/°C
MSB V_{IH} V_{IL}	Digital Input Logic Levels High Level, Logic "1" Low Level, Logic "0"	*(Figure 3)*	2		0.8	V_{DC} V_{DC}
MSB	Digital Input Current High Level Low Level	*(Figure 3)* V_{IH} = 5V V_{IL} = 0.8V		0 -0.003	0.040 -0.8	mA mA
I_{15}	Reference Input Bias Current	*(Figure 3)*		-1	-3	μA
	Output Current Range	*(Figure 3)* V_{EE} = $-5V$ V_{EE} = $-15V$, T_A = 25°C	0 0	2.0 2.0	2.1 4.2	mA mA
I_O	Output Current	V_{REF} = 2.000V, R14 = 1000Ω, *(Figure 3)*	1.9	1.99	2.1	mA
	Output Current, All Bits Low	*(Figure 3)*		0	4	μA
	Output Voltage Compliance (Note 2) V_{EE} = $-5V$, I_{REF} = 1 mA V_{EE} Below $-10V$	$E_r \le 0.19\%$, T_A = 25°C			$-0.55, +0.4$ $-5.0, +0.4$	V_{DC} V_{DC}

Appendix B

National Semiconductor
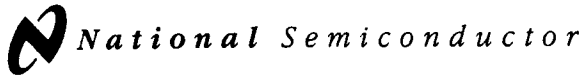
LH0021/LH0021C 1.0 Amp Power Operational Amplifier
LH0041/LH0041C 0.2 Amp Power Operational Amplifier

General Description

The LH0021/LH0021C and LH0041/LH0041C are general purpose operational amplifiers capable of delivering large output currents not usually associated with conventional IC Op Amps. The LH0021 will provide output currents in excess of one ampere at voltage levels of ±12V; the LH0041 delivers currents of 200 mA at voltage levels closely approaching the available power supplies. In addition, both the inputs and outputs are protected against overload. the devices are compensated with a single external capacitor and are free of any unusual oscillation or latch-up problems.

The excellent input characteristics and high output capability of the LH0021 make it an ideal choice for power applications such as DC servos, capstan drivers, deflection yoke drivers, and programmable power supplies.

The LH0041 is particularly suited for applications such as torque driver for inertial guidance systems, diddle yoke driver for alpha-numeric CRT displays, cable drivers, and programmable power supplies for automatic test equipment.

The LH0021 is supplied in a 8 pin TO-3 package rated at 20 watts with suitable heatsink. The LH0041 is supplied in both

12 pin TO-8 (2.5 watts with clip on heatsink) and a power 8 pin ceramic DIP (2 watts with suitable heatsink). The LH0021 and LH0041 are guaranteed over the temperature range of −55°C to +125°C while the LH0021C and LH0041C are guaranteed from −25°C to +85°C.

Features

■ Output current

LH0021	1.0 Amp
LH0041	0.2 Amp

■ Output voltage swing

LH0021	±12V into 10Ω
LH0041	±14V into 100Ω

■ Wide full power bandwidth	15 kHz
■ Low standby power	100 mW at ±15V
■ Low input offset voltage and current	1 mV and 20 nA
■ High slew rate	3.0V/μs
■ High open loop gain	100 dB

Schematic Diagram
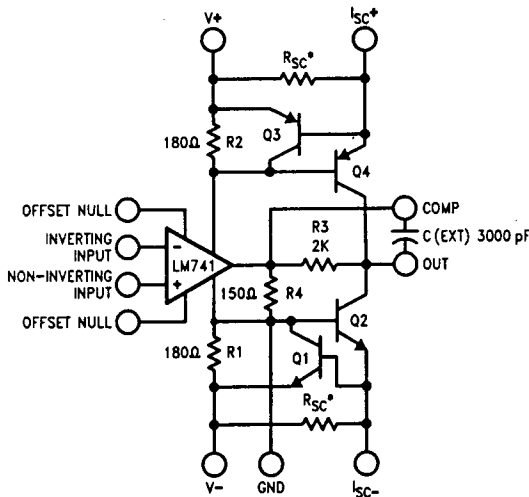
*R_{SC} external on "G" and "K" packages. R_{SC} internal on "J" package. Offset Null connections available only on "G" package.

TL/H/9298–1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	±18V
Power Dissipation	See Curves
Differential Input Voltage	±30V
Input Voltage (Note 1)	±15V
Peak Output Current (Note 2)	
LH0021/LH0021C	2.0 Amps
LH0041/LH0041C	0.5 Amps

Output Short Circuit Duration (Note 3)	Continuous
Operating Temperature Range	
LH0021/LH0041	−55°C to +125°C
LH0021C/LH0041C	−25°C to +85°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C
ESD rating to be determined.	

