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1. INTRODUCTION

Salix Technology is a newly established R&D Company whose main focus is patented product development using an interdisciplinary approach in Electrical & Electronics Engineering field. After examining the officially announced problem, the company made an official proposal and started the relevant studies to design the mentioned product as a solution to the problem.

Within the proposal company's understanding of the given problem is provided. It is convenient to put the emphasis on this issue here again in order to recall the demander's preferences and initiatives about the solution. It is stated in the announcement that the expectation is the design and implementation of a system with all of its components, a system with a device maintaining its position on a moving platform where the platform speed is varied in some range. There are some significant derivations from the statement of problem such that the speed range of the platform and device, the initial position of the device and maximum allowed deviation from this position, the transient period to reach the steady state, maximum tolerable oscillatory motion before reaching to steady state and system dependency on the environment are undefined by the demander meaning that it is expected from the solution provider to determine these parameters in an efficient way. This fact provides a freedom to the solution provider to contribute with creative solutions; but it may result in poor performance systems also. Here in this report Salix Technology is defining its objectives and related solution procedures according to a high level performance system. Considering the undefined conditions of the problem, first of all, the proposed solution aims to continue maintaining its position even the device loses its horizontal position on the platform. Platform speed range will be determined according to low cost, low power consumption and reliability criteria. Possible motion of the platform due to devices oppositely directed acceleration is considered and will be prevented. The algorithm for the speed change compensation, measuring the distance of the device to some reference point and adjusting its speed according to calculated speed change of the treadmill, has been improved. A system engineering approach is also brought into the picture. Analysis of the system type, order etc. is conducted and possible simplified models of the system are studied. These studies show that the closed loop control model to have the best transient response characteristics together with the steady state error calculations is Proportional – Derivative Closed Loop Control. It is important to note here that system control approach is based on specific input excitations leading to response analysis rather than mathematically modeling and design approach by locating the poles and zeros to desired locations. This is due to first of all, the unknown frictional and reactive forces between the masses. Secondly exact modeling of dynamic systems is highly challenging such that it is eligible to be a graduate level research topic. The second statement does not lead to company's incompetence for high level system design, but gives the main effect determining the criteria to be followed while establishing the company's own approach to the problem. Therefore, with the given limited time and budget and considerably low level requirements, a challenging system design is unnecessary for the solution.

With the above explained testing – based approach designing a system with more than sufficient transient and steady state response is possible. After claiming this, it is the place to mention that this report is provided to the demander to explain the engineering approach that will be used during the production and testing. So this report is a detailed summary of the company's studies during the design of the system defined and detailed above and in previous reports and a roadmap drawn for the start of efficient progress duration. The report begins with background information about the company and members, mentioning each individual's duties and contributions. The definition and explanation of the project's goals and objectives, which is pretty much the same with the previous similar declarations, follows as the successive title. Main body of the report is the section where all the detailed explanation of the concepts defining the blocks; justifications of the goals and objectives in terms of methods, components to be used, calculations carried out; and illustrations, figures and diagrams contributing to the verbal statements are provided. The discussions carried out inside this section are supported by the relevant data present at the end of the report in Appendices. The time schedule to realize the design explained newly is the following topic. Supporting graphical demonstration is also available in the Appendices section. Instrumentation & Facilities and Deliverables are added to the report also to convince the demander that implementation of the concerning design is possible with the company's own sources and let the demander be aware of what to expect as a product at the end of the process. A cost analysis illustration is also attached in order to let demander have an idea about the expected required funding for the completion of the project.

2. BRIEF DESCRIPTION OF THE COMPANY

2.1. MAIN STRUCTURE

Salix Technology is a virtually founded company for the scope of EE493 – EE494 Senior Design Courses. The company is founded by 5 talented engineer candidates, who are all senior students of Electrical and Electronics Engineering Department of Middle East Technical University.

Pre-bureaucratic organization structure is adopted as its being the most appropriate structure for an Entrepreneurial Business. Each shareholder of the company has voice in all subjects. However, in order to work efficiently there are some organizational duties which are assigned to each member but also flexible in the sense that a different member can also contribute to or substitute in case of need. Technical responsibilities of members are undefined in the sense that it will be defined according to current project requirements. Organizational structure can be summarized as:

Project Manager

This member associates the directors' actions with each other so that all actions together can serve for the project's benefit as a whole. He manages the project according to the milestones established, but serves as a management control mechanism on the directors.

Technical Process Director

This is the member who is authorized to plan the technical development of the project throughout the design and implementation duration. Besides his own assigned part (block) within the project, he is also expected to be supervising the progress in all other parts.

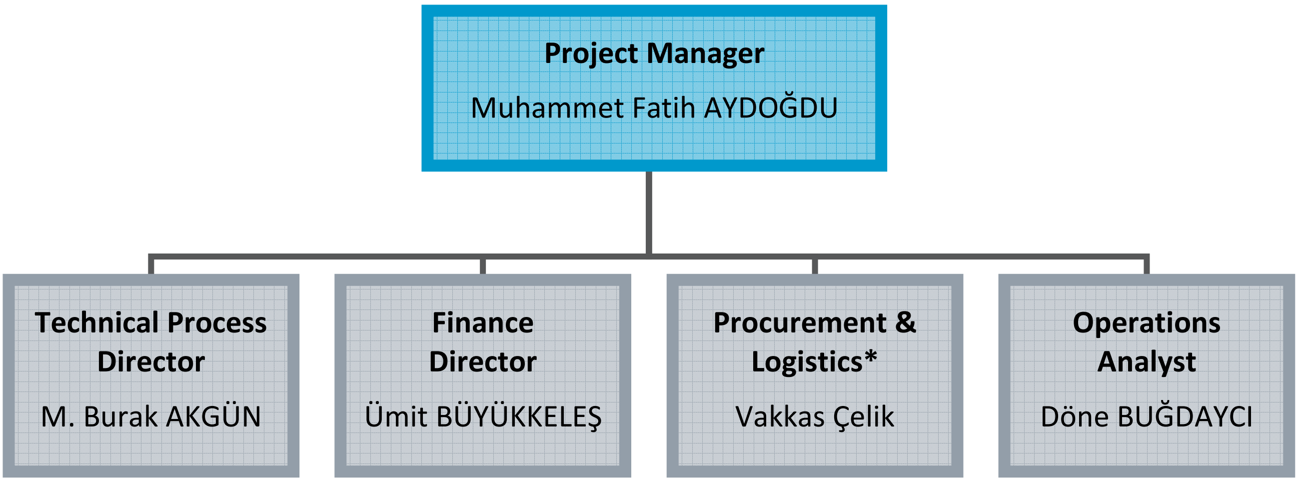


Figure 1 Organizational Chart

Finance Director

This member is concerned with the financial management of the project to prevent cost overrun. He is to plan the sub budgets of each block, supervise members through choosing components in their designs and keep the account.

Procurement & Logistics

This member mainly deals with market conditions, component availabilities, optimum purchasing strategies etc. He is the holder of the necessary information about the suppliers', sales campaigns and company's orders.

*This member is also the contact person for issues about the weekly meeting with the coordinator in addition to the meetings within the company.

Operations Analyst

This member is responsible from the compilation of detailed operations reports that are aimed to inform the demander/customer about the progress of the project. These reports also stand for the notification of individual studies.

2.2 QUALIFICATIONS

Salix Technology is a company established by engineers who have team work experience already from the previous laboratory course design projects. Some of these projects and the related areas can be stated as follows:

- Design of a Variable Gain Amplifier maintaining its output peak voltage in the range 0.9 – 1.1 V independent of the small signal input peak voltage. An analog electronics and feedback control systems project.
- Design of a Tuner Circuit capable of comparing the input signal's frequency with a predefined frequency (a note in music e.g. Re) with a visual output indicating the difference in frequency to tune the musical instrument (a LED blinking at the difference frequency). An analog electronics and signal processing project.
- Design of a Credit Card System with POST and BANK units capable of communicating with a single line (information coding, error detection & correction, asynchronous communication, data manipulation) –A communication systems and computer related software project developed in Xilinx to be implemented with FPGAs.
- Design of a PWM circuit to control the speed of a DC motor. Power electronics and control systems related project.

