Home Interactive Notification Tracking (H.I.N.T)

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Abstract — **HINT is an interactive notification system that effectively assists a homeowner to teach their children responsibility and remind them to do tasks around the home. This paper lays out the design methodology used to incorporate the human senses into notification systems. The two-component system allows the user to schedule notifications in a fun and interactive way using light, sound, and touch. The primary technologies used to create a "smart" notification system are wireless communication and range detection. In addition, the modular HINT design can be applied to other users who require interactive notifications, as opposed to standard mobile notifications.**

Index Terms **— wearable sensors, internet of things, received signal strength indicator, Bluetooth, micro-controllers, real-time systems**

I. INTRODUCTION

HINT is a project that aims to make notification tracking and task learning fun and interactive. With all the "noise" in the modern-day world, notification tracking has become one of technology's hottest commodities. HINT hosts such notification tracking with the twist of being interactive with the user, primarily children learning chores and organizational tasks.

The system will interact with the user in ways that stimulate more of the senses than traditional notification tracking. Sight, touch, and hearing will be triggered beyond the typical stimulation level to produce a more natural response from the user, as if another person is telling them what to do. Such interaction with the senses will make the response more rapid, effective, and pleasant than the trained automatic response of the average notification system on a computer or handheld device.

HINT allows the user to set up notifications for a room in the house to trigger alerts at specific times. The project seeks to eliminate, or at least reduce, notification bypassing. This is accomplished by using a sensor module and a small wearable device around the home, or a room of choice.

The user will have a wearable device on their person and a module will be placed within a room. The collaboration of these devices will be used to apply interactive pressure to the user, so that the task will be completed.

The system will use wireless communication and range detection to output notifications at the correct time, for the correct person. Interactive notifications that are supported include audio output, a visual on an LCD screen, flashing light, and vibration. A fun, arcade-style, user response button is included so that the user can tell HINT when any given task is completed. The communication between the devices also helps determine if the task was or was not completed when it needed to be. The log of completion will be kept.

The product is also intended to help others who would like interactive reminders and avoid such activities on cell phones.

II. SYSTEM COMPONENTS

There are two major components in the system: a wearable device for the wrist and module that will be placed on a table in any given room. The following sections will cover both devices and their printed circuit board (PCB) designs.

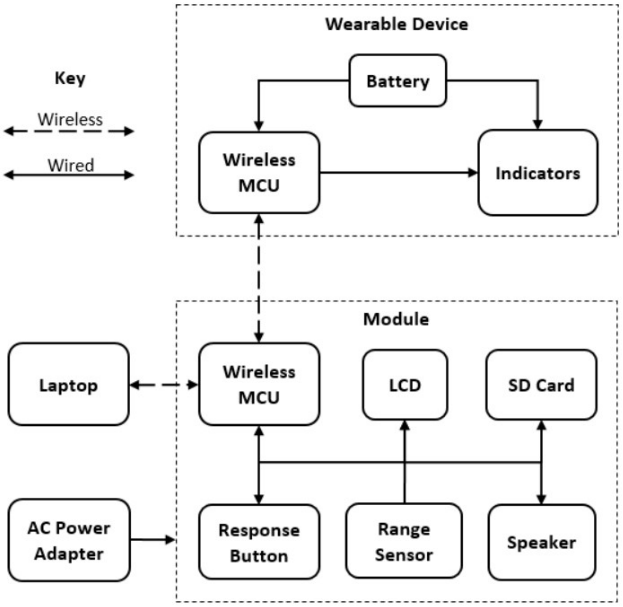


Fig. 1. HINT design overview.

A. Module

The primary job of the module is to utilize a sensory output notification system when a user is detected. It works in conjunction with the wearable device through a Bluetooth communication interface. When module receives information from the wearable device and determines if the correct person is near, the outputs synchronize and target the user. Feedback signals are sent back to the wearable, as well to synchronize both devices. The following sections explore the implementation, control, and design around each of the module's main components.

