Baby Guard Final Project Review Report

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Abstract—Tracking the physical status of our beloved children is one of a parents' key priorities. However, when parents try to use market products to ease their exhausted baby-care task, they can hardly find a user-friendly tool that takes care of both temperature monitoring and activity tracking, as well as distance alert.

BabyGuard is designed as a wearable & rich featured baby monitoring and safety system, which is able to provide real-time feedback that will allow parents to remotely monitor several key physical status indicators of a baby, including temperature, motion and distance status. It is also able to provide instant distance alarm, preventing severe circumstances such as kidnapping, getting burned when playing with fire, or heatstroke when left alone in a car.

The BabyGuard alarm system contains three major components: a wearable device, a home server, and an Android app that installed on a mobile phone.

The wearable device is designed to be worn by a baby, and to send detected data to a pre-paired parent's mobile phone or home server through Bluetooth.

On connection of the wearable device, the home server will receive the data in a user-defined time period and stream the data to the local drive. The home server has the capability to perform post-data analysis and data sharing.

The Android app is able to receive the data transmitted from the wearable device and synchronize the data in the user interface of the app. The app has the capability to provide a real-time alarm if the detected temperature exceeds a pre-defined threshold and if the Bluetooth is disconnected.

1 Introduction

Child safety has become a growing concern in recent years, despite the effort put on developing modern equipment to secure our valued children. There are several common concerns around children:

1) Missing/kidnapping. Every year, there are 200,000 children kidnapped/stolen/missing in China [1], and 800,000 missing in the USA [2]. That equates to roughly 2,700 per day!
2) Children are burned when playing with fire. Every day, over 300 children between the ages of 0 to 19 are admitted in emergency rooms for burning-related injuries and two children die as a result of being burned [3]. Younger children are more likely to sustain injuries from scald burns that are caused by hot liquids or steam, while older children are more likely to sustain injuries from flame burns that are caused by direct contact with fire.
3) Heatstroke is caused when the child is left alone in a car in summer. On average, every 10 days there will be a case of a child who dies from heatstroke in a vehicle. In more than half of these tragedies, the caregiver forgot the child was in the car. Since the car can heat up 19 degrees in just 10 minutes, the young children that are left alone face extremely high risk [4].
4) The body temperature of infants is not stable in the first several months after birth since they have not fully developed body heat stabilize system. Thus, a rapid increase in body temperature in a short period of time may happen, and this requires parents to take extra care about their baby especially when they have a fever [11].

Although being vulnerable and facing uncertainties, an infant or toddler only can use limited words and expressions to indicate their situation. Hence, an instant alarm and regular monitoring are essential ways to secure young babies.

In order to help with these needs, several products have been developed to solve specific problems:

1) Product A- Wireless Baby Monitor (Vvcare-851) [5], monitors temperature, but only works in a fixed location, and does not include a distance alarm and is not wearable.

2) Product B- Mini Smart Finder (Digoo DG-KF30) [6], which is a wireless anti-lost locator for kids with a distance alarm and it is wearable. The designer has not included temperature tracking. Another major drawback of this product is that it is too small to be carried by a baby and may lead to suffocation.

TABLE 1 Comparison of BabyGuard with Current Products

	Product A	Product B	BabyGuard
Body Temp.	X		X
Distance alarm		X	X
Wearable		X	X
Cost	US$74	US$ 4.71	US$ 45

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So, to counter with the known limitations of the current products in the market, BabyGuard is introduced. This monitoring system consists of three major components: one wearable device, one home server, and an Android app installed on a mobile phone. We have summarized the comparison of our project to the two previously-mentioned products currently available in the market in table 1.

The sensor device can be worn by a baby to send a baby's body temperature and motion data to a pre-paired parent's mobile phone or home server through Bluetooth.

On connection of the wearable device, the home server will receive the data in a user-defined time period and stream the data to the local drive. The home server has the capability to perform post-data analysis and data sharing.

The Android app is able to receive the data transmitted from the wearable device and synchronize the data in the user interface of the app. The app is able to monitor the baby's body temperature and send a sound and vibration alarm to the parents immediately whenever an abnormal body temperature is detected. In this context, an abnormal situation occurs due to the suddenly fluctuation the body temperature from normal. The app is also capable of providing a distance alarm when the baby moves out of the safety zone, i.e., 21 meters from the device and when the Bluetooth connection is disconnected.