Technical responsibilities of the members for this project are determined according to members' education, experience and interests intersecting with the main blocks of the project. Task division can be listed as follows:

- Ümit BÜYÜKKELEŞ: Power Units, Motion Actuators,
- Vakkas ÇELİK: Algorithm Implementation, Controller unit,
- Fatih AYDOĞDU: Mechanical Design, Algorithm Development,
- Burak AKGÜN: Feedback Control System Design, Algorithm Development
- Döne BUĞDAYCI: Sensing Units, Hardware Compatibility

3. PROJECT GOALS AND OBJECTIVES

Project aims to design a treadmill whose speed can be varied for some time intervals and a vehicle that can remain on this unit by aiming to reach and maintain the steady state equilibrium position. So principal objective of the project is to make sure that the vehicle will stay on the platform after any kind of previously defined disturbances is added to the system. Other objectives can be stated as followings:

- ***Good Performance***

Acceleration of the vehicle is the key point for good performance because vehicle must respond to the speed variation of the platform with a larger speed change to return back to the equilibrium point. There are some factors that affect the acceleration of the vehicle. First factor is the inertia of the platform and motors that drive the platform. The second factor is the variance type of the platform speed. It is thought to provide a control unit on the treadmill allowing speed changes with constant acceleration. This property will let the device know that it should respond to a ramp input. In terms of system analysis, knowing that the input is one of the special types (unit impulse, step, ramp and parabola) will help the designer a lot to have an idea about the systems transient response. Platform length also is a factor but maximum value of it is specified as 75cm. At this moment quantifiable measures of the acceleration can’t be stated. According to the mentioned factors it will be determined later.

Another key point for good performance is the speed range of the vehicle. Minimum speed range of the moving platform is specified as 0-15cm/sec. Speed range of the vehicle must be greater than the range of the platform since the vehicle lags the platform. Even the vehicle may have to go in the opposite direction. Treadmill will be driven by cylinders which are connected to motors. Therefore radius of the cylinders will be chosen according to the motor specification.

- ***Low cost***

Low cost is another object of the project. Inexpensiveness of the project is important for marketability therefore project cost must be reduced. This reduction will be reasonable in order not to decrease the quality of the material.

- ***Low Energy Consumption***

The treadmill will be energized by an adapter. Adapter and the motor that drive the treadmill will be chosen for low energy consumption. The vehicle will be energized by batteries number of the batteries and size of the batteries will be determined later. This objective implies some other objectives such that, in order not to consume so much power, the torque demanded from the motors must be reduced and this torque depends on the weight of the vehicle. So the vehicle must be light. Another implied objective is to minimize the number of sensors used.

According to these qualitatively determined objectives, following expectations are defined:

- Length of the vehicle will be less than 20cm.
- The vehicle will at least capable of realizing an object at 50cm distance.
- Number of sensors on the vehicle will be at most if IR sensors are used.
- Number of sensors on the vehicle will be at most 2 if ultrasonic sensors are used.

- The vehicle will be capable of moving with a speed at least 10 cm/s faster than the treadmill. (maximum speed will be at least 25 cm/s)
- The treadmill will be designed according to the maximum allowed size.
- Inexpensive and light materials will be used in the construction of the vehicle body.
- The vehicle will be aware of its at least last state (previous position or speed or change in speed, acceleration etc.)
- The system will be capable of staying in steady state for at least 10 minutes.
- The vehicle will be capable of returning its original direction i.e. parallel to the treadmill's motion direction, in case of losing its path during the speed change compensation action.

4. SOLUTION PROCEDURE

The aim of the project is to design a device capable of maintaining its position on a moving platform whose speed may change in time. According to the requirements the device has no communication and contact with the outside world.

In the given problem since the device adjusts its speed according to treadmills, continuous data reception is necessary to maintain the original position. System obviously requires a closed loop control having the distance to a reference is fed back continuously. However the system order and characteristics must be studied to determine the combination giving the best transient response. So the first part is the system analysis.

4.1. SYSTEM ANALYSIS

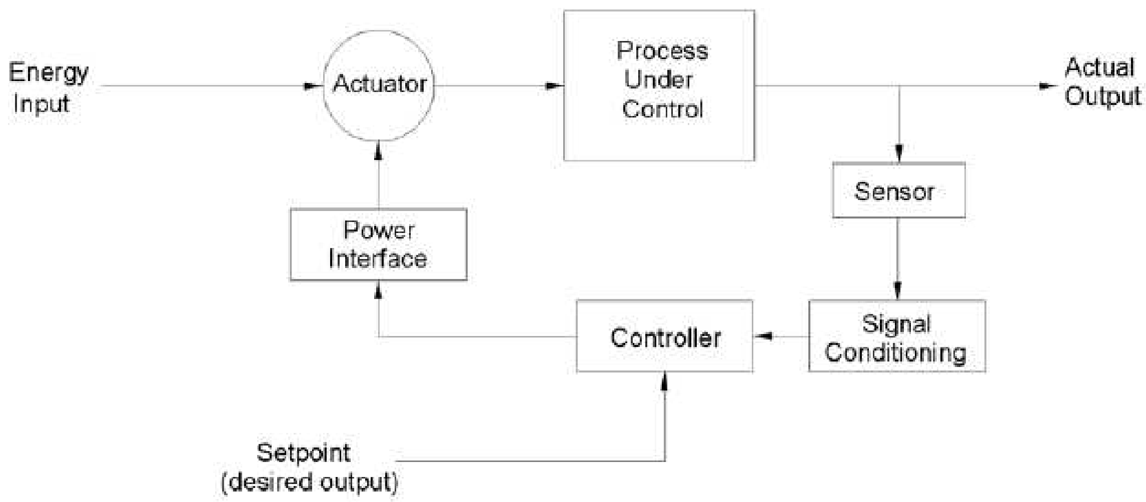


Figure 2 Block diagram of the overall system

Actuator: Servo Motors on the device's wheels

Controller: Microcontroller

Sensor: Ultrasonic Sensor, IR sensors,

Temperature Sensor

Signal conditioning: Generation of a pulse from the receiver ultrasonic sensor

Calculation of the distance from the pulse by taking the effect of temperature sensor data into account also

Process Under Control: Position of the Device on the moving treadmill

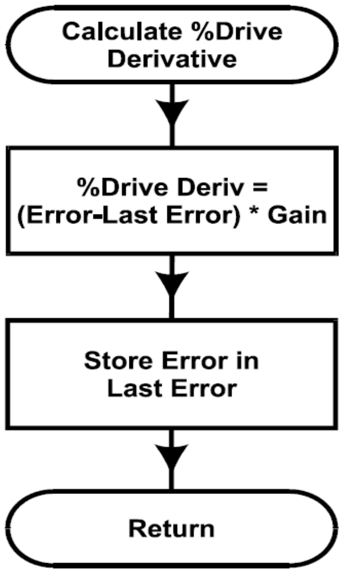


Figure 3 Flow Chart of the Algorithm to be used to implement Proportional Derivative Closed Loop Control

Modeling of an actual system is a very challenging task. Since the frictional forces, the exact mathematical response model of the servos to the controlling input, data sampling accuracy etc. are not known precisely, transfer function of the system cannot be obtained. From a roughly performed analysis it can be said that the system can be thought as a second order system. The desired transient response is minimum oscillations, short settling time, minimum steady state error etc. In fact the limit is the critically damped response. However since we cannot control the systems pole and zero locations as a synthesis process, the response of the system to some specific inputs (unit step, ramp etc.) must be studied so that necessary adjustments can be done to improve the transient behavior.

In the figure, actual output represents the distance of the vehicle to the reference point, which is measured by the ultrasonic sensor. Set point is the desired distance of the vehicle to the reference point. Thus the actual output is fed back to the controller, which is the backbone of the closed loop control systems. However, most ultrasonic sensors do not have exactly linear characteristics, that is, their output is not directly proportional to the distance. Thus, the characteristics curve will be obtained from datasheets and converted to a function using interpolation. In addition to this problem, temperature of the medium affects the speed of the sound, which causes another error factor. Data obtained from the temperature sensor will be used to calculate the coefficient to compensate temperature effect. Considering these two error factors, actual distance will be calculated within the microcontroller. After this stage, calculated value will be compared with the set-point by the microcontroller. The difference between these signals forms the error signal. Microcontroller checks the sign of the error signal to decide whether the vehicle is in front of or behind the set point. Next step is the calculation of the response to the error signal. In this step there are two choices: first method is the implementation of only proportional control mechanism. Second method is the implementation of derivative control in addition to proportional control.

Proportional control directly multiplies the error signal with a constant. The resulting value is added to current value and applied to the servo motors. Firstly proportional control will be implemented and various tests will be performed on the system. If the proportional control fails to meet the specifications (desired settling time and overshoot limit), we will switch to second option. Derivative control monitors the change of error signal in addition to proportional control. It gives idea about the behavior of the error signal, and compensation of fluctuations around the set-point is easier. Hence, derivative control is a better understanding of the situation and during tests it is supposed to give better results.

During the design of the closed-loop control system, proportional and on-off with differential gap control modes are considered first. Two possible solutions each designed by using one of these two modes were proposed in the proposal. On-off sensing method was added as an alternative in case of an unavailability of units that will provide proportional control (the sensitiveness of the ultrasonic sensors were being studied then). After the proposal, when the necessary components are obtained and the related tests are carried out, on-off with differential gap control mode is abandoned. During testing process derivative control methods will be implemented to investigate the transient response.

Up to now in this section, response of the system in vertical direction, i.e. direction of motion of treadmill, is explained. However, vehicle may fall of the horizontal edges if it looses correct direction. To avoid this problem, line follower mechanism will be working together with the distance measurement system. Line follower system has discrete inputs. The inputs may be; on the line, on the left or on the right of default position. So the algorithm to keep the correct position in horizontal is easier. If the vehicle is found to be on the right of the default position, speed of the right wheel should be increased with respect to left. Hence a differential data will be produced by the line follower system.

