

November 5, 2014

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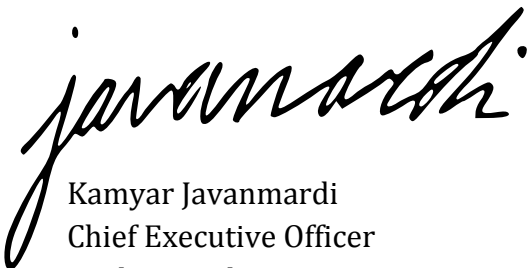
RE: ENSC 440W Design Specification for 360-NS-HS, a Haptic Feedback Gaming System

Dear Dr. Rawicz,

Enclosed in this document contains the design specification for our device, the 360-NS-HS. The design and implementation of the device will bring a realistic experience to players who have a passion for weaponry tag. The device will consist of Radio-Frequency Identification (RFID) technology in junction with a tactical vest, light-emitting diodes (LEDs), and vibration motors to bring forth this realistic experience.

The design specification will detail hardware and software designs implemented to meet the initial requirements. It will provide explanations to the approaches in order to give an understanding of how each system will integrate with each other. The designs outlined in this document are intended for the prototype product, but the final product approaches will also be briefly mentioned.

RealSimTech consist of four promising and adept engineers: Kamyar Javanmardi, Nielven Jay Olis, Anthony Nguyen, and James Fong. Should you have any questions or concerns, feel free to contact us at 778-881-5751 or by email at kjavanma@sfu.ca.



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Enclosure: Design Specification for 360-NS-HS, a Haptic Feedback Gaming System



Haptic Feedback Gaming System

Design Specification

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Revision 1

EXECUTIVE SUMMARY

The goal of RealSimTech is to bring more excitement to the alternative sports by implementing a new feedback system. This device makes gameplay more stimulating and it delivers a realistic feeling of an actual shooting combat. While it helps the players feel the gameplay more realistically, it also helps them to keep track of the play more accurately. As the number of gaming enthusiasts grow every year and there is more demand for alternative sports, players are always seeking more advanced and exciting activities to enjoy.

The proposed solution by RealSimTech addresses inadequacies by introducing Haptic Feedback Gaming System (HFGS), which will help players achieve the utmost excitement in their gaming adventures. This device employs an RFID reader that detects each projectile's micro RFID tag. After the tag is sensed, a microprocessor will produce a suitable signal to the feedback circuitry and hardware. The feedback hardware, which consists of vibration motors and LEDs, produces physical and visual effects.

What follows is a breakdown of each of the components' specifications and it covers the requirements for the design. This information will also be accompanied by a test plan and the design modifications that will take place in the future. The RealSimTech members will apply their electronics and programming skills to create the hardware and software of the device.

- RFID system: the reader module reads the tags from the projectile.
- CPU module: the program reads the data from the reader, analyzes the input, and sends signal to the feedback system.
- Feedback System: it utilizes a power management circuitry and it drives the motors and turns on the LED's.
- Enclosure: all electronic components will be placed in an enclosure that is fitted into a vest.

Each section of this document will outline one component of the system. A test plan is included to ensure each subsystem will function as intended. The best effort is to be made in designing and integrating the components for the highest safety and efficiency standards achieved.

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GLOSSARY OF TERMS

HFGS	Haptic Feedback Gaming System
RFID	Radio Frequency Identification
IR	Infrared
FPS	First Person Shooter
360-NS-HS	360 Nexus-Series Haptic-System
CPU	Central Processing Unit
PCB	Printed Circuit Board
LED	Light Emitting Diode
DC	Direct Current

1. INTRODUCTION

The 360° Nexus-Series Haptic-System, 360-NS-HS, is an alternative gaming product that promotes active physical activities while capturing the engaging gameplay of a First Person Shooter (FPS). The system will be designed for ruggedness to be able to withstand rapid body movement and will provide a thrilling experience both indoors and outdoors. Our objective is to give the user an immersive experience by utilizing rumbling features to simulate a FPS action. 360-NS-HS consists of three major components. The first component is the RFID module, which includes RFID transponders and readers. The RFID transponders are embedded into the projectiles and the readers are attached into the vest. The second major component is the microcontroller and the supporting board. We have chosen Arduino Mega for this part because it can support and connect all the other elements of the design well. The third component is the feedback unit. The feedback unit comprises the vibrating motors, LEDs, and the related circuitry. All the mentioned components will be parted together with wirings, and the batteries will be enclosed in casings and placed inside the vest.

1.1 SCOPE

This document outlines the design behind the 360-NS-HS and it will explain the system architecture and the reasons for choosing certain components. The design specification includes the discussion of the requirements for the prototype system. In addition, a series of test plans of all the modules is provided to evaluate and ensure the functionality of the prototype system.

1.2 INTENDED AUDIENCE

This design specification is intended for use by members of RealSimTech to help in the overall development of the 360-NS-HS. During the implementation, the design specification shall serve as the main guideline for implementing and testing of the prototype. This document is expected to be used by the engineers who are tasked to implementing the design and the ones involved with testing and troubleshooting of the implemented system.

2. SYSTEM OVERVIEW

The Input of the system is a projectile with an embedded RFID transponder which is used to give a tag to the RFID reader. The reader acts as a Buffer that reads the tag and sends the information, via serial communication, to the CPU Module containing an Arduino microcontroller. The behavior of the Signal Processing is dictated by the input from the user interface which determines the game mode. The microcontroller will process this information and outputs the appropriate signals to the Output Control. The switching circuit contains multiple switches which activates the vibration motors and control the state of the LEDs, providing the output feedback. The user will have the option to reset the system by pressing an external button, and change the game mode by flipping a toggle switch to a different position. The high-level diagram is provided in Figure 1.

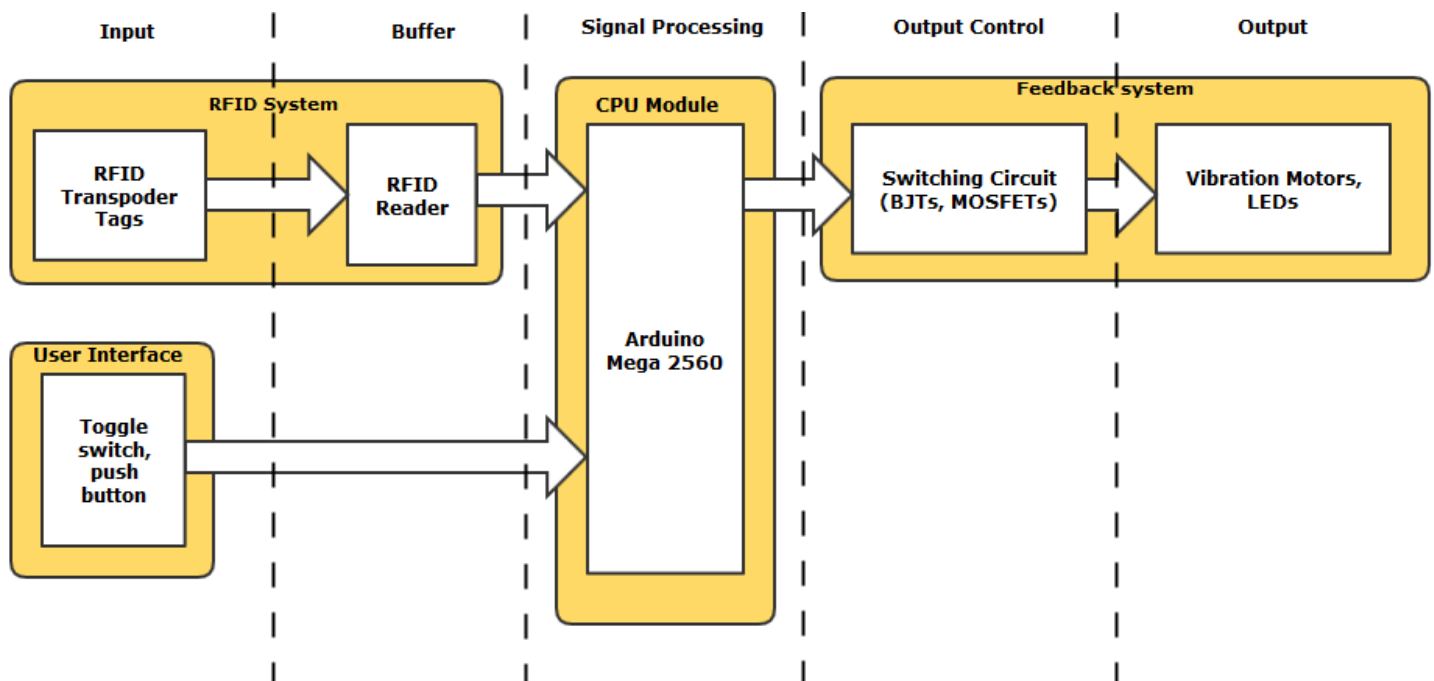


FIGURE 1: HIGH-LEVEL SYSTEM DIAGRAM

The prototype system is powered on by a 6V power supply that uses 4-AA batteries as well as a 9V battery for the microcontroller. The final product will have central power supply that powers the feedback system and the CPU module. A look at the prototype of the 360-NS-HS is shown in Figure 2. The low level design for the 360-NS-HS will be discussed in more details in the subsequent sections.