2 Related Work

2.1 Survey of Existing Monitoring System

Looking after our babies is not similar to taking care of aged people and conscious patients since adults can give immediate feedback if they are not feeling well. Hence, a properly tailored home monitoring system, which is specially designed for a baby is truly needed.

We have performed a literature review for existing monitoring systems that are able to monitor a baby's physical status by using the Android mobile phone as a control interface. The following ideas have already been evaluated.

- Using a GSM module to send an alert to the mobile phone in the form of SMS, when the designed system detects a wet baby diaper [12].
- Taking care of an infant by controlling the movement of a cradle automatically [13] [14].

2.2 The Needs of End User

Certain survey results have revealed that parents are keen to understand their young baby's following manifestation:

1) Parents want to understand their baby's need when they are crying or making a sound [16].
2) An alarm should be sounded in a timely manner when irregular symptoms are shown on their children [17].
3) A parent needs to know if a child falls sick while the parent is working and away from home [18].

3 Design And Implementation

3.1 Design Overview

The architecture of the overall system is shown in figure 1. It consists of both hardware and software and is designed to satisfy the needs of parents from the mentioned survey results as indicated in the section 2.2 as much as possible.

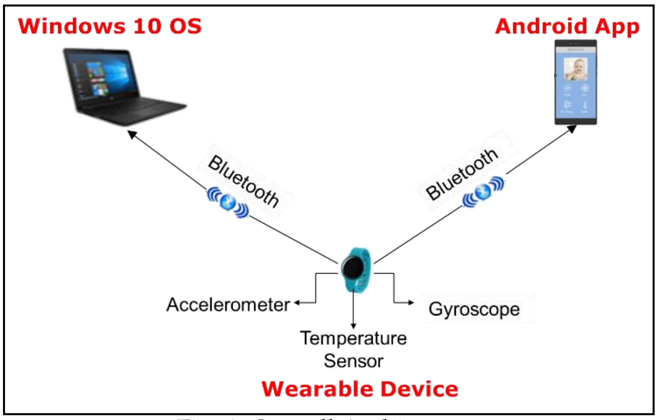


Fig. 1. Overall Architecture

The wearable device, which generally contains three sensors, is attached to a baby's ankle (Figure 2) to track a baby's physical data, including body temperature and motion. The detected data is then ready to be sent to the home server and parents' mobile phone through Bluetooth.

An Android application is developed for parents to view the real-time synchronized data. In addition, the application is able to provide an alarm signal by using vibration and sound of the smartphone to alert parents if an irregular symptom is detected, i.e., body temperature is higher than a pre-defined threshold.

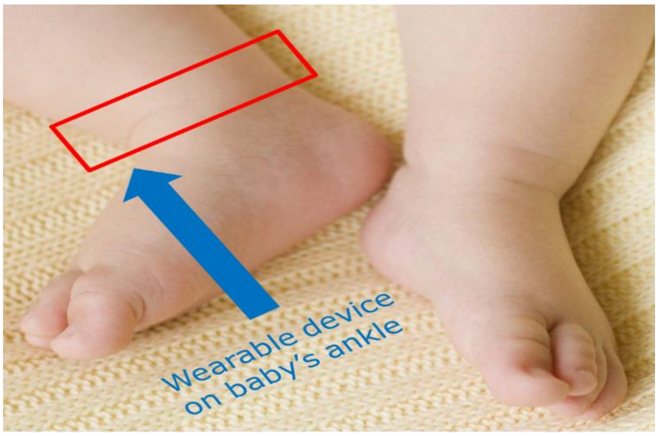


Fig. 2. Monitoring Device Attached Location

A home server is used when parents are at the office or away from home. In this circumstance, an effective connection between the wearable and the smartphone is not able to be established. Then, the home server will take over the responsibility to receive the physical data from the baby. The received data in the home server is able to be shared with other family members and used to perform post-data analysis if needed.