## DC Electrical Characteristics for LH0021/LH0021C (Note 4)

Parameter	Conditions	LH0021 Min	LH0021 Typ	LH0021 Max	LH0021C Min	LH0021C Typ	LH0021C Max	Units
Input Offset Voltage	$R_S < 100\Omega$, $T_C = 25°C$		1.0	3.0		3.0	6.0	mV
	$R_S < 100\Omega$			5.0			7.5	mV
Voltage Drift with Temperature	$R_S < 100\Omega$		3	25		5	30	$\mu V/°C$
Offset Voltage Drift with Time			5			5		$\mu V/week$
Offset Voltage Change with Output Power			5	15		5	20	$\mu V/W$
Input Offset Current	$T_C = 25°C$		30	100		50	200	nA
				300			500	nA
Offset Current Drift with Temperature			0.1	1.0		0.2	1.0	$nA/°C$
Offset Current Drift with Time			2			2		$nA/week$
Input Bias Current	$T_C = 25°C$		100	300		200	500	nA
				1.0			1.0	μA
Input Resistance	$T_C = 25°C$	0.3	1.0		0.3	1.0		$M\Omega$
Input Capacitance			3			3		pF
Common Mode Rejection Ratio	$R_S\ 100\Omega$, $\Delta V_{CM} = ±10V$	70	90		70	90		dB
Input Voltage Range	$V_S = ±15V$	±12			±12			V
Power Supply Rejection Ratio	$R_S \leq 100\Omega$, $\Delta V_S = ±10V$	80	96		70	90		dB
Voltage Gain	$V_S = ±15V$, $V_O = ±10V$ $R_L = 1\,k\Omega$, $T_C = 25°C$	100	200		100	200		V/mV
	$V_S = ±15V$, $V_O = ±10V$ $R_L = 100\Omega$	25			20			V/mV
Output Voltage Swing	$V_S = ±15V$, $R_L = 100\Omega$	±13.5	14		±13	±14		V
	$V_S = ±15V$, $R_L = 10\Omega$, $T_C = 25°C$	±11.0	±12		±10	±12		V
Output Short Circuit Current	$V_S = ±15V$, $T_C = 25°C$, $R_{SC} = 0.5\Omega$	0.8	1.2	1.6	0.8	1.2	1.6	Amps
Power Supply Current	$V_S = ±15V$, $V_{OUT} = 0$		2.5	3.5		3.0	4.0	mA
Power Consumption	$V_S = ±15V$, $V_{OUT} = 0$		75	105		90	120	mW

AC Electrical Characteristics for LH0021/LH0021C ($T_A = 25°C$, $V_S = ±15V$, $C_C = 3000\ pF$)

Parameter	Conditions	LH0021 Min	LH0021 Typ	LH0021 Max	LH0021C Min	LH0021C Typ	LH0021C Max	Units
Slew Rate	$A_V = +1$, $R_L = 100\Omega$	0.8	3.0		1.0	3.0		$V/\mu s$
Power Bandwidth	$R_L = 100\Omega$		20			20		kHz
Small Signal Transient Response			0.3	1.0		0.3	1.5	μs
Small Signal Overshoot			5	20		10	30	%
Settling Time (0.1%)	$\Delta V_{IN} = 10V$, $A_V = +1$		4			4		μs
Overload Recovery Time			3			3		μs
Harmonic Distortion	$f = 1\ kHz$, $P_O = 0.5W$		0.2			0.2		%
Input Noise Voltage	$R_s = 50\Omega$, B.W. = 10 Hz to 10 kHz		5			5		$\mu V/rms$
Input Noise Current	B.W. = 10 Hz to 10 kHz		0.05			0.05		nA/rms

DC Electrical Characteristics for LH0041/LH0041C (Note 4)

Parameter	Conditions	Limits						Units
		LH0041			LH0041C			
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$R_S < 100\Omega$, $T_A = 25°C$ $R_S < 100\Omega$		1.0	3.0 5.0		3.0	6.0 7.5	mV mV
Voltage Drift with Temperature	$R_S < 100\Omega$		3			5		μV/°C
Offset Voltage Drift with Time			5			5		μV/week
Offset Voltage Change with Output Power			15			15		μV/W
Offset Voltage Adjustment Range	(Note 5)		20			20		mV
Input Offset Current	$T_A = 25°C$		30	100 300		50	200 500	nA nA
Offset Current Drift with Temperature			0.1	1.0		0.2	1.0	nA/°C
Offset Current Drift with Time			2			2		nA/week
Input Bias Current	$T_A = 25°C$		100	300 1.0		200	500 1.0	nA μA
Input Resistance	$T_A = 25°C$	0.3	1.0		0.3	1.0		MΩ
Input Capacitance			3			3		pF
Common Mode Rejection Ratio	$R_S\ 100\Omega$, $\Delta V_{CM} = \pm 10V$	70	90		70	90		dB
Input Voltage Range	$V_S = \pm 15V$	+12			+12			V
Power Supply Rejection Ratio	$R_S \leq 100\Omega$, $\Delta V_S = \pm 10V$	80	96		70	90		dB
Voltage Gain	$V_S = \pm 15V$, $V_O = \pm 10V$ $R_L = 1\ k\Omega$, $T_A = 25°C$ $V_S = \pm 15V$, $V_O = \pm 10V$ $R_L = 100\Omega$	100 25	200		100 20	200		V/mV V/mV
Output Voltage Swing	$V_S = \pm 15V$, $R_L = 100\Omega$	±13	14		±13	±14		V
Output Short Circuit Current	$V_S = \pm 15V$, $T_A = 25°C$ (Note 6)		200	300		200	300	mA
Power Supply Current	$V_S = \pm 15V$, $V_{OUT} = 0$		2.5	3.5		3.0	4.0	mA
Power Consumption	$V_S = \pm 15V$, $V_{OUT} = 0$		75	105		90	120	mW