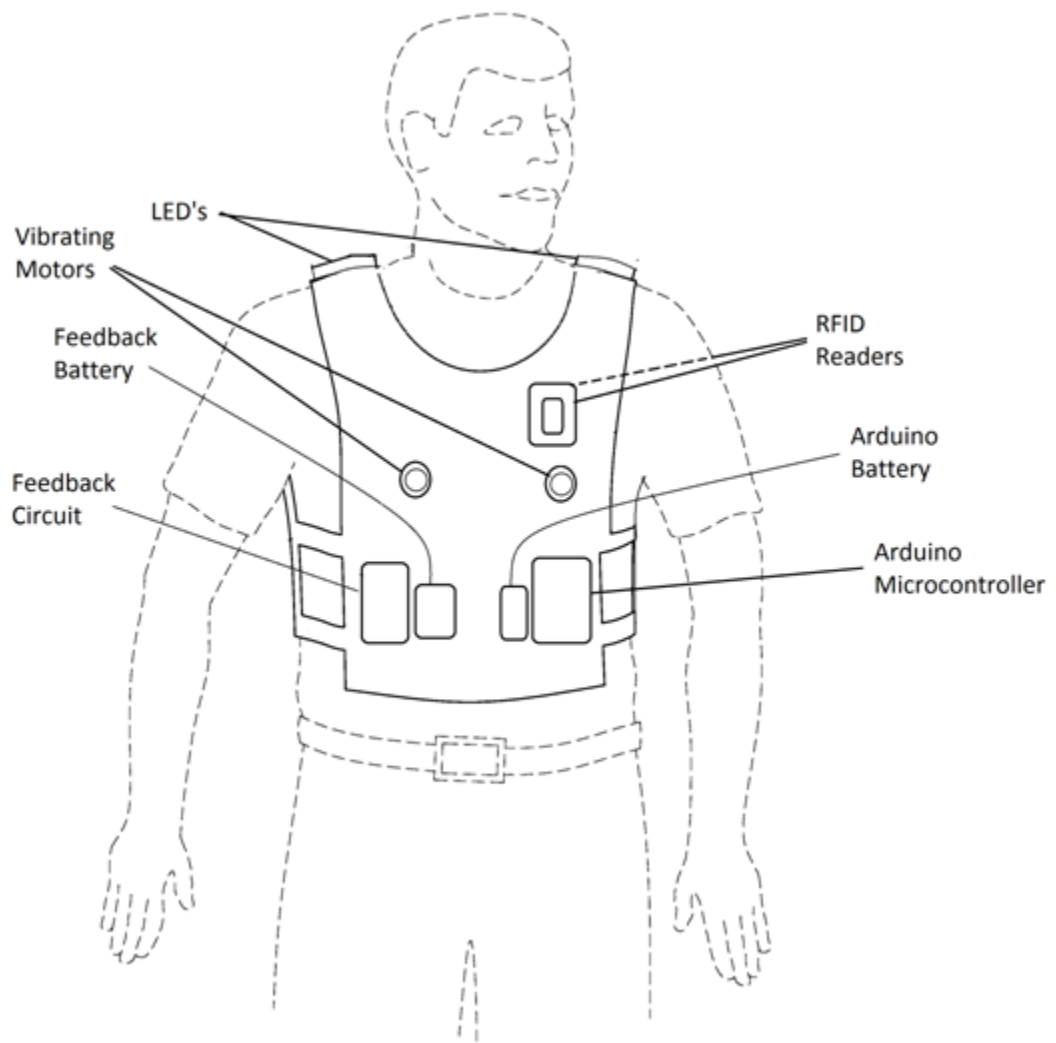


FIGURE 2: FULL PROTOTYPE MODEL OF 360-NS-HS

3. USER INTERFACE

The 360-NS-HS, in its final product form, will include an indicator for the power, game mode and reset. The prototype will not have a power indicator but will have a game mode switch and reset push-button.

3.1 POWER INDICATOR + POWER ON/OFF

The power indicator is to allow the user to keep track of power available to keep the 360-NS-HS running. The indicator is made of a multi-diode display with one diode lit to indicate low battery (10% < battery) and the maximum amount of diode are lit to indicate high or full battery (90% > battery). Moderate battery power (90% > battery > 10%) is indicated with two or more diode lit where each additional diode lit is indicative of how much power is available. The power ON/OFF switch is directly on the power supply by the power indicator switch for the user to power on or off the 360-NS-HS. The final product will have a custom-made power supply that includes this feature and function. The prototype will have a separate power supply for the microcontroller and the feedback circuitry.

3.2 GAME MODE TOGGLE-SWITCH + RESET PUSH BUTTON

The final production form of the 360-NS-HS can have multiple game modes as a feature of the product. The prototype will feature two game modes; this feature is expanded upon in the Embedded Software Design section. A toggle switch will be implemented to choose between game modes connecting to a digital input pin Figure 3. A similar circuit used with a push-button instead of a switch to reset the Arduino board. This is expanded upon in section 5.2 Embedded Software Design.

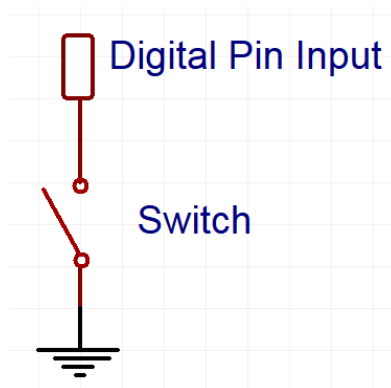


FIGURE 3: TOGGLE-SWITCH/RESET CIRCUIT

4. RFID SYSTEM DESIGN

The 360-NS-HS makes use of an RFID system for automatic identification of tags embedded in a projectile such as a foam dart. The prototype will make use of a Low Frequency (LF) RFID system. The limitation of our prototype is the reading speed [7]. The reader is required to be able to read the tags before the tags begin to fall to the ground or away from the vicinity of the reading range of the reader. The prototype will make use of Velcro to address this limitation by ensuring the tag latches onto the reader and is fully read.

Our final product will make use of a High Frequency (HF) RFID system. A HF RFID system allows for faster read speeds of the tags. There are currently RFID readers that provide reading capability of tags projected at speeds of up to 113 km/h by companies such as Optys Corporation [6]. This speed is far greater than what modern handheld dart-projector can achieve. The reading speed is more than enough to automatically identify a tag upon immediate impact to the reader and before it falls out of range. Hence, the Velcro will not be used in our final product.

4.1 RFID READER

The prototype of 360-NS-HS will use a Parallax RFID Card Reader-Serial, Figure 4. It is capable of reading EM41000 tags at 125 kHz LF. It is a relatively low-powered reader that only requires 4.5-5.5 V which our microcontroller can provide.



FIGURE 4: RFID READER

There are some requirements to encasing this reader. The reader is required to be mounted as close to one side of the case to allow the reading vicinity of the reader to be in the surface of the case as much as possible. In the prototype, the surface is lined with Velcro hooks to allow the tag to latch on and be read. Again, the final product will not use the Velcro. Since we are making use of multiple readers, the rest of the casing must be lined with a material that shields the readers from one another in order for them to not interfere with one another's reading vicinity [5]. An alternative software solution is expanded upon in Embedded Software Design 5.2.4 to combat multiple reader interferences. The construction of the casing and other design specification is expanded upon in section Enclosure 7.5.

4.2 RFID TRANSPONDER REQUIREMENTS

The transponder tag used for the prototype 360-NS-HS operates at LF and is in a passive state. The tag chosen is 12.4 mm which is small enough to be embedded on to various standard dart sizes for prototyping and still be compatible with our chosen reader. The placement of the tag is required to be as close to the front of the projectile as possible to ensure the projectile's impact to the reader is noted immediately.