Last step of the overall control system is the superposition of the outputs of the distance control and line follower mechanisms. Since the modeling of frictions, inertia of the car and the acceleration of the treadmill is not precisely known, superposition constants will be determined during testing stage.

Process Control Mode	Evaluation	Action
On-off	Is the variable below or above a specified value	Drive the output fully ON or fully OFF.
On-off with differential gap	Is the variable above or below a range defined by an upper and lower limit?	Output is turned fully ON and fully OFF to drive the measured value through a range.
Proportional	How far is the measured variable away from the desired value?	Take a degree of action relative to the magnitude of the error.
Integral	Does the error still persist?	Continue taking more forceful action for the duration the error exists.
Derivative	How fast is the error occurring?	Take action based on the rate at which the error is occurring.

Table 1 Closed Loop Control Modes

4.2. ALGORITHMIC STATE MACHINE – THE FLOW CHART

The general algorithm which is the implementation step of the control mode will be explained in detail at the next chapter. Now before the verbal expressions, here the flow chart of the algorithmic state machine derived from the developed algorithm is provided.

4.3. THE ALGORITHM

The chart above describes the algorithm, i.e. system behavior that will be controlled by the microcontroller. Microcontroller has two inputs from the environment. First input is the vertical position data supplied by the ultrasonic distance sensor. Second one is the horizontal position data that will be supplied by the line follower system. In total there are 9 cases for position. Below tables express the state assignments.

V1	V0	Vertical Position	H1	H0	Horizontal Position
0	0	Default position	0	0	Default position
0	1	Front	0	1	Left
1	0	Behind	1	0	Right

Table 2 State Assignments for the Position of the Device

‘11’ is not used for both inputs since there is not such a need i.e. ‘00’, ‘01’, ‘10’ are enough to state the horizontal and vertical positions.

When the system is turned on the state of the system will be changed from T_0 to T_1 which is the state that the system always will try to be in while it is working. In T_1 the vehicle is in a suitable position in the middle of the conveyor belt and it is ready to react to the changes in the speed of the conveyor belt.

When the system works it will always check its horizontal (H_1, H_0) and vertical (V_1, V_0) positions and try to return to the T_1 state.

When the system is checking the horizontal and vertical positions it will behave as:

- If H_1H_0 = 10 and V_1V_0 = 10 it means that the vehicle is on the left and behind of the optimum position therefore the speed of the right wheel must be increased and the speed of the left wheel must be increased more than the right one.
- If H_1H_0 = 10 and V_1V_0 = 00 it means that the vehicle is on the left of the optimum position therefore the speed of the right wheel must be decreased and the speed of the left wheel must be increased.
- If H_1H_0 = 10 and V_1V_0 = 01 it means that the vehicle is on the left and in front of the optimum position therefore the speed of the left wheel must be decreased and the speed of the right wheel must be decreased more than the left one.
- If H_1H_0 = 00 and V_1V_0 = 10 it means that the vehicle is behind of the optimum position therefore the speed of the right and left wheels must be increased in the same amount.
- If H_1H_0 = 00 and V_1V_0 = 00 it means that the vehicle is in the optimum position so no significant changes must be applied to the speed of the wheels.

- If H_1H_0 = 00 and V_1V_0 = 01 it means that the vehicle is in front of the optimum position therefore the speed of the right and left wheels must be decreased in the same amount.
- If H_1H_0 = 01 and V_1V_0 = 10 it means that the vehicle is on the right and behind of the optimum position therefore the speed of the left wheel must be increased and the speed of the right wheel must be increased more than the left one.
- If H_1H_0 = 01 and V_1V_0 = 00 it means that the vehicle is on the left of the optimum position therefore the speed of the right wheel must be increased and the speed of the left wheel must be decreased.

If H_1H_0 = 01 and V_1V_0 = 01 it means that the vehicle is on the right and in front of the optimum position therefore the speed of the right wheel must be decreased and the speed of the left wheel must be decreased more than the right one.

4.4 THE CONTROLLER

A microcontroller that is interfaced with other circuit elements will be used to control the whole system. It can be thought as the brain of the device. According to the data taken from the environment with the help of some sensors etc, it makes the decision and drives some motors to make the device maintain its position. Microcontroller is chosen as the controller units among the many controller choices since microcontrollers are programmable, inexpensive, small, can handle abuse, require almost zero power, and there are so many varieties to suit every need.

PIC 16F877A is a high performance capability, full-static, 8-bit microcontroller. It has specific properties which decrease the number of circuit elements in the design and provide a drop in both the cost and energy consumption significantly. Moreover, this microcontroller includes 4 different oscillator types. Among these RC (4 MHz) oscillator has low cost price, LP (40 KHz) oscillator minimize the energy consumption, XT crystal and resonator oscillator has standard speed and HS crystal oscillator has very high speed (20 MHz).

One of the most important properties of PIC microcontrollers is sleep mode property. When no operation is being performed, microcontroller passes to sleep mode and so pulls very low current, so energy consumption decreases. User or system can take microcontroller out from sleep mode by some internal and external interrupts.

EEPROM memory of PIC16F877A makes it possible to change the program again and again. By this property, it is possible to update the code involved when necessary.

This microcontroller is preferred due to the fact that it has high performance on high speed, decreases the energy consumption and cost price significantly and can be programmed by C programming language. Detailed information can be found in Appendix F.

4.5. ACTUATORS – THE DRIVING UNIT

Actuators of the system are the motors. However from central control unit to the motors there should be some interfacing elements. General block diagram is the following one blocks of which is specified according to testing and comparison of many possible choices :

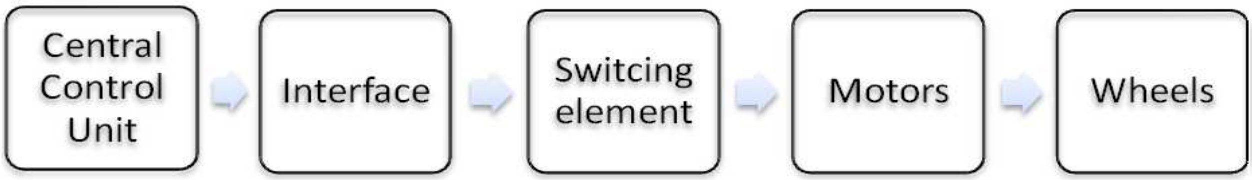


Figure 4 Block Diagram of a Motion Control Unit

Control signals to the driving block come from Central processing unit. However voltage and current level of the control signals from the controller side is not suitable to drive a motor. Output voltage level of a microcontroller can be up to 7.5V, which can meet the requirement of the motor. However maximum output current sourced by any I/O pin of a microcontroller is approximately 25 mA but motors may sink up to 2A input current therefore interface circuitry is needed between high power and low power sides. Control signals from the interface circuitry are applied to the switching element. Switching element is used to vary the speed of the motors. Finally motion of the rotor is transferred to the shaft of the wheels. It is planned that, Pulse Width Modulation technique will be used in the control strategy. PWM of a signal involves the modulation of its duty cycle to control the amount of the power sent to a load. By changing the duty cycle of the signal we can change the average value of the voltage so we can change the amount of power delivered. This can be easily seen in **Figure 5.**

PWM technique is very ease to operate. It doesn’t requires complex control circuitry (expect interfacing circuitry between high and low power sides). Moreover most microcontrollers provide own PWM signals. Therefore we can directly apply PWM signal from the control unit to switching element with interfacing. By using PWM technique terminal voltage of the motor is turn on and off repeatedly. Motors are inductive elements and for inductive elements the current and voltage relationship is Equation 1.

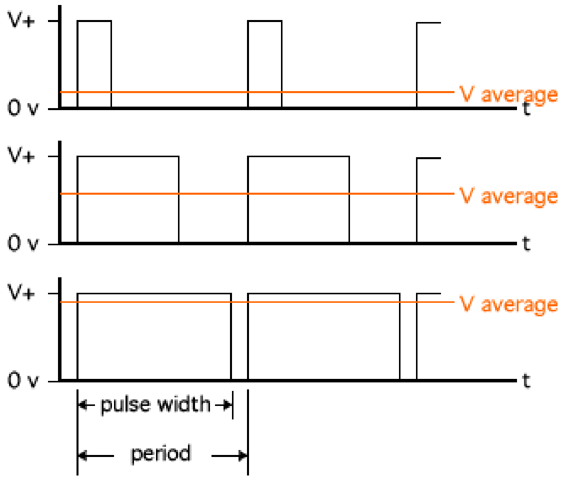


Figure 5 Average voltages of three different square waves

$$V = L\frac{di}{dt}$$ Equation 1

Important point is that, when the motor is turn on and off; current changes (derivative of the current) reaches very high values so motors or switching elements may be damaged due to over voltage. In order to prevent this, power diodes should be connected parallel to motors to decrease the current changes when turning on and off.