Figure 3 shows the basic block diagram of the wearable device system. The system consists of the following blocks:

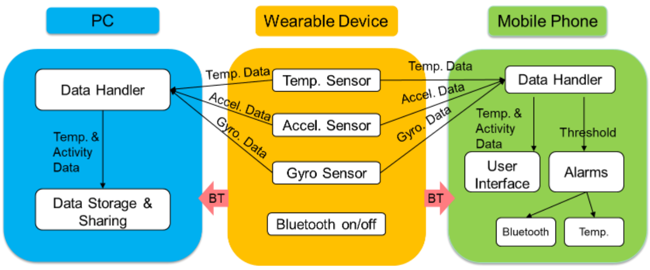


Fig. 3. Block Diagram

- Temperature Sensor: A temperature sensor is installed in the wearable device that measures the temperature intensity. The sensor detects the baby's body temperature when the wearable is attached to his/her ankle and the detected temperature data is converted to an electrical signal.
- Accelerometer and Gyroscope: Those two sensors also reside in the wearable device. The major function of the sensors is to monitor the motion data of the baby and convert the detected data to an electrical signal.
- Bluetooth: The major component exists in the wearable device, which is able to send electrical signal data to the home server and mobile phone.
- Data Handler: There is a data handler in both the home server and mobile phone. The data handler receives the electrical signals sent by various sensors via Bluetooth and converts them back to data.
- User Interface: The GUI in the mobile phone which displays the temperature and motion data transferred from the data handler.
- Data Storage and Sharing: This function in the home server is able to record the activity and temperature fluctuation pattern of baby and enable data mining and further activity baseline studies.
- Alarm System: The alarm system is triggered under the following conditions:
    - If the detected body temperature is higher than the user-defined threshold, which may be set according to past experience.
    - If the Bluetooth connection between the wearable device and mobile is lost, then there is a high possibility that the baby is out of the safety zone.

3.2 Design of Wearable

The wearable is a small and compact device worn on the ankle of a baby. It connects via Bluetooth (BT) to the mobile phone or home server and transmits temperature, acceleration and gyro data to them. An alarm is triggered in the mobile phone if the Bluetooth connection is broken when the mobile phone or home server is not reachable. The detailed state chart of the wearable device may refer to figure 4.

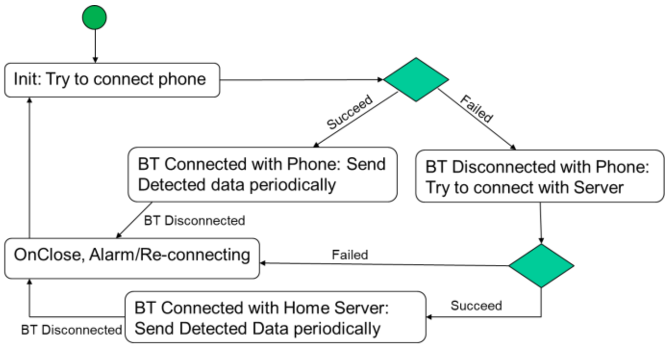


Fig. 4. State Chart of Wearable Device

The wearable device is available in a round form-factor which is coin-cell powered (replaceable battery). The device is equipped with Bluetooth, memory and a Microprogrammed Control Unit. Those components are protected by a 2-sided plastic case. The general arrangement of the device is illustrated in figure 5.

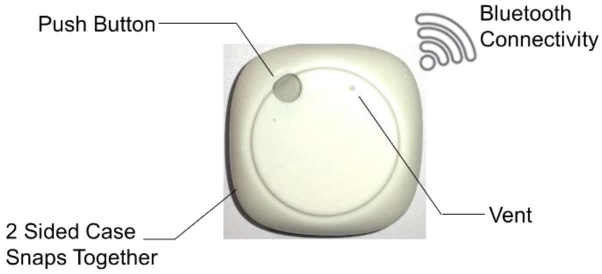


Fig. 5. Overview of Wearable Device

The internal view of the wearable device, which clearly displays the location of various sensors, coin battery, and push button, is shown in figure 6.

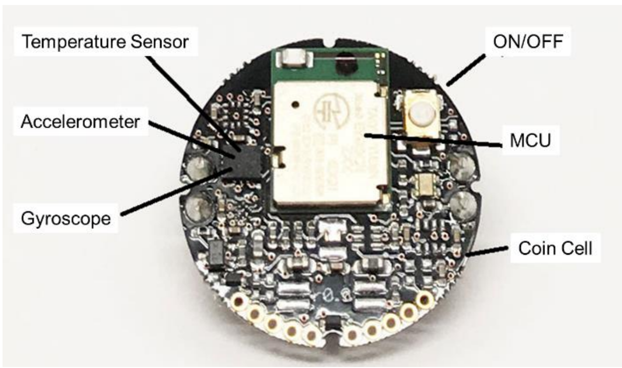


Fig. 6. Internal View of Wearable Device

The accelerometer and gyroscope (BMI160) form a small, low power, low noise 16-bit inertial measurement unit designed for use in a mobile application like augmented reality or indoor navigation which requires highly accurate, real-time sensor data [8]. This sensor is ideal for our project since it has already been calibrated and has high accuracy to track our baby's movement. The orientation (X, Y, Z) of the BMI160 is defined in figure 7. This definition of orientation is essential when tracking a baby's activity.