The dart used for our prototype will be assembled as shown in Figure 5:

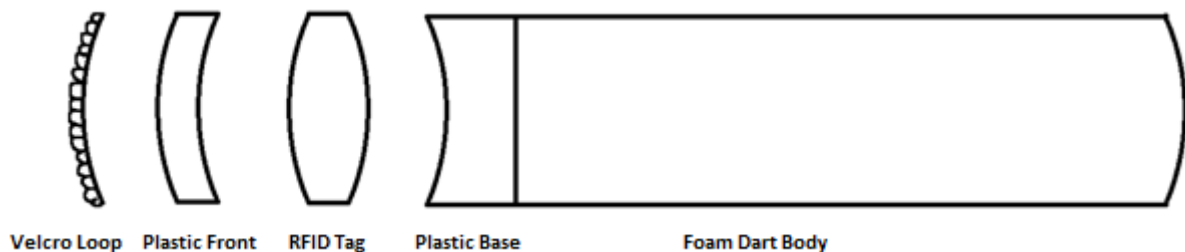


FIGURE 5: DART ASSEMBLY

In the prototype, the surface of the tip (plastic front) is covered with Velcro loops to allow the dart to latch on and the tag read. The plastic front is shaped to be slightly hemispherical to allow angled shots to stick Figure 6. Again, the final product will not use the Velcro. The tip of the dart will have the tag embedded within the plastic front and plastic base. A soft tip is used to minimize the piercing impact of the dart and the body is made of foam to minimize weight. The final product version can be shipped with fully assembled darts or include just the tip. Foam darts are relatively easy to modify to fit various projectors barrel sizes and a personally modified dart with our tags embedded can be a more practical solution for those that require various/custom sized darts. Furthermore, with a final product making use of HF RFID system, the tip can be designed with a smaller tag embedded within it as HF tags can be produced to be smaller than LF tags [7].

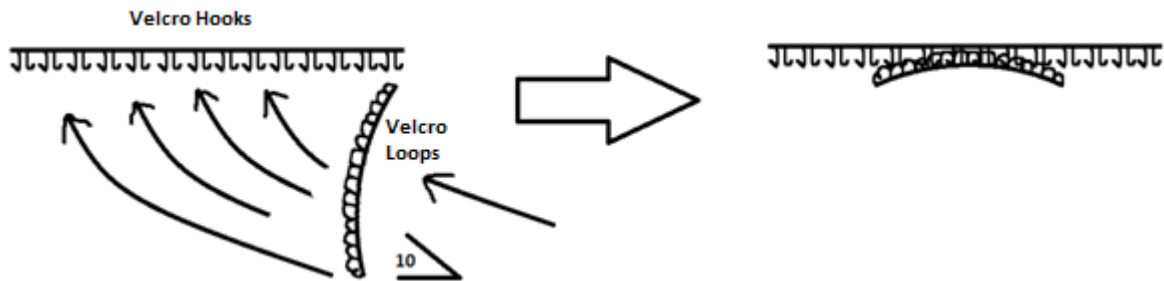


FIGURE 6: EFFECT OF ANGLED IMPACT

5. CPU MODULE

The CPU module acts as the control center that bridges the RFID and feedback system. For the prototype design, the module utilizes two RFID readers, but for the final product, an upgraded module will be used to utilize multiple readers.

5.1 MICROCONTROLLER

The 360-NS-HS uses the ATmega2560 microprocessor (Figure 7 [3]) to control the flow of the RFID and Feedback system. It is built onto the Arduino Mega 2560 board, a device with low power consumption (5V) and multiple hardware serial communication pins, which makes this microcontroller very suitable for the product. The ATmega2560 can be programmed using the Arduino IDE and it can utilize open source libraries, making it easy to program. The board also has over 50 digital pins which provide flexibility in the inclusion of extra output devices. In the prototype design, the microcontroller board will be powered by a 9V battery but in the final design, it will have a shared power supply with the motors and LEDs.



FIGURE 7: ARDUINO MEGA 2560 - ATMEGA 2560 MICROPROCESSOR

Table 1 [3] is the specification summary of the Arduino Mega 2560.

TABLE 1: ARDUINO MEGA 2560 SUMMARY

Microcontroller	ATmega2560
Operating Voltage	5 V
Number of Digital I/O Pins	54
Hardware Serial Communications (UART)	4
DC Current per I/O Pin	40 mA
Flash Memory	256 KB
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

5.2 EMBEDDED SOFTWARE DESIGN

5.2.1 MICROCONTROLLER LOGIC

When the microcontroller is powered, it will run its setup function. Within this function, serial ports are initialized and the LEDs and motors will be set as outputs. With the initialization of the serial ports, communication between the microcontroller and the RFID readers is set. The Boolean state of the toggle switch will also be read to determine which game mode to run. Once the initial setup is done, the workflow will jump into the loop function and the RFID will begin to scan for RFID tags. Inside the loop function is where capturing of data and writing to outputs will be done. Depending on the game mode chosen in the setup function, a case statement will be present to determine the path of the workflow. Figure 8 is the overall workflow of the microcontroller. Two games modes will be implemented in the prototype design but more game modes may be added for the final product.

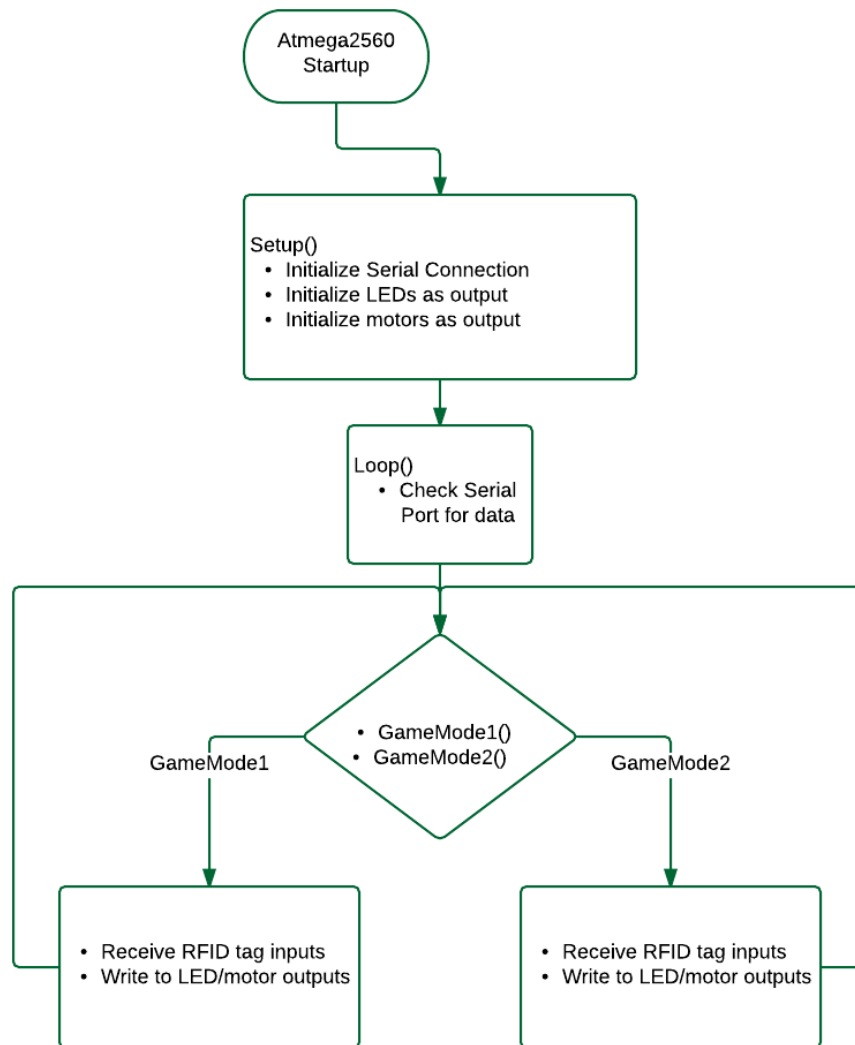


FIGURE 8: OVERALL MICROCONTROLLER WORKFLOW

When an RFID reader is enabled, it will constantly emit radio frequency in order to locate an RFID tag. When two readers are placed together within close distance, they will interfere with each other’s ability to read tags [5]. The solution to this is to alternate the active state of each reader. In the initial setup function, the two readers will be disabled. Once setup is complete, the readers will alternate enabled and disabled states so that there will be no collision in scanning for RFID tags. In the prototype, there will be a 500 ms delay between each state change to give the readers a sufficient amount of time to read a tag. In the final product the rate of state change can be brought down to 50 ms.

The following snippet of code outlines the flow of the RFID readers' state changes:

```
Setup()

digitalWrite(Reader1Enable, HIGH);    //set reader 1 and 2 to disable state
digitalWrite(Reader2Enable, HIGH);    //HIGH represents disable state
Loop()

digitalWrite(Reader1Enable, LOW);     //enable reader 1
delay(500);                           //set a delay to give sufficient reading time
digitalWrite(Reader1Enable, HIGH);    //disable reader 1
digitalWrite(Reader2Enable, LOW);     //enable reader 2
delay(500);                           //set a delay to give sufficient reading time
digitalWrite(Reader2Enable, HIGH);    //disable reader 2
//run loop()
```

5.2.2 SERIAL COMMUNICATION

Tag-reading input signals will be sent through the RX1 and RX2 pins for their respective RFID reader. Once a tag comes into close proximity with the RFID reader, the reader will send the tag data to the microcontroller. To capture the data from the readers, the microcontroller will call the `.available()` command inside the loop function. When the `.available()` command runs, it will execute the outputs within it. Once the outputs finish running, the program will delay up to 20 seconds before it performs another read to the RFID reader to check if the tag is still present. This is to ensure outputs will not be written to constantly and give users enough time to remove projectile from the vest. This read will clear the buffer so that the previous `.available()` command does not remain true. Figure 9 outlines the serial communication workflow.

