Project: SJB-2A13

BLINDSIGHT
ULTRASONIC ENVIRONMENT SENSING FOR THE VISUALLY IMPAIRED

A Major Qualifying Project submitted to the faculty of
Worcester Polytechnic Institute
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

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Worcester, 2014
Abstract

Each year, people with impaired vision suffer from a significant number of head injuries that often require hospitalization. Although white-canes and seeing-eye dogs provide the primary means of assistance to the visually impaired, they are often inadequate for detecting objects above waist level. Open cabinet doors, overhangs, and low-hanging tree branches are among a number of obstacles that are difficult to avoid. Our product idea promises an elegant and affordable solution to this problem. BlindSight will detect objects above waist level, provide tactile feedback in a non-intrusive manner, be comfortable to wear and easy to use. A prototype has been developed over the course of this past year. This paper details the design and development of this device, as well as the challenges faced and the solutions implemented to overcome them.
Acknowledgments

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## Authorship

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Chapter 1

Introduction

Currently in the United States, there are 6 million individuals who are either completely blind or legally blind. Many people who are blind are susceptible to head injuries which can result in serious medical consequences. These head injuries may also result in a change in behavior when walking such as having a lack of confidence in walking alone or trying to protect their heads as much as possible.

This paper details the development of a solution called Blind-Sight, a device which detects nearby head level objects using ultrasonic sensors, and notifies them using vibrotactile feedback. The developed device comes makes use of three components: glasses with sensor, a controller, and a feedback garment. The proposed solution has been made into a fully functional prototype over the first seven weeks of development. Market research was collected by creating an online survey and distributing it through blind associations and advocacy groups, conducted in-depth interviews, human trials, and assessed our competitors. Research shows that the developed device has a very interested market and low competitors. Blind-Sight has shown to be able to detect objects from up to two meters away and has a fast response time. It has a sensitivity controller that allows the user to choose the intensity of the vibrotactile feedback. The Blind-Sight has a wide range with multidirectional response. The device will be used in conjunction with a cane or guide dog on the grounds that it focuses on above waist objects. The focus of development throughout this project was to bring the power consumption to a level considered realistic for a marketable device while laying the groundwork for a whole product.
Chapter 2

Background

2.1 Problem Statement

Approximately 6 million people who are exceptionally visually impaired currently live in the United States. Among this community there exists an ongoing problem with head level injuries, some of which cause serious medical consequences. In a survey conducted in 2011 about head injuries, 47% of respondents indicated that they experience head injuries with frequency of one per month or less. From these reported accidents, 23% resulted in serious medical consequences. The product under development aims to mitigate, or prevent these injuries by enabling individuals in the blind community to more easily detect and maneuver around obstacles above waist level.

2.2 Survey and Data Collection

Initial background research was conducted via an online survey and distributed to a number of associations serving the blind as well relevant advocacy groups in the Massachusetts, Connecticut, and Pennsylvania areas. Given the exploratory nature of the research it was, by design, rather brief and consisted of ten questions. The survey covered three main subjects:

1. **Blindness and Mobility Status**: Survey takers were asked about their level of blindness, as well as their level of mobility in a normal week. People who possess perfect eyesight or those who are completely immobile are not considered in the later analyses as they are not relevant to the market for the present device.

2. **Current Assisted Devices**: Survey takers were asked which variety of mobility assistance, if any, they are currently using. Some respondents are utilizing a
cane or seeing-eye dog.

3. **Product Evaluation**: Survey takers were asked to evaluate the proposed product in terms of interest and expected price point.

The survey focused on the features people felt would be most important to focus on in the design. There were eight specific features that participants were asked to rank from “not important at all” to “extremely important”. These features include: comfort, affordability, vibration response, light weight, long battery life, durability, safety, and compactness. The frequency of injury and rate that they walked throughout the past week was explored to see if the product would have a use. Aspects such as cost were evaluated in the survey to see when a price point would be too much for the device to become useful. The survey had a field time of several weeks, after which the results were analyzed. To gain an understanding of how to analyze the data, a more personal view was necessary. Thus, the data collected via the survey was only interpreted after a series of in-depth interviews with potential users. This process is detailed in Figure 2.1.

When evaluating the data pertaining to the features of the device considered most important, a weighted scatter plot was made to view the results as seen in Figure 2.3. Respondents voiced a necessity for high levels of safety with the product. The next parameter with the closest consensus was “affordability” which had 80% of the
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respondents indicating that it was extremely important. “Durability” and “battery” were also seen to have an 80% group rating with durability being slightly more important than long battery life. “Comfort” and “Compact” were both given a 50% group rating of 6 for importance. “Light weight” and “vibration response” were the most spread out of the features for importance but still showed to be highly needed.

Figure 2.3: Weighted Scatter Plot of Device Features vs. Importance

From the optional comments of the survey, the conclusion was made that there was interest in the product under development, though there were some questions about the appearance wearing the device:

“Would it make a person look silly wearing it? Can it be worn underneath clothing or would that interfere with the ultrasonic aspect? I’m guessing the product would not sense things like fire hydrants, as they are short”

From the In-Depth Interviews, reasoning from the survey results was learned. This allowed for a better insight into what the results mean and how they can be
2.3. IN-DEPTH INTERVIEWS

In social science and market research, in-depth interviews (IDIs) are often used as a methodology to uncover the correct way to ask questions, the appropriate ranges for scales, and the motivations behind answers. In the present research efforts, all of these were rationales for using IDIs. Over the course of the initial background research, several in-depth interviews were conducted. Interviews allowed for more information on important features to be discussed. These interviews were held at the Massachusetts Commission for the Blind, Bucks County Association for the Blind, and the National Federation for the Blind.

The interview schedules were developed around the potential users interest in optimal pricing, attribute importances, rate of collision with above waist objects currently, and potential improvements. As a way of looking at attribute importances, the interviews looked into what current difficulties people had with the white cane and guide dog. To elicit attribute importance and potential improvements the interviewer queried as to what features should be included in the design.

Because the responses to the survey were explored through the IDIs, there was, by necessity, a good deal of similarity in the questions asked in the two. The IDI questions went into the motivations behind the responses observed in the surveys. The results of which allowed for the development of the necessary follow up questions such as asking what types of objects they walked into on a daily basis, or reasoning behind what features they felt were most important to have.

From the interviews, there was a wide array of responses to the product profile. In total there were four in-depth interviews conducted overall. Two were conducted at the Massachusetts Commission for the Blind, one at the National Federation of the Blind – PA, and one at the Bucks County Association for the Blind. This allowed for a wide spectrum of answers since the NFB is located in a heavily populated city, the MCB is in a mid-level city, and the BCAB is located in a rural/suburban area. Across the four major substantive areas the results were quite useful.

1. Rate of Collision with Above Waist Objects

   a) “Tree branches are not supposed to be long enough to be in the sidewalk, though if they are will often break them off so won’t get hit again” –
CHAPTER 2. BACKGROUND

Interviewee from NFB
b) “Scaffolding and when cabinet doors are half open, utility poles. When scaffolding was up, had to walk more slowly, people on the street would assist” – Interviewee from MCB

c) “Problems in new locations with confusing layouts” – Interviewee from BCAB

2. Attribute Significance

a) “Comfort is extremely important” – Interviewee from MCB

b) “Main thing device must do is still allow for independence” – Interviewee from BCAB

c) “Not use something like headphone which could get in the way of hear” – Interviewee from NFB

3. Potential Improvement

a) “Being light weight is important” – Interviewee from MCB

b) “Suspenders are cumbersome and take too much space” – Interviewee from BCAB

c) “Don’t just make something as a proof of concept, needs to be designed with a price in mind that people could be able to buy” – Interviewee from NFB

4. Optimal Pricing

a) “Don’t just make something as a proof of concept, needs to be designed with a price in mind that people could be able to buy” – Interviewee from NFB

b) “Should be around $200 at most for a person gets disability money to be able to afford” – Interviewee from MCB

From these major areas, what is most important to the next stages of development was observed. From the frequency of collisions, it is seen that people with low vision tend to get injured from object on the sidewalk that are not there on a regular basis such as scaffolding and tree branches. For the attribute significance it can be seen that from the IDIs that the device will not interfere with current living arrangements. People with low vision want to keep living independently and will not want a device that impedes on this. A device that interferes with a blind persons hearing will not be useful especially if the person uses echolocation to walk around. The device should also be comfortable to wear and not be a hassle to put on. For the area of potential
improvement it can be seen that the current design of using suspenders will need to be changed. Light weight is an important feature to have and that with suspenders currently take too much space, and should have something that is easy to put on and wear. For pricing the device, it should be held at an affordable cost that a person with a limited income who receives disability money could buy.

2.4 User Testing

A completed initial prototype was utilized by individuals through the MCB in order to test the wear-ability and usability. Using this method of testing allowed subjects to provide more feedback on specific improvements that could be taken into consideration for the next phase of the design.

There were three main parts to the device testing period:

a) **In-Depth Interview**: This phase inquired subjects on their current thoughts regarding the project and the device prior to experiencing interactions with the device. The process was identical to the in-depth interview process mentioned within the previous section.

b) **User Device Testing**: The interviewees were able to test the device by wearing the prototype in indoor and outdoor environments for approximately 20-30 minutes. The subject was asked to explain if they could easily tell if the glasses were able to detect objects.

c) **Follow-Up Questions**: Opinions from subjects were gathered regarding the project, including the overall usability of the project, potential improvements, and the general experience.

![User Device Testing Flowchart](image)

For human testing, participants would put on the device and perform a test indoors and outdoors. The first location was within a conference room at the MCB and then outside in the surrounding area of Worcester. The initial location enabled the subject to adjust to wearing the device and understand how it works. The outdoors location provided more of an experience of how well the subject could navigate
around a section of the city when using the device. While walking through Worces-
ter, people were asked if they were able to accurately detect utility poles, scaffolding, 
other pedestrians, and other obstructions a blind pedestrian may face.

User device testing was done with both individuals that used the white cane, as 
well as the seeing-eye dog. Obtained from this, was an accurate idea of how the 
device behaved to people who walked through everyday life by different means. The 
user device testing showed to have very positive results from participants. Two peo-
ple participated in the human testing, though a smaller sample size than originally 
intended, it was still provided vital information. The small sample size is mostly due 
to time constraints and the fact that it was during summer when most people are 
away for vacation.

The first test conducted was on December 11th at the Mass Commission of the 
Blind. The participant used a white cane on a daily basis. For the testing, it was 
done in both indoor and outdoor spaces.

For the indoor space, the user was instructed to walk around the Com-
mmission for the Blind office space to get accustomed to the glasses and 
then to go up and down the hallway near to the elevators. For the 
outdoor space, the participant went out the main street entrance and 
from there turned right and then another right on Pearl Street. She was 
then asked to turn around and go back to Main Street and turn left 
and go until Foster Street. From 
there she turned around and went back to the Commission for the 
Blind.
Due to low power issues the device did not work as well as intended and did not detect objects that should have been within the field of vision. The glasses for most of the test were pointed downward because the participant normally used echolocation in conjunction with using the cane, so it would not detect objects normally at head level. There was seen to be slight delays between when an object was in range of detection, and when the vibration would happen, because of this delay the participant could detect an object using echolocation before the vibration would occur. Because the center vibration motor was not held down tight enough, often times it could not be felt. The prototype proved to be difficult to put on and several times was mention to look suspicious.

The next test was very positive and also conducted at the Mass Commission of the Blind. This test was conducted on June 27th. This participant used the seeing-eye dog instead of the white cane. This participant also differed from the other one in that they were not blind since birth.

Participant B had a similar indoor experience as Participant A. For the outdoor experience it was similar to the first route, though once at Foster Street the group turned around, went to Pleasant Street, then turned around and finally went back to the Commission for the Blind.

For this test, the glasses were fully charged unlike the previous test. The participant for this trial had an easier time operating the glasses and overall a better experience with it. There was still seen to be a delay between the time it detected an object and the time of vibration. The participant had a better time detecting objects like scaffolding and utility poles, though it was found that there was not enough of a range to detect chest level object like mailbox or transformers which one could run into. One thing to take note from this was that
the device was able to detect the crosswalk pole and inform him of it, and noted that a guide-dog would normally have him walk around it so that he would not be informed it was there.

Figure 2.8: Second User Route

2.5 Technical Overview

This section aims to prepare the reader for the technical sections of the report. A brief overview of some of the essential components will be made in this section. Due to the complexity of some of the components, details will be kept to minimum; however, datasheets for the specific product are provided in section 7.5 of this report.