AC Electrical Characteristics for LH0041/LH0041C ($T_A = 25°C$, $V_S = \pm 15V$, $C_C = 3000\ pF$)

Parameter	Conditions	Limits						Units
		LH0041			LH0041C			
		Min	Typ	Max	Min	Typ	Max	
Slew Rate	$A_V = +1$, $R_L = 100\Omega$	1.5	3.0		1.0	3.0		V/μs
Power Bandwidth	$R_L = 100\Omega$		20			20		kHz
Small Signal Transient Response			0.3	1.0		0.3	1.5	μs
Small Signal Overshoot			5	20		10	30	%
Settling Time (0.1%)	$\Delta V_{IN} = 10V$, $A_V = +1$		4			4		μs
Overload Recovery Time			3			3		μs
Harmonic Distortion	$f = 1\ kHz$, $P_O = 0.5W$		0.2			0.2		%
Input Noise Voltage	$R_s = 50\Omega$, B.W. = 10 Hz to 10 kHz		5			5		μV/rms
Input Noise Current	B.W. = 10 Hz to 10 kHz		0.05			0.05		nA/rms

Note 1: Rating applies for supply voltages above ±15V. For supplies less than ±15V, rating is equal to supply voltage.

Note 2: Rating applies for LH0041G and LH0021K with $R_{SC} = 0\Omega$.

Note 3: Rating applies as long as package power rating is not exceeded.

Note 4: Specifications apply for ±5V ≤ V_S ±18V, and −55°C ≤ T_C = ≤ 125°C for LH0021K and LH0041G, and −25°C ≤ T_C ≤ +85°C for LH0021CK, LH0041CG and LH0041CJ unless otherwise specified. Typical values are for 25°C only.

Note 5: TO-8 "G" packages only.

Note 6: Rating applies for "J" DIP package and for TO-8 "G" package with $R_{SC} = 3.3$ ohms.

Note 7: See Typical Performance Characteristics.

Appendix C

National Semiconductor
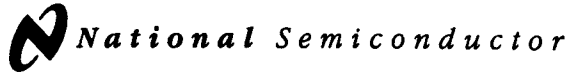
AH0014/AH0014C* DPDT, AH0015/AH0015C Quad SPST, AH0019/AH0019C* Dual DPST-TTL/DTL Compatible MOS Analog Switches

General Description

This series of TTL/DTL compatible MOS analog switches feature high speed with internal level shifting and driving. The package contains two monolithic integrated circuit chips: the MOS analog chip is similar to the MM450 type which consists of four MOS analog switch transistors; the second chip is a bipolar I.C. gate and level shifter. The series is available in hermetic dual-in-line package.

These switches are particularly suited for use in both military and industrial applications such as commutators in data acquisition systems, multiplexers, A/D and D/A converters, long time constant integrators, sample and hold circuits, modulators/demodulators, and other analog signal switching applications.

The AH0014, AH0015 and AH0019 are specified for operation over the $-55°C$ to $+125°C$ military temperature range. The AH0014C, AH0015C and AH0019C are specified for operation over the $-25°C$ to $+85°C$ temperature range.

Features

■ Large analog voltage switching $\quad\quad\quad\quad\quad\quad \pm 10V$
■ Fast switching speed $\quad\quad\quad\quad\quad\quad\quad\quad\quad$ 500 ns
■ Operation over wide range of power supplies
■ Low ON resistance $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad$ 200Ω
■ High OFF resistance $\quad\quad\quad\quad\quad\quad\quad\quad\quad$ $10^{11}\Omega$
■ Analog signals in excess of $\quad\quad\quad\quad\quad$ 25 MHz
■ Fully compatible with DTL or TTL logic
■ Includes gating and level shifting

Block and Connection Diagrams
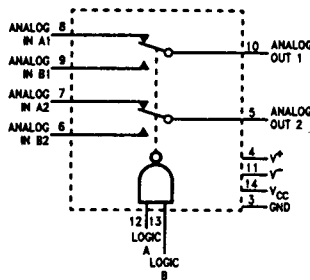
Note: All logic inputs shown at logic "1".   TL/K/10125–1
Order Number AH0014D or AH0014CD
See NS Package Number D14D

Quad SPST
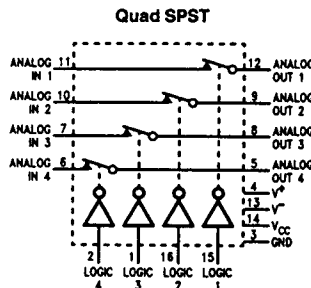
Note: All logic inputs shown at logic "1".   TL/K/10125–2
Order Number AH0015D or AH0015CD
See NS Package Number D16C

Dual DPST
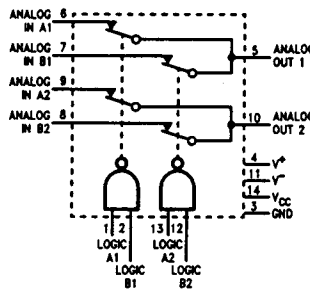
Note: All logic inputs shown at logic "1".