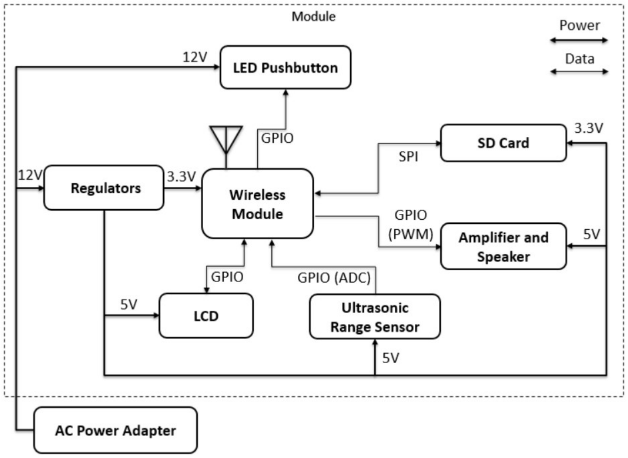


Fig. 2. Components and power/data interfaces of the Module printed circuit board.

1. Power Distribution

The module power distribution system is composed of the usage of a 120VAC power outlet, DC adapter, a TPS62160 DC/DC buck converter and a LP2985 low dropout (LDO) voltage regulator. The DC adapter will output 12 volts once connected to the power outlet. The 12-volt power rail is used to power the user response button and is also fed into the buck converter. To get an accurate DC load regulation, a voltage feedback loop is used on the DC/DC buck converter along with passive external components to step down the voltage to 5 volts with up to a 1 Amp continuous output current. This voltage rail will power the ultrasonic range sensor, liquid crystal display, amplifier, speaker and will be the input voltage to the LDO voltage regulator. The LDO voltage regulator will step down the voltage to 3.3 volts, which will power the Wireless module and SD card. Test points are also conveniently available for monitoring the health of each power rail.

2. Wireless Module

The wireless module used in this design is the Cypress CY8KIT-142. The module contains a flexible programmable system on chip (PSoC), an integrated trace antenna, and an oscillator. The PSoC itself is comprised of a 32-bit, 48-Mhz microcontroller, integrated voltage regulators, communication peripherals, digital logic blocks, pull-up and pull-down resistors, and a radio front end for Bluetooth communication. The chip is powerful enough to support the input and output requirements of the system and is flexible to growth.

The module is integrated into a reprogrammable design for easily changing the prototype. A connector on the Module PCB interfaces with the PSoC through a serial wire debugging (SWD) connection. This connector mates with a Cypress SWD to USB programmer, used to load and debug the PSoC firmware. The development software used to accomplish this is Cypress PSoC Creator, which allows for visual and C programming configuration of the PSoC. In the development environment, major peripheral and internal blocks of the PSoC are added to a "schematic" where attributes can be set through a graphical user interface. The software then builds an application programming interface (API) to control the components in the software design. The following module components are controlled in the software with their respective API functions.

3. Ultrasonic Range Sensor

The MaxBotix LV-MaxSonar-EZ0 is a high performance ultrasonic range sensor that provides distance measuring and proximity zone detection in a very small package, satisfying the design requirements. It has the capability of three different interface formats to a controller. Analog was chosen for this design implementation. This output format requires certain voltage scaling to determine the range because the output is scaled to the input power that is provided to the sensor. Depending on how close or far away the user is positioned, the sensor will output different voltage levels, clearly indicating a higher voltage if the user is far away in range or a lower voltage if the user is at a close range to the sensor. The following equation will determine how many volts are indicated per inch:

$$V_i = \frac{V_{cc}}{512} \text{ [V/in]}. \tag{1}$$

V_{cc} is the supply voltage, in this case 5 volts. Once the voltage scaling is known, the range can be properly calculated using the following equation:

$$R_i = \frac{V_m}{V_i} \text{ [in]}. \tag{2}$$

V_m is the measured voltage. The sensor also has high sensitivity and wide beam capabilities that give a 2D representation. These beam patterns are read by looking at the target size and detection.