2.5.1 Definitions

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microprocessor:</td>
<td>A microprocessor incorporates the functions of a computer’s central processing unit (CPU) on a single integrated circuit (IC) [3]. Uses for microprocessors include anything from clocks to cellphones, to even the keys to a modern car. A microprocessor is used in this project to handle the information processing and response generation.</td>
</tr>
<tr>
<td>Transistor:</td>
<td>A semiconductor device that amplifies, oscillates, or switches the flow of current between two terminals by varying the current or voltage between one of the terminals and a third [4]. Transistors are used in most electronics today, including anything from power supplies to PC graphics cards. Transistors are used in this project to accommodate high power demands from the vibration motors in the feedback garment.</td>
</tr>
</tbody>
</table>
2.5. TECHNICAL OVERVIEW

### Component Description

**Diode:**
In electronics, a diode is a two-terminal electronic component with asymmetric conductance: it has low (ideally zero) resistance to current flow in one direction, and high (ideally infinite) resistance in the other. The most common function of a diode is to allow an electric current to pass in one direction (called the diode’s forward direction), while blocking current in the opposite direction (the reverse direction). [5]

**Vibrotactile Feedback:**
Vibrotactile feedback is a method of sensory substitution used in a variety of applications. It makes use of a source of controlled vibration that corresponds to a stimulus and may vary intensity or time between pulses to indicate a change in stimulus. In this project it is used to help the user gauge the distance to obstacles.

**Ultrasonic:**
Refers to any sound waves with a frequency above the upper limit of human hearing. Sensors make use of this frequency range because it is not intrusive to the human ear while remaining capable of high resolution proximity measurements.

### 2.5.2 Customer Requirements

1. **Comfortable:** The device needs to be comfortable for the user. This means that it will not cause any physical pain, hindrance, or annoyance to the user.

   a) **Unobtrusive:** The device should be fairly inaudible to people around the user, as well as not interfere with the daily life of the user. It will not interfere with that person’s style of dress, nor encumber them in any way.

   b) **Lightweight:** Efficient use of space is an important issue to take into account in order to design a small portable device. The product also has to be light in terms of weight so that the device meets customers expec-
tations regarding comfort.

2. **Affordable**: The device has to be affordable for all socio-economic strata. (200-300 USD)

3. **Safe**: The device should not cause any harm to the user, or anyone around them.

4. **Durable**: This product will face various conditions and potential damages. As such, the product will need to last as long as possible before needing technical maintenance. This requirement is influenced by the implicit need for durability from the customers. Should theoretically be able to survive a ten foot drop test.
   
   a) **Weatherproof**: Inclement weather is responsible for damaging many portable electronic devices such as cellphones and cameras. Since this device will be located on a users body at all times, it is imperative that the device is weather proof.

5. **Accurate**: The device shall provide a reasonable level of fidelity. This requires that, not only will it provide an accurate representation of the environment, but also make an effort to reject misreadings.
   
   a) **Mapping**: The ability to maintain a certain field of view specific to each user must be sufficient. Sensors have to be located at the appropriate distance and angles so that they can efficiently map the objects in front of the user without having considerable blind spots.

   b) **Fast Response Time**: Should not have a noticeable lag between detection and notification for warning users.

6. **Battery Life**: Should have an expected battery life of at least 14 hours before recharge

7. **Fast Learning Curve**: Should be easy to learn, and have ergonomic and straightforward functions.
2.5.3 Product Specifications

The following list provides the product specifications derived from the customer and product requirements:

- **Ultrasonic Sensors**  The emitted ultrasonic waves will be reflected from obstacles within their range and be picked up by the sensor. The sensors will then relay this information to the Microcontroller.

  ![Typical Ultrasonic Sensor](image)

  Figure 2.9: Typical Ultrasonic Sensor

- **Microcontroller/Microprocessor** - The figurative brain of this device. Will receive the signals from the sensor, decode them into meaningful information, and convey said information to the vibrators.

  ![Typical Microprocessor](image)

  Figure 2.10: Typical Microprocessor

- **Vibration Motors**  The primary notification device. When a sensor detects an obstacle, the respective motor will vibrate. The motor will vibrate more as the distance between the user and the object is reduced.

  ![Typical Vibration Motor](image)

  Figure 2.11: Typical Vibration Motor

- **Rechargeable Battery**  The main power source of the device.
• **On/Off button**  Turns the device On and Off

• **Sensitivity Setter**  Will allow the user to input custom settings for the strength of the motors vibrations.

• **Voltage Regulator**  Will make sure that the voltage supplied to the device remains satisfactory despite the charge state of the battery. Necessary so that the device works efficiently even when the battery charge is low.

• **Output/Device Driver**  Perform various functions, such as converting digital signals from the microcontroller into analog, and providing the necessary current to drive the vibrators.

• **Glasses or Headgear**  Primarily contain the sensors. Since the glasses move with the users head, it will allow a large range of motion, and enable the user to sense objects at the location of their choice. These glasses will replace the standard glasses worn by many blind individuals.

Appendix A contains a variety of pertinent data sheets for the components that may make up the final version of Blind Sight.
Chapter 3

Methodology

3.1 Overview

Throughout the development of the BlindSight apparatus, iterative design processes were undertaken. The design process was broken down into the individual modules which make up the entire apparatus. These modules include the controller, the glasses, and the feedback apparel. Priority will be given to fulfilling all of engineering requirements, in turn fulfilling the customer requirements. Under this priority, the cost limitation and consumer appeal were considered. Efforts were made to minimize the sensor size so as to decrease the footprint on the headgear. Also a priority was increasing the comfort of the feedback apparel. Finally, importance was placed on increasing the overall efficiency of the controller and driver circuits whilst also minimizing cost. Throughout the development phase these efforts were addressed as needed.

The design process began with a review of past schematics from the alpha stage prototype. From this, the power consumption and functionality were reevaluated. The observation was made that in constant use, the prototype was capable of a maximum battery life of 6 hours. It was determined that a person must be able to use the device for a constant work days use, for which a target battery life of 14 hours was made. A major factor contributing to the poor battery life in the alpha prototype is the microcontroller, the Arduino Uno R3, which uses approximately 50mA. Knowing this, the decision to change the microcontroller to the MSP430 (which uses at most 5mA) was made. This change of platform will drastically improve the longevity of the batteries. The decision had been made to cut both a sensor and a feedback motor from the second revision, drastically reducing the potential power consumption.

Power consumption could also be improved by altering the programming method.
The initial prototype was designed in such a way that the motors were constantly running. We modified the microcontroller to utilize low power modes to extend battery life.

In improving the functionality of the device, we aimed to alter the appearance of the device as well as the way it is worn on the body of the user. In the original prototype the vibration motors were placed in a pair of suspenders, which were found to be burdensome to put on. Instead, the motors and control circuit will be placed in a belt worn around the abdomen and under clothing. This will ease the process of putting on and removing the item. For the glasses, we created a more streamlined design using 3D printing technology. Having a more aesthetically pleasing headpiece will make the product more appealing to customers. Refer to Appendix B for concept art of the product.

3.2 Preliminary Component Testing

The initial phase of development included the building of a second prototype as per the designs of the alpha prototype. This approach allowed for the development of the two peripheral units to take place with less troubleshooting. To complete the testing phase, the Arduino-based platform was reconstructed with a modified motor driver circuit. From this point, both the sensors and motors selected were tested for functionality.

The parameters that were tested for these components include:

- Power Consumption under varying load conditions.

- Thermal response to heavy usage.

- Accuracy or dynamic range.

3.3 Iterative Design Process

The iterative design process makes use of a three phase cycle where the team of developers first design, then prototype, and finally evaluate the product before beginning the cycle again. Each component in the system underwent this design process individually, and as a system. These components were addressed in the order of priority as given in the order of design section.
3.4 Revision Order and Design Priorities

This section details the order in which project tasks were prioritized and in which the individual modules were revised. Priorities have been chosen to bring a balance between the global goal of creating a marketable device and the fulfillment of the short term goals determined by the nature of the project. These priorities aim to make the best use of the short development cycle whilst still providing a solid foundation for a marketable product.

3.4.1 Priorities of the Development Period

1. Satisfaction of all engineering demands and customer requirements.

2. Meeting the demographically determined cost targets and further reducing costs if possible.

3. Creation of a device considered “sleek”, or “nice” by market and style standards.

3.4.2 Programming Revision Order

<table>
<thead>
<tr>
<th>Module</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Drivers:</td>
<td>Developing a new sensor driver was the primary focus when programming. The driver enables the information from the sensor to be interpreted by other functions carried out by the microcontroller. Without this driver functioning, the system will not function at all.</td>
</tr>
<tr>
<td>Motor Output:</td>
<td>The motor output driver is essential in delivering feedback to the user. The driver needs to be faultless before other functions are added.</td>
</tr>
<tr>
<td>Distance Settings:</td>
<td>Distance settings were considered to be additional features and thus held a lower priority in the development of the software.</td>
</tr>
</tbody>
</table>
### Module Reasoning

<table>
<thead>
<tr>
<th>Module</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power Management:</strong> Considering that the microcontroller selected for this task is already in the ultra-low-power class of devices, power reductions in this module were of minimal concern.</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 4

Results

4.1 Feedback Belt

The belt portion alerts users of head and chest level obstacles. Small vibration motors are integrated within the belt in order to provide this feedback. From the concept art, a sewing pattern was made and cut from a thin but durable fabric. Finally, the belt pieces were sewn together. The belt includes a pocket for inserting the electrical components, and Velcro for fastening the garment around the waist.

4.1.1 Implementation

The second prototype of the belt holds two vibration motors connected to a separate power source and integrated processing circuit. The belt connects to this separate component in order to fulfill customer requirements regarding comfort and aesthetics. The customer requirement of comfort is also addressed by the type of material used. The current prototype utilizes fabric prior to an urethane coating which offers additional resistance and toughness against abrasions, yet provides essential breathability. The shape of the belt is maintained with soft, lightweight polyester cushioning and utilizes Velcro for fastening the garment around the waist, enabling adjustability as the user sees fit.

4.1.2 Concerns

Aesthetics are an important design consideration given the customer requirements. Currently the power source is bulky and will clearly protrude from under the clothing if stored inside the belt. New batteries have been selected which are much thinner and more capable of being stored in the belt component of the design, but these batteries have not yet been tested.
4.1.3 Previous Prototypes

The belt was designed to alter the alpha prototype from a harness design to one made from a light, breathable fabric and an additional pocket for insertion of electrical components.

Additional methods of implementation used materials which were too lightweight or breathable, where it was found unable to keep its shape under once components were attached. Snap buttons were also considered for the course of the belt design for security and aesthetics, but discarded due to degree of difficulty for user adjustability.

4.1.4 Images
4.2 Glasses

In the early stages of development, a frame was designed to be visually similar to frames in common use today. This was achieved with the use of Solidworks, a computer aided drafting software. The design had some faults initially in the manufacturing stage, but once these issues were addressed, a nice prototype was produced. This prototype revealed some fundamental issues with the manufacturing technique chosen, most importantly, a precision too poor to make a functioning hinge.

![Figure 4.1: Printer Error Results After Trimming Loose Strands](image1)

![Figure 4.2: Original Frame Design](image2)

The first model had the sensors mounted immediately in front the lens window, but were otherwise functional and less bulky than modified sunglasses. The front mounted sensor proved to violate some customer requirements, so a new revision was made. Some potential users of the device have partial or spotted vision. Placing the sensor in front of the eye violated the necessity of non-intrusive design for all users.

Due to the inadequacy of the original design, a revision was made. To improve upon the form of the glasses, a new model was constructed to be aesthetically pleasing and non-intrusive to the user. This new design, also created using Solidworks modeling software, incorporated an outcropping to mount the LV-MaxSonar-EZ2 sensors on.

4.2.1 Concerns

The use of three dimensional printing for the manufacture of the glasses is adequate for prototyping, but results in a design that is flat and uncomfortable. In addition to aesthetic and comfort shortcomings of this model, the structure is too weak, and there are no accommodations for wire routing.
4.2.2 Proposed Solutions to Concerns

A temporary solution to the lack of wire routing channels was implemented on a printed prototype. This solution involved the use of a rotary sanding tool with a thin pad wherein a channel of approximate width of 4mm and approximate depth of 5mm was etched from the top rim of the frame. The channel was capable of disguising the necessary three wires which connect the right sensor. Despite the success of this modification, the process takes far too long to justify performing multiple times. If three dimensional printing is to remain the primary means of manufacture, a new model with the channel pre-printed will suffice as a solution.