TL/K/10125–3
Order Number AH0019D or AH0019CD
See NS Package Number D14D

*Previously called NH0014/NH0014C and NH0019/NH0019C

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

V_{CC} Supply Voltage	7.0V
V^- Supply Voltage	−30V
V^+ Supply Voltage	+30V

V^+/V^- Voltage Differential	40V
Logic Input Voltage	5.5V
Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	
AH0014, AH0015, AH0019	−55°C to +125°C
AH0014C, AH0015C, AH0019C	−25°C to +85°C
Lead Temperature (Soldering, 10 sec)	300°C

Electrical Characteristics (Notes 1 and 2)

Parameter	Conditions	Min	Typ	Max	Units
Logical "1" Input Voltage	V_{CC} = 4.5V	2.0			V
Logical "0" Input Voltage	V_{CC} = 4.5V			0.8	V
Logical "1" Input Current	V_{CC} = 5.5V, V_{IN} = 2.4V			5	μA
Logical "1" Input Current	V_{CC} = 5.5V, V_{IN} = 5.5V			1	μA
Logical "0" Input Current	V_{CC} = 5.5V, V_{IN} = 0.4V		0.2	0.4	mA
Power Supply Current Logical "1" Input—Each Gate (Note 3)	V_{CC} = 5.5V, V_{IN} = 4.5V		0.85	1.6	mA
Power Supply Current Logical "0" Input—Each Gate (Note 3)	V_{CC} = 5.5V, V_{IN} = 0V				
AH0014, AH0014C			1.5	3.0	mA
AH0015, AH0015C			0.22	0.41	mA
AH0019, AH0019C			0.22	0.41	mA
Analog Switch ON Resistance—Each Gate	V_{IN} (Analog) = +10V		75	200	Ω
	V_{IN} (Analog) = −10V		150	600	Ω
Analog Switch OFF Resistance			10^{11}		Ω
Analog Switch Input Leakage Current— Each Input (Note 4)	V_{IN} = −10V				
AH0014, AH0015, AH0019	T_A = 25°C		25	200	pA
	T_A = 125°C		25	200	nA
AH0014C, AH0015C, AH0019C	T_A = 25°C		0.1	10	nA
	T_A = 70°C		30	100	nA
Analog Switch Output Leakage Current—Each Output (Note 4)	V_{OUT} = −10V				
AH0014, AH0015, AH0019	T_A = 25°C		40	400	pA
	T_A = 125°C		40	400	nA
AH0014C, AH0015C, AH0019C	T_A = 25°C		0.05	10	nA
	T_A = 70°C		4	50	nA
Analog Input (Drain) Capacitance	1 MHz @ Zero Bias		8	10	pF
Output Source Capacitance	1 MHz @ Zero Bias		11	13	pF
Analog Turn-OFF Time—t_{OFF}	See Test Circuit; T_A = 25°C		600	750	ns
Analog Turn-ON Time—t_{ON}	See Test Circuit; T_A = 25°C				
AH0014, AH0014C			350	425	ns
AH0015, AH0015C			100	150	ns
AH0019, AH0019C			100	150	ns

Note 1: Min/max limits apply across the guaranteed temperature range of −55°C to +125°C for AH0014, AH0015, AH0019 and −25°C to +85°C for AH0014C, AH0015C, AH0019C. V^- = −20V. V^+ = +10V and an analog test current of 1 mA unless otherwise specified.

Note 2: All typical values are measured at T_A = 25°C with V_{CC} = 5.0V. V^+ = +10V, V^- = −22V.

Note 3: Current measured is drawn from V_{CC} supply.

Note 4: All analog switch pins except measurement pin are tied to V^+.

Appendix D

N *National Semiconductor*
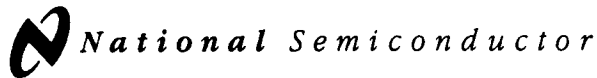
ADC08231/ADC08234/ADC08238 8-Bit 2 μs Serial I/O A/D Converters with MUX, Reference, and Track/Hold

General Description

The ADC08231/ADC08234/ADC08238 are 8-bit successive approximation A/D converters with serial I/O and configurable input multiplexers with up to 8 channels. The serial I/O is configured to comply with the NSC MICROWIRE™ serial data exchange standard for easy interface to the COPS™ family of controllers, and can easily interface with standard shift registers or microprocessors.

Designed for high-speed/low-power applications, the devices are capable of a fast 2 μs conversion when used with a 4 MHz clock.

All three devices provide a 2.5V band-gap derived reference with guaranteed performance over temperature.

A track/hold function allows the analog voltage at the positive input to vary during the actual A/D conversion.

The analog inputs can be configured to operate in various combinations of single-ended, differential, or pseudo-differential modes. In addition, input voltage spans as small as 1V can be accommodated.