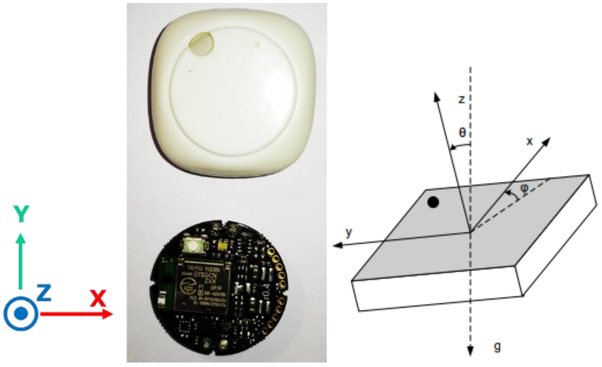


Fig. 7. Axial Definition for BMI160

The temperature sensor (NCP15XH103F03RC) is a type of sensor where the output is an analog DC voltage signal and can measure a temperature range from -40 degree to 125 degree, which is suitable enough to measure targeted human body temperature and ambient temperature [9]. This type of sensor is preferable for a baby especially since the sensor only requires a small output voltage (5V) and will not cause any harm to health. With an accuracy of ± 0.5°C, the output can be converted from voltage to degree Celsius based on the function: ***Temp (C) = Output Voltage*** * V_{input}***/1024*** [10]

Each wearable device has a unique 6-byte MAC address as an identifier. This important feature allows users to track multiple babies' status if there is more than one baby in the family. Meanwhile, the Bluetooth signal strength can also be tracked separately according to the device's MAC address when multiple devices are in use. The continuous signal strength monitoring is the foundation for distance alert.

A 220mAH CR2032 coin cell battery is used in designing the device so it can be thin, light and powerful. We propose this solution rather than using a popular lithium battery since the consequences of misusing a lithium battery include serious safety issues. Considering the unpredictable activity pattern of babies, we do not want to place our beloved ones in a dangerous situation.

A detailed product specification of the wearable device is listed in table 2. The design documentation, developer SDKs for the sensor and board integration, and tutorial and training materials on code usage are available on the manufacturer's website [7].

TABLE 2 Specification of The Wearable Device

Dimension	– Diameter: 0.94in / 24mm
	– H: 0.24in / 6mm
Weight	– 5.6gms
Connectivity	– Bluetooth LE 4.0 – 2.4Ghz
	– Stream sensor Data from 1 Hz to 100 Hz
	– Log sensor Data from 1 Hz to 400 Hz
Core	– Nordic nRF51822 32-bit ARM® Cortex™ M0 CPU
	– 256kB/128kB flash + 32kB/16kB RAM
	– RGB LED
	– Micro push-button
	– I2C + 4 GPIOs
Logging / Memory	– Streaming ONLY Sensor
	– 80KB FLASH Memory – On the board
	– 5K – 10K sensor data entries with a timestamp
Battery	– 200 – 220mAH CR2032 Coin cell battery
Accelerometer	Accelerometer (A): 16 bit
	±2g: 16384LSB/g
	±4g: 8192LSB/g
	±8g: 4096LSB/g
	±16g: 2048LSB/g
	Noise density (typ.): 180 µg/√Hz
Gyroscope	Gyroscope (G): 16bit
	±125°/s: 262.4 LSB/°/s
	±250°/s: 131.2 LSB/°/s
	±500°/s: 65.6 LSB/°/s
	±1000°/s: 32.8 LSB/°/s
	±2000°/s: 16.4 LSB/°/s
	Noise density (typ.): 0.008 °/s/√Hz
Temperature	Thermistor (Degrees C): 16bit
	±0.5°C, Accuracy
	±0.1°C Resolution
	-40…85°C Range

3.3 Design of APP

The Android application provides an easy to use, clean, and visually appealing interface for the user. Figure 8 shows the application used in this project to display a baby's physical status. Some of the main goals of the app design are to represent data in a friendly fashion, show progression over time, and provide feedback. The app includes views for temperature and graphs of history temperature data for a single wearable device. It can also indicate the motion condition received from the sensor. It is equipped with a menu screen to provide navigational functions. Web socket technology has been chosen to allow for communication between the mobile application and a computer application. This is a versatile, platform-agnostic protocol that is supported on many platforms. More importantly, it allows two-way communication in an arbitrary manner. Either party can send a message to the other at any time.