The firmware used to control the ultrasonic range sensor utilizes an analog to digital converter (ADC) block in the peripheral features of the PSoC. The ADC is configured with 12-bit resolution and 55,555 samples per second. The conversion is then read into a register and processed into range (in inches). This distance measurement is then fed into the higher-level algorithm.

4. Audio

The general-purpose speaker is included in the design to enforce the execution of tasks and stimulate the sense of hearing. It is an 8 ohm, 0.5-watt speaker. It is controlled by the Texas Instruments LM386 low-voltage audio amplifier, which isolates the drive current and improves audio quality. A default gain of 20 dB is applied for a stronger audio output by configuring an open between pins 1 and 8. The resistive network on the front end acts as a voltage divider to reduce the PSoC output to the acceptable input range for the amplifier. Adding a 100uF electrolytic capacitor between the voltage rail and ground, close to the pin, cleans up the noise and allows a clearer audio output signal. The series capacitor at the positive input of the amplifier is used to block DC signals. The rest of the configuration supports low pass filtering for the audio signals.

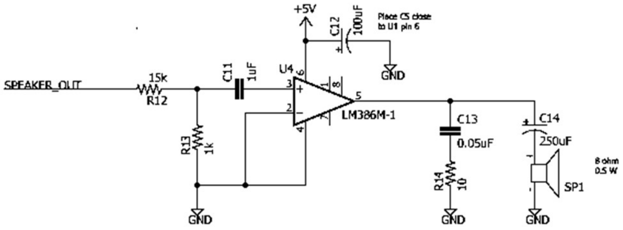


Fig. 3. Design configuration of the audio amplifier and speaker.

The software currently used to control the audio circuitry instantiates a pulse-width modulation (PWM) block within the PSoC. The PWM block utilizes the programmable logic resource of the chip and is controlled through software accessible registers. The block is configured for 16-bit resolution and the frequency can be changed on the fly to output different tones. An example frequency range that is set in the design is 500-5,000 Hz. The duty cycle of the PWM can also be changed to increase or decrease the volume. The closer the duty cycle is to 50%, the stronger the intensity of the sound. The PWM control registers are accessed by the higher-level algorithm to integrate audio in the notification system. A future design exploration will be using a current digital to analog converter (IDAC) block to output raw audio data (i.e. voice recording) to the audio circuitry and speaker.

5. Liquid Crystal Display

The LCD is only a digital output that supplements the sensory output. Its sole purpose is to show the specific instructions of the scheduled task. The display is the Electronic Assembly DIP162, composed of a 2 x 16-character segmented array. It is simple enough that it doesn't take away from the sensory aspect of the project, yet large enough to be useful to the user. The DIP package allows for easy system integration and the four-bit interface allows for low MCU peripheral consumption. The hardware connection is through GPIO and doesn't consume any peripheral block on the PSoC.

The firmware used to control the display simply sets digital input/output pins high or low. No peripheral is taken up by the display, but timing is important to make sure the LCD module understands the data correctly. The developed API allows for simple string writing, which lets the higher-level algorithm easily control the display, per the specific task.

6. Response Button

The arcade style LED pushbutton serves two functions. It is used as a sight-stimulating light output, as it's light intensity is easily noticed thanks to a 12 volt supply. It also fulfills HINT's purpose and requirements to have the capabilities to be interactive and reliable by being the input interface of the user. The button contains an internal switch which shorts two pins when it is pressed.

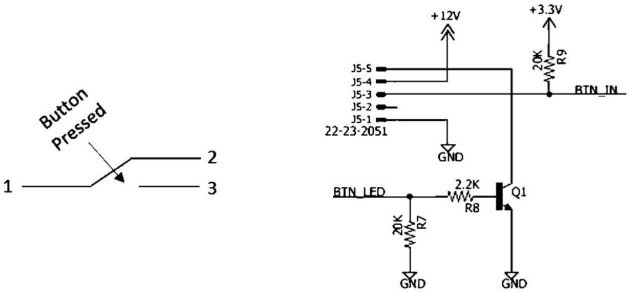


Fig. 4. Simplified model (left) and schematic design (right) of the 5-pin user response button.