![Modified Frame With Wires Routed](image)

A more permanent solution to all of the concerns for the frame model is to design a frame to be manufactured via die-cutting with a plastic such as cellulose acetate. The durability and availability of this material, and its common use in glasses frames make it the most feasible mass production method available. For smaller runs, injection molding may prove to be the best choice due to the flexibility in design versus cost to modify designs. In either solution, a stronger, more stylish design can be produced.
4.3  Power

4.3.1  Status

The newest revision of the design was made with power consumption minimization as a primary focus. The previous version of the system consumed significantly more power as noted in the following table:

<table>
<thead>
<tr>
<th>Module</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headpiece</td>
<td>45 mA</td>
</tr>
<tr>
<td>Belt</td>
<td>≈ 270 mA(PEAK)</td>
</tr>
<tr>
<td>Controller</td>
<td>40 mA</td>
</tr>
<tr>
<td>Total</td>
<td>355 mA</td>
</tr>
</tbody>
</table>

Table 4.1: Power Consumption of Alpha Prototype.

Major reductions in power were made in all power consuming modules of the system. The elimination of one motor, and furthermore, the selection of slightly more efficient motors allowed for a drop of approximately 140 mA of power needs from the belt. The transition from three HC-SR04 sensors to two EZ4 sensor has eliminated the bulk of the power consumption at the headpiece, dropping approximately 41 mA. The microprocessor change also eliminated a significant amount of power with a reduction of ≈ 39.77 mA. The new system’s power consumption is tabulated in the following table:

<table>
<thead>
<tr>
<th>Module</th>
<th>Power Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headpiece</td>
<td>4 mA</td>
</tr>
<tr>
<td>Belt</td>
<td>≈ 130 mA(PEAK)</td>
</tr>
<tr>
<td>Controller</td>
<td>230 µA</td>
</tr>
<tr>
<td>Total</td>
<td>134.23 mA</td>
</tr>
</tbody>
</table>

Table 4.2: Power Consumption of Alpha Prototype.

4.3.2  Concerns

As mentioned in the section on the construction of the circuit board, a primary issue with the design is the voltage regulator. With the intended dropout voltage of ≈ 0.5 V, the system would be quite efficient with a linear regulator. This efficiency is essentially eliminated when increasing the input voltage to 7.4 V because the regulator will have to drop more than half of the voltage in order to output the desired 3.3 V to the system. This issue has to be addressed if the design is to take advantage of the massive power savings that were focused on in the component selection process. Other than this issue, the power consumption specifications of the design have made marked improvements.
4.3.3 Plan of Action

The current plan of action to improve the power consumption of the design is to select a more appropriate voltage regulator. Making use of a switching regulator with buck and boost circuitry will allow even greater extension of battery life, and will open the design to a wider variety of input voltages and battery technologies. Aside from this, the power consumption minimization in the design has proved to be successful, and will need very little attention in the future.
4.4 Arduino Test Bench

Although a functioning prototype existed, the team decided to create a secondary prototype mirroring the existing one, in order to further test the original product without altering the design and configuration of the working device. The Arduino test bench implementation included the atmega328 microprocessor on the ArduinoUno platform connected to one ultrasonic sensor. This environment provided a set of secondary test values to ensure the understanding of the current prototype and how the design of the beta prototype would be improved upon.

Data from this portion led to the utilization of a microcontroller in order to draw less current than the ArduinoUno board. This implementation subsequently ensured a method to providing a longer battery life.

4.4.1 Concerns

The data collected from this portion of the project did not have a significant impact upon the beta prototype itself, but provided the team with additional data to reiterate functionality. This led to areas for improvement, such as seeking sensors with a wider field of view and range.

4.4.2 Plan of Action

The plan for this component was to proceed with the connection of the Arduino microcontroller to the current ultrasonic sensor. Data from this portion led to a choice microcontroller which will draw less current than the ArduinoUno board and further implementing a way to ensure longer battery life.
4.5 Software

This section includes the code outline for the MSP430 based BlindSight design using specifically the EZ2 Ultrasonic Sensor. The MSP430 platform offers ultra-low power performance while still providing robust processing and I/O capabilities. The model chosen for this application was the MSP430G2553. This microprocessor is available in a dip package, a feature that expedited the programming and debugging process of the design. Unfortunately, this processor cannot accept the previous designs code directly, and new code had to be developed.

The EZ2 Ultrasonic Sensor was one of three sensors considered for the BlindSight headpiece. It offers a compact, coaxial design, low power consumption, and a range suitable for this application. The EZ2 sensor handles the distance sensing completely on board and outputs both a voltage and a PWM signal which correspond to the distance to an object. When writing this outline code, a focus was made on reading the pulse width of the PWM signal rather than the voltage output of the EZ2. This approach offers a lower processing load and potentially higher resolution than sampling the voltage with the 10 bit ADC.

The HC-SR04 Sensor was not considered in this program due to its differences in operation. The HC-SR04 does not handle its distance calculations on board, and thus requires a different approach for integration. Due to the intention to move forward with a more compact Ultrasonic Sensor, programming the integration of the HC-SR04 was at a slightly lower priority.

The code in this section was tested and proved to work with only one sensor working at a time. A major effort was expended in the debugging of this issue, but the issue was never resolved. Details on the execution of the code can be pulled from the comments in the source, or interpreted from descriptions of the following sections.

4.5.1 Concerns

After initial testing showed favorable results with regard to functionality, combination of functions began. Upon testing the circuit with two sensors feeding data into the system, it was revealed that the logical flow was breaking somewhere in the second interrupt service routine. This failure is documented in detail in the following section.

4.5.2 Software Logical Flow and Failures

The system makes use of three primary functions to accomplish the its operation. These blocks include:
1. **Sensor Driver**: This portion of the code is implemented in two interrupt service routines, one per sensor. The system uses the PWM signal’s rising edge as an interrupt trigger to begin a measurement. The system uses two timer channels counting up at 1MHz to measure the elapsed time between the rising edge and the falling edge. This value can be converted to centimeters by dividing by 58. This value or the centimeter value can be used for other functions from this point on. When the measurement and calculations are complete, the ISR clears its pending flag and exits.

2. **Motor Driver**: This portion makes use of a similar timing scheme where an up counting timer is used to change the time between steps. This portion of the program was not tested in tandem with the sensors due to ongoing troubleshooting issues with that portion of the code.

3. **User Input**: Two Buttons are available for use on the prototype board design. These buttons are considered momentary switches because they are only in a changed state when the user is interfacing directly button. The buttons are configured such that in their normal state, the switch is open, and the input pin is pulled to ground by a resistor. When the button is pressed, the input is pulled high. These buttons are intended for sensitivity setting incrementation, but this step in programming was not completed. A typical approach for this operation is to debounce the inputs, and process the incrementation in the main loop of the program.

### 4.5.3 Nature of the Sensor

The data type passed from the sensor to the microprocessor is in the form of a pulse with a time high proportional to the distance from the nearest object. The logic implemented to convert this waveform to a numerical value is explained in the previous section, however, the following figures are provided to give visual explanation of the sensor’s behavior.

Here, the general behavior of the sensors is captured in sequence of increasing magnitudes.

![Figure 4.4: PWM Operation](image)
4.5. SOFTWARE

Figure 4.5: Waveform at 2.5cm

Figure 4.6: Waveform at 30cm

Figure 4.7: Waveform at 2.5m
4.5.4 Source Code

//****************************************************************************
// MSP430G22x1
// -----------------
// This Code configures a G2231 Chip To make use of The EZ2
// UltraSound Sensor
// This code includes some sections from the web page:
// http://letsmakerobots.com/node/22970
// Modifications to this code were made By Dominic Lopriore to suit
// the needs of the
// BlindSight device
//
// Output pins and parameters for driving the motor will be chosen
// when the MSP430 Arrives
//
//
//****************************************************************************

#include "msp430G2231.h"

#define MCU_CLOCK 1100000
#define PWM_FREQUENCY 46

unsigned int measure;
unsigned int measure_1;
unsigned int measure_2;
char up=0;

static int UPPER_BOUND = 31320; //Sets the initial range boundary to 15ft
static int LOWER_BOUND = 882; //Sets the initial range boundary to 6in
static int DISTANCE; //Will be used to Drive the motor PWM Signal Appropriately

unsigned int PWM_Period = (MCU_CLOCK / PWM_FREQUENCY); // PWM Period
unsigned int PWM_Duty = 0; // %

main()
{

    WDTCTL = WDTPW + WDTHOLD; // Stop WDT

    //***Configure clock
    // Set the DCO@1MHZ -> SMCLK -> TA
    BCSCTL1 |= CALBC1_1MHZ; //
    DCOCTL |= CALDCO_1MHZ; // DCO at 1mhz
    BCSCTL2 &= ~SELS; // select DCO for SMCLK source
    BCSCTL2 |= DIVS0; // select no division
4.5. SOFTWARE

//***TimerA capture configuration
//rising edge + synchronous + p1.1 + capture + capture/compare
interrupt enable
TACCTL0 |= CM_1 + SCS + CCIS_0 + CAP + CCIE;
// select smclock for timer a source + make taccr0 count
continously up + no division
TACTL |= TASSEL_2 + MC_2 + ID_0;

//***Enable interrupts
_BIS_SR(GIE); // general interrupt enable

// Setup the PWM, etc.
TACCTL1 = OUTMOD_7; // TACCR1 reset/set
TACTL = TASSEL_2 + MC_1; // SMCLK, upmode
TACCR0 = PWM_Period-1; // PWM Period
TACCR1 = PWM_Duty; // TACCR1 PWM Duty Cycle --------> Make
Sure this doesnt conflict
P1DIR |= BIT2; // P1.2 = output
P1SEL |= BIT2; // P1.2 = TA1 output

//***Loop
while (1)
{
    PWM_Duty = PWM_Period - PWM_Period*DISTANCE/(UPPER_BOUND - LOWER_BOUND)
}

}

//***timerA interrupt routine: Reads the Sensor pulse width and sets the
distance parameters to the most recent
#pragma vector=TIMER0_VECTOR
__interrupt void TimerA0(void)
{
    /*timerA was configured to CM_1(rising edge)
    * so let’s check if this is the first time the routine
    * is called
    * we check this by ensuring we are not capturing falling
    * edges (CM_2)
    */
    if(!(TACCTL0 & CM_2)) //rising edge (first time)
    {
        measure_1=TACCR0;
        TACCTL0 |= CM_3; //after the first time we want to
catch both edges (CM_3)
else // this is not the first time
{
    if(up) // is this the rising edge?
    {
        measure_1=TACCR0; // take first time measure
    }
    else // is this the falling edge?
    {
        measure_2=TACCR0; // take second time measure
        measure=(measure_2-measure_1)/147; // microseconds / 147 = inches
        if(measure > LOWER_BOUND && measure <
            UPPER_BOUND) // is the distance within the constraints of the sensitivity setting
        {
            DISTANCE = measure;
        }
    }
    else
    {
        if(measure < LOWER_BOUND){DISTANCE = LOWER_BOUND;} // Sets the the distance to the minimum value when the measurement is lower than lowerbound
        else{DISTANCE = UPPER_BOUND;} // Sets the the distance to the maximum value when the measurement is higher than upperbound
    }
}
up=!up; // if this was the rising edge, the next one will be a falling edge, and vice-versa
TACTL &= ~TAIFG; // clear timer A interrupt flag, so the chip knows we handled the interrupt
4.6 Prototype and Proposed Circuits

For the purpose of testing the system, a prototype circuit board was constructed on a perforated protoboard with DIP and through-hole components. This section details the design of this prototype, and a proposed design for a printed circuit. Details covered for this section include bills of materials, schematics, and concerns.