Applications

- High-speed data acquisition
- Digitizing automotive sensors
- Process control/monitoring
- Remote sensing in noisy environments
- Disk drives
- Portable instrumentation
- Test systems

Features

- Serial digital data link requires few I/O pins
- Analog input track/hold function
- 4- or 8-channel input multiplexer options with address logic
- On-chip 2.5V band-gap reference (±2% over temperature guaranteed)
- No zero or full scale adjustment required
- TTL/CMOS input/output compatible
- 0V to 5V analog input range with single 5V power supply
- Pin compatible with Industry-Standards ADC0831/4/8

Key Specifications

- Resolution   8 Bits
- Conversion time (f_C = 4 MHz)   2 μs (Max)
- Power dissipation   20 mW (Max)
- Single supply   5 V_{DC} (±5%)
- Total unadjusted error   ± ½ LSB and ± 1 LSB
- Linearity Error (V_{REF} = 2.5V)   ± ½ LSB
- No missing codes (over temperature)
- On-board Reference   + 2.5V ± 1.5% (Max)

ADC08238 Simplified Block Diagram
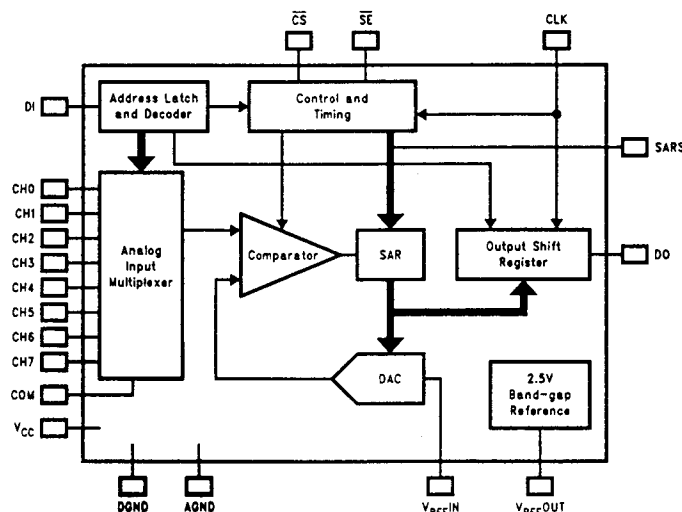
TL/H/11015-4
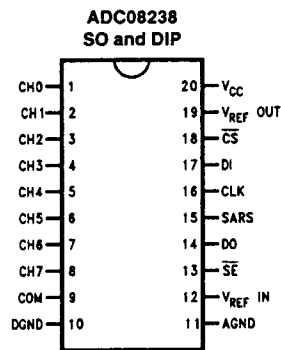
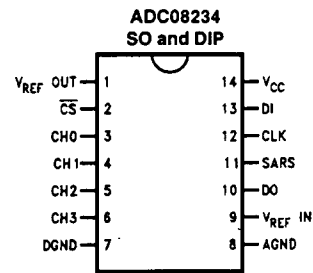## Ordering Information

Industrial ($-40°C \le T_A \le +85°C$)	Package
ADC08231BIN, ADC08231CIN	N08E, DIP
ADC08234BIN, ADC08234CIN	N14A, DIP
ADC08234CIMF	MTB24, TSSOP
ADC08238BIN, ADC08238CIN	N20A, DIP
ADC08231BIWM, ADC08231CIWM	M14B, SO
ADC08234BIWM, ADC08234CIWM	M14B, SO
ADC08238BIWM, ADC08238CIWM	M20B, SO

Connection Diagrams

ADC08238
SO and DIP

```
CH0 ─┤1        20├─ V_CC
CH1 ─┤2        19├─ V_REF OUT
CH2 ─┤3        18├─ CS
CH3 ─┤4        17├─ DI
CH4 ─┤5        16├─ CLK
CH5 ─┤6        15├─ SARS
CH6 ─┤7        14├─ DO
CH7 ─┤8        13├─ SE
COM ─┤9        12├─ V_REF IN
DGND─┤10       11├─ AGND
```

TL/H/11015–1

ADC08231
DIP

```
CS   ─┤1       8├─ V_CC
V_IN+─┤2       7├─ CLK
V_IN-─┤3       6├─ DO
GND  ─┤4       5├─ V_REF C
```

TL/H/11015–3

ADC08231
SO

```
CS   ─┤1       14├─ V_CC
NC   ─┤2       13├─ NC
V_IN+─┤3       12├─ CLK
NC   ─┤4       11├─ NC
V_IN-─┤5       10├─ DO
NC   ─┤6       9├─ NC
GND  ─┤7       8├─ V_REF C
```

TL/H/11015–26

ADC08234
SO and DIP

```
V_REF OUT─┤1        14├─ V_CC
CS       ─┤2        13├─ DI
CH0      ─┤3        12├─ CLK
CH1      ─┤4        11├─ SARS
CH2      ─┤5        10├─ DO
CH3      ─┤6         9├─ V_REF IN
DGND     ─┤7         8├─ AGND
```