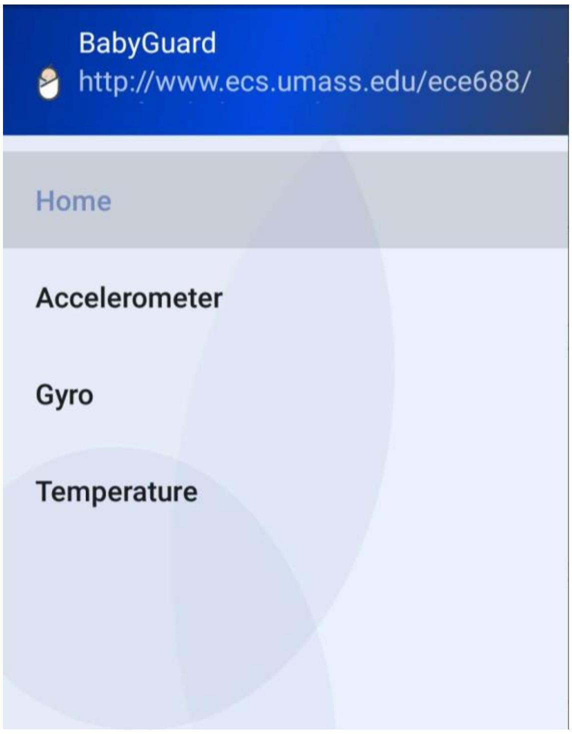


Fig. 8. User Interface of the APP

The state chart of the Android Application is indicated in figure 9.

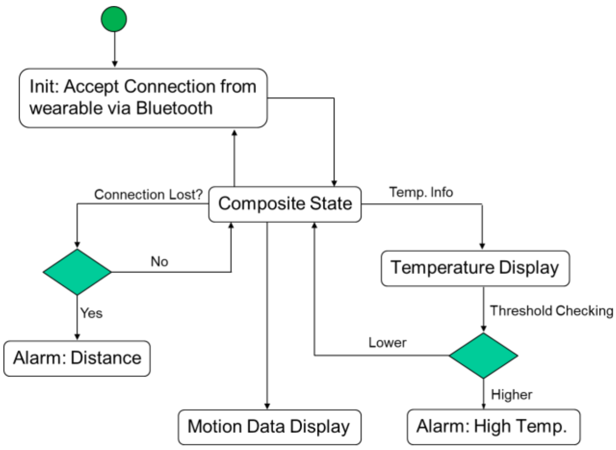


Fig. 9. State chart of APP

The detail of the composite state is further illustrated in figure 10:

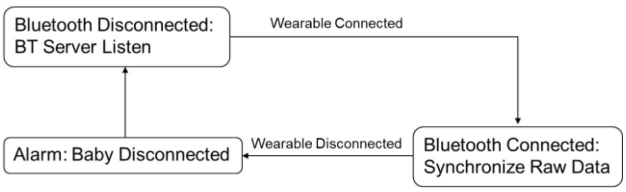


Fig. 10. State Chart of Composite State

Android application development was done in the Android language using Android Studio. This format was chosen as it is modern and well-supported, targeting interactive application development of all kinds. Software development techniques learned in the past were useful in learning this new platform and problem-solving during the development.

The computer runs a server to establish a connection with the application over a network. This web socket server is created running on the node.js JavaScript environment. It listens on a port to establish a link with clients, in this case, the application. The socket.io engine was used to implement this functionality. In addition, to support running the server with node.js, there is a socket.io library available for Android development which was integrated into the mobile application.

The Accelerometer and Gyro pages show the motion condition for the wearable device by tracking the movement amplitude of the wearable. Every time slot the movement created by the wearable device creates a data point and plots a point on the app 2-dimensional coordinate plot. The most recent dot will indicate whether the baby is moving and the trend will let the app user know whether the baby is asleep.

The Temperature page provides the historical temperature data that has been received from the sensor. It also plots a graph with which a user can easily track body temperature since normally there is minor fluctuation in a healthy person's temperature. For a baby, temperature changes can indicate if medications have kicked-in.