4.6.1 Bill of Materials: Prototype Circuit

<table>
<thead>
<tr>
<th># of Items</th>
<th>Item</th>
<th>Manufacturer #</th>
<th>Distributer #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MSP430G2553 Processor</td>
<td>296-28429-5-ND</td>
<td>MSP430G2553IN20</td>
</tr>
<tr>
<td>2</td>
<td>2N3904 NPN BJT</td>
<td>2N3904BU</td>
<td>2N390FS-ND</td>
</tr>
<tr>
<td>2</td>
<td>100pF Capacitor</td>
<td>D101K20Y5PL63L6R</td>
<td>1451PH-ND</td>
</tr>
<tr>
<td>1</td>
<td>0.01µF Capacitor</td>
<td>K104K10X7RF5UH5</td>
<td>BC2665TB-ND</td>
</tr>
<tr>
<td>1</td>
<td>0.33µF Capacitor</td>
<td>C330C334K1R5TA</td>
<td>399-4407-ND</td>
</tr>
<tr>
<td>1</td>
<td>UA78M33C Regulator</td>
<td>UA78M33CKCS</td>
<td>296-21633-5-ND</td>
</tr>
<tr>
<td>2</td>
<td>1N5819 Diode</td>
<td>1N5819</td>
<td>1N5819FSTR-ND</td>
</tr>
<tr>
<td>2</td>
<td>310-101 Motors</td>
<td>310-101</td>
<td>Not Available</td>
</tr>
<tr>
<td>2</td>
<td>Vibration Motor</td>
<td>28821</td>
<td>28821</td>
</tr>
<tr>
<td>1</td>
<td>20 Pin IC Socket</td>
<td>AR20-HZL-TT-R</td>
<td>AE10015-ND</td>
</tr>
</tbody>
</table>
Chapter 5

Conclusion

The focus of this project was set on developing a prototype to increase the efficiency in power consumption, as well as improve upon the aesthetics in order to better meet customer requirements. This beta prototype takes each main component of the alpha prototype (e.g. glasses, sensor, controller, feedback garment) and utilizes a redesigned method in order to fulfill the intentions of this project. This second design incorporates manufactured glasses for better sensor mounting purposes, a vibrotactile feedback belt, and an efficient microprocessor that improves upon the endurance of the power supply.

Under the time constraints, the beta prototype in its current state is only formed to a satisfactory state. Several different approaches were explored for the future implementation of the prototype. With more time allotted, consumer tests could be made in order to collect more follow-up data on the improvements made since the prototype’s alpha phase.

Overall, there are several ideas for regarding improvements for the next generation of this device, however the final goals for this second prototype were accomplished. This end product is a solution for the customer to detect nearby, head level objects and receive tactile feedback over a longer period of time.
[1]

[2]


Appendices
A.1 ATmega 328PA

Features
- High Performance, Low Power AVR® 8-Bit Microcontroller
  - 131 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 20 MIPS Throughput at 20 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 4/8/16/32K Bytes of In-System Self-Programmable Flash program memory
    (ATmega48PA/88PA/168PA/328P)
  - 256/512/1K2K Bytes EEPROM (ATmega48PA/88PA/168PA/328P)
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/100 years at 25°C (1)
  - Optional Boot Code Section with Independent Lock Bits
- In-System Programming by On-chip Boot Program
- True Read-While-Write Operation
- Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
  - Temperature Measurement
  - 6-channel 10-bit ADC in PDIP Package
  - Temperature Measurement
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Byte-oriented 2-wire Serial Interface (Philips PC compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 28-pin QFP, 32-pad QFN/MLF and 32-pad QFN/MLF
- Operating Voltage:
  - 1.6 - 5.5V for ATmega48PA/88PA/168PA/328P
- Temperature Range:
  - -40°C to 85°C
- Speed Grade:
  - 0 - 20 MHz @ 1.6 - 5.5V
- Low Power Consumption at 1 MHz, 1.8V, 25°C for ATmega48PA/88PA/168PA/328P:
  - Active Mode: 0.2 mA
  - Power-down Mode: 0.1 µA
  - Power-save Mode: 0.75 µA (Including 3 kHz RTC)
1. Pin Configurations

Figure 1-1. Pinout ATmega48PA/88PA/168PA/328P
1.1 Pin Descriptions

1.1.1 VCC
Digital supply voltage.

1.1.2 GND
Ground.

1.1.3 Port B (PB7:0) XTAL1/XTAL2/TOSC1/TOSC2
Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port B output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port B pins that are externally pulled low will source current if the pull-up resistors are activated. The Port B pins are tri-stated when a reset condition becomes active, even if the clock is not running.

Depending on the clock selection fuse settings, PB6 can be used as input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

Depending on the clock selection fuse settings, PB7 can be used as output from the inverting Oscillator amplifier.

If the Internal Calibrated RC Oscillator is used as chip clock source, PB7..6 is used as TOSC2..1 input for the Asynchronous Timer/Counter2 if the AS2 bit in ASSR is set.

The various special features of Port B are elaborated in "Alternate Functions of Port B" on page 82 and "System Clock and Clock Options" on page 26.

1.1.4 Port C (PC5:0)
Port C is a 7-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The PC5..0 output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port C pins are tri-stated when a reset condition becomes active, even if the clock is not running.

1.1.5 PC6/RESET
If the RSTDISBL Fuse is programmed, PC6 is used as an I/O pin. Note that the electrical characteristics of PC6 differ from those of the other pins of Port C.

If the RSTDISBL Fuse is unprogrammed, PC6 is used as a Reset input. A low level on this pin for longer than the minimum pulse length will generate a Reset, even if the clock is not running. The minimum pulse length is given in Table 28-3 on page 318. Shorter pulses are not guaranteed to generate a Reset.

The various special features of Port C are elaborated in "Alternate Functions of Port C" on page 85.

1.1.6 Port D (PD7:0)
Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). The Port D output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port D pins that are externally pulled low will source current if the pull-up resistors are activated. The Port D pins are tri-stated when a reset condition becomes active, even if the clock is not running.
The various special features of Port D are elaborated in "Alternate Functions of Port D" on page 88.

1.1.7 AVCC

AVCC is the supply voltage pin for the A/D Converter, PC3:0, and ADC7:6. It should be externally connected to VCC, even if the ADC is not used. If the ADC is used, it should be connected to VCC through a low-pass filter. Note that PC6..4 use digital supply voltage, VCC.

1.1.8 AREF

AREF is the analog reference pin for the A/D Converter.

1.1.9 ADC7:6 (TQFP and QFN/MLF Package Only)

In the TQFP and QFN/MLF package, ADC7:6 serve as analog inputs to the A/D converter. These pins are powered from the analog supply and serve as 10-bit ADC channels.
2. Overview

The ATmega48PA/88PA/168PA/328P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega48PA/88PA/168PA/328P achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

2.1 Block Diagram

Figure 2-1. Block Diagram

The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting
architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The ATmega48PA/88PA/168PA/328P provides the following features: 4K/8K bytes of In-System Programmable Flash with Read-While-Write capabilities, 256/512/512/1K bytes EEPROM, 512/1K/1K/2K bytes SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible Timer/Counters with compare modes, internal and external interrupts, a serial programmable USART, a byte-oriented 2-wire Serial Interface, an SPI serial port, a 6-channel 10-bit ADC (8 channels in TQFP and QFN/MLF packages), a programmable Watchdog Timer with internal Oscillator, and five software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, USART, 2-wire Serial Interface, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or hardware reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except asynchronous timer and ADC, to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator Oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low power consumption.

The device is manufactured using Atmel’s high density non-volatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed In-System through an SPI serial interface, by a conventional non-volatile memory programmer, or by an On-chip Boot program running on the AVR core. The Boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega48PA/88PA/168PA/328P is a powerful microcontroller that provides a highly flexible and cost effective solution to many embedded control applications.

The ATmega48PA/88PA/168PA/328P AVR is supported with a full suite of program and system development tools including: C Compilers, Macro Assemblers, Program Debugger/Simulators, In-Circuit Emulators, and Evaluation kits.

### 2.2 Comparison Between ATmega48PA, ATmega88PA, ATmega168PA and ATmega328P

The ATmega48PA, ATmega88PA, ATmega168PA and ATmega328P differ only in memory sizes, boot loader support, and interrupt vector sizes. Table 2-1 summarizes the different memory and interrupt vector sizes for the three devices.

<table>
<thead>
<tr>
<th>Device</th>
<th>Flash</th>
<th>EEPROM</th>
<th>RAM</th>
<th>Interrupt Vector Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATmega48PA</td>
<td>4K Bytes</td>
<td>256 Bytes</td>
<td>512 Bytes</td>
<td>1 instruction word/vector</td>
</tr>
<tr>
<td>ATmega88PA</td>
<td>8K Bytes</td>
<td>512 Bytes</td>
<td>1K Bytes</td>
<td>1 instruction word/vector</td>
</tr>
<tr>
<td>ATmega168PA</td>
<td>16K Bytes</td>
<td>512 Bytes</td>
<td>1K Bytes</td>
<td>2 instruction words/vector</td>
</tr>
<tr>
<td>ATmega328P</td>
<td>32K Bytes</td>
<td>1K Bytes</td>
<td>2K Bytes</td>
<td>2 instruction words/vector</td>
</tr>
</tbody>
</table>

ATmega88PA, ATmega168PA, and ATmega328P support a real Read-While-Write Self-Programming mechanism. There is a separate Boot Loader Section, and the SPM instruction can only execute from there. In ATmega48PA, there is no Read-While-Write support and no separate Boot Loader Section. The SPM instruction can execute from the entire Flash.
Ultrasonic Ranging Module HC - SR04

**Product features:**

Ultrasonic ranging module HC - SR04 provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work:

1. Using IO trigger for at least 10us high level signal,
2. The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back.
3. IF the signal back, through high level, time of high output IO duration is the time from sending ultrasonic to returning.

Test distance = (high level time×velocity of sound (340M/S) / 2,

**Wire connecting direct as following:**

- 5V Supply
- Trigger Pulse Input
- Echo Pulse Output
- 0V Ground

**Electric Parameter**

<table>
<thead>
<tr>
<th>Working Voltage</th>
<th>DC 5 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Current</td>
<td>15mA</td>
</tr>
<tr>
<td>Working Frequency</td>
<td>40Hz</td>
</tr>
<tr>
<td>Max Range</td>
<td>4m</td>
</tr>
<tr>
<td>Min Range</td>
<td>2cm</td>
</tr>
<tr>
<td>MeasuringAngle</td>
<td>15 degree</td>
</tr>
<tr>
<td>Trigger Input Signal</td>
<td>10uS TTL pulse</td>
</tr>
<tr>
<td>Echo Output Signal</td>
<td>Input TTL lever signal and the range in proportion</td>
</tr>
<tr>
<td>Dimension</td>
<td>45<em>20</em>15mm</td>
</tr>
</tbody>
</table>
The Timing diagram is shown below. You only need to supply a short 10μS pulse to the trigger input to start the ranging, and then the module will send out an 8 cycle burst of ultrasound at 40 kHz and raise its echo. The Echo is a distance object that is pulse width and the range in proportion. You can calculate the range through the time interval between sending trigger signal and receiving echo signal. Formula: μS / 58 = centimeters or μS / 148 = inch; or: the range = high level time * velocity (340M/S) / 2; we suggest to use over 60ms measurement cycle, in order to prevent trigger signal to the echo signal.
Attention:

- The module is not suggested to connect directly to electric, if connected electric, the GND terminal should be connected the module first, otherwise, it will affect the normal work of the module.
- When tested objects, the range of area is not less than 0.5 square meters and the plane requests as smooth as possible, otherwise, it will affect the results of measuring.

www.ElecFreaks.com
LV-MaxSonar®-EZ4™
High Performance Sonar Range Finder

With 2.5V - 5.5V power the LV-MaxSonar®-EZ4™ provides very short to long-range detection and ranging, in an incredibly small package. The LV-MaxSonar®-EZ4™ detects objects from 0-inches to 254-inches (6.45-meters) and provides sonar range information from 6-inches out to 254-inches with 1-inch resolution. Objects from 0-inches to 6-inches range as 6-inches. The interface output formats included are pulse width output, analog voltage output, and serial digital output.

Features
- Continuously variable gain for beam control and side lobe suppression
- Object detection includes zero range objects
- 2.5V to 5.5V supply with 2mA typical current draw
- Readings can occur up to every 50mS, (20-Hz rate)
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- All interfaces are active simultaneously
- Serial, 0 to 5Vcc, 9600Baud, 81N
- Analog, (Vcc/512) / inch
- Pulse width, (147uS/inch)
- Learns ringdown pattern when commanded to start ranging
- Designed for protected indoor environments
- Sensor operates at 42KHz
- High output square wave sensor drive (double Vcc)

Benefits
- Very low cost sonar ranger
- Reliable and stable range data
- Sensor dead zone virtually gone
- Lowest power ranger
- Quality beam characteristics
- Mounting holes provided on the circuit board
- Very low power ranger, excellent for multiple sensor or battery based systems
- Can be triggered externally or internally
- Sensor reports the range reading directly, frees up user processor
- Fast measurement cycle
- User can choose any of the three sensor outputs

Beam Characteristics
Many applications require a narrower beam or lower sensitivity than the LV-MaxSonar®-EZ1™. Consequently, MaxBotix Inc., is offering, the EZ2™, EZ3™, & EZ4™ with progressively narrower beam angles allowing the sensor to match the application. Sample results for the LV-MaxSonar®-EZ4™ measured beam patterns are shown below on a 12-inch grid. The detection pattern is shown for:
- (A) 0.25-inch diameter dowel, note the narrow beam for close small objects,
- (B) 1-inch diameter dowel, note the long narrow detection pattern,
- (C) 3.25-inch diameter rod, note the long controlled detection pattern,
- (D) 11-inch wide board moved left to right with the board parallel to the front sensor face and the sensor stationary. This shows the sensor’s range capability.