TL/H/11015–2

ADC08234
TSSOP

```
N/C      ─┤1        24├─ N/C
N/C      ─┤2        23├─ N/C
CLK      ─┤3        22├─ SARS
DI       ─┤4        21├─ DO
V_CC     ─┤5        20├─ V_REF IN
V_REF OUT─┤6        19├─ AGND
CS       ─┤7        18├─ DGND
CH0      ─┤8        17├─ CH3
CH1      ─┤9        16├─ CH2
N/C      ─┤10       15├─ N/C
N/C      ─┤11       14├─ N/C
N/C      ─┤12       13├─ N/C
```

TL/H/11015–27

Absolute Maximum Ratings (Notes 1 & 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (V_{CC})	6.5V
Voltage at Inputs and Outputs	$-0.3V$ to $V_{CC} + 0.3V$
Input Current at Any Pin (Note 4)	± 5 mA
Package Input Current (Note 4)	± 20 mA
Power Dissipation at $T_A = 25°C$ (Note 5)	800 mW
ESD Susceptibility (Note 6)	1500V
Soldering Information	
N Package (10 sec.)	260°C
TSSOP and SO Package (Note 7):	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C
Storage Temperature	$-65°C$ to $+150°C$

Operating Ratings (Notes 2 & 3)

Temperature Range $\quad T_{MIN} \leq T_A \leq T_{MAX}$
ADC08231BIN, ADC08231CIN, $\quad -40°C \leq T_A \leq +85°C$
ADC08234BIN, ADC08234CIN,
ADC08238BIN, ADC08238CIN,
ADC08231BIWM, ADC08231CIWM,
ADC08234BIWM, ADC08238BIWM,
ADC08234CIWM, ADC08238CIWM,
ADC08234CIMF
Supply Voltage (V_{CC}) $\quad$ 4.5 V_{DC} to 6.3 V_{DC}

Electrical Characteristics

The following specifications apply for $V_{CC} = +5\,V_{DC}$, $V_{REF} = +2.5\,V_{DC}$ and $f_{CLK} = 4$ MHz, $R_{Source} = 50\Omega$ unless otherwise specified. Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits $T_A = T_J = 25°C$.

Symbol	Parameter	Conditions	ADC08231, ADC08234 and ADC08238 with BIN, CIN, BIWM, CIWM, or CIMF Suffixes		Units (Limits)
			Typical (Note 8)	Limits (Note 9)	
CONVERTER AND MULTIPLEXER CHARACTERISTICS					
	Linearity Error	$V_{REF} = +2.5\,V_{DC}$			
	BIN, BIWM			$\pm \frac{1}{2}$	LSB (max)
	CIN, CIMF, CIWM			± 1	LSB (max)
	Gain Error	$V_{REF} = +2.5\,V_{DC}$			
	BIN, BIWM			± 1	LSB (max)
	CIN, CIMF, CIWM			± 1	LSB (max)
	Zero Error	$V_{REF} = +2.5\,V_{DC}$			
	BIN, BIWM			± 1	LSB (max)
	CIN, CIMF, CIWM			± 1	LSB (max)
	Total Unadjusted Error	$V_{REF} = +5\,V_{DC}$ (Note 10)			
	BIN, BIWM			± 1	LSB (max)
	CIN, CIMF, CIWM			± 1	LSB (max)
	Differential Linearity	$V_{REF} = +2.5\,V_{DC}$		**8**	Bits (min)
R_{REF}	Reference Input Resistance	(Note 11)	3.5		$k\Omega$
				1.3	$k\Omega$ (min)
				6.0	$k\Omega$ (max)
V_{IN}	Analog Input Voltage	(Note 12)		**(V_{CC} + 0.05)**	V (max)
				(GND − 0.05)	V (min)

Electrical Characteristics (Continued)

The following specifications apply for $V_{CC} = +5\ V_{DC}$, $V_{REF} = +2.5\ V_{DC}$ and $f_{CLK} = 4\ MHz$, $R_{source} = 50\Omega$ unless otherwise specified. **Boldface limits apply for $T_A = T_J = T_{MIN}$ to T_{MAX};** all other limits $T_A = T_J = 25°C$.