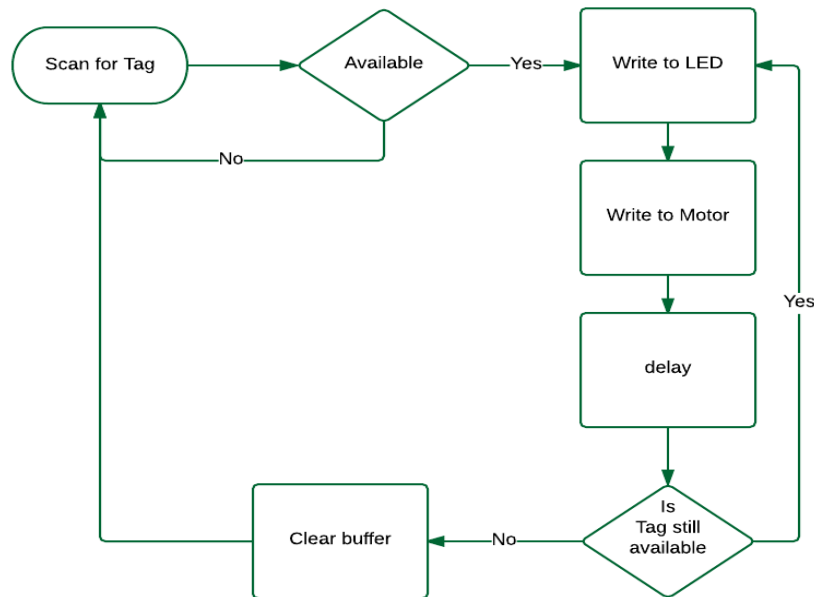


FIGURE 9: SERIAL COMMUNICATION WORKFLOW

5.2.3 SYSTEM RESET

The Arduino Mega microcontroller board has a built in software reset pin [3]. To provide users with the option to restart the game mode, an external reset button is connected to the board. When the button is triggered, the flow of program will go back to the setup function. Figure 10 outlines how to reset the system.

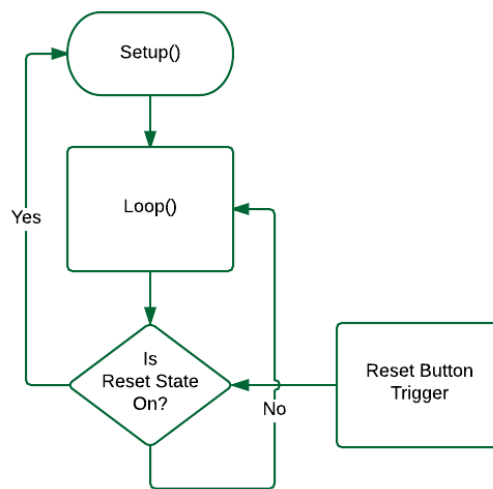


FIGURE 10: RESET SYSTEM WORKFLOW

5.2.4 INTERRUPT HANDLING

If at any point during the workflow that the toggle switch state has been changed, the workflow will reset to the beginning and will follow the path of the changed state. The purpose is to allow users to toggle between game modes at any point of usage. The program will implement an Interrupt Service Routine (ISR) to trigger when the toggle state is changed. Figure 11 outlines the ISR when it is triggered.

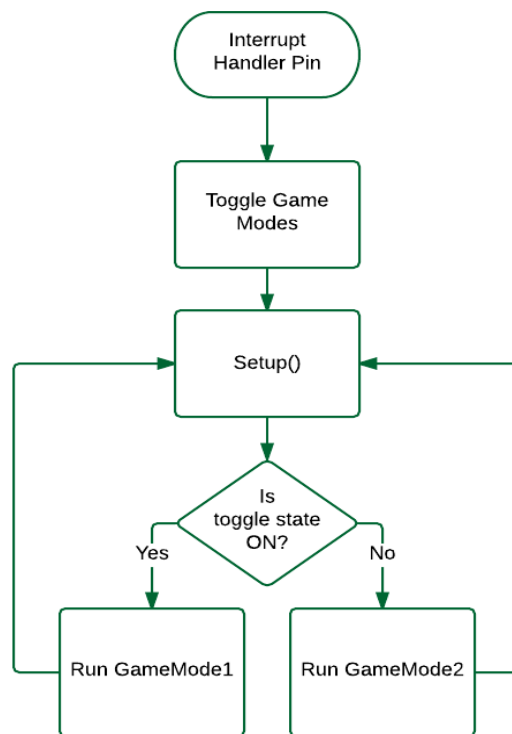


FIGURE 11: TOGGLE SWITCH INTERRUPT HANDLING

5.2.5 GAME MODE 1 PROCESSING

The first game mode will involve a one-health life system. In the initial state of the game mode, green LED pins will be turned on by setting them to HIGH state. Once a tag is read, the green LEDs will turn off and red LEDs will turn on. A health state counter will be implemented and the change of LED’s state will be done inside the health state cases. Once the red LED pins are on, it will signify that the game is over. User will have to reset the game in order to read extra tags.

5.2.6 GAME MODE 2 PROCESSING

The second game mode will have a three-health life system. Similar to Game Mode 1, initial state of the game mode will have green LED pins set to HIGH. When a tag is read, green LEDs will turn off and the yellow LEDs will turn on signifying one life loss. The health state counter will decrement and the workflow will begin at the start of the loop function again. The next tag reading will turn the first half of the yellow LEDs off and leave the second half of the yellow LEDs on. The last tag reading will turn the yellow LED off and red LED on signifying game over. User will have to reset the game to continue. Figure 12 shows the flow of the two game modes:

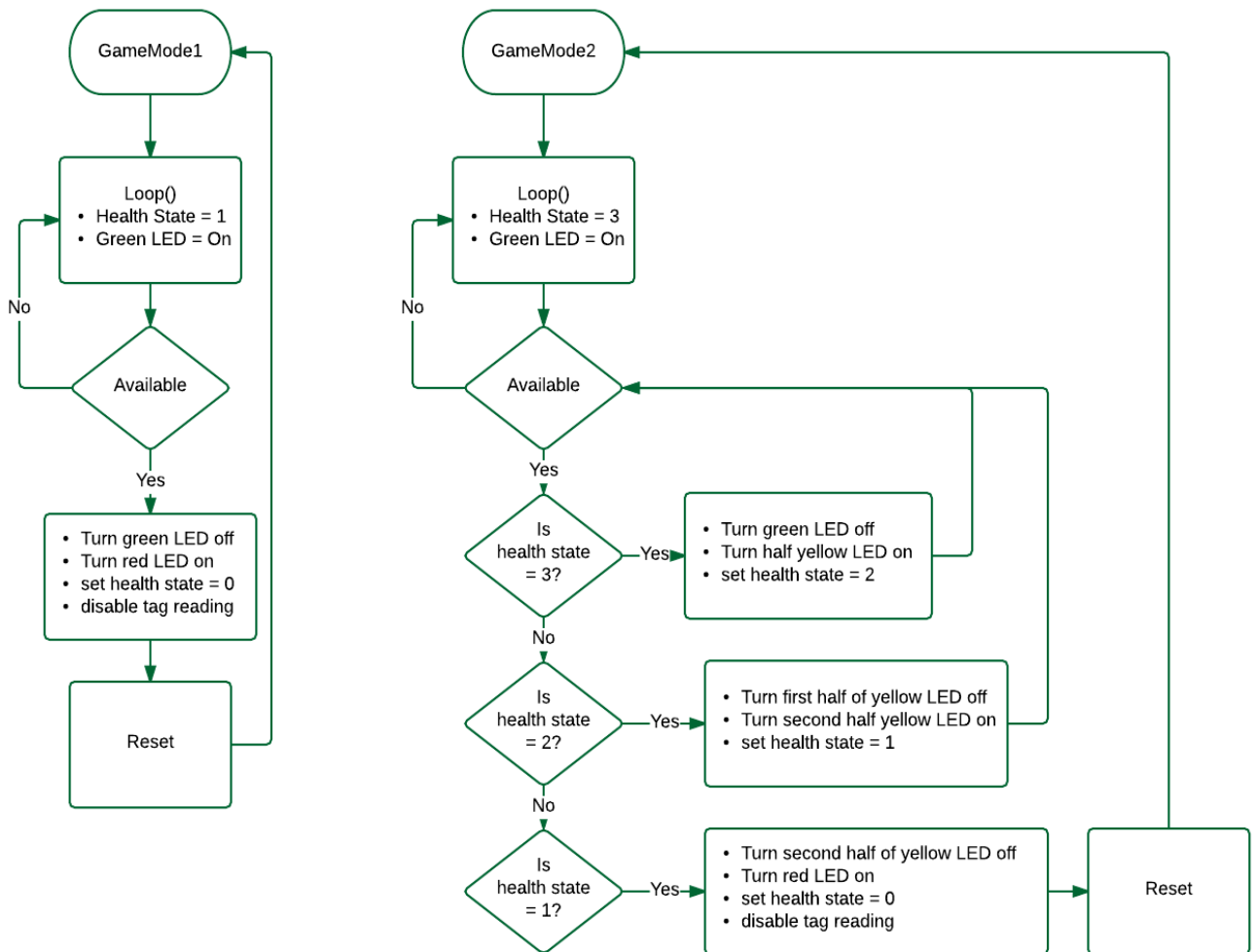


FIGURE 12: GAME MODE 1 AND GAME MODE 2 WORKFLOW

5.2.7 MOTOR PROCESSING

Four digital pins are used for the motor output. Each RFID reader is assigned two motor outputs to write to so that the respective motors respond to a specific reader. The motor outputs are not dependent on the game modes with the exception of when the game is over, the motor outputs will be disabled.

6. FEEDBACK SYSTEM

The motor and LED Feedback system consists of multiple vibrating motors and LEDs. The vibrating motors provide haptic feedback for the wearer of the 360-NS-HS and the LEDs provide visual feedback to none wearers.

6.1 MOTOR FEEDBACK SYSTEM

The motor feedback system for our prototype design consists of 4 vibration motors, the enclosures for the motors, the switching circuitry, and a power supply. The vibration motors vibrate for a set amount of time each time an RFID transponder-embedded projectile is read by the RFID reader. The section below will describe each of the components and the design choices in more detail as well as the justification for the design approach.

6.1.1 VIBRATION MOTORS

The vibration motor provides the main feedback to the user in response to a tagged projectile. A vibration motor is also known as an Eccentric Rotating Mass (ERM) vibration motor because it consist of a normal DC motor with an offset mass attached to the shaft of the motor. Whenever the shaft rotates, the offset mass also rotates and this produces a net centrifugal force that constantly displaces the motor. This constant displacement is considered to be the vibration sensation the motor creates [2].

Figure 13 shows the vibration motor that is used in our design. The motors we chose meet several requirements:

1. The motors are able to run properly with our power supply.
2. The motors are large enough such that it can provide adequate feedback to the user.
3. They are relatively lightweight such that they will not bog the user down.

In order to drive a vibration motor, the positive lead is connected to a constant voltage source and the negative lead is connected to ground. This drives the motor at a constant speed with a constant frequency, vibration amplitude, and current. The motor current draw is also dependent on how tight the vibration motor is held in place. A loosely gripped vibration motor will draw more current than a tightly gripped one [2]. This will be important when we enclose the vibration motors.

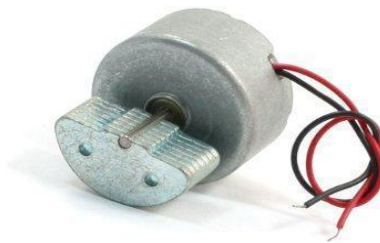


FIGURE 13: AN ECCENTRIC ROTATING MASS (ERM) VIBRATION MOTOR

The equation that describes the linear relationship between the speed and voltage (V) of a motor is given by,

$$V = RI + EMF = RI + K_E \omega$$

where R = parasitic resistance inside a motor (Ω)
 ω = angular velocity of the motor (kRPM)
 K_E = motor voltage constant (V/kPRM)

We see that as the supply voltage increases, the angular velocity of the motor will increase as well. The current I is also proportional to the torque T of the motor where,

$$I = T/K_T$$

where K_T = motor torque constant (N·M/A)

If the vibration motor is held loosely, the torque required to keeping the offset mass spinning will increase thus increasing the current draw. If the vibration motor is held tightly, the torque and current will decrease linearly. Figure 14 [2] shows the performance of a particular vibration motor (not the one we will be using).

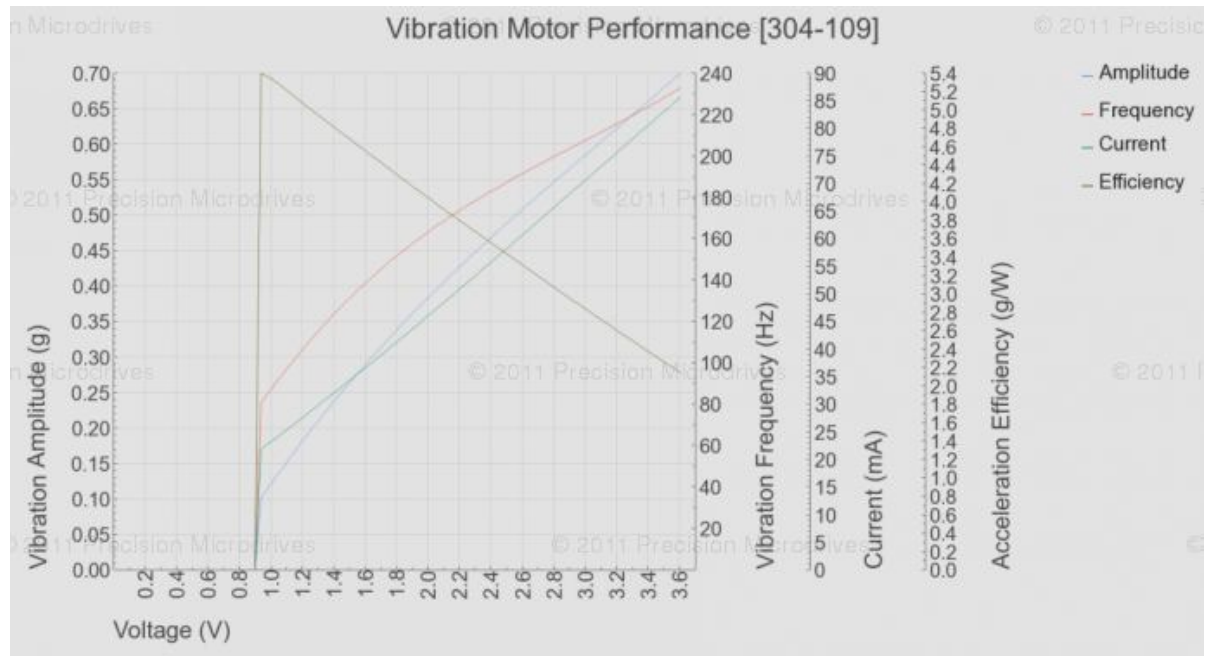


FIGURE 14: VIBRATION MOTOR PERFORMANCE

Table 2 shows the specification for our motor

TABLE 2: MOTOR SPECIFICATION

Rated voltage	3 – 6VDC
No-load speed	3000RPM
Body Size	12 x 24mm / 0.47” x 0.95” (Length x Diameter)
Total length	24mm / 0.95”
Material	Metal, Plastic
Weight	30g

6.1.2 POWER SUPPLY

The power supply in our prototype design consists of four AA alkaline batteries in series inside a battery enclosure box with an ON/OFF switch. The switch on the enclosure box is a safety feature to prevent the motors from accidentally turning on and to prevent the batteries from constantly discharging. Each alkaline battery has a voltage of 1.5V, therefore connecting four in series will produce a power supply voltage of 6V, which is within the range of the motors’ rated voltage. The final production version of our design will utilize a single rechargeable battery pack with a higher current capacity.

6.1.3 SWITCHING CIRCUITRY

The switching circuit is used to control the vibration motors. Since each digital I/O pin on the Arduino Mega can only output a maximum DC current of 40mA [3], these pins alone cannot turn the motors on and off. Each motor can draw constant currents ranging from 150mA to 250mA, depending on the voltage source and the torque as explained above. Therefore, a transistor is needed to provide the on/off function. Figure 15 shows the schematic of the motor switching circuit for a single vibration motor.