It is four inches in diameter, it has a five terminal device with independent LED and switch circuit that can be easily replaced. The button runs on 12 volts with an internal 480 ohms current limiting resistor. Max power dissipation is .24 watts with a longevity use of 10 million cycles. An NPN bipolar junction transistor (BJT) is used to isolate the load of the LED from the PSoC drive current, and pull-up and pull-down resistors are used to ensure states aren't floating in standby conditions.

The firmware used to control the button instantiates GPIO input and output pins. The LED output is toggled at a specific frequency and the state of the button is captured to detect user response. The higher-level algorithm accesses the registers where this data is stored.

7. Secure Digital Card Reader

The Secure Digital (SD) Card reader gives the PSoC an interface for extended memory storage. The reader interfaces to the PSoC through serial peripheral interface (SPI) communication. The Yamaichi FPS009-3001-BL is used in this design. It contains a write protection line that is driven as an inverted "write-enable" signal from the PSoC. It also contains a detect signal that will alert the PSoC if an SD card is present in the reader. The rest of the signals define the SD card interface in SPI mode.

While the main purpose for the extended memory is for future growth, the firmware control has already been explored. A SPI communication block will be instantiated to control the SD Card at the physical layer. This means that 512 byte transactions will occur at a time between the PSoC and the SD Card. The PSoC will be able to read and write to the card as if it were extended memory. However, it is slower and uses large transaction widths [1].

B. Wearable Device

The wearable is the essential counterpart of the module for realization of the HINT concept. The primary job of the wearable is to provide a proximity detection to the module for initiating notifications when the correct user is detected. The secondary function of the wearable is to emit auxiliary notifications. These notifications will add extra sight and touch stimulation in the form of an LED and a vibrating motor.

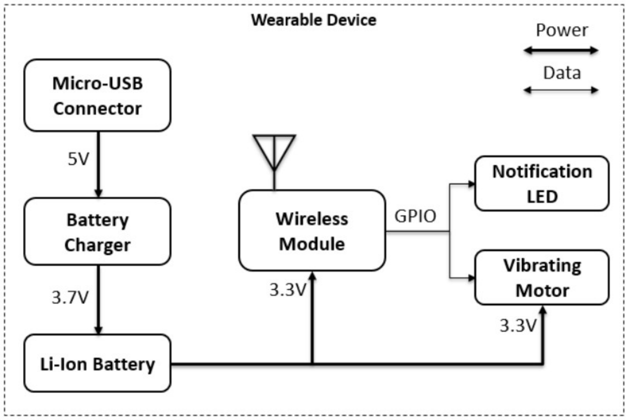


Fig. 5. Components and power/data interfaces of the Wearable Device printed circuit board.

1. Power Distribution

The power distribution through the wearable consists of a lithium ion battery and a battery management IC. A small 3.7-volt battery was selected to power the device. Measuring only 3 x 9 x 10 mm, it is the smallest battery available that is fit for the design. For charging, the Texas Instruments BQ25101 battery management IC was selected because of its ability to utilize a relatively low charge current for the battery. The input voltage range is 3.5-28, which provides a broad compatibility to multiple voltage sources. When plugged in through micro-USB it charges the battery at an externally programmed current of 12mA. It is programmed using external resistors and capacitors, and the charge current was setup by using the following equation:

$$R_{ISET} = K_{ISET}/I_{OUT} \tag{3}$$

Where $K_{ISET} = 135A\Omega$ and is the fast charge current factor for the output charge current. So, for 12mA, $R_{ISET} = 11.25k$. Similarly, a Pre-termination current was selected to be 10% if 12mA by using the following equation:

$$R_{PT} = \%T \times K_T = \%PC \times K_{PC} \tag{4}$$

Where %T is the percent of fast charge where termination occurs, PC is the percent of fast charge current that is desired during pre-charge, K_T & K_{PC} are gain factors for the current. The battery selection and programming is one of the most essential design requirements for the system as it is a sensitive design.