Note: The displayed beam width of (D) is a function of the specular nature of sonar and the shape of the board (i.e. flat mirror like) and should never be confused with actual sensor beam width.
LV-MaxSonar®-EZ4™ Pin Out

GND — Return for the DC power supply. GND (& Vcc) must be ripple and noise free for best operation.

+5V —Vcc — Operates on 2.5V - 5.5V. Recommended current capability of 3mA for 5V, and 2mA for 3V.

TX — When the *BW is open or held low, the TX output delivers asynchronous serial with an RS232 format, except voltages are 0-Vcc. The output is an ASCII character of “R”, followed by three ASCII character digits representing the range in inches up to a maximum of 255, followed by a carriage return (ASCII 13). The baud rate is 9600, 8 bits, no parity, with one stop bit. Although the voltage of 0-Vcc is outside the RS232 standard, most RS232 devices have sufficient margin to read 0-Vcc serial data. If standard voltage level RS232 is desired, invert, and convert to a MAX232. When BW pin is held high, the TX output sends a single pulse, suitable for low noise chaining. (no serial data).

RX — This pin is internally pulled high. The EZ4™ will continually measure range and output if RX data is left unconnected or held high. If held low the EZ4™ will stop ranging. Bring high for 20uS or more to command a range reading.

AN — Outputs analog voltage with a scaling factor of (Vcc/512) per inch. A supply of 5V yields ~9.8mV/in. and 3.3V yields ~6.4mV/in. The output is buffered and corresponds to the most recent range data.

PW — This pin outputs a pulse width representation of range. The distance can be calculated using the scale factor of 147μS per inch.

BW — Leave open or hold low for serial output on the TX output. When BW pin is held high the TX output sends a pulse (instead of serial data), suitable for low noise chaining.

LV-MaxSonar®-EZ4™ Timing Description

250μS after power-up, the LV-MaxSonar®-EZ4™ is ready to accept the RX command. If the RX pin is left open or held high, the sensor will first run a calibration cycle (49μS), and then it will take a range reading (49μS). After the power up delay, the first reading will take an additional ~100μS. Subsequent readings will take 49μS. The LV-MaxSonar®-EZ4™ checks the RX pin at the end of every cycle. Range data can be acquired once every 49μS.

Each 49μS period starts by the RX being high or open, after which the LV-MaxSonar®-EZ4™ sends thirteen 42KHz waves, after which the pulse width pin (PW) is set high. When a target is detected the PW pin is pulled low. The PW pin is high for up to 37.5μS if no target is detected. The remainder of the 49μS time (less 4.7μS) is spent adjusting the analog voltage to the correct level. When a long distance is measured immediately after a short distance reading, the analog voltage may not reach the exact level within one read cycle. During the last 4.7μS, the serial data is sent. The LV-MaxSonar®-EZ4™ timing is factory calibrated to one percent at five volts, and in use is better than two percent. In addition, operation at 3.3V typically causes the objects range, to be reported, one to two percent further than actual.

LV-MaxSonar®-EZ4™ General Power-Up Instruction

Each time after the LV-MaxSonar®-EZ4™ is powered up, it will calibrate during its first read cycle. The sensor uses this stored information to range a close object. It is important that objects not be close to the sensor during this calibration cycle. The best sensitivity is obtained when it is clear for fourteen inches, but good results are common when clear for at least seven inches. If an object is too close during the calibration cycle, the sensor may then ignore objects at that distance.

The LV-MaxSonar®-EZ4™ does not use the calibration data to temperature compensate for range, but instead to compensate for the sensor ringdown pattern. If the temperature, humidity, or applied voltage changes during operation, the sensor may require recalibration to reacquire the ringdown pattern. Unless recalibrated, if the temperature increases, the sensor is more likely to have reduced up close sensitivity. To recalibrate the LV-MaxSonar®-EZ4™, cycle power, then command a read cycle.

Product / specifications subject to change without notice. For more info visit www.maxbotix.com/MaxSonar-EZ1_FAQ

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MaxBotix, MaxSonar, EZ2, EZ3 & EZ4 are trademarks of MaxBotix Inc.
LV-EZ4™ - v3.0c - Patent 7,679,996 - Copyright 2005 - 2011

Email: info@maxbotix.com
Web: www.maxbotix.com
1. General

This specification applies to coin permanent-magnetic motors DC model C1026B series.

2. Operating condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1 Rated voltage</td>
<td>3.0 V DC</td>
</tr>
<tr>
<td>2-2 Operating voltage</td>
<td>2.7~3.3 V DC</td>
</tr>
</tbody>
</table>
### 2. Measuring condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3 Rotation</td>
<td>CW(clockwise) or CCW(contrary clockwise)</td>
</tr>
<tr>
<td>2-4 Operating environment</td>
<td>-20°C ~ +60°C, Ordinary Humidity</td>
</tr>
<tr>
<td>2-5 Storage environment</td>
<td>-30°C ~ +70°C, Ordinary Humidity</td>
</tr>
</tbody>
</table>

### 3. Measuring condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1 Temperature</td>
<td>25±3°C</td>
</tr>
<tr>
<td>3-2 Humidity</td>
<td>65±20% RH</td>
</tr>
<tr>
<td>3-3 Air pressure</td>
<td>1013±40 hPa</td>
</tr>
<tr>
<td>3-4 Power supply</td>
<td>DC power supply or battery 3.0V</td>
</tr>
</tbody>
</table>

### 4. Electrical initial characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1 Rated speed</td>
<td>9,000 rpm Min</td>
<td>At rated voltage</td>
</tr>
<tr>
<td>4-2 Rated current</td>
<td>90 mA Max</td>
<td></td>
</tr>
<tr>
<td>4-3 Starting current</td>
<td>120 mA Max</td>
<td></td>
</tr>
<tr>
<td>4-4 Starting voltage</td>
<td>2.3 V DC Max</td>
<td>Motor is rotating at min starting voltage.</td>
</tr>
<tr>
<td>4-5 Insulation resistance</td>
<td>10 MΩ Min</td>
<td>At DC 100V between lead wire and case.</td>
</tr>
<tr>
<td>4-6 Terminal resistance</td>
<td>31 Ω ± 15%</td>
<td>At 25°C*</td>
</tr>
<tr>
<td></td>
<td>59 Ω ± 15%</td>
<td></td>
</tr>
</tbody>
</table>

### 5. Mechanical characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-1 Bracket deflection strength</td>
<td>9.8 N or more</td>
</tr>
<tr>
<td>5-2 Mechanical noise</td>
<td>50 dB(A)Max</td>
</tr>
</tbody>
</table>

At rated voltage, background noise 28dB(A) Max
### 6. Durability characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-1 Lifetime</td>
<td><img src="image" alt="Diagram" /></td>
<td>After the test, motors shall be approved as specified in item 7-1.</td>
</tr>
</tbody>
</table>
| 6-2 Low temp exposure | Temperature : -30°C  
Time : 96 h                         |                                                                              |
| 6-3 High temp exposure | Temperature : +70°C  
Time : 96 h                         | After 4 hours exposure in ordinary temperature and humidity, motors shall be approved as specified in item 7-2. |
| 6-4 Humidity exposure | Temperature : +40°C  
Humidity : 95%RH  
Exposure time : 96 h                         | No condensation of moisture                                                  |
| 6-5 Vibration | Displacement : 1.5mm (p-p)  
Frequency: 10–55Hz  
Acceleration: 22m/s²  
Period: 10 Minutes log sweep (10–55–10Hz)  
Condition : This motion shall be applied for a period of 10 minutes in each of 3 mutually perpendicular axes. | After the test motors shall be approved as specified in item 7-2.            |
| 6-6 Free fall | Test state: Set the motor to the approximately 100 g (include the motor) weight of block drop the motor on the concrete floor.  
Height : 1.5 m  
Direction : ±x, ±y, ±z  
Number of times: Each 3 times  
Shock : 29,420 N m/s² Equivalent (3,000 G) | After the test the motors shall be approved as specified in item 7-2.         |
| 6-7 Heat stock test | ![Diagram](image)                                   | After the test motors shall be approved as specified in item 7-2.            |

### 7. Requirements
### Item Requirements

#### 7-1 Table A

1. **Rated speed:** data-30 % Initial Min/ data+50 % Initial Max
2. **Rated current:** data-30 % Initial Min/ data+50 % Initial Max
3. **Starting voltage:** 2.5 V DC Max
4. **Insulation resistance:** 10 MΩ Min

#### 7-2 Table B

1. **Rated speed:** Initial data±20 % Max
2. **Rated current:** Initial data±20 % Max
3. **Starting voltage:** 2.5 V DC Max
4. **Terminal resistance:** Initial data±15% Max

---

**8. Matters to be paid attention to when using motor**

8-1 Unless it is used in accordance with the specifications, the performance and life may be considerably reduced. Due attention should be paid to voltage and range for use.

8-2 Avoid use or save the motor in the following environment.

1. High temperature and high humidity area.
2. Corrosive gas such as H₂S, SO₂, NO₂, Cl₂.
3. Dusty area.

8-3 Due attention must be paid to the handling and working environments because such objects as iron powder if attracted by the motor magnet, will cause noise, characteristic deterioration thus reducing the reliability.

8-4 Please confirm enough no problem of standards and laws and ordinances on your cellular.

8-5 To handle the motor, hold the motor case softly.

8-6 Rust of plate (steel) and similar edge should be OK.
A.5 Precision Micodrives 310-101

Model: 310-101

Ordering Information
The model number 310-101 fully defines the model, variant and additional features of the product. Please quote this number when ordering. For stocked types, testing and evaluation samples can be ordered directly through our online store.

Datasheet Versions
It is our intention to provide our customers with the best information available to ensure the successful integration between our products and your application. Therefore, our publications will be updated and enhanced as improvements to the data and product updates are introduced. To obtain the most up-to-date version of this datasheet, please visit our website at: www.precisionmicrodrives.com

The version number of this datasheet can be found on the bottom left hand corner of any page of the datasheet and is referenced with an ascending R-number (e.g. R0002 is newer than R0001). Please contact us if you require a copy of the engineering change notice between revisions.