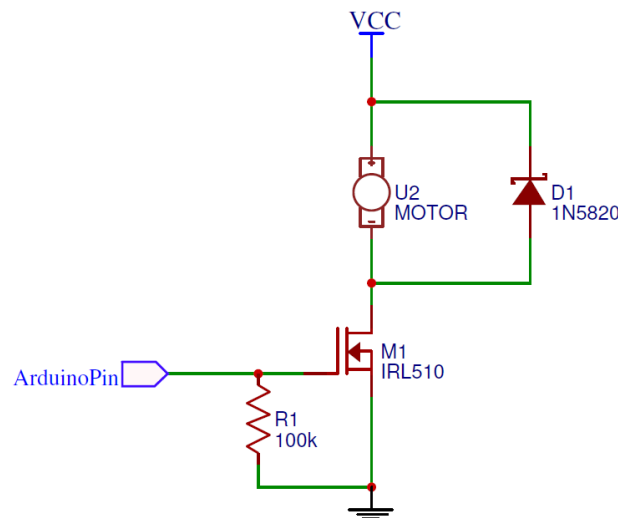


FIGURE 15: MOTOR SWITCHING CIRCUIT

In this schematic design, an n-channel MOSFET is used as a transistor switch. We chose to use a MOSFET instead of a NPN BJT in our design because of its very high impedance at the gate and its switching efficiency [1]. Because of the high impedance at the gate, no current will flow through the gate of the MOSFET, therefore there will not be any worries about drawing too much current from the Arduino digital output pin. Since we are using it as a switch, putting the MOSFET in its saturation region is simple compared to putting the BJT into saturation; there is no need to calculate any base resistor value. We chose the IRL510 power NMOS for its low $R_{DS(on)}$ for a V_{GS} specified at 5V, and the high drain current rating to handle the motor's inrush current and continuous current draw.

The resistor that connects the gate to ground is a pull-down resistor and it is used to keep the MOSFET off when the Arduino signal is low. A flyback diode is used to prevent any voltage spike across the inductive load of the motor since the current in an inductor cannot instantaneously change and a voltage spike compensates for it.

For our prototype design, a digital low-high (0 – 5V) signal from the Arduino controls the vibration motors. For the final production version, a pulse width modulation (PWM) signal will be used to control the motors. By varying the duty cycle of the PWM signal, the Arduino can control the speed and rotation of the vibration motors.

6.2 LED LIGHTING FEEDBACK SYSTEM

The LED lighting feedback system provides the secondary feedback for the gaming vest. The coloured LEDs are used as a health system for the user, with each colour indicating the different health that the user is in after each hit from a projectile, ranging from full health to game over. This system consists of various coloured LEDs, a PCB shield, BJTs, insulated wiring, an enclosure, and the same power supply used for the motors. Since these LEDs will be placed on the shoulders of the user via a PCB shield, the LED system must be properly designed for safety and reliability. The section below will explain the components used in this design and the overall design approach that we chose.

6.2.1 LEDS

Green, yellow, and red LEDs are used to indicate the health of the user, with green indicating full health, yellow indicating danger health, and red indicating game over status. Each coloured LED are characterized by its forward voltage, intensity (measured in millicandela, mcd), and current rating. Table 3 shows typical characteristics of the LEDs that are used today.

TABLE 3: CHARACTERISTICS OF TYPICAL LEDS

660	Ultra Red	1.8	2000mcd @50mA	15°	GaAlAs/GaAs -- Gallium Aluminum Arsenide/Gallium Aluminum Arsenide
635	High Eff. Red	2.0	200mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
633	Super Red	2.2	3500mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
595	Super Yellow	2.2	5500mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
592	Super Pure Yellow	2.1	7000mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
585	Yellow	2.1	100mcd @20mA	15°	GaAsP/GaP - Gallium Arsenic Phosphide / Gallium Phosphide
570	Super Lime Green	2.0	1000mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
565	High Efficiency Green	2.1	200mcd @20mA	15°	GaP/GaP - Gallium Phosphide/Gallium Phosphide
560	Super Pure Green	2.1	350mcd @20mA	15°	InGaAlP - Indium Gallium Aluminum Phosphide
555	Pure Green	2.1	80mcd @20mA	15°	GaP/GaP - Gallium Phosphide/ Gallium Phosphide

For our prototype design, an LED board is placed on the both shoulder of the vest. Each LED board consists of twelve through-hole LEDs soldered to a plated through-hole PCB shield: four red, four yellow, four green. Through-hole design enables us to quickly replace any broken or burnt out components. We also chose to solder the LEDs on a double-sided, plated perfboard. Perfboards allow placements of components to be more compact. A double-sided plated board allows components such as resistors to be hidden under the board. The final production unit will have specialized LED strips with surface mounted, programmable LEDs. The LED strips will also be powered by the custom rechargeable battery pack used to power the motors. Figure 16 shows the placements of the LEDs on a prototype perfboard.

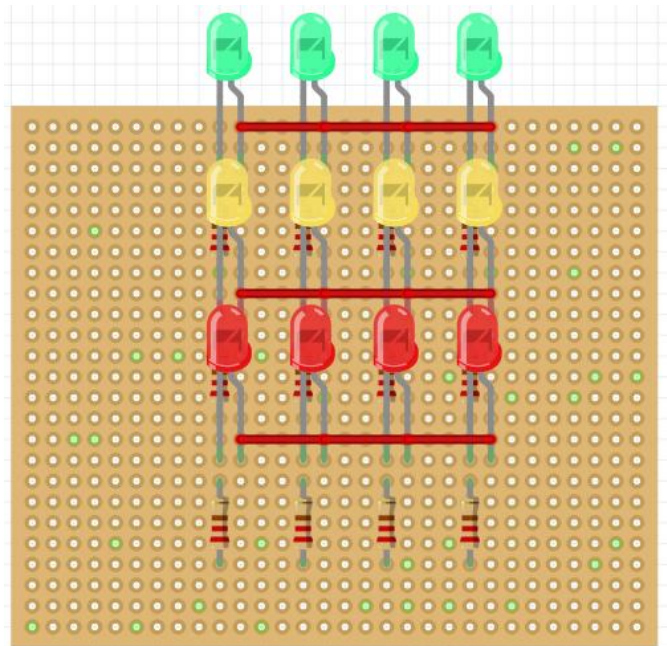


FIGURE 16: LED PLACEMENTS ON A PROTOTYPE PERFBOARD

The power is supplied by the 6V battery voltage source that also powers the vibration motors. To prevent any electrical hazard to the user, the LED board is enclosed in a transparent ABS plastic enclosure, and all wires that connect from the LED board to the main switching circuit are insulated. Figure 17 - 19 shows the simplified model of the LED board and the state of each LED for the different game mode that is included in the Arduino code (as mentioned in Embedded Software Design).