For added functionality, the BQ25101 also has a pull-down /CHG pin that is used to provide a charging indication via an LED. The best benefit found from this IC was also the ease of integration into the final design since it could connect directly to the host system. Since it did not require any switching requirements the BQ25100 essentially handled all power requirements seamlessly. It's size of 1.60 mm x 0.90mm also made it the smallest available IC on the market at the time.

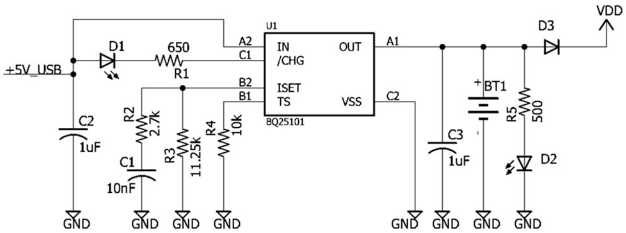


Fig. 6. Charge management IC receives power from micro-USB connector and governs the battery.

2. Wireless Module

For wireless communication with the Module PCB, the Cypress Cyble-022001-00 EZ-BLE programmable radio on chip (PRoC) Module was selected. It provides a 128-KB flash memory, 16-KB SRAM memory, and 32-bit processor operating at up to 48 MHz. Additional features include integrated voltage regulators, simple communication blocks, and pull-up and pull-down resistors. For communication, it provides a radio front end for the Bluetooth interface needed in the system. Due to its small size of 10 x 10 x 1.80 mm, it could fit within the 1.3" x .80" board dimension requirement. A Bluetooth firmware stack was provided by Cypress with the module, as well as hassle-free development application examples.

As with the Module PCB, the programming interface is over SWD, making it programmable with the same Cypress adapter. The module itself also contains an integrated ceramic chip antenna, which makes it a superior choice over modules that require external radio-frequency hardware. Its transmission output power ranges from -18 dbm to +3 dbm with a -1dB resolution for the received signal strength indicator (RSSI) feature.

3. Sensory Notification

For sensory outputs, a standard 0805 SMD LED was selected along with a mini vibrating disk motor. Since this is a LED that needs to be noticed, a high current of 20mA was selected to illuminate the LED to a high brightness. The LED is connected to a GPIO pin on the EZ-BLE module and is programmed to go high upon receiving a notification signal from the module.

The mini vibrating disk is placed on the bottom side of the wearable so the user can feel the output vibration when there is a notification. A higher current of 100mA was selected to provide sufficient energy to the motor. A MOSFET is connected between the module and motor to provide a switching function to the motor and interchange notification outputs, depending on the user's preference. The output vibration is set by the EZ-BLE module GPIO pin.

The higher-level algorithm can access the registers of the LED and motor to toggle the outputs at any given frequency.

III. SYSTEM CONCEPT

The concept behind the HINT system is simple: an alert needs to be produced for the correct person at the correct time. With the hardware and software control already in place for each component, the next step is the integration of each. The first important question HINT needs to ask is "Is it the correct time for a notification?" Once this question is answered and range detection is actively sensing, the follow-up question is "Is the person detected the correct person for receiving the alert (i.e. the user)?" The following detection algorithm section describes in detail the steps taken by the system software and hardware to answer these questions and increase accuracy as much as possible. If the algorithm returns an alert output, the system proceeds to synchronize the proper outputs, and then determines completion of the task. The next subsections cover these concepts.