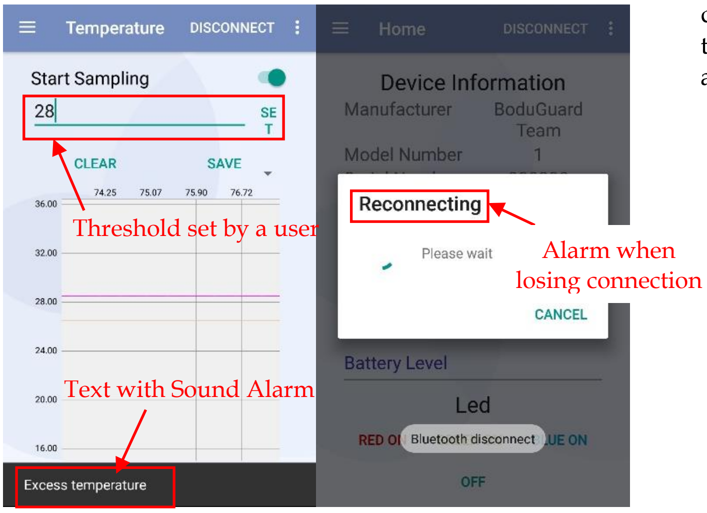
The app also provides functions to connect and disconnect with wearable devices and supports device functions to change the LED display based on user preferences. To enable a user to quickly use the device, an embedded help function provides a simple how-to guide.

In the final version of our application, we have implemented the alarm system into our existing app. The newly added function is considered an essential part of the whole system since we would like our product to be able to immediately alert parents when their baby is in an irregular or abnormal condition.

The first alarm system is for temperature. A user could pre-set the threshold in our system by referring to the previously collected data or clinical advice. When the detected temperature data is higher than the threshold, the type 1 alarm sound will be triggered and the phone will vibrate. A detailed illustration of this function is shown in the left part of figure 11, which elaborates a scenario in which the detected temperature is higher than the user-defined threshold.

The second one is a distance alarm system, in which the application will instantly alert parents when the Bluetooth connection between the wearable device and the mobile phone is lost. Once the Bluetooth connection is broken, the type 2 alarm sound will be triggered and the application will try to re-connect the wearable by itself. The display of this function is demonstrated in the right part of figure 11. We have also performed a detailed data analysis and background study showing why the disconnection of Bluetooth can be treated as a good indicator for distance alerts. Readers can refer to section 4.2 for more detail.

This function for synchronizing motion data currently is just to track data, but in reality, there are applicable scenarios that can leverage this function. Parents can track their baby's motion in a period of time to set the baseline record and then set the threshold in the device. Once the baby motion is irregular or strange, the alarm needs to be triggered to warn the parents. For our product to be improved further, this will be our next discussion topic.



(a) (b)

Fig. 11. Alarm System of Application (a) Temperature Alarm; (b) Distance Alarm

The future functionality of this app may also include a video/audio interface with the home server, which would enable parents to chat with the baby and monitor the baby's status. This function would be attractive since a face-to-face interaction will pacify the baby when parents are not around.

3.4 Design of Home Server

The home server is to be installed inside the baby's room and connects to a wearable device when the connection between the wearable device and mobile phone is not available. When the connection between the wearable device and home server has been established, the physical data from the baby detected by various sensors in the wearable device is sent to the server via Bluetooth. Figure 12 demonstrates the state chart of the home server design.

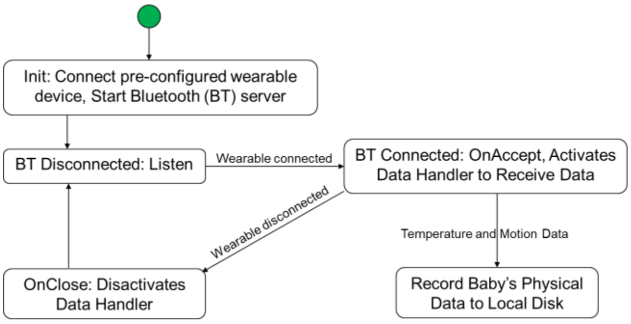


Fig. 12. State Chart of Home Server

The principle of receiving raw data from the wearable device to the home server is generally similar to that from the wearable device to the Android application, but there are two distinguished functions of the home server.

- Users have more flexibility to adjust the time interval for data reception. This function may satisfy different user needs, i.e., more intensive monitoring for temperature when a baby has a fever or less data detection when recording the activity pattern of the baby.
- The home server allows the user to stream data from 2-3 sensors at the same time. When collecting data from multiple sensors, users can synchronize the data to a single set of timestamps.