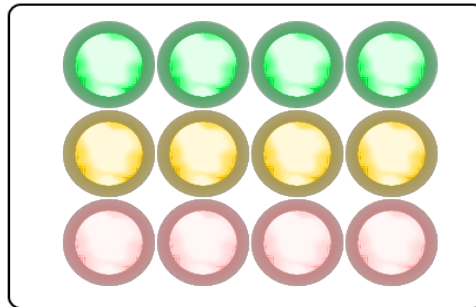


FIGURE 17: SIMPLIFIED LED BOARD. RESISTORS NOT SHOWN

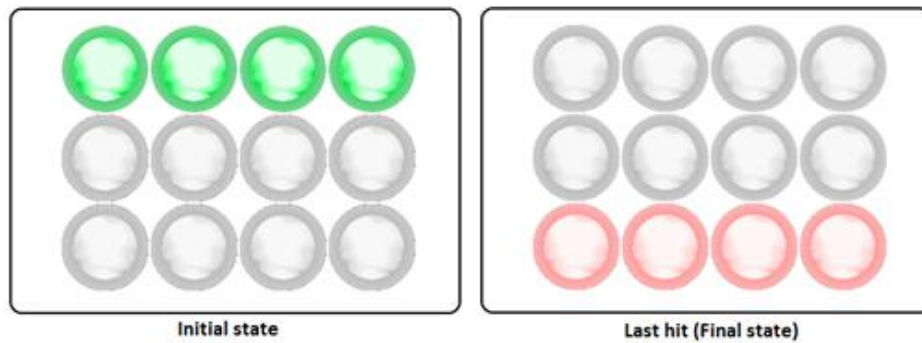


FIGURE 18: STATES OF EACH LEDS WHEN THE USER IS TAGGED BY THE PROJECTILE. SINGLE HEALTH MODE

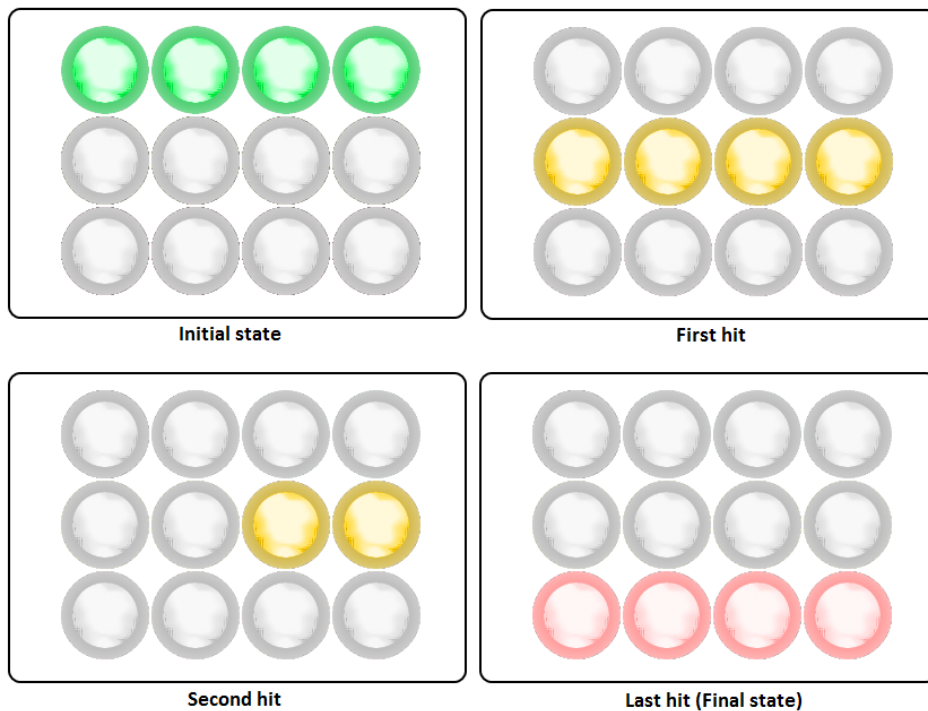


FIGURE 19: STATES OF EACH LEDS WHEN THE USER IS TAGGED BY THE PROJECTILE. MULTIPLE HEALTH MODE

6.2.2 LED CIRCUITRY

The design of the LED circuit is geared towards simplicity and modularity. Each coloured LED group is controlled by the Arduino digital pin through a transistor. The choice of transistor for our design is a BJT. The benefit of using BJTs as a switch for the LED circuit rather than MOSFETs is that the price per unit for BJTs is always cheaper compared to MOSFETs. The variety and availability of BJTs is greater as well, especially if we need to replace a BJT in a hurry. To act a switch rather than an amplifier, the BJTs are operated in the saturation region to control the LEDs. A base resistor is used to control the amount of current that flows through the base and ultimately through the collector.

Since the Arduino digital pins are connected to the base of each BJTs, the BJTs are placed on the switching circuit board instead of the LED board. This allows the use of shorter wires going from the Arduino board to the switching circuit board.

To power a group of four LEDs using the 6V power supply, the LEDs are connected in parallel with a current limiting resistor in series with each of them. The resistor in series with each LED ensures that all LEDs behave the same and each resistor dissipates the same amount of power. This is a safer design compared to placing a single resistor before the parallel LED chain where that resistor has to dissipate much more heat. Figure 20 shows the circuit for a coloured group of LED.

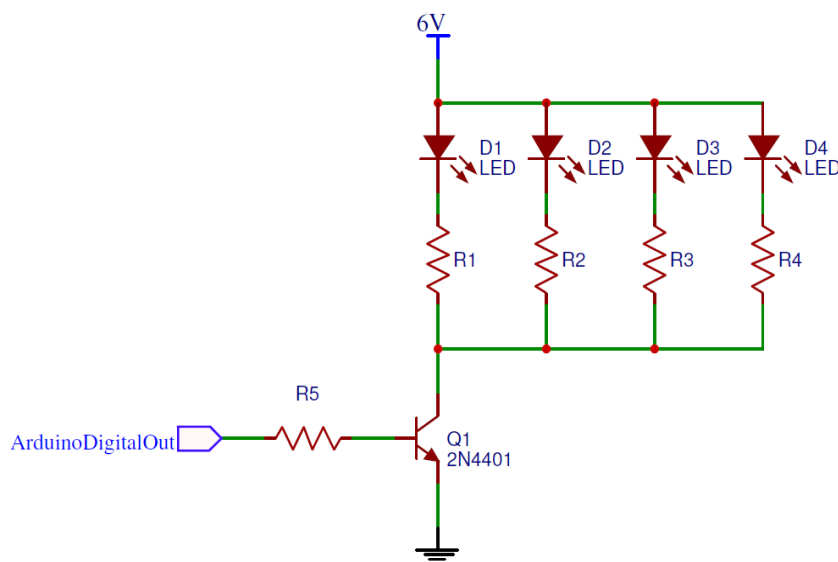


FIGURE 20: LED CIRCUIT SCHEMATIC

Since each color LEDs has different forward voltages, the resistors are chosen such that each LED draws 5 - 10mA of current. Although the LEDs are usually operated with a current draw of 20mA, maximum brightness is not necessary for our prototype. However, our production units require that the LED can be seen from a distance of 30.5 m (100 ft), therefore maximum brightness may be required.

7. ENCLOSURE

The enclosure keeps all the components together and protects the components from impacts and physical stress.

7.1 MICROCONTROLLER

Figure 21 shows the microcontroller enclosure. The material used to make this case is ABS plastic and it is designed to be light weight and small enough to be least noticeable inside the vest. The dimensions are 110 x 75 x 25 mm. It is placed inside the vest close to the front bottom-left corner. The casting and the lid consist of cut outs and holes for the USB ports and the power jack as well as some of the wirings.



FIGURE 21: MICROCONTROLLER ENCLOSURE

7.2 FEEDBACK CIRCUITRY

The enclosure for the feedback circuitry is also designed to be light weight and compact to fit comfortably inside the vest. Please refer to the Appendix, Figure 26A and 26B [4], for detailed specifications of the feedback circuitry enclosure and drawings. The enclosure is designed to house the circuitry for the motors and the LEDs. The enclosure contains the reset push button and the game mode toggle switch. Since MOSFETs and BJTs are used in the control circuit, there are vents to dissipate excess heat. The device controller is placed close to the microcontroller for short distance wirings between the two.

7.3 VIBRATING MOTORS

Since loose vibrating motors draw more current, the enclosure for these motors must be very sturdy. The prototype has four vibrating motors in the front and back of the vest. In the final production version more vibrating motors with variable speed and strengths will be used. Motors are placed inside a plastic enclosure that will isolate them from directly touching the body of the user for protection and safety and it will be the main medium for the user to feel the vibration. In order to feel the maximum effect of the vibration, the offset mass on the motor must not be impeded by any material. In our prototype design, the enclosure is made using PVC plastic cap fitting: the bottom piece will house the base of the vibration motor and the top piece will cover the offset mass and seal the vibration motor shut. A foam rubber will be wrapped around the base of the vibration motor to provide a tight fit when placed inside the plastic cap. A hole is drilled through the bottom cap in order to access the positive and negative leads of the motor. Figure 22 shows the side view of the motor enclosure.

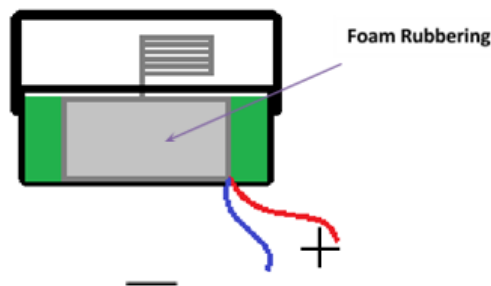


FIGURE 22: SIDE VIEW OF MOTOR ENCLOSURE WITH FOAM RUBBER SURROUNDING

7.4 BATTERY

There are two battery packs for this system. One battery pack holds a 9V battery for the Arduino board (Figure 23) and it has a switch to power the board ON or OFF. The dimensions for this battery pack are 68 x 33 x 21 mm.

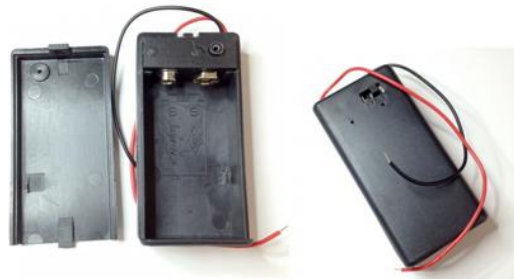


FIGURE 23: 9V BATTERY PACK FOR THE ARDUINO BOARD

The second battery pack holds four 1.5V AA batteries and it is used to power the LED's and the motors (Figure 24). This battery pack also has an ON/OFF switch.



FIGURE 24: 6V BATTERY PACK FOR THE LED'S AND MOTORS

7.5 RFID READER

Each of the RFID readers is enclosed between two 96.8 x 114.4 mm plastic plates. The middle section of the cover that faces outside has a cut-out, which is covered with Velcro strips. The reader is held in place using plastic spacer and screws. Figure 25 shows the dimensions of the RFID reader enclosure.