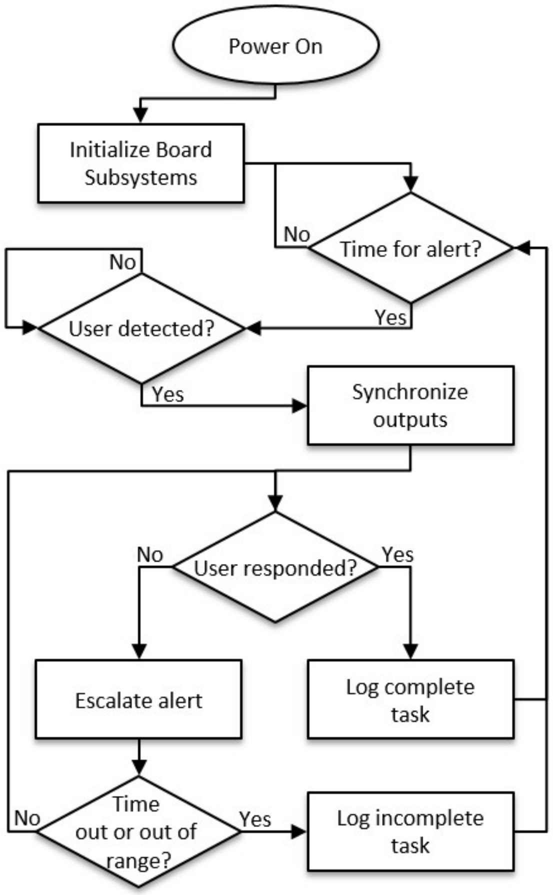


Fig. 7. Software flow diagram for the complete HINT system.

A. Detection Algorithm

A pre-requisite for detecting the user is a schedule of tasks implemented in the software. The user can schedule a specific notification for a specific time. Although the system is scalable for high-level software through a mobile Bluetooth connection, this is currently done by either (1) implementing it in the embedded software of the Module or (2) sending data from a laptop with a Bluetooth dongle. Thus, the schedule of these programmed tasks is stored on the Module MCU's non-volatile memory, the Module's SD Card, or the memory of the laptop (externally). The schedule is also correctly synchronized to the real world by implementing a real-time clock in the Module MCU. The system can then "wake up" and begin detection when the correct time for an alert comes.

The detection algorithm begins by using the ultrasonic range sensor. The sensor gets configured to read if there is any activity in its field of view (FOV). This is one criteria that leads to proper notification and alert delivery. However, this method alone introduces high error. There may be multiple people in the FOV at any given time, for instance, or one person that is not supposed to see receive the notification. HINT needs a specific way to also determine if the person it "senses" is the person it needs to deliver the alerts to.

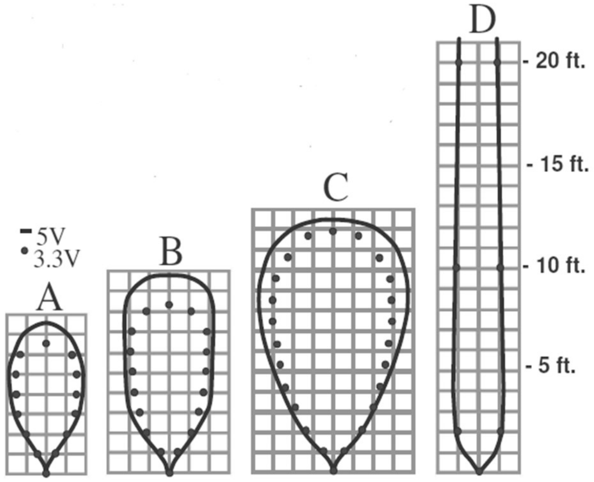


Fig. 8. Ultrasonic range sensor's beam characteristics under certain test cases. Notice wide beam pattern capability for close range and range distance capability in case D [2].