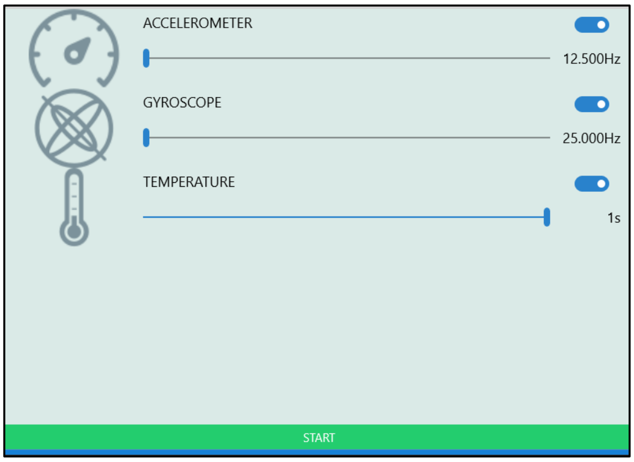


Fig. 13. The Interface of Home Server

Easy data mining is another important feature of the home server. Parents or researchers can easily identify the activity pattern by studying the raw data received by the home server.

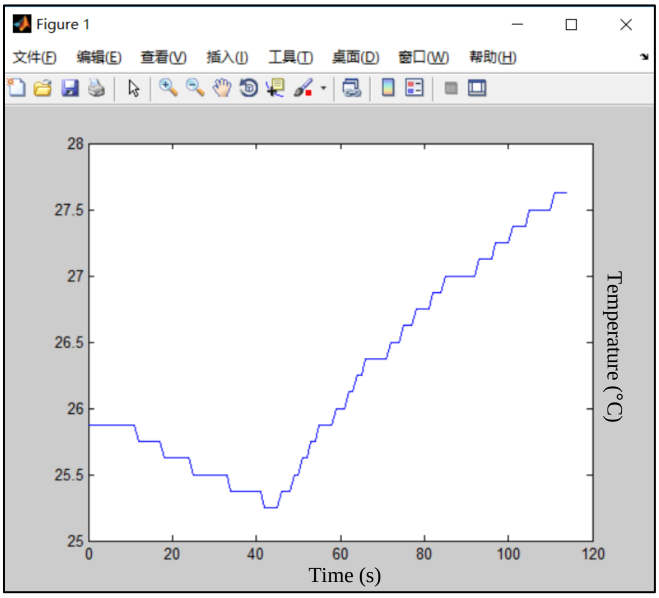


Fig. 14. Matlab Output from Processed Temperature Log

We can retrieve the log file from the home server and import it into Matlab. Then a historical temperature data trend similar to Figure 14 is plotted. When monitoring the temperature of a baby with a fever over a period of time, temperature volatility can help parents decide whether another dose of fever control medication should be given to a baby.

4 Implementation Result & Data Analysis

After integrating the three major components into one piece, we tested the system as a medium for parent-child communication. The tested results were positive and we were able to verify the features that were initially proposed.

4.1 Bluetooth Signal Strength Test

We performed an experiment to test Bluetooth signal strength. The aim of this experiment was to identify how far the Android app is able to receive data transmitted from the wearable device.

This test was conducted by using various distances between the BLE device and a smartphone. Figure 15 summarized the general output of this test.

This experiment has several practical meanings for our product.

- The Bluetooth signal strength decreases as the distance increases. This fact complies with the formula from the textbook, which is "**RSSI[dBm] = -10nlog(d) +A[dBm]**" [19]. In this formula, "d" equals the distance from a device; "n" represents the constant dependent on environment and "A[dBm]" means the RSSI value measured 1 meter from the device.

  This formula also indicates the Bluetooth signal strength will drop down while the device is apart from the receiver. The trend is similar to the output of our experiment.

  We also identify that the environment factor "n" would impact the Bluetooth signal strength significantly. In our result, the factor "n" equals 1.5~2.0 to match our test result.

- From the test result, we could identify that the Bluetooth connection will be lost when the device is 21 meters away from the receiver (our mobile phone). This is an important remark since our system will automatically alert us when the connection is broken. Twenty-one meters is a reasonable distance at which parents can physically see their children and perform immediate action if their kids are facing dangerous situations. For example, if children are locked in a car alone, our system would automatically alert parents when they are 20 meters away from the car.