If you have any questions, suggestions or comments regarding this publication or need technical assistance, please contact us via email at: enquiries@precisionmicrodrives.com or call us on +44 (0) 1932 252 482

Typical Vibration Motor Performance Characteristics

![Vibration Motor Performance](image)

**Key Features**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Diameter</td>
<td>10 mm</td>
</tr>
<tr>
<td>Body Length</td>
<td>3.4 mm</td>
</tr>
<tr>
<td>Typical Operating Current</td>
<td>63 mA</td>
</tr>
<tr>
<td>Typical Power Consumption</td>
<td>190 mW</td>
</tr>
<tr>
<td>Typical Normalised Amplitude</td>
<td>1.4 G</td>
</tr>
<tr>
<td>Rated Voltage</td>
<td>3 V</td>
</tr>
<tr>
<td>Rated Speed</td>
<td>12,000 rpm</td>
</tr>
<tr>
<td>Lead Length</td>
<td>45 mm</td>
</tr>
<tr>
<td>Lead Wire Gauge</td>
<td>32 AWG</td>
</tr>
</tbody>
</table>
### Physical Specification

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
<th>VALUE</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Diameter</td>
<td>Max body diameter or max face dimension where non-circular</td>
<td></td>
<td>10 mm</td>
<td>+/- 0.1 mm</td>
</tr>
<tr>
<td>Body Length</td>
<td>Excl. shafts, leads and terminals</td>
<td></td>
<td>3.4 mm</td>
<td>+/- 0.1 mm</td>
</tr>
<tr>
<td>Unit Weight</td>
<td></td>
<td></td>
<td>1.2 g</td>
<td></td>
</tr>
</tbody>
</table>

### Construction Specification

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Construction</td>
<td>Flat Coreless</td>
<td></td>
</tr>
<tr>
<td>Commutation</td>
<td>Precious Metal Brush</td>
<td></td>
</tr>
<tr>
<td>No. of Poles</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Bearing Type</td>
<td>Sintered Bronze</td>
<td></td>
</tr>
</tbody>
</table>

### Leads & Connectors Specification

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
<th>VALUE</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Length</td>
<td>Lead lengths defined as total length or between motor and connector</td>
<td></td>
<td>45 mm</td>
<td>+/- 2 mm</td>
</tr>
<tr>
<td>Lead Strip Length</td>
<td></td>
<td></td>
<td>1.5 mm</td>
<td>+/- 0.5 mm</td>
</tr>
<tr>
<td>Lead Wire Gauge</td>
<td></td>
<td></td>
<td>32 AWG</td>
<td></td>
</tr>
<tr>
<td>Lead Configuration</td>
<td></td>
<td></td>
<td>Straight</td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td>See drawing for details</td>
<td></td>
<td>Self Adhesive Backing</td>
<td></td>
</tr>
</tbody>
</table>

### Conformity Limits Specification

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
<th>VALUE</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage</td>
<td></td>
<td>3 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inertial Test Load</td>
<td>Mass of standard test sled</td>
<td>100 g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Start Current</td>
<td>At rated voltage</td>
<td>105 mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Operating Voltage</td>
<td>At rated voltage</td>
<td>3.8 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Certified Start Voltage</td>
<td>With the inertial test load</td>
<td>2.3 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rated Speed</td>
<td>At rated voltage using the inertial test load</td>
<td>12,000 rpm</td>
<td>+/- 2,500 rpm</td>
<td></td>
</tr>
<tr>
<td>Min. Vibration Amplitude</td>
<td>Peak-to-peak value at rated voltage using the inertial test load</td>
<td>1 G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. Operating Current</td>
<td>At rated voltage using the inertial test load</td>
<td>75 mA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Important: The characteristics of the motor is the typical operating parameters of the product. The data herein offers design guidance information only and supplied batches are validated for conformity against the specifications on the previous page.

### Typical Electrical Characteristics

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Operating Current</td>
<td>At rated voltage using the inertial test load</td>
<td>63 mA</td>
</tr>
<tr>
<td>Typical Power Consumption</td>
<td>At rated voltage and load</td>
<td>190 mW</td>
</tr>
<tr>
<td>Typical Vibration Amplitude</td>
<td>Peak-to-peak value at rated voltage using the inertial test load</td>
<td>1.4 G</td>
</tr>
<tr>
<td>Typical Normalised Amplitude</td>
<td>Peak-to-peak vibration amplitude normalised by the inertial test load at rated voltage</td>
<td>1.4 G</td>
</tr>
<tr>
<td>Typical Vibration Efficiency</td>
<td>At rated voltage using the inertial test load</td>
<td>7.3 G/W</td>
</tr>
<tr>
<td>Typical Max. Terminal Resistance</td>
<td></td>
<td>60 Ohm</td>
</tr>
<tr>
<td>Typical Max. Terminal Inductance</td>
<td></td>
<td>530 uH</td>
</tr>
<tr>
<td>Min. Insulation Resistance</td>
<td>At 50V DC between motor terminal and case</td>
<td>10 MOhm</td>
</tr>
<tr>
<td>Typical Start Voltage</td>
<td>With the inertial test load</td>
<td>1.6 V</td>
</tr>
<tr>
<td>Typical Start Current</td>
<td>At rated voltage</td>
<td>105 mA</td>
</tr>
</tbody>
</table>

### Typical Haptic Characteristics

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Lag Time</td>
<td>At rated voltage using the inertial test load</td>
<td>37 ms</td>
</tr>
<tr>
<td>Typical Rise Time</td>
<td>At rated voltage using the inertial test load</td>
<td>92 ms</td>
</tr>
<tr>
<td>Typical Stop Time</td>
<td>At rated voltage using the inertial test load</td>
<td>116 ms</td>
</tr>
<tr>
<td>Typical Active Brake Time</td>
<td>Time taken from steady-state to 0.04 G under inverse polarity at max. voltage</td>
<td>46 ms</td>
</tr>
</tbody>
</table>

### Typical Mechanical Characteristics

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Max. Mech. Noise</td>
<td></td>
<td>50 dB(A)</td>
</tr>
</tbody>
</table>

### Environmental Characteristics

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. Operating Temp.</td>
<td></td>
<td>-20 Deg.C</td>
</tr>
<tr>
<td>Max. Operating Temp.</td>
<td></td>
<td>70 Deg.C</td>
</tr>
<tr>
<td>Min. Storage Temp.</td>
<td></td>
<td>-30 Deg.C</td>
</tr>
<tr>
<td>Max. Storage Temp.</td>
<td></td>
<td>80 Deg.C</td>
</tr>
</tbody>
</table>
## Typical Packing Conditions

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONDITIONS</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carton Type</td>
<td></td>
<td>Boxed Trays</td>
</tr>
</tbody>
</table>
Life Support Policy

Precision Microdrives products are not authorised for use as critical components in life support devices or systems without the express written approval of Precision Microdrives Limited.

As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.
LM78XX / LM78XXA
3-Terminal 1 A Positive Voltage Regulator

Features
• Output Current up to 1 A
• Output Voltages: 5, 6, 8, 9, 10, 12, 15, 18, 24 V
• Thermal Overload Protection
• Short-Circuit Protection
• Output Transistor Safe Operating Area Protection

Description
The LM78XX series of three-terminal positive regulators is available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down, and safe operating area protection. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed-voltage regulators, these devices can be used with external components for adjustable voltages and currents.

Ordering Information(1)

<table>
<thead>
<tr>
<th>Product Number</th>
<th>Output Voltage Tolerance</th>
<th>Package</th>
<th>Operating Temperature</th>
<th>Packing Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM7805CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7806CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7808CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7809CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7810CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7812CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7815CT</td>
<td>±4%</td>
<td>TO-220  (Single Gauge)</td>
<td>-40°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7824CT</td>
<td>±2%</td>
<td>TO-220  (Single Gauge)</td>
<td>0°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7805ACT</td>
<td>±2%</td>
<td>TO-220  (Single Gauge)</td>
<td>0°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7809ACT</td>
<td>±2%</td>
<td>TO-220  (Single Gauge)</td>
<td>0°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7810ACT</td>
<td>±2%</td>
<td>TO-220  (Single Gauge)</td>
<td>0°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7812ACT</td>
<td>±2%</td>
<td>TO-220  (Single Gauge)</td>
<td>0°C to +125°C</td>
<td>Rail</td>
</tr>
<tr>
<td>LM7815ACT</td>
<td>±2%</td>
<td>TO-220  (Single Gauge)</td>
<td>0°C to +125°C</td>
<td>Rail</td>
</tr>
</tbody>
</table>

Note:
1. Above output voltage tolerance is available at 25°C.
Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at $T_A = 25^\circ C$ unless otherwise noted.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_I$</td>
<td>Input Voltage</td>
<td>$V_O = 5, \text{V to 18, V}$</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$V_O = 24, \text{V}$</td>
<td>40</td>
</tr>
<tr>
<td>$R_{\text{JUC}}$</td>
<td>Thermal Resistance, Junction-Case (TO-220)</td>
<td>5</td>
<td>°C/W</td>
</tr>
<tr>
<td>$R_{\text{JJA}}$</td>
<td>Thermal Resistance, Junction-Air (TO-220)</td>
<td>65</td>
<td>°C/W</td>
</tr>
<tr>
<td>$T_{\text{OPR}}$</td>
<td>Operating Temperature Range</td>
<td>LM78xx</td>
<td>-40 to +125</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LM78xxxA</td>
<td>0 to +125</td>
</tr>
<tr>
<td>$T_{\text{STG}}$</td>
<td>Storage Temperature Range</td>
<td></td>
<td>-65 to +150</td>
</tr>
</tbody>
</table>
Electrical Characteristics (LM7805)

Refer to the test circuit, -40°C < Tj < 125°C, IO = 500 mA, VI = 10 V, C1 = 0.1 μF, unless otherwise specified.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO</td>
<td>Output Voltage</td>
<td>Tj = +25°C, IO = 5 mA to 1 A, PO ≤ 15 W, VI = 7 V to 20 V</td>
<td>4.80</td>
<td>5.00</td>
<td>5.20</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.75</td>
<td>5.00</td>
<td>5.25</td>
<td>V</td>
</tr>
<tr>
<td>Regline</td>
<td>Line Regulation(2)</td>
<td>Tj = +25°C, VI = 7 V to 25 V</td>
<td>0.4</td>
<td>100.0</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
<td>50.0</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Regload</td>
<td>Load Regulation(2)</td>
<td>Tj = +25°C, IO = 5 mA to 1.5 A, I0 = 250 mA to 750 mA</td>
<td>9.0</td>
<td>100.0</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.0</td>
<td>50.0</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td>Quiescent Current</td>
<td>Tj = +25°C</td>
<td>5.0</td>
<td>8.0</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>δIQ</td>
<td>Quiescent Current Change</td>
<td>IO = 5 mA to 1 A, VI = 7 V to 25 V</td>
<td>0.03</td>
<td>0.50</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.30</td>
<td>1.30</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>ΔVO/ΔT</td>
<td>Output Voltage Drift(3)</td>
<td>IO = 5 mA</td>
<td>-0.8</td>
<td>mV/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VN</td>
<td>Output Noise Voltage</td>
<td>f = 10 Hz to 100 kHz, Tj = +25°C</td>
<td>42.0</td>
<td>μV/V0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>Ripple Rejection(3)</td>
<td>f = 120 Hz, VI = 8 V to 18 V</td>
<td>62.0</td>
<td>73.0</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>VDROP</td>
<td>Dropout Voltage</td>
<td>Tj = +25°C, IO = 1 A</td>
<td>2.0</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RO</td>
<td>Output Resistance(3)</td>
<td>f = 1 kHz</td>
<td>15.0</td>
<td>mΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISC</td>
<td>Short-Circuit Current</td>
<td>Tj = +25°C, VI = 35 V</td>
<td>230</td>
<td>mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPK</td>
<td>Peak Current(3)</td>
<td>Tj = +25°C</td>
<td>2.2</td>
<td>A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
2. Load and line regulation are specified at constant junction temperature. Changes in VO due to heating effects must be taken into account separately. Pulse testing with low duty is used.
3. These parameters, although guaranteed, are not 100% tested in production.
**Electrical Characteristics (LM7805A)**

Refer to the test circuit, 0°C < TJ < 125°C, IIO = 1 A, VIO = 10 V, C1 = 0.33 μF, C2 = 0.1 μF, unless otherwise specified.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO</td>
<td>Output Voltage</td>
<td>TJ = +25°C</td>
<td>4.9</td>
<td>5.0</td>
<td>5.1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIO = 5 mA to 1 A, P0 ≤ 15 W, VIO = 7.5 V to 20 V</td>
<td>4.8</td>
<td>5.0</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>Regline</td>
<td>Line Regulation(20)</td>
<td>V1 = 7.5 V to 25 V, IIO = 500 mA</td>
<td>5.0</td>
<td>50.0</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1 = 8 V to 12 V</td>
<td>3.0</td>
<td>50.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>TJ = +25°C</td>
<td>5.0</td>
<td>50.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1 = 7.3 V to 20 V</td>
<td>5.0</td>
<td>50.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1 = 8 V to 12 V</td>
<td>1.5</td>
<td>25.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regload</td>
<td>Load Regulation(20)</td>
<td>TJ = +25°C, IIO = 5 mA to 1.5 A</td>
<td>9.0</td>
<td>100.0</td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIO = 5 mA to 1 A</td>
<td>9.0</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIO = 250 mA to 750 mA</td>
<td>4.0</td>
<td>50.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IIO</td>
<td>Quiescent Current</td>
<td>TJ = +25°C</td>
<td>5.0</td>
<td>6.0</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>ΔIIO</td>
<td>Quiescent Current Change</td>
<td>TJ = +25°C</td>
<td>0.5</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IIO = 5 mA to 1 A</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1 = 8 V to 25 V, IIO = 500 mA</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V1 = 7.5 V to 20 V, TJ = +25°C</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔVO/ΔT</td>
<td>Output Voltage Drift(21)</td>
<td>IIO = 5 mA</td>
<td>-0.8</td>
<td></td>
<td></td>
<td>mV/°C</td>
</tr>
<tr>
<td>VN</td>
<td>Output Noise Voltage</td>
<td>f = 10 Hz to 100 kHz, TJA = +25°C</td>
<td>10.0</td>
<td></td>
<td></td>
<td>μV/V0</td>
</tr>
<tr>
<td>RR</td>
<td>Ripple Rejection(21)</td>
<td>f = 120 Hz, VO = 500 mA, VIO = 8 V to 18 V</td>
<td>68.0</td>
<td></td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>VDROP</td>
<td>Dropout Voltage</td>
<td>IIO = 1 A, TJ = +25°C</td>
<td>2.0</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>R0</td>
<td>Output Resistance(21)</td>
<td>f = 1 kHz</td>
<td>17.0</td>
<td></td>
<td></td>
<td>mΩ</td>
</tr>
<tr>
<td>ISC</td>
<td>Short-Circuit Current</td>
<td>V1 = 35 V, TJ = +25°C</td>
<td>250</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>IPK</td>
<td>Peak Current(21)</td>
<td>TJ = +25°C</td>
<td>2.2</td>
<td></td>
<td></td>
<td>A</td>
</tr>
</tbody>
</table>

**Notes:**

20. Load and line regulation are specified at constant junction temperature. Changes in VO due to heating effects must be taken into account separately. Pulse testing with low duty is used.