Therefore, HINT will also use the RSSI feature of the Bluetooth communication protocol to determine if that is the right person. A distinct RSSI threshold value is compared to the measured value. This part of the algorithm attempts to reject detection of the user at a far distance or in an adjacent room, as signal strength decreases at a distance and through a medium that is not air (like a wall). While this method still isn't bulletproof, the accuracy of detection greatly increases, as opposed to only using range and motion detection. The physical placement of the Module in a room will help improve this algorithm, as well. Placing the Module in a corner will optimize the FOV for the range sensor and reduce the error in RSSI measurements, since a weaker signal will be read behind the sensor.

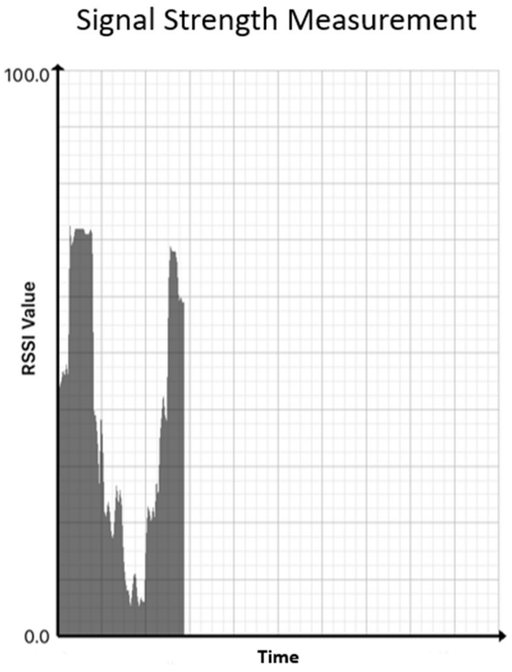


Fig. 9. Example RSSI measurement moving closer and farther from the point of measurements.

Thus, the detection algorithm returns a detection if the range sensor detects nearby motion and the RSSI threshold is met. If the correct user is not detected (or nobody is within range) when it is time for an alert, the system remains in a standby mode, with an interrupt that re-runs the detection algorithm upon sensing human motion. This loop continues until the notification is fulfilled.

B. Alert Synchronization

Once detection is successfully completed, the outputs synchronize to optimize the alert experience. This is where the functional software control comes into play for each component on both devices, and they harmoniously work together.

Light and sound synchronize via the user response button (which has a LED inside) and the speaker. A pleasant tone is produced at the same frequency of the light flashes to influence a natural human response to the alert. Although this is the current configuration, the hardware is in place to also output voice recording through the speaker. One future expansion will be recording a voice through a Bluetooth-enabled mobile device, transmitting the recording to the Module, storing it in the SD Card, and playing back the recording at the correct time.

LED flashing and motor vibrating on the wearable also synchronize with the output frequency on the module. The coordination is done through Bluetooth communication and is used to further enhance the sense stimulation offered by the module.

The LCD screen is the last resource to aid the output. In the current configuration, where no voice reminders are given (only tones), the LCD is used to give the specific task instructions. The idea behind this is that the user may want to read the specific task, once the primary alert system has gotten his or her attention.

C. Task Completion Detection

Once the outputs of the system are successfully synchronized and delivered, the HINT system enters a routine to determine if the task for the given notification was completed. In the simplest case, the user presses the response button to show that the task was completed or recognized. HINT can implement a few levels of alert "escalation" if no user response is recorded via the response button. This further influences the completion of a task if it was bypassed for any reason. In the current configuration with only a single module, HINT can escalate notifications by continuing RSSI and range readings, while increasing the volume and frequency of the outputs on both the Module and the Wearable Device. The "smart" aspect of this algorithm would be the transition of output intensity from the Module to the Wearable Device if the person continues to go away from the Module, without responding to it. The vibration and light output on the wearable will persist for a brief amount of time when the user goes out of the Module's range. If a response is still not recorded, the task is logged as incomplete. A timeout is also available if the user remains in range and does not respond.