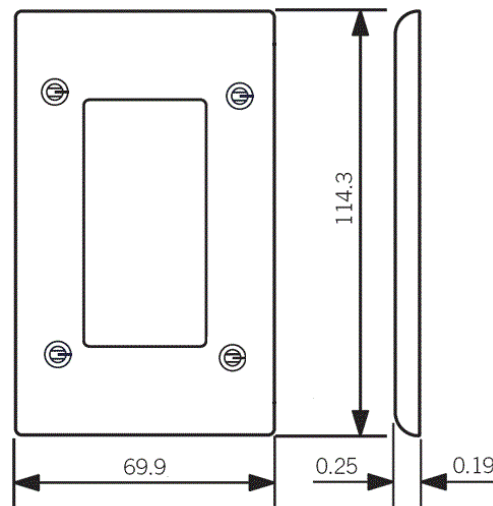


FIGURE 25: RFID READER COVER AND ITS DIMENSIONS

7.6 LED CIRCUIT

The LED circuit is mounted on a plastic base that protects the connections and soldering from touching the user's body and short circuit. The LED's are placed on both shoulder tops.

8. SYSTEM TEST PLAN

As outlined in the functional specification, the System Test Plan consists of Stage 1 Testing and Stage 2 Testing. In Stage 1 Testing we will be testing individual systems and their components. Each system can be tested separately and simultaneously. In Stage 2 Testing we will be testing the integrated system by combining all the systems together. By the end of Stage 2 Testing, product should be able to adhere to a typical usage as outlined in the functional specification [8]. A failure in any of the tests would require a redesign of the system or components that make up the system.

8.1 STAGE 1 TESTING

The CPU Module, at this stage, is USB powered for quick debugging of the RFID system. The feedback system circuits make use of a DC power supply for constant power. The verification procedure of testing at this stage is outlined for each system in Table 4.

TABLE 4: STAGE 1 TESTING PLAN AND PROCEDURE

Stage 1 Testing			
Unit Tested	Test	Verification Procedure	Pass/Fail
RFID System	Reader module is able to read the RFID tags at projected speeds	With the RFID reader enabled by the microcontroller, project the RFID tag towards the antenna.	
Feedback System	LEDs and motors adheres to programming requirements	Let the microcontroller output a voltage onto a pin that connects to the LED and motor circuitry to enable them	
	Vibrating motors provide adequate haptic feedback	Fine tune the haptic feedback by choosing a voltage that best provides the vibration needed.	
Enclosures	Vest is rugged enough to handle user maneuver and wear	Have a test subject wear the vest with a few components embedded. Take feedback on the comfort and maneuverability with the vest.	
	Casings of components can handle relatively strong impactful force	Perform a pressure test to ensure the casing can handle a heavy load (125+ Kg) that simulates a user falling on it.	

8.2 STAGE 2 TESTING

The CPU Module and the feedback system, at this stage, is battery powered to simulate the integration of the components. The verification procedure of testing at this stage is outlined for the integrated system in Table 5.

TABLE 5: STAGE 2 TESTING PLAN AND PROCEDURE

Stage 2			
Unit Tested	Test	Verification Procedure	Pass/Fail
Integrated System	User interface is handled adequately	Change the game modes via a toggle switch. The game mode is reset via push-button. Change in LED color will reflect health loss in health system game mode.	
	The vest is comfortable to wear and maneuver with	Have a test subject wear the vest with full components embedded. Take feedback on the comfort and maneuverability with the vest.	
	Feedback is provided in response to the RFID System	Project a RFID tag onto a test subject wearing the vest. Check to see if the feedback system performs adequately	

9. CONCLUSION

In this document, we described the hardware and software specifications of 360-NS-HS and we clearly stated the goals upon the completion of each component. These precise design details will be the guide for RealSimTech engineers to fulfill the requirements mentioned in the functional specifications, leading to a functioning prototype device.

The design of the circuits and the programming of the Arduino board have begun and the development is underway. We are confident that the proof of concept device will be completed by November 25th, 2014.

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APPENDIX

MECHANICAL DRAWING

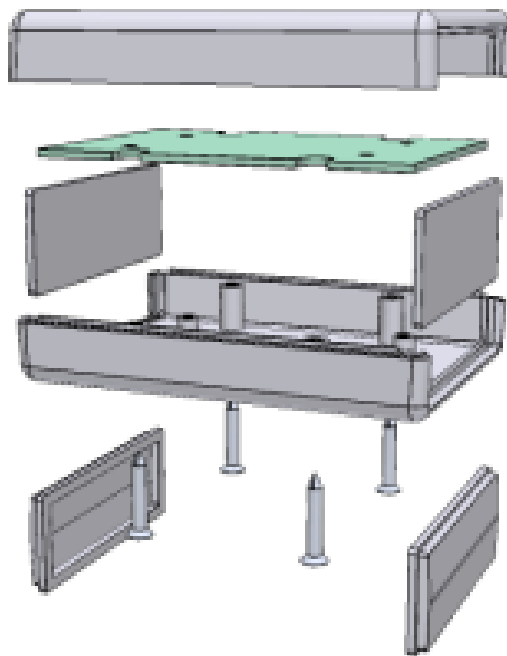


FIGURE 26A: FEEDBACK SYSTEM MECHANICAL SPECIFICATIONS

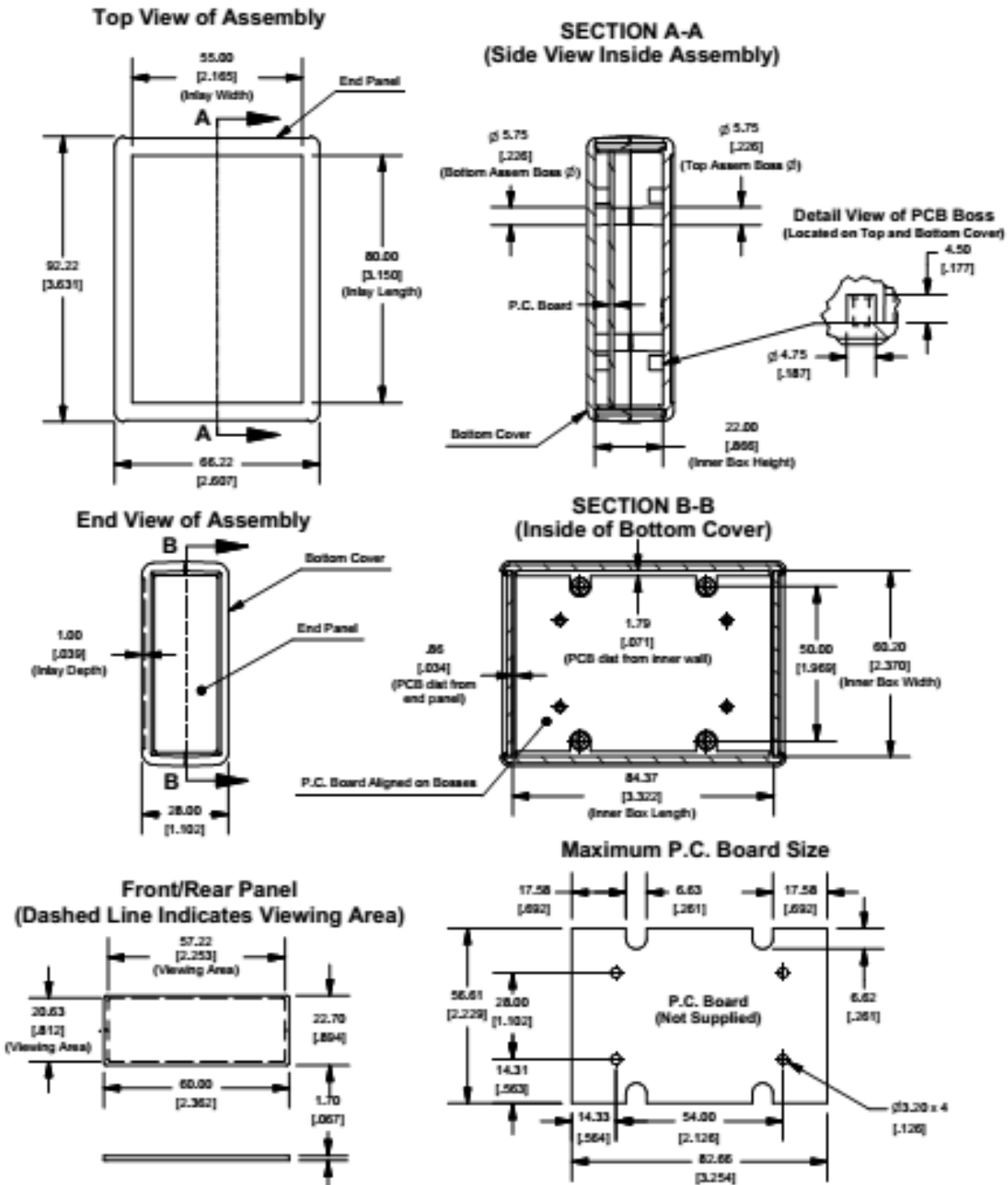


FIGURE 27B: FEEDBACK SYSTEM MECHANICAL SPECIFICATIONS