Symbol	Parameter	Conditions	ADC08231, ADC08234 and ADC08238 with BIN, CIN, BIWM, CIWM, or CIMF Suffixes		Units (Limits)
			Typical (Note 8)	Limits (Note 9)	
CONVERTER AND MULTIPLEXER CHARACTERISTICS (Continued)					
	DC Common-Mode Error	$V_{REF} = +2.5\ V_{DC}$		$\pm\frac{1}{2}$	LSB (max)
	Power Supply Sensitivity	$V_{CC} = +5V \pm 5\%$, $V_{REF} = +2.5\ V_{DC}$		$\pm\frac{1}{4}$	LSB (max)
	On Channel Leakage Current (Note 13)	On Channel = 5V, Off Channel = 0V		0.2 **1**	μA (max)
		On Channel = 0V, Off Channel = 5V		-0.2 **-1**	μA (max)
	Off Channel Leakage Current (Note 13)	On Channel = 5V, Off Channel = 0V		-0.2 **-1**	μA (max)
		On Channel = 0V, Off Channel = 5V		0.2 **1**	μA (max)
DYNAMIC CHARACTERISTICS (see Typical Converter Performance Characteristics)					
$\frac{S}{N+D}$	Signal-to- (Noise + Distortion) Ratio	$V_{REF} = +5V$ Sample Rate = 286 kHz $V_{IN} = +5\ V_{p-p}$			
		$f_{IN} = 10\ kHz$	48.35		dB
		$f_{IN} = 50\ kHz$	48.00		dB
		$f_{IN} = 100\ kHz$	47.40		dB
DIGITAL AND DC CHARACTERISTICS					
$V_{IN(1)}$	Logical "1" Input Voltage	$V_{CC} = 5.25V$		**2.0**	V (min)
$V_{IN(0)}$	Logical "0" Input Voltage	$V_{CC} = 4.75V$		**0.8**	V (max)
$I_{IN(1)}$	Logical "1" Input Current	$V_{IN} = 5.0V$		**1**	μA (max)
$I_{IN(0)}$	Logical "0" Input Current	$V_{IN} = 0V$		**-1**	μA (max)
$V_{OUT(1)}$	Logical "1" Output Voltage	$V_{CC} = 4.75V$: $I_{OUT} = -360\ \mu A$ $I_{OUT} = -10\ \mu A$		**2.4** **4.5**	V (min) V (min)
$V_{OUT(0)}$	Logical "0" Output Voltage	$V_{CC} = 4.75V$ $I_{OUT} = 1.6\ mA$		**0.4**	V (max)
I_{OUT}	TRI-STATE® Output Current	$V_{OUT} = 0V$ $V_{OUT} = 5V$		**-3.0** **3.0**	μA (max) μA (max)
I_{SOURCE}	Output Source Current	$V_{OUT} = 0V$		**-6.5**	mA (min)
I_{SINK}	Output Sink Current	$V_{OUT} = V_{CC}$		**8.0**	mA (min)
I_{CC}	Supply Current ADC08234, ADC08238 ADC08231 (Note 16)	$\overline{CS}$ = HIGH		**3.0** **6.0**	mA (max) mA (max)

Electrical Characteristics (Continued)

The following specifications apply for $V_{CC} = +5\ V_{DC}$ and $f_{CLK} = 4$ MHz unless otherwise specified. **Boldface limits apply for** $T_A = T_J = T_{MIN}$ to T_{MAX}; all other limits $T_A = T_J = 25°C$.

Symbol	Parameter	Conditions	ADC08231, ADC08234 and ADC08238 with BIN, CIN, BIWM, CIWM, or CIMF Suffixes		Units (Limits)
			Typical (Note 8)	Limits (Note 9)	
REFERENCE CHARACTERISTICS					
$V_{REF}OUT$	Output Voltage	BIN, BIJ, BIWM	**2.5 ±2%**	2.5 ±1.5%	V
		CIN, CIJ, CIWM, CMJ	**2.5 ±3.5%**	2.5 ±3.0%	
$\Delta V_{REF}/\Delta T$	Temperature Coefficient		40		ppm/°C
$\Delta V_{REF}/\Delta I_L$	Load Regulation (Note 17)	Sourcing ($0 \leq I_L \leq +4$ mA) ADC08234, ADC08238	0.003	**0.1**	%/mA (max)
		Sourcing ($0 \leq I_L \leq +2$ mA) ADC08231	0.003	**0.1**	
		Sinking ($-1 \leq I_L \leq 0$ mA) ADC08234, ADC08238	0.2	**0.5**	
		Sinking ($-1 \leq I_L \leq 0$ mA) ADC08231	0.2	**0.5**	
	Line Regulation	$4.75V \leq V_{CC} \leq 5.25V$	0.5	**6**	mV (max)
I_{SC}	Short Circuit Current	$V_{REF} = 0V$ ADC08234, ADC08238	8	**25**	mA (max)
		$V_{REF} = 0V$ ADC08231	8	**25**	
T_{SU}	Start-Up Time	V_{CC}: 0V → 5V $C_L = 100\ \mu F$	20		ms
$\Delta V_{REF}/\Delta t$	Long Term Stability		200		ppm/1 kHr

Electrical Characteristics (Continued)

The following specifications apply for V_{CC} = +5 V_{DC}, V_{REF} = +2.5 V_{DC} and t_r = t_f = 20 ns unless otherwise specified. **Boldface limits apply for T_A = T_J = T_{MIN} to T_{MAX}; all other limits T_A = T_J = 25°C.**