IV. TESTING

Specific test conditions were developed to better demonstrate the systems functions. First, the module was placed in an open location perpendicular with the floor so the range sensor would have a clear field of view for detection. The wearable was carried around and was programmed to output a notification when the module detected it. Initially, the module was programmed to output a notification when the user was detected up to 8 feet in front of the module. When the range sensor detected a being within 8ft. it checked the corresponding RSSI value for the wearable. If the RSSI value was within the preprogrammed threshold for that range, the module would output its required notifications and would send a signal to the wearable to output the notifications on the wearable as well. The same procedure was repeated at 12, 20, and 30 feet. To determine the correct RSSI value that corresponded to a specific distance there was a trial and error test to calibrate the notifications to their respective distance. In other words, at 8ft. only the LED would turn on, at 12ft. the vibrating disk motor would initiate and LED off, at 20ft. both notification outputs were set HIGH, and at 30ft only the LED was illuminated again. These were tested in this manner to better give an understanding on the latency between RSSI measures and to assist in the development of performance parameters required for testing.

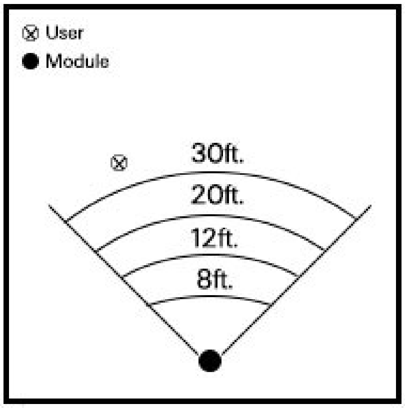


Fig. 10. System Range Overview

To test a notification output only for a user wearing the wearable, another individual was used. With the module setup to initiate its notifications only at an 8ft. detection, a user walked in front without the wearable. The module did not respond to the presence of the individual with no wearable present. Once the user with the wearable came closer, approaching from 30ft. away, and got within 8ft. the module initiated its notification sequence.

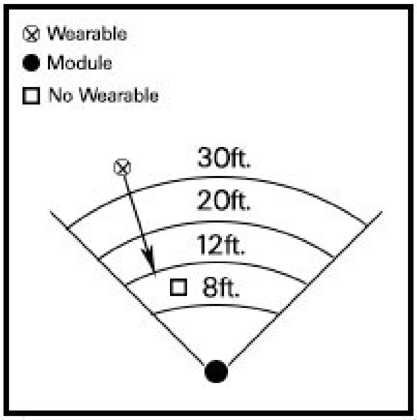


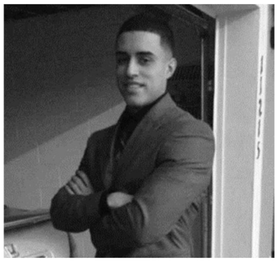
Fig. 11. System Range Test Setup

Overall the proximity detection testing by the system using RSSI was a success and proved to provide a simple solution.

V. CONCLUSION

HINT is a modular and scalable design that integrates the human senses in a reminder system. The Bluetooth platforms on both devices allow the designs to easily integrate into mobile applications and the cloud, namely the Internet of Things (IoT). The "on the fly" programmability of both devices allow the prototype to be consistently modified and improved, and integrated into different applications for different users. The multiple methods used to detect the user increase detection accuracy and allow for future growth.

THE DESIGNERS



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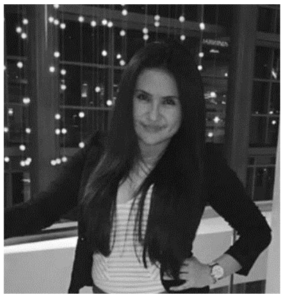

Maria-Camila Nuñez is graduating with an Electrical Engineering degree from UCF. She interned for 16 months within Lockheed Martin's Testability and Electrical Engineering departments. Her interests are in analog hardware design and system integration and test. She enjoys working on power systems, motor control solutions and troubleshooting electronic hardware. Post-graduation she plans to pursue her Master in Electrical Engineering.

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