Several alternatives for the driving blocks were researched; advantages and disadvantages of them were determined and evaluated according to the design requirements. Alternatives for the blocks are seen in Table 3.

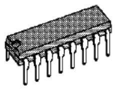
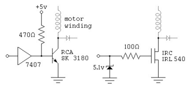
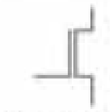
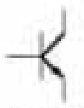
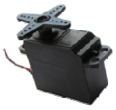
Central Control Unit	 Microprocessor			
Interface	 Driving IC's	 Driving Circuitry		
Switching element	 Power Mosfet	 BJT	 IGBT	 Relay
Motors	 Servo Motor	 Dc Motor	 Step motor	
Wheels	 Wheels with Openings	 Wheels without Openings	 Stringed Wheel	

Table 3 Alternatives for Driving Blocks

Primary design requirements of the project are good performance, low cost, low power consumption and lightness. According to these requirements, alternatives are evaluated:

Interface

Driving IC's	Driving Circuitry
o Low cost o Low power consumption o Small sizes o Fast response Extra Features Over temperature, Over voltage, short circuit protection, High noise immunity.	o High cost o Bigger sizes

Table 4 Comparison of IC and Circuitries as a driving unit

After the evaluation, our first choice for interfacing is to use Driving IC's.

- ***Switching element***

Power Mosfet	BJT	IGBT	Relay
Low cost Low power consumption Very fast switching High input impedance Positive temperature coefficient (Increase current handling)	Low cost High power consumption Slow switching Quite sizeable Need complex driver circuitry Require more base current to turn on and off Negative temperature coefficient (liable for thermal runaway)	High cost Low power consumption Fast switching High input impedance High current and voltage capability (up to 1000A and Thousands of volts!!)	Low cost Low power consumption High noise Debouncing and arcs in switching!!

Table 5 Comparison of Switching Elements

IGBTs are mostly used in high power application. Breakdown voltage and current capabilities of IGBTs is better than Mosfets, however voltage and current level of the motors are up to 12V and 2A respectively. Therefore we don't need IGBT. If we consider also cost aspect, power mosfets are the first choice for switching element.

- ***Motors***

Servo Motor	DC Motor	Step Motor
High cost Low power consumption High speed High torque Ease to control Ease to setup Fast response Requires hacking for continuous motion	Low cost Low power consumption High Speed Low torque Needs complex control Needs for gear to setup	High cost Low power consumption Low speed Low torque Needs complex control Needs for gear to setup

Table 6 Comparison of Motor Types

According to comparison of the performance of the motor type's servo motor is the best one but DC motors also meet the requirements. Moreover from the perspective of economy, DC motors are more suitable since servo motors are more expensive. However the major problem with DC motors is that, they are difficult to setup since they need gears for connections to the wheels. Therefore priority is on the servo motors but if the setup problem of DC motors can be overcame servo motors can be replaced with DC motors in order to reduce the cost of the project.

- ***Wheels***

Wheels with Openings	Wheels without Openings	Stringed wheels
Low cost Lighter	Low cost Heavier	High cost Lighter

Table 7 Comparison of Wheel Types

Wheels with openings are the first choice for lighter weight. Rubber outside the wheels may also be used in order to increase the friction so to prevent sliding.

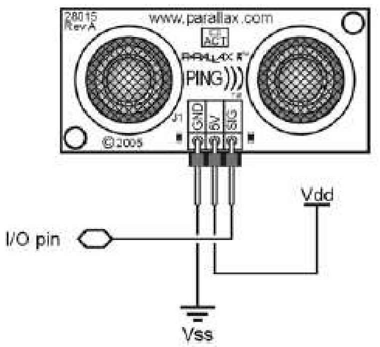
4.6. SENSORS

4.6.1. VERTICAL DISTANCE SENSING

Vertical distance of the device from the reference point will be measured to recognize the changes in the speed of the treadmill. Among various possible procedures, ultrasonic ranging is chosen. The idea is too simple in this method. With the given command the sensor transmits a 40 kHz ultrasonic burst produced by the supportive circuitry provided on the sensors PCB. With the moment of transmitting a burst the sensor also produces a pulse. After the burst is reflected from the object at the moment of reception of the echo signal, the pulse is terminated. Hence the width of the pulse produced is the time required for the ultrasonic signal to travel to the object and back. So it is not directly the distance. The variance of the speed of sound for changing temperature is also considered. The temperature information will be passed to the units calculating the distance from the acquired data.

Pin Definitions

GND	Ground (Vss)
5 V	5 VDC (Vdd)
SIG	Signal (I/O pin)



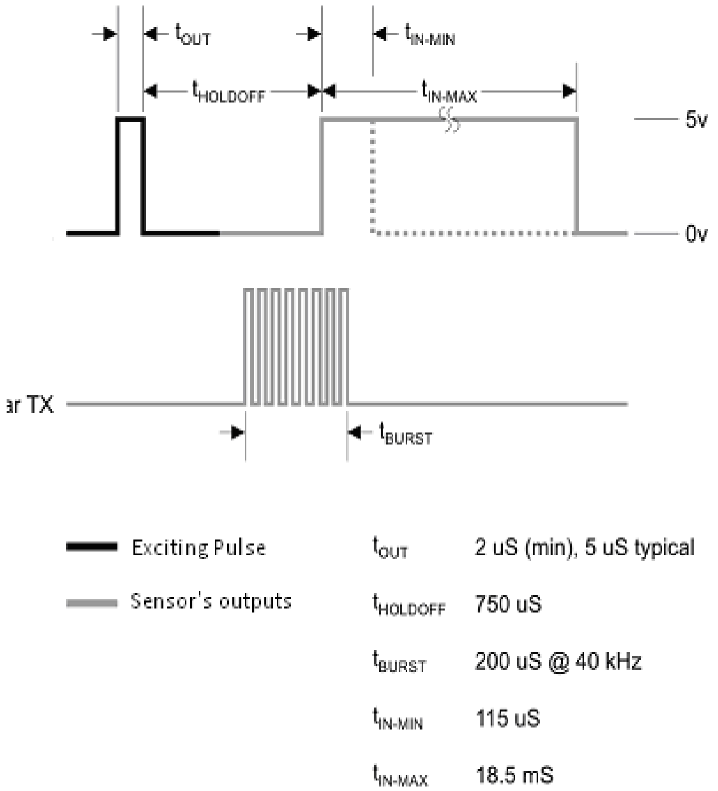


Figure 6 Ultrasonic Sensor Kit and Pin Definitions

Figure 7 Transmitted, Received and the Outputted Signals

The ultrasonic sensor can be seen on the left hand side. I/O pin is the bidirectional terminal from where the triggering input pulse is accepted and the corresponding reflected echo signal is provided by the internal pulse generating unit, an oscillator. Power and ground pins are connected to global voltage sources of the circuitry.

4.6.2 EFFECT OF TEMPERATURE VARIATIONS ON DISTANCE MEASUREMENTS

Sound wave propagation speed in air is changed by the temperature. At 0°C it is 331.5m/sec. At 40°C it is 355.5 m/sec. A range meter calculates a distance by dividing the propagation time which was measured by the capture feature. A possible temperature compensation unit may be like the circuit shown here. We must know that the measured echo time does not give directly the distance. With the temperature information taken from the sensor, the algorithm in the microprocessor will calculate the corresponding distance according to the following information: The sound wave propagation speed can be calculated by the following formula:

$v = 331.5 + 0.6 * t$ [m/sec]   t: The temperature (°C)

The speed of sound at each temperature is as follows:

Temperature (°C)	Speed of sound (m/sec)
-10	325.5
0	331.5
10	337.5
20	343.5
30	349.5
40	355.5
50	361.5

Table 8 Speed of Sound in air for different temperatures

4.6.3. HORIZONTAL ORIENTATION

Line Follower

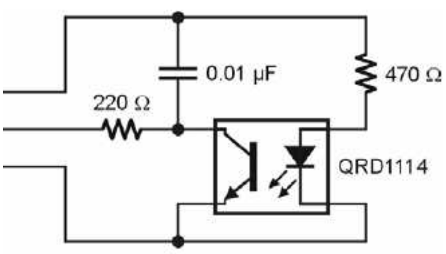


Figure 8 Schematic of the Circuit for Line Follower Sensors

Line following method is based on a simple idea. The reflectivity of the QRD1114 is very low on the dark surface and high on the light surface. Seeing the white line causes high reflectivity which results in reading from the sensor. Sensor is activated by placing 5V (Vdd) on the upper pin. This will cause current to flow through the 470 Ω resistor to the LED side of the QRD1114. IR light reflecting of the surface below will cause a change in the ability for current to flow through the phototransistor side of the QRD1114. The transistor, in effect, behaves like an IR controlled resistance.

Compass Method

The Hitachi HM55B Compass Module product documentation has example programs that all use a subroutine named **Compass_Get_Axes** that returns x and y magnetic field strength measurements. The value of x is the component of the earth's magnetic field acting on the sensor's Xm axis shown in Figure 9. The value of y is the negative of the earth's magnetic field acting on the Ym axis. If N is the value reported by x or y when it is aligned with the earth's magnetic field, then the x measurement a some angle θ will be Ncos θ, and the y measurement will be −Nsin θ. With these known quantities compass module’s angle from north will give us the orientation information.

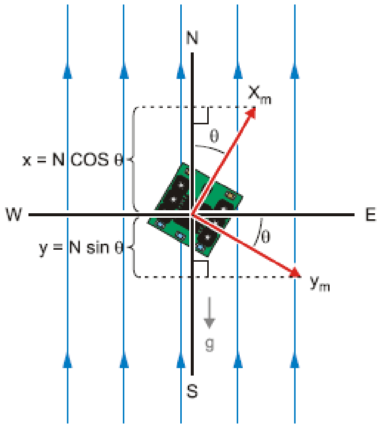


Figure 9 Compass Module and Position Decomposition into Rectangular Coordinates

$$\tan\theta = \frac{-N\sin\theta}{N\cos\theta} = \frac{-y}{x}$$ Equation 2

$$\theta = \tan^{-1}\left(\frac{-y}{x}\right)$$ Equation 3

The deviation in horizontal direction on the platform is highly related with the system parameters like acceleration of the device and treadmill, maximum speed etc. and materials used for treadmill surface, device wheels (in terms of friction). So performance and cost analysis will determine the method to be used. But it is sure that both methods do meet the requirements of the project in terms of deviation prevention.

4.7 THE TREADMILL

This is the platform that the robot will be tested on. It includes the treadmill, controllers to adjust the speed of the treadmill and some panels showing the speed of the treadmill to the users.

Figure 10 Side View of the Treadmill

To implement this unit high torque providing motors is thought to be used. The hoop may move with the help of the cylinders and be in contact with a fixed platform in order to protect the smoothness of the hoop. A smooth platform should be formed on which the robot can move to perform its designated tasks. Furthermore, the treadmill will have a control unit from where the speed and may be some other parameters can be changed. A panel maybe used as an output device to show the instantaneous speed of the treadmill to inform outside about the current conditions.

4.8. THE DEVICE

The mechanical design of the device is roughly decided. A three wheeled vehicle model is obtained. In this model the front wheels will be responsible from both the speed and the direction of the robot. Since two front wheels are connected to two different continuous servo motors their speeds can be adjusted differently to obtain a steering action while the robot still moves with respect to the speed of the treadmill. The other wheel in the three wheeled design does not make any active motion. It only moves with respect to the other wheels and helps the other wheels to make the robot straight horizontally.

During some studies and data collection, a product is found which is very close to the roughly discussed three-wheeled model. After a time-cost analysis it is decided that purchasing the components of the vehicle is more appropriate than constructing them. Since this is the development stage of the product a solution which eases the progress of the project is preferable. The components are two wheels and tires, passive back wheel, the main chassis and the connection pins. It is obvious that all these components are made of low cost material and have very little processing on them. In case of the mass production or even in case of construction of a one unit the production cost will be comparably negligible. The chassis is made of metal, has a very simple geometry, however with lack of equipments it might be challenging to give the desired shape to the metal. Wheels are made of plastic and together with the battery pack and servos approximate weight of the device is less than a half kilograms which sufficiently meets the goal of reduced weight and reduced energy consumption. The battery pack requires for standard 1.5V AA batteries.

More detailed information providing the dimensions of the device, wheels, specifications of the servos etc. can be found in Appendix I.

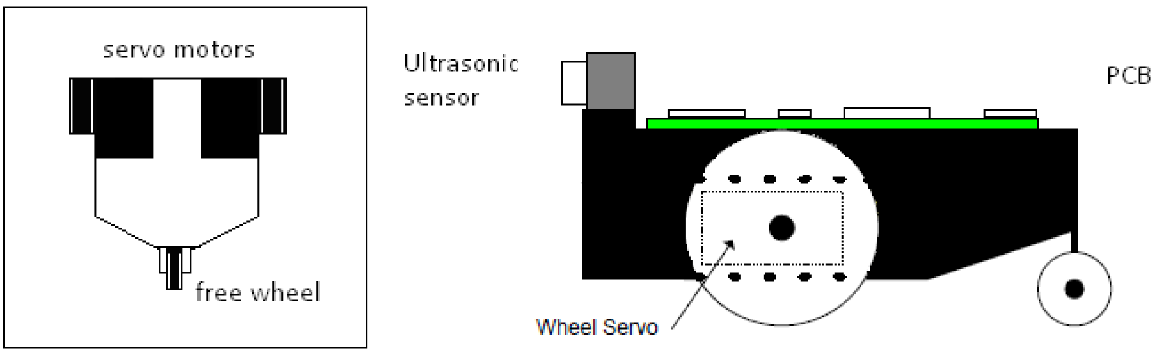


Figure 11 Three wheeled device Top (Left) and Side Views

5. TIMELINE

Up to now the company has progressed on some issues. Before giving the future work plan it is necessary to state here the completed tasks:

Sensor Testing: Effective range, noise sensitivity and input/output signal levels are investigated through testing and comparison. Performances of the different types mentioned in the proposal are compared and exact sensor models are decided for each sensing unit. (Datasheets are provided in the Appendices)

Car Design: According to goals and objectives and project requirements, the model of the car is decided (among 3 and 4 wheeled models 3 is the final one). Components leading to a device with the desired size and weight are purchased and the car is mounted.

Microcontroller type is selected, programmer unit is obtained. Sample programs are operated to investigate the chip properties.

Motor types for the device and treadmill are decided, necessary blocks are studied, and interface circuitries are defined.

For the future studies of the company on the project, the proper sequence of actions can be summarized as follows:

- Construction and testing of each individual block
- Combining the separate blocks interface issues
- Testing the control of units with microcontroller individually
- Implementation of the code according to the algorithm developed
- Tests carried out for the Proportional derivative control mode, examining the responses
- Improvements on block performances by individual block hardware optimization
- Improvements on overall system performance by control method optimization
- Improvements on overall system performance by algorithm optimization

6. INSTRUMENTATION AND FACILITIES

In order to conduct design and implementation of the previously explained solution methods, there are some necessary instrumentation and facilities. The list and availability of these needs are as follows:

- Laboratory or laboratory condition is required for maintenance of project design and assuring working environment. This problem is solved by having the privilege of using EE493 – EE 494 Senior Design Course Laboratory.

- Computers are required for developing embedded software of microcontrollers, documentation, researching, and project simulations. All members have their own personal computers and also computer rooms of METU CC are available.
- Desired electronic components and electronic measurement tools are required for electronic design. These are voltmeter, ampere meter, oscilloscope, microcontroller, electronic switches, resistors, wires, capacitors, inductors, etc… Instrumentations are available in laboratory and company has instruments from early studies (voltmeters, boards, components, wires, etc.)
- PCB design and fabrication components are required for PCB design. The necessary software is available. There are many techniques for production of PCBs such as using printers, at this moment we aim to produce it with our own facilities, but there are also many companies available to work with.
- For mechanical design and implementation, mechanical components are also required, such as copper plates, gear boxes, cap screws, wheels, motor shafts, solder tools, clippers, etc. Like PCB fabrication mechanical production can also be performed by another company.

7. DELIVERABLES

Final version of the project solution will be composed of three main parts; vehicle, treadmill and the reference obstacles (They will be designed to be mounted on the treadmill).

Vehicle is the mobile system that it does not have any electrical connection to outside world. Thus, it will operate on battery power. A battery pack is included within the prototype. The exact type and number of batteries will be decided later. But it will either be rechargeable or easily be replaced with standard commercial batteries.

Treadmill is the stationary part that will be powered by line voltage through an adapter which will also be included in the package. It also will have a control panel on it.

A user manual explaining the usage of the system under different conditions will be included within the project.

As an after sale service, the mounting and first time running of the product may be provided by the producer.

8. SUMMARY AND CONCLUSION

Salix Technology has presented this conceptual design report to inform the reader about the almost final picture capturing the technical details of the product that will be presented by the end of May 2008. Some points of the solution are not specified with certain circuitries but alternative solution methods, from which the writer is sure that it is a reasonable and reliable solution that will work properly with the system, are explained. Both demander and provider may benefit from this approach. Alternatives may give the demander a chance to make a decision on the product letting him/her be a part of the solution and obtain a product which is somewhat specialized to person. The provider may benefit from this fact in the sense that alternatives are like substitute players in a championship tournament. The one with better substitutes win the competition since the players of all team's in the game almost equally as good as each other. Salix Technology as being a R&D company prefers the way of study, in which alternatives always promoted. During the design of the product even the main concept remain the same, the members did not stop generating ideas about the solution techniques whose implementation method is almost decided as the decided one is the most powerful candidate to be in the conceptual design report. It is important to note here that with the study carried out up to now, acquired knowledge and completed workshop, the company became eligible to conduct a far more difficult robotics project (difficult in performance requirements, definitions (a walking or running robot) etc.).

In the previous sections of this report company's current employee profile, projects completed in the past as references, its organizational structure, what is aimed to be achieved from the current project and how is it thought to be conducted is explained with detailed technical statements. The required equipment, time and funds are mentioned to let the demander be aware. Completed studies are mentioned and an estimate work plan is provided.

To sum up, with the evidences throughout the report, it is declared that the design of the project even with its open-ended sections (left undecided between alternatives in order to try each alternative and get the best solution) is compatible with the requirements of the demander and gives strong signals of a high performance device besides the poor funding and limited time factors. Since the conceptual design of the project is provided here, now it is time to wait for the final product to appreciate its performance.

APPENDICES

APPENDIX A

An average cost for one unit of production is estimated as follows:

ITEM	Maximum Budget Fund Available
Sensors Ultrasonic SONAR pack (PING))) QRD1114s for LINE follower or Hitachi HM55B Compass DS 1620 Temperature Sensor	$40
Motors 2 modified servos	$40
Microcontroller	$5
Software Tools for PCB Design, PIC Programming, Circuit Simulations etc	0 - Available
Material & Production Costs of Mechanical Parts (Both for Treadmill and Vehicle)	$40
Main Components of Circuitries (resistors, capacitors, inductors, LEDs, op-amps, boards, wires, transistors, diodes, IC chips etc…)	$10
Power & Control unit components (adapters, converters, electronic switches, batteries, regulators, fuses etc...)	$20
Measurement Devices (CROs, Multimeter, Signal Generators)	0 - Available
Computers, connection cables, possible testing equipment	0 - Available
Total	**~$155**

Table A.1 Cost Analysis of the Project

APPENDIX B

The following Gantt chart displays an estimated work plan up to the completion of the project.

APPENDIX C
Temperature Sensor IC

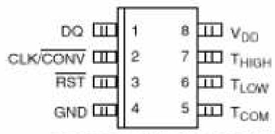
DALLAS SEMICONDUCTOR

DS1620
Digital Thermometer and Thermostat

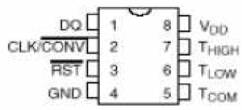
FEATURES

- Requires no external components
- Supply voltage range covers from 2.7V to 5.5V
- Measures temperatures from –55°C to +125°C in 0.5°C increments. Fahrenheit equivalent is –67°F to +257°F in 0.9°F increments
- Temperature is read as a 9–bit value
- Converts temperature to digital word in 1 second (max)
- Thermostatic settings are user–definable and non–volatile
- Data is read from/written via a 3–wire serial interface (CLK, DQ, $\overline{\text{RST}}$)
- Applications include thermostatic controls, industrial systems, consumer products, thermometers, or any thermally sensitive system
- 8–pin DIP or SOIC (208 mil) packages

PIN ASSIGNMENT



DS1620S 8–PIN SOIC (208 MIL)
See Mech Drawings Section



DS1620 8–PIN PDIP (300 MIL)
See Mech Drawings Section

PIN DESCRIPTION

DQ	–	3–Wire Input/Output
CLK/$\overline{\text{CONV}}$	–	3–Wire Clock Input and Stand–alone Convert Input
$\overline{\text{RST}}$	–	3–Wire Reset Input
GND	–	Ground
T_{HIGH}	–	High Temperature Trigger
T_{LOW}	–	Low Temperature Trigger
T_{COM}	–	High/Low Combination Trigger
V_{DD}	–	Power Supply Voltage (3V – 5V)

DESCRIPTION

The DS1620 Digital Thermometer and Thermostat provides 9–bit temperature readings which indicate the temperature of the device. With three thermal alarm outputs, the DS1620 can also act as a thermostat. T_{HIGH} is driven high if the DS1620's temperature is greater than or equal to a user–defined temperature TH. T_{LOW} is driven high if the DS1620's temperature is less than or equal to a user–defined temperature TL. T_{COM} is driven high when the temperature exceeds TH and stays high until the temperature falls below that of TL.

User–defined temperature settings are stored in non–volatile memory, so parts can be programmed prior to insertion in a system, as well as used in stand–alone applications without a CPU. Temperature settings and temperature readings are all communicated to/from the DS1620 over a simple 3–wire interface.

APPENDIX D
HITACHI MAGNETIC COMPASS SENSOR

3. Absolute Maximum Ratings

No.	Item	Symbol	Limitation	Unit
1	Power Supply	AVcc/DVcc	-0.3_+6.7	V
2	Terminal Voltage	Vin	-0.3 _Avcc/DVcc_+0.3	V
3	Operating Temp.	TOPE	-20_+85	degC
4	Storage Temp.	TSTG	-40_+95	degC
5	Max. Acceptable Loss	P	126	mW

Note) In case being operated out of the Absolute Maximum Ratings, the sensor/circuit may permanently be destroyed. It is necessary to be used following specified operating conditions as shown 4. If it is exceeded, the product(s) may work improperly and/or its reliability may be affected.

4. Electrical Characteristics

(Vcc:2.7 – 3.3V, Ta: -20 – +85degC)

	Item	Symbol	Condition for measurement	Min.	Typ.	Max.	Unit
	Supply Voltage	Vcc		2.7	3.0	3.3	V
*1	Current Consumption (active)	Icc1	Measurement operation	—	9	13	mA
	Current Consumption (standby)(1)	Iccst(1)	Ta= -20degC - +60degC, Vcc=3.0V	—	—	1	uA
	Current Consumption (standby)(2)	Iccst(2)	Ta= +60degC - +85degC, Vcc=3.0V	—	—	5	uA
*1	Current Consumption(ave)	Iccave	Measurement period:100ms	—	3	5	mA
	Measuring Time	Tmes		—	30	40	ms
	Sensitivity	Bse	Ta= 25degC, Vcc=3.0V	1.0	—	1.6	LSB/uT
	Magnetic field range	H	Ta= 25degC, Vcc=3.0V	-180	—	180	uT
	Linearity	linia	Ta= 25degC, Vcc=3.0V, F.S.=+/-180uT	-5	—	5	% / FS
	Low-Level Input Voltage	V_{IL}		-0.3	—	Vcc x 0.2	V
	High-Level Input Voltage	V_{IH}		Vcc x 0.8	—	Vcc + 0.3	V
	Low-Level Output Voltage	V_{OL}	Vcc=3V, IL=1mA	-0.3	—	Vcc x 0.1	V
	High-Level Output Voltage	V_{OH}	Vcc=3V, IL= -1mA	Vcc x 0.9	—	Vcc + 0.1	V

APPENDIX E
555 TIMER IC

INTERSIL

555 Precision Timer

6

FEATURES

- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- High current output can source or sink 200mA
- Output can drive TTL
- Temperature stability of 0.005%/°C

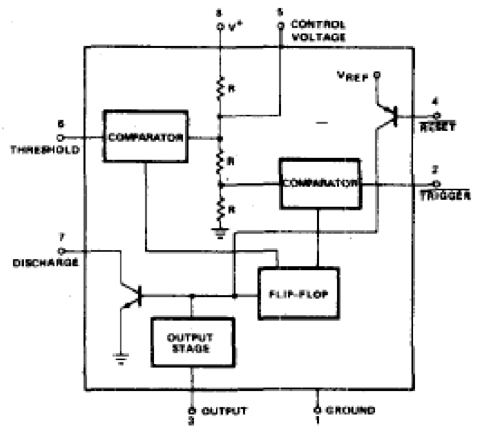
APPLICATIONS

- Precision Timing
- Pulse Generation
- Sequential Timing
- Time Delay Generation
- Pulse Width Modulation
- Pulse Position Modulation
- Missing Pulse Detector

GENERAL DESCRIPTION

The NE/SE 555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays, or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor; the circuit may be triggered and reset on falling waveforms, and the output structure can source or sink large currents or drive TTL circuits.

BLOCK DIAGRAM



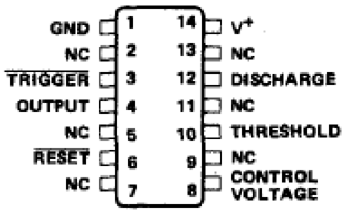
ORDERING INFORMATION

NE555/D NE555F NE555N NE555T	0°C to +70°C	Dice 14 pin CERDIP 8 pin plastic DIP TO-99 can
SE555/D SE555F* SE555T*	-55°C to +125°C	Dice 14 pin CERDIP TO-99 can

*Add /883B to order number if 883B processing is desired.

PIN CONFIGURATIONS

(OUTLINE DRAWING JD)



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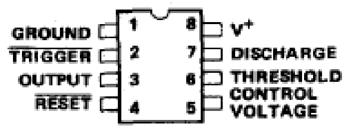

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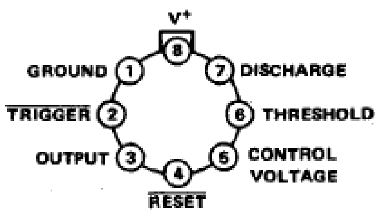


6-3

APPENDIX F
MICROCONTROLLER

MICROCHIP

PIC16F87X

28/40-Pin 8-Bit CMOS FLASH Microcontrollers

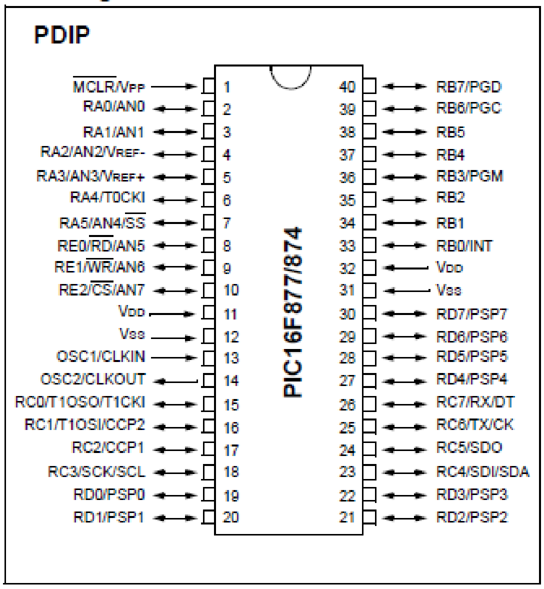
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

Microcontroller Core Features:

- High performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and
  Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low power, high speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial, Industrial and Extended temperature ranges
- Low-power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 µA typical @ 3V, 32 kHz
  - < 1 µA typical standby current

Pin Diagram



Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

FIGURE 2-3: PIC16F877/876 REGISTER FILE MAP

Bank 0	File Address	Bank 1	File Address	Bank 2	File Address	Bank 3	File Address
Indirect addr.(*)	00h	Indirect addr.(*)	80h	Indirect addr.(*)	100h	Indirect addr.(*)	180h
TMR0	01h	OPTION_REG	81h	TMR0	101h	OPTION_REG	181h
PCL	02h	PCL	82h	PCL	102h	PCL	182h
STATUS	03h	STATUS	83h	STATUS	103h	STATUS	183h
FSR	04h	FSR	84h	FSR	104h	FSR	184h
PORTA	05h	TRISA	85h		105h		185h
PORTB	06h	TRISB	86h	PORTB	106h	TRISB	186h
PORTC	07h	TRISC	87h		107h		187h
PORTD(1)	08h	TRISD(1)	88h		108h		188h
PORTE(1)	09h	TRISE(1)	89h		109h		189h
PCLATH	0Ah	PCLATH	8Ah	PCLATH	10Ah	PCLATH	18Ah
INTCON	0Bh	INTCON	8Bh	INTCON	10Bh	INTCON	18Bh
PIR1	0Ch	PIE1	8Ch	EEDATA	10Ch	EECON1	18Ch
PIR2	0Dh	PIE2	8Dh	EEADR	10Dh	EECON2	18Dh
TMR1L	0Eh	PCON	8Eh	EEDATH	10Eh	Reserved(2)	18Eh
TMR1H	0Fh		8Fh	EEADRH	10Fh	Reserved(2)	18Fh
T1CON	10h		90h	General Purpose Register 16 Bytes	110h–11Fh	General Purpose Register 16 Bytes	190h–19Fh
TMR2	11h	SSPCON2	91h		111h		191h
T2CON	12h	PR2	92h		112h		192h
SSPBUF	13h	SSPADD	93h		113h		193h
SSPCON	14h	SSPSTAT	94h		114h		194h
CCPR1L	15h		95h		115h		195h
CCPR1H	16h		96h		116h		196h
CCP1CON	17h		97h		117h		197h
RCSTA	18h	TXSTA	98h		118h		198h
TXREG	19h	SPBRG	99h		119h		199h
RCREG	1Ah		9Ah		11Ah		19Ah
CCPR2L	1Bh		9Bh		11Bh		19Bh
CCPR2H	1Ch		9Ch		11Ch		19Ch
CCP2CON	1Dh		9Dh		11Dh		19Dh
ADRESH	1Eh	ADRESL	9Eh		11Eh		19Eh
ADCON0	1Fh	ADCON1	9Fh		11Fh		19Fh
General Purpose Register 96 Bytes	20h–7Fh	General Purpose Register 80 Bytes	A0h–EFh	General Purpose Register 80 Bytes	120h–16Fh	General Purpose Register 80 Bytes	1A0h–1EFh
		accesses 70h-7Fh	F0h–FFh	accesses 70h-7Fh	170h–17Fh	accesses 70h - 7Fh	1F0h–1FFh
Bank 0		Bank 1		Bank 2		Bank 3	

Unimplemented data memory locations, read as '0'.
* Not a physical register.

Note 1: These registers are not implemented on the PIC16F876.
2: These registers are reserved, maintain these registers clear.

APPENDIX G
MODIFIED SERVO

Continuous Rotation Servo (#900-00008)

General Information

The Parallax Continuous Rotation servo is ideal for robotic products that need a geared wheel drive or other projects that require a 360 degree rotation geared motor. The Parallax Continuous Rotation servo output gear shaft is a standard Futaba configuration. The servo can be adjusted with a small Phillips screw driver if the unit becomes out adjustment on its center set point. Servo is custom manufactured for Parallax by Futaba.

Technical Specifications

> Power 6vdc max

> Average Speed 60 rpm
Note: with 5vdc and no torque

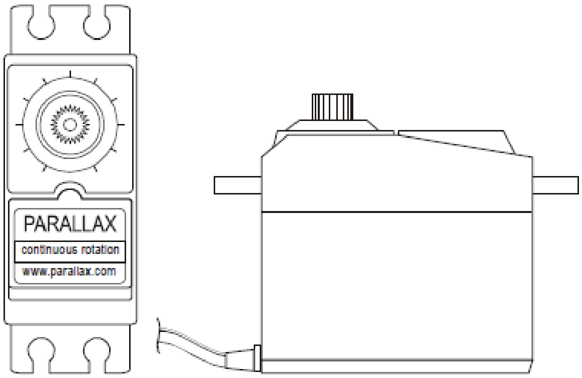
> Weight 45.0 grams/1.59oz

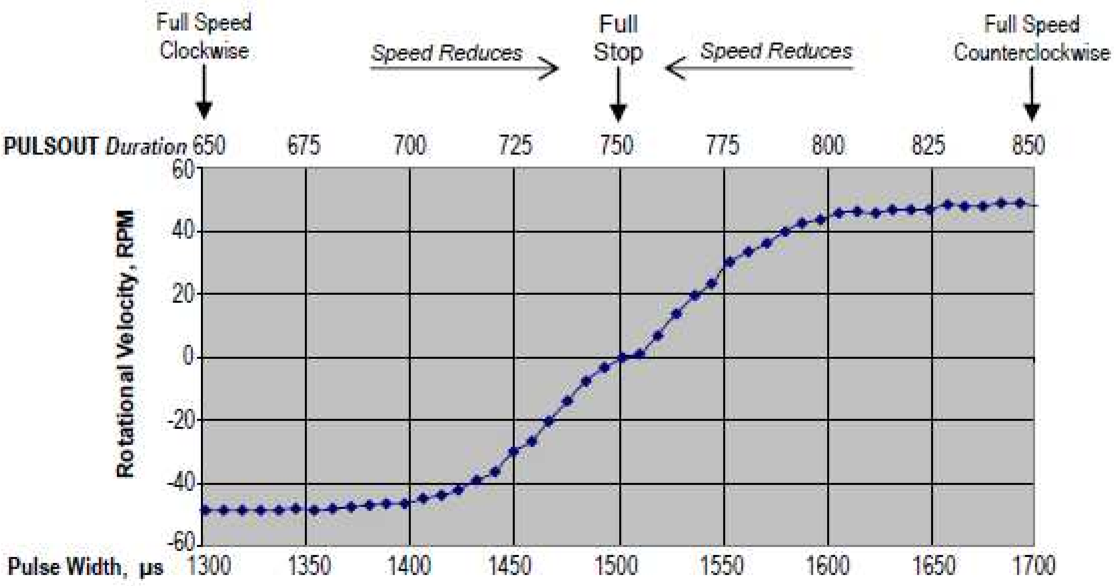
> Torque 3.40 kg-cm/47oz-in

> Size mm (L x W x H)
40.5x20.0x38.0

> Size in (L x W x H)
1.60x.79x1.50

> Manual adjustment port





APPENDIX H
ULTRASONIC SENSOR

PING))) ™ Ultrasonic Distance Sensor (#28015)

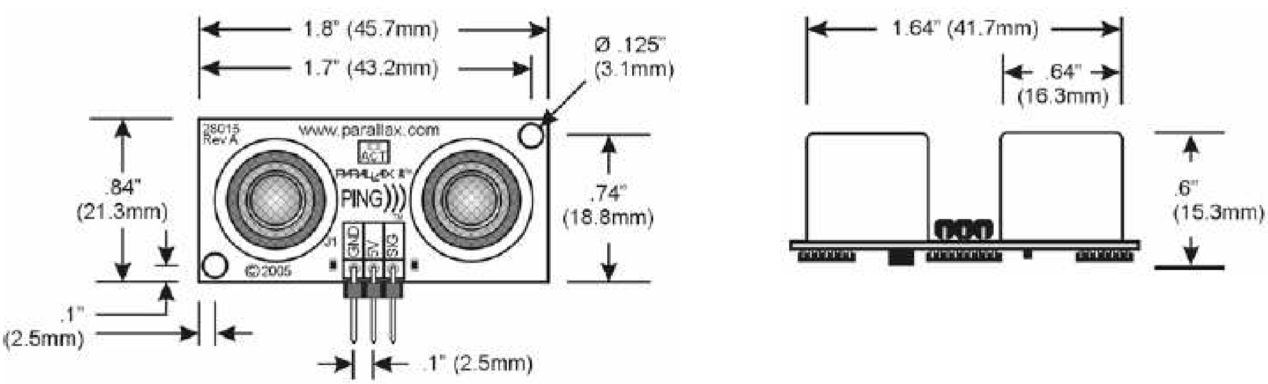
The Parallax PING))) ultrasonic distance sensor provides precise, non-contact distance measurements from about 2 cm (0.8 inches) to 3 meters (3.3 yards). It is very easy to connect to BASIC Stamp® or Javelin Stamp microcontrollers, requiring only one I/O pin.

The PING))) sensor works by transmitting an ultrasonic (well above human hearing range) burst and providing an output pulse that corresponds to the time required for the burst echo to return to the sensor. By measuring the echo pulse width the distance to target can easily be calculated.

Features

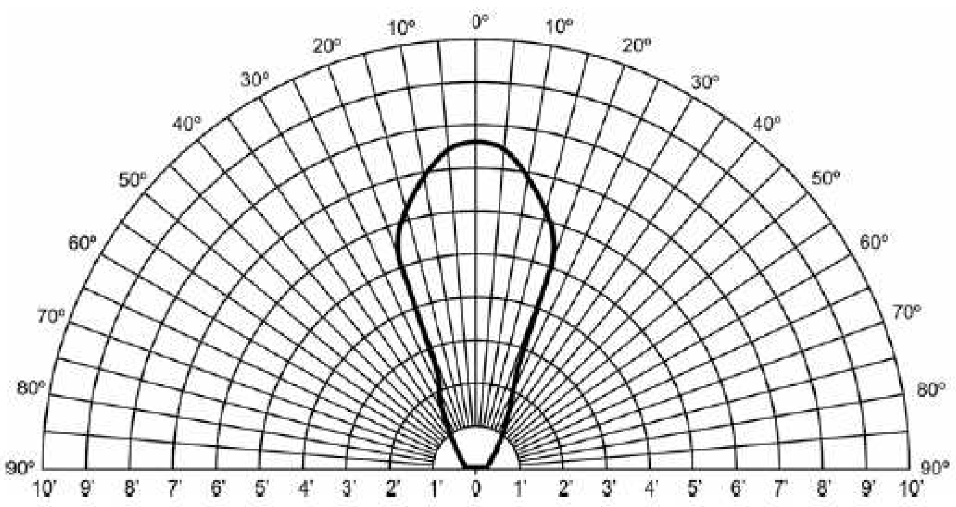
- Supply Voltage – 5 VDC
- Supply Current – 30 mA typ; 35 mA max
- Range – 2 cm to 3 m (0.8 in to 3.3 yrds)
- Input Trigger – positive TTL pulse, 2 uS min, 5 µs typ.
- Echo Pulse – positive TTL pulse, 115 uS to 18.5 ms
- Echo Hold-off – 750 µs from fall of Trigger pulse
- Burst Frequency – 40 kHz for 200 µs
- Burst Indicator LED shows sensor activity
- Delay before next measurement – 200 µs
- Size – 22 mm H x 46 mm W x 16 mm D (0.84 in x 1.8 in x 0.6 in)

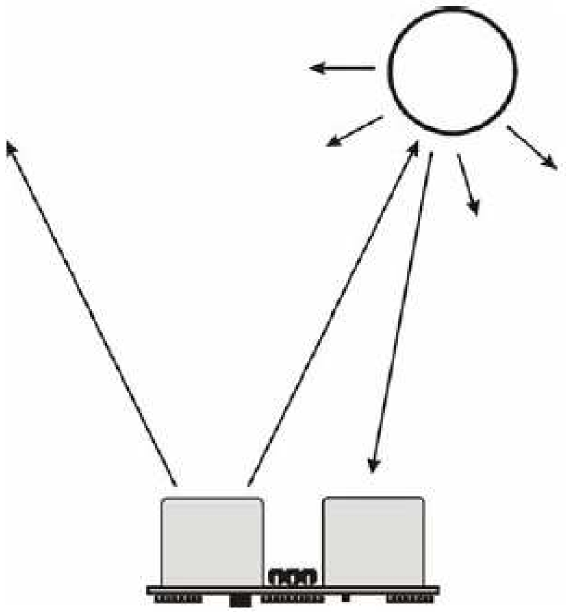
Dimensions



Test 1

Sensor Elevation: 40 in. (101.6 cm)
Target: 3.5 in. (8.9 cm) diameter cylinder, 4 ft. (121.9 cm) tall – vertical orientation

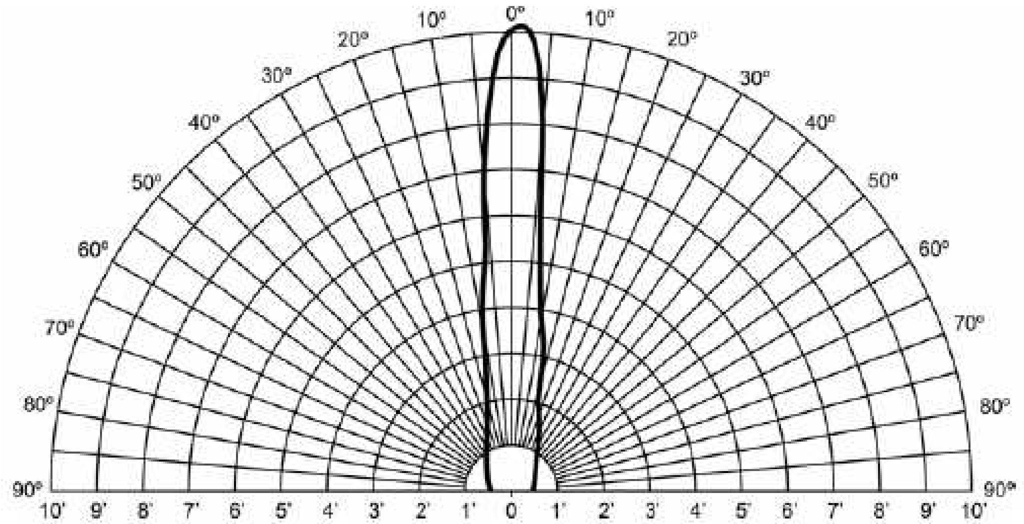


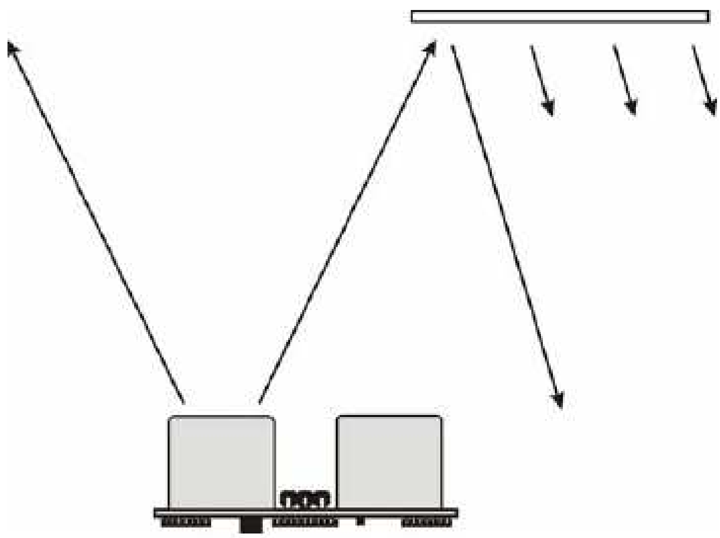


Test 2

Sensor Elevation: 40 in. (101.6 cm)
Target: 12 in. x 12 in. (30.5 cm x 30.5 cm) cardboard, mounted on 1 in. (2.5 cm) pole

- target positioned parallel to backplane of sensor





APPENDIX I

COMPONENTS OF THE CAR

Chassis of the car

Battery holder

Wheels and tires