21. These parameters, although guaranteed, are not 100% tested in production.
Typical Performance Characteristics

Figure 2. Quiescent Current

Figure 3. Peak Output Current

Figure 4. Output Voltage

Figure 5. Quiescent Current
A.7 Battery - Tenergy Li 18650

Specification Approval Sheet

Name: Lithium Ion Battery
Model: 30006
SPEC: Li-18650 3.7V 2600mAh with PCM

<table>
<thead>
<tr>
<th>Approved By</th>
<th>Checkup</th>
<th>Make</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huanchun Li</td>
<td>Shaopeng Yi</td>
<td>Cong Huang</td>
</tr>
<tr>
<td>2012-3-6</td>
<td>2012-3-6</td>
<td>2012-3-6</td>
</tr>
</tbody>
</table>

Customer Confirmation

<table>
<thead>
<tr>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Company Name :
Stamp :

436 Kato Terrace, Fremont, CA 94539 U.S.A.
Tel: 510.687.0388 Fax: 510.687.0328
www.TenergyBattery.com
## Amendment Records

<table>
<thead>
<tr>
<th>Revision</th>
<th>Description</th>
<th>Issued Date</th>
<th>Approved By</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>New release</td>
<td>2010-03-16</td>
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</tr>
<tr>
<td>A1</td>
<td>Document Revision</td>
<td>2012-2-15</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Document Revision</td>
<td>2012-3-6</td>
<td></td>
</tr>
</tbody>
</table>
1 Scope

This document describes the performance characteristics and testing methods for Li-ion battery produced by Tenergy Corporation.

2 Product type and model number

2.1 Product type
Lithium-ion Battery

2.2 Model number 30006
Li-18650 3.7V 2600mAh with PCM

3 Rated performance

Form 1: Battery rated performance

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Rated performance</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rated capacity</td>
<td>Nominal capacity 2600mAh</td>
<td>Standard discharge after standard charge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimum capacity 2520mAh</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Nominal voltage</td>
<td>3.7V</td>
<td>Mean operation voltage during standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>discharge after standard charge</td>
</tr>
<tr>
<td>3</td>
<td>Voltage at end of discharge</td>
<td>2.75V</td>
<td>Discharge cut-off voltage</td>
</tr>
<tr>
<td>4</td>
<td>Charging voltage</td>
<td>4.2V</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Impedance</td>
<td>&lt;105mΩ</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Standard charge</td>
<td>Constant current 0.2 C; A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constant voltage 4.2V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cut-off current ≤0.02 C; A</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Standard discharge</td>
<td>Constant current 0.2 C; A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>End voltage 2.75V</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Fast charge</td>
<td>Constant current 0.5 C; A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constant voltage 4.2V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cut-off current ≤0.02 C; A</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Fast discharge</td>
<td>Constant current 0.5 C; A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>End voltage 2.75V</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Maximum continuous discharge current</td>
<td>3.5A</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Operation temperature range</td>
<td>Charge: 0–45°C</td>
<td>60±25% RH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge: -20–60°C</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Cycle life</td>
<td>&gt;300cycles</td>
<td>Charging/discharging in the below condition:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Charge: standard charge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Discharge: 0.5 C; A to 2.75V</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rest time between charge/discharge: 30min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Until the discharge capacity &lt;60% of NC</td>
</tr>
<tr>
<td>13</td>
<td>Storage temperature</td>
<td>≤1 month -20–45°C</td>
<td>60±25% RH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤3 months -20–40°C</td>
<td>Best 10–25°C for long-time storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤1 year -20–30°C</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Weight</td>
<td>Approx: 50g</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Dimension(mm)</td>
<td>Diameter<em>Height (Max) 18.7</em>68.0</td>
<td></td>
</tr>
</tbody>
</table>
## Electrical performances

### Form 2: Battery electrical performances

<table>
<thead>
<tr>
<th>No</th>
<th>Items</th>
<th>Test procedure</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nominal voltage</td>
<td>The average value of the working voltage during the whole discharge process.</td>
<td>3.7V</td>
</tr>
<tr>
<td>2</td>
<td>Discharge performance</td>
<td>The discharge capacity of the battery, measured with 0.2C, down to 2.75V within 1 hour after a standard charge</td>
<td>Discharge time ≥ minimum capacity</td>
</tr>
<tr>
<td>3</td>
<td>Capacity retention</td>
<td>After 28 days storage at 25±5°C, after having been standard charged and discharged at 0.2C, to 2.75V (the residual capacity is above 85% of nominal capacity)</td>
<td>Discharge time ≥ 4.25h</td>
</tr>
<tr>
<td>4</td>
<td>Cycle life</td>
<td>Charging/discharging in the below condition: Charge: standard charge Discharge: 0.5C down to 2.75V Rest time between charge/discharge: 30min Until the discharge capacity ≤ 60% of NC</td>
<td>&gt;300 cycles</td>
</tr>
<tr>
<td>5</td>
<td>Storage</td>
<td>(Within 3 months after manufactured) The cells is charged with 0.2C to 40-50% capacity and stored at ambient temperature 25±5°C, 65±20%RH for 12 months. After the 12 months storage period the cell is fully charged and discharged to 2.75V with 0.2C</td>
<td>Discharge time ≥ 4h</td>
</tr>
</tbody>
</table>

### Standard test conditions

Test should be conducted with new batteries within one week after shipment from our factory and the batteries shall not be cycled more than five times before the test. Unless otherwise defined, test and measurement shall be done under temperature of 20±5°C and humidity 25~85%RH.

### Cautions in use

To ensure proper use of the battery please read the manual carefully before using it.

#### 6.1 Handling

- Do not expose to, dispose of the battery in fire.
- Do not put the battery in a charger or equipment with wrong terminals connected.
- Avoid shorting the battery.
- Avoid excessive physical shock or vibration.
- Do not disassemble or deform the battery.
- Do not immerse in water.
- Do not use the battery mixed with other different make, type, or model batteries.
- Keep out of the reach of children.

#### 6.2 Charge and discharge

Battery must be charged in appropriate charger only.

Never use a modified or damaged charger.
Do not leave battery in charge over 24 hours.

6.3 Storage
Store the battery in a cool, dry and well-ventilated area.

6.4 Disposal
Regulations vary for different countries, Dispose of in accordance with local regulations.

7 Battery operation instruction

7.1 Charging
Charging current: Cannot surpass the biggest charging current which in this specification book stipulated.
Charging voltage: Does not have to surpass the highest amount which in this specification book stipulated to decide the voltage.
Charge temperature: The battery must carry on the charge in the ambient temperature scope which this specification book stipulated. Uses the constant electric current and the constant voltage way charge, the prohibition reverse charges. If the battery positive electrode and the cathode meet instead, can damage the battery.

7.2 Discharging current
The discharging current does not have to surpass this specification book stipulation the biggest discharging current, the oversized electric current electric discharge can cause the battery capacity play to reduce and to cause the battery heat.

7.3 Electric discharge temperature
The battery discharge must carry on in the ambient temperature scope which this specification book stipulated.

7.4 Over-discharges
After the short time excessively discharges charges immediately cannot affect the use, but the long time excessively discharges can cause the battery the performance, battery function losing. The battery long-term has not used, has the possibility to be able to be at because of its automatic flashover characteristic certain excessively discharges the condition, or prevented excessively discharges the occurrence, the battery should maintain the certain electric quantity.

7.5 Storing the batteries
The battery should store in the product specification book stipulation temperature range. If has surpasses above for six months the long time storage, suggested you should carry on additional charge to the battery.

8 Period of warranty
The period of warranty is one year from the date of shipment. Tenergy guarantees to give a replacement in case of batteries with defects proven due to manufacturing process instead of the customers’ abuse and misuse.

9 Other the chemical reaction
Because batteries utilize a chemical reaction, battery performance will deteriorate over time even if stored for a long period of time without being used. In addition, if the various usage conditions such as charge, discharge, ambient temperature, etc. are not maintained within the specified ranges the life expectancy of the battery may be shortened or the device in which the battery is used may be damaged by electrolyte leakage. If
the batteries cannot maintain a charge for long periods of time, even when they are charged correctly, this may indicate it is time to change the battery.

10 Note

Any other items which are not covered in this specification shall be agreed by both parties.

11 PCM performance

11.1 Electrical characteristics

Form 3: PCM electrical characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>Content</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over charge Protection</td>
<td>Over charge detection voltage</td>
<td>4.325±0.025V</td>
</tr>
<tr>
<td></td>
<td>Over charge release voltage</td>
<td>4.075±0.025V</td>
</tr>
<tr>
<td>Over discharge protection</td>
<td>Over discharge detection voltage</td>
<td>2.5±0.05V</td>
</tr>
<tr>
<td></td>
<td>Over discharge release voltage</td>
<td>2.9±0.05V</td>
</tr>
<tr>
<td></td>
<td>Rated operational current</td>
<td>3.5A</td>
</tr>
<tr>
<td>Over current protection</td>
<td>Over current detection current</td>
<td>6.5A±2A</td>
</tr>
<tr>
<td></td>
<td>Release condition</td>
<td>Cut load</td>
</tr>
<tr>
<td></td>
<td>Detection delay time</td>
<td>7.2～11.0ms</td>
</tr>
<tr>
<td>Short protection</td>
<td>Detection condition</td>
<td>Exterior short circuit</td>
</tr>
<tr>
<td></td>
<td>Release condition</td>
<td>Cut short circuit</td>
</tr>
<tr>
<td>Interior resistance</td>
<td>Main loop electrify resistance</td>
<td>( V_r=4.2V ); ( R_{in}&lt;50\text{m}\Omega )</td>
</tr>
<tr>
<td>Current consumption</td>
<td>Current consume in normal operation</td>
<td>4.0μA Type10,0μA Max</td>
</tr>
</tbody>
</table>

Dimension (L*W*H)          \( 8.65*0.5*0.5 \text{mm} \)

11.2 Parts list

Form 4: PCM parts list

<table>
<thead>
<tr>
<th>No</th>
<th>Location</th>
<th>Part name</th>
<th>Specification</th>
<th>Pack type</th>
<th>Q’ty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U1</td>
<td>Battery protection IC</td>
<td>IC-S-8261AJMD-G2J</td>
<td>SOT-23-6</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Q1, Q2</td>
<td>Silicon MOSFET</td>
<td>MOS-SME82O5</td>
<td>TSSOP-8</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>R1</td>
<td>Resistance</td>
<td>SMD 470Ω±5%</td>
<td>0603</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>R2</td>
<td>Resistance</td>
<td>SMD 2KΩ±5%</td>
<td>0603</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>C1</td>
<td>Capacitance</td>
<td>SMD 0.1μF</td>
<td>0603</td>
<td>1</td>
</tr>
</tbody>
</table>

11.3 Application circuit

Specifications and data are subject to change without notice. Contact Tenergy for latest information. ©2010 Tenergy Corporation. All rights reserved.
11.4 PCM layout