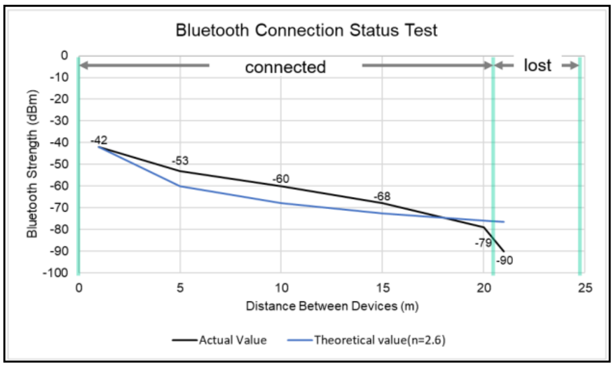


Fig. 15. Bluetooth Signal Strength Test W/O Obstruction

4.2 Bluetooth Signal Test with Objections

Another important experiment for Bluetooth signal strength was performed. This test verified the signal strength by using different obstructions.

We have tested four materials, wood, metal (aluminum), glass and concrete. These materials are common obstructions in our daily life. The thickness of wood, metal, and glass are similar in our experiment. But the concrete (wall, in our case) is 10 times thicker than the rest of the materials. Our BLE device and mobile phone are placed on opposite surfaces of these materials.

From the result shown in figure 16, we could identify that the wood gives the smallest obstruction for the Bluetooth signal, while concrete (wall) obstructs a large number of signals. Although this result follows our common sense, we still could not ignore the thickness of concrete, which is much thicker than other materials. The impact factor by material thickness is a good research topic for the future.

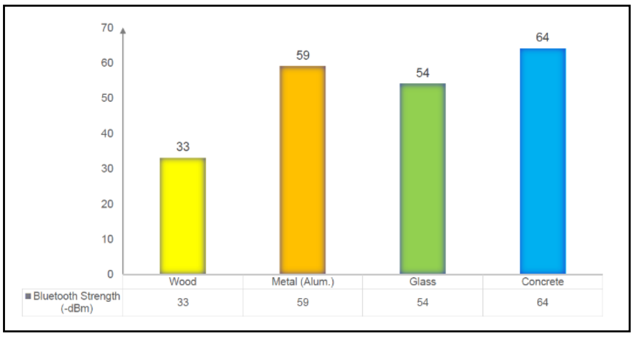


Fig. 16. Bluetooth Signal Strength Test W/Obstruction

The result also gives us a good indication that when a child and its parents are separated by a concrete wall, we need to monitor the children's status more frequently since the signal may be lost when the distance is smaller than 21 meters, which was the test result with no obstruction.

4.3 IoT Device Data Sensitivity Test

In order to verify the data accuracy of our wearable device, we have performed two tests regarding the quality verification of temperature and motion data accuracy.

In the first test, we see whether the temperature trend of our baby is reasonable. We have attached the wearable device to a baby (3 years old) and set the home server to receive the body temperature every 1 hour. The temperature trend is shown in figure 17. We believe the trend is generally reasonable. At night, the baby's body temperature is lower since less activity was present during sleep. In the daytime, the temperature increased, probably because she was playing leading to higher body temperature than at night.

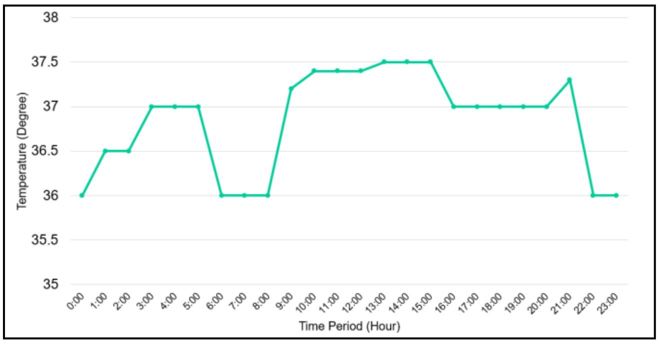


Fig. 17. Data Accuracy Test - Temperature

The same idea was implemented in the second test, which intended to figure out the activity level of the same girl. The motion data was retrieved from our home server on an hourly basis, and we did a simple calculation for the acceleration that the receiver received in excel. The formula we used is:

$$v_{Baby} = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

In this equation, V_x is the acceleration in the x-axis, V_y is the acceleration in the y-axis and V_z is the acceleration in the z-axis. By calculating the value of V_{Baby}, we manually set the value of highest activity as 100 and compared the rest of values with this figure.

The comparison output was plotted in Figure 18, and in this chart