Symbol	Parameter	Conditions	Typical (Note 8)	Limits (Note 9)	Units (Limits)
f_{CLK}	Clock Frequency		10	**4**	kHz (min) MHz (max)
	Clock Duty Cycle (Note 14)			**40** **60**	% (min) % (max)
T_C	Conversion Time (Not Including MUX Addressing Time)	f_{CLK} = 4 MHz		**8** **2**	1/f_{CLK} (max) μs (max)
t_{CA}	Acquisition Time			1½	1/f_{CLK}(max)
t_{SELECT}	CLK High while $\overline{CS}$ is High		50		ns
t_{SET-UP}	$\overline{CS}$ Falling Edge or Data Input Valid to CLK Rising Edge			**25**	ns (min)
t_{HOLD}	Data Input Valid after CLK Rising Edge			**20**	ns (min)
t_{pd1}, t_{pd0}	CLK Falling Edge to Output Data Valid (Note 15)	C_L = 100 pF: Data MSB First Data LSB First		**250** **200**	ns (max) ns (max)
t_{1H}, t_{0H}	TRI-STATE Delay from Rising Edge of $\overline{CS}$ to Data Output and SARS Hi-Z	C_L = 10 pF, R_L = 10 kΩ (see TRI-STATE Test Circuits)	50		ns
		C_L = 100 pF, R_L = 2 kΩ		**180**	ns (max)
C_{IN}	Capacitance of Logic Inputs		5		pF
C_{OUT}	Capacitance of Logic Outputs		5		pF

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur.

Note 2: Operating Ratings indicate conditions for which the device is functional. These ratings do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 3: All voltages are measured with respect to AGND = DGND = 0 V_{DC}, unless otherwise specified.

Note 4: When the input voltage (V_{IN}) at any pin exceeds the power supplies (V_{IN} < (AGND or DGND) or V_{IN} > AV_{CC}.) the current at that pin should be limited to 5 mA. The 20 mA maximum package input current rating limits the number of pins that can safely exceed the power supplies with an input current of 5 mA to four pins.

Note 5: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{JMAX}, θ_{JA} and the ambient temperature, T_A. The maximum allowable power dissipation at any temperature is P_D = (T_{JMAX} − T_A)/θ_{JA} or the number given in the Absolute Maximum Ratings, whichever is lower. For devices with suffixes BIN, CIN, BIJ, CIJ, BIWM, and CIWM T_{JMAX} = 125°C. For devices with suffix CMJ, T_{JMAX} = 150°C. The typical thermal resistances (θ_{JA}) of these parts when board mounted follow: ADC08231 with BIN and CIN suffixes 120°C/W, ADC08234 with BIN and CIN suffixes 95°C/W, ADC08234 with CIMF suffix 167°C/W, ADC08238 with BIN and CIN suffixes 80°C/W. ADC08231 with BIWM and CIWM suffixes 140°C/W, ADC08234 with BIWM and CIWM suffixes 140°C/W, ADC08238 with BIWM and CIWM suffixes 91°C/W.

Note 6: Human body model, 100 pF capacitor discharged through a 1.5 kΩ resistor.

Note 7: See AN450 "Surface Mounting Methods and Their Effect on Product Reliability" or *Linear Data Book* section "Surface Mount" for other methods of soldering surface mount devices.

Note 8: Typicals are at T_J = 25°C and represent the most likely parametric norm.

Note 9: Guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 10: Total unadjusted error includes zero, full-scale, linearity, and multiplexer error. Total unadjusted error with V_{REF} = +5V only applies to the ADC08234 and ADC08238. See Note 16.

Note 11: Cannot be tested for the ADC08231.

Note 12: For $V_{IN(-)}$ ≥ $V_{IN(-)}$ the digital code will be 0000 0000. Two on-chip diodes are tied to each analog input (see Block Diagram) which will forward-conduct for analog input voltages one diode drop below ground or one diode drop greater than V_{CC} supply. During testing at low V_{CC} levels (e.g., 4.5V), high level analog inputs (e.g., 5V) can cause an input diode to conduct, especially at elevated temperatures. This will cause errors for analog inputs near full-scale. The specification allows 50 mV forward bias of either diode; this means that as long as the analog V_{IN} does not exceed the supply voltage by more than 50 mV, the output code will be correct. Exceeding this range on an unselected channel will corrupt the reading of a selected channel. Achievement of an absolute 0 V_{DC} to 5 V_{DC} input voltage range will therefore require a minimum supply voltage of 4.950 V_{DC} over temperature variations, initial tolerance and loading.

Note 13: Channel leakage current is measured after a single-ended channel is selected and the clock is turned off. For off channel leakage current the following two cases are considered: one, with the selected channel tied high.(5 V_{DC}) and the remaining off channels tied low (0 V_{DC}), total current flow through the off channels is measured; two, with the selected channel tied low and the off channels tied high, total current flow through the off channels is again measured. The two cases considered for determining on channel leakage current are the same except total current flow through the selected channel is measured.

Note 14: A 40% to 60% duty cycle range insures proper operation at all clock frequencies. In the case that an available clock has a duty cycle outside of these limits the minimum time the clock is high or low must be at least 120 ns. The maximum time the clock can be high or low is 100 μs.

Note 15: Since data, MSB first, is the output of the comparator used in the successive approximation loop, an additional delay is built in (see Block Diagram) to allow for comparator response time.

Note 16: For the ADC08231 V_{REF}IN is internally tied to the on chip 2.5V band-gap reference output; therefore, the supply current is larger because it includes the reference current (700 μA typical, 2 mA maximum).

Note 17: Load regulation test conditions and specifications for the ADC08231 differ from those of the ADC08234 and ADC08238 because the ADC08231 has the on-board reference as a permanent load.

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