Figure 2: PCM layout

11.5 Terminal explanations

11.5.1 B+: Connected to the battery’s positive terminal

11.5.2 B-: Connected to the battery’s negative terminal

11.5.3 P+: Connected to the battery’s output or the charger’s positive terminal

11.5.4 P-: Connected to the battery’s output or the charger’s negative terminal

12 Battery pack drawing
Appendix B

Concept Art
B.1 Senor Module Concepts

B.1.1 Glasses
B.1.2 Baseball Hat Add-on
B.2 Feedback Garment

B.2.1 Waistband
B.2.2 Waistband Open
Appendix C

Source Code
C.0.3 Test Bench Code

/*
  * arduinoB13.c
  * 
  * Created on: Nov 10, 2013
  *
  * This program executes the existing code to replicate the process on a
test bench scale.
  * The code is amended for test bench implementation with one sensor 
feedback.
  *    "Example NewPing Library sketch that does a ping about 20 times 
    per second."
  */

#include <NewPing.h>

#define TRIGGER_PIN_CENTER 8 // Arduino pin tied to trigger pin on the 
    ultrasonic sensor.
#define ECHO_PIN_CENTER 2 // Arduino pin tied to echo pin on the 
    ultrasonic sensor.
#define MAX_DISTANCE 300 // Maximum distance we want to ping for (in 
    centimeters). Maximum sensor distance is rated at 400-500cm.
#define SPLUS 4
#define SMINUS 5

int RANGE = 200;
int t = 0;
int calibra=50;
int sens_min = 0;
int sens_plus = 0;
int SENS = 50;

NewPing sonar_CENTER(TRIGGER_PIN_CENTER, ECHO_PIN_CENTER, MAX_DISTANCE); 
    // NewPing setup of pins and maximum distance.

void setup() {
  Serial.begin(115200); // Open serial monitor at 115200 baud to see 
    ping results.
}

void loop() {
```cpp
long int inv_CENTER;
long int cm_RIGHT;

int cm_old_CENTER = RANGE -1;

// Serial.print("Minus:");
Serial.print (sens_min);
Serial.print ('
');
Serial.print("Plus:");
Serial.print (sens_plus);*/

const int Motor_CENTER=6;    //Motor 2 output
// const int Motor_LEFT=9;    //Motor 1 output
// const int Motor_RIGHT=5;    //Motor 3 output

/* CENTER SENSOR CALCULATIONS*/
/*****************************************************************************/
unsigned int uS_CENTER = sonar_CENTER.ping(); // Send ping, get ping
time in microseconds (uS).
    cm_CENTER=uS_CENTER/US_ROUNDTRIP_CM;

delay(30);

if(((cm.CENTER!=0) &&(cm.CENTER<=RANGE))){
    cm_old_CENTER = cm_CENTER;
    Serial.print("Ping: ");
    Serial.print(cm.CENTER); // Convert ping time to distance and print
    result (0 = outside set distance range, no ping echo)
    Serial.println("cm_CENTER");

    inv_CENTER=((RANGE-cm.CENTER)*(255-calibra)/RANGE) +calibra -SENS;
    analogWrite(Motor_CENTER, inv_CENTER);
    // Serial.print(inv);
    // Serial.println("INV:");
    //Serial.print(inv.CENTER);
}
else if ((cm.CENTER<=RANGE)){
```
cm_CENTER = cm_old_CENTER;
Serial.print("Ping: ");
Serial.print(cm_CENTER); // Convert ping time to distance and print result (0 = outside set distance range, no ping echo)
Serial.println("cm_CENTER");

inv_CENTER=((RANGE-cm_CENTER)*(255-calibra)/RANGE) +calibra-SENS;
analogWrite(Motor_CENTER, inv_CENTER);
// Serial.println("INV:");
// Serial.print(inv_CENTER);
}
else {
  Serial.print("\n");
  Serial.print("Out of Range");
  inv_CENTER = 0;
analogWrite(Motor_CENTER, inv_CENTER);
  Serial.println("INV:");
  Serial.print(inv_CENTER);
}


/* Sensitivity Controller */
/*************************************************************************
 sens_min = analogRead(SMINUS);
sens_plus = analogRead(SPLUS);
if ((sens_plus > 512)&&(SENS >5)){
  SENS = SENS - 5;
} else if ((sens_min >512)&&(SENS < calibra )){
  SENS=SENS+5;
} //Serial.print ("SENSE:" );
//Serial.print(SENS);
/*************************************************************************/

C.0.4 Legacy Code

// Example NewPing library sketch that does a ping about 20 times per second.
```c
#include <NewPing.h>

#define TRIGGER_PIN_LEFT 13 // Arduino pin tied to trigger pin on the 
ultrasonic sensor.
#define TRIGGER_PIN_RIGHT 12 // Arduino pin tied to trigger pin on the 
ultrasonic sensor.
#define TRIGGER_PIN_CENTER 8 // Arduino pin tied to trigger pin on the 
ultrasonic sensor.
#define ECHO_PIN_LEFT 7 // Arduino pin tied to echo pin on the 
ultrasonic sensor.
#define ECHO_PIN_RIGHT 4 // Arduino pin tied to echo pin on the 
ultrasonic sensor.
#define ECHO_PIN_CENTER 2 // Arduino pin tied to echo pin on the 
ultrasonic sensor.
#define MAX_DISTANCE 300 // Maximum distance we want to ping for (in 
centimeters). Maximum sensor distance is rated at 400-500cm.
#define SPLUS 4
#define SMINUS 5

int RANGE = 200;
int t = 0;
int calibra=50;
int sens_min = 0;
int sens_plus = 0;
int SENS = 50;
NewPing sonar_LEFT( TRIGGER_PIN_LEFT, ECHO_PIN_LEFT, MAX_DISTANCE ); // 
NewPing setup of pins and maximum distance.
NewPing sonar_CENTER(TRIGGER_PIN_CENTER, ECHO_PIN_CENTER, MAX_DISTANCE);
// NewPing setup of pins and maximum distance.
NewPing sonar_RIGHT( TRIGGER_PIN_RIGHT, ECHO_PIN_RIGHT, MAX_DISTANCE ); // 
NewPing setup of pins and maximum distance.

void setup() {
  Serial.begin( 115200 ); // Open serial monitor at 115200 baud to see 
  ping results.
}

void loop() {
  long int inv_LEFT, inv_CENTER, inv_RIGHT, cm_LEFT, cm_RIGHT, cm_CENTER;
  int cm_old_LEFT = RANGE -1;
  int cm_old_RIGHT = RANGE -1;
  int cm_old_CENTER = RANGE -1;
  /* Serial.print("Minus:");
  Serial.print (sens_min);
```
Serial.print ('\n');
Serial.print("Plus: ");
Serial.print (sens_plus);*/

const int Motor_LEFT=9; //Motor 1 output
const int Motor_CENTER=6; //Motor 2 output
const int Motor_RIGHT=5; //Motor 3 output

/****************************************************************************/
**************************
delay(30); // Wait 40ms between pings (about 20 pings/sec).
29ms should be the shortest delay between pings.

unsigned int uS_LEFT = sonar_LEFT.ping(); // Send ping, get ping time
in microseconds (uS).
   cm_LEFT=uS_LEFT/US_ROUNDTRIP_CM;

if((cm_LEFT!=0) &&(cm_LEFT<=RANGE)){
    cm_old_LEFT = cm_LEFT;
    /* Serial.print("Ping: ");
    Serial.print(cm_LEFT); // Convert ping time to distance and print
    result (0 = outside set distance range, no ping echo)
    Serial.println("cm_left");*/

    inv_LEFT=((RANGE-cm_LEFT)*(255-calibra)/RANGE) +calibra -SENS;
    analogWrite(Motor_LEFT, inv_LEFT);
    // Serial.print(inv);
}
else if ((cm_LEFT<=RANGE)){
    cm_LEFT = cm_old_LEFT;
    /* Serial.print("Ping: ");
    Serial.print(cm_LEFT); // Convert ping time to distance and print
    result (0 = outside set distance range, no ping echo)
    Serial.println("cm_left");*/

    inv_LEFT=((RANGE-cm_LEFT)*(255-calibra)/RANGE) +calibra -SENS;
    analogWrite(Motor_LEFT, inv_LEFT);
    // Serial.print(inv);
}
APPENDIX C. SOURCE CODE

}  
else {
    /* Serial.print('\n');
    Serial.print("Out of Range"); */
    inv_LEFT = 0;
    analogWrite(Motor_LEFT, inv_LEFT);
}

/*************************
****************************/
unsigned int uS_CENTER = sonar_CENTER.ping(); // Send ping, get ping
time in microseconds (uS).
    cm_CENTER = uS_CENTER / US_ROUNDTRIP_CM;

delay(30);

if((cm_CENTER!=0) &&(cm_CENTER<=RANGE)){
    cm_old_CENTER = cm_CENTER;
    Serial.print("Ping: ");
    Serial.print(cm_CENTER); // Convert ping time to distance and print
        result (0 = outside set distance range, no ping echo)
    Serial.println("cm_CENTER");

    inv_CENTER=((RANGE-cm_CENTER)*(255-calibra)/RANGE) +calibra -SENS;
    analogWrite(Motor_CENTER, inv_CENTER);
    // Serial.print(inv);
    // Serial.println("INV:");
    // Serial.print(inv_CENTER);
}
else if ((cm_CENTER<=RANGE)){
        cm_CENTER = cm_old_CENTER;
    Serial.print("Ping: ");
    Serial.print(cm_CENTER); // Convert ping time to distance and print
        result (0 = outside set distance range, no ping echo)
    Serial.println("cm_CENTER");

    inv_CENTER=((RANGE-cm_CENTER)*(255-calibra)/RANGE) +calibra -SENS;
    analogWrite(Motor_CENTER, inv_CENTER);
    // Serial.print(inv);
    // Serial.println("INV:");
    // Serial.print(inv_CENTER);
}
else {
    Serial.print('\n');
Serial.print("Out of Range");
inv_CENTER = 0;
analogWrite(Motor_CENTER, inv_CENTER);
Serial.println("INV:");
Serial.print(inv_CENTER);
}

/*===========================================================================
***************************************************/
unsigned int uS_RIGHT = sonar_RIGHT.ping(); // Send ping, get ping time in microseconds (uS).
   cm_RIGHT=uS_RIGHT/US_ROUNDTRIP_CM;

delay(30);

if((cm_RIGHT!=0) &&(cm_RIGHT<=RANGE)){
   cm_old_RIGHT = cm_RIGHT;
   /* Serial.print("Ping: ");
      Serial.print(cm_RIGHT); // Convert ping time to distance and print result (0 = outside set distance range, no ping echo)
      Serial.println("cm_RIGHT");*/
   inv_RIGHT=((RANGE-cm_RIGHT)*(255-calibra)/RANGE)+calibra-SENS;
analogWrite(Motor_RIGHT, inv_RIGHT);
   /* Serial.print(inv);*/
}
else if ((cm_RIGHT<=RANGE)){
   cm_RIGHT = cm_old_RIGHT;
   /* Serial.print("Ping: ");
      Serial.print(cm_RIGHT); // Convert ping time to distance and print result (0 = outside set distance range, no ping echo)
      Serial.println("cm_RIGHT");*/
   inv_RIGHT=((RANGE-cm_RIGHT)*(255-calibra)/RANGE)+calibra-SENS;
analogWrite(Motor_RIGHT, inv_RIGHT);
   /* Serial.print(inv);*/
}
else {
   /*Serial.print('
');
      Serial.print("Out of Range");*/
   inv_RIGHT = 0;
analogWrite(Motor_RIGHT, inv_RIGHT);"}
/* Sensitivity Controller */
/***************************/
sens_min = analogRead(SMINUS);
sens_plus = analogRead(SPLUS);
if ((sens_plus > 512)&&(SENS >5)){
SENS = SENS - 5;
}
else if ((sens_min >512)&&(SENS < calibra )){
SENS=SENS+5;
}
//Serial.print ("SENSE:");
//Serial.print(SENS);
/******************************/
*/
Appendix D

Diagrams and Schematics
D.1  Top Level Diagrams

D.1.1  MSP430 Top Level Diagram
# List of Symbols and Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPI</td>
<td>“Worcester Polytechnic Institute”, the institute that the students of the project group attended.</td>
</tr>
<tr>
<td>MQP</td>
<td>“Major Qualifying Project”, effectively the senior project of students that attend Worcester Polytechnic Institute.</td>
</tr>
<tr>
<td>MCB</td>
<td>“Massachusetts Commission for the Blind” MCB provides the highest quality rehabilitation and social services to blind individuals, leading to independence and full community participation</td>
</tr>
</tbody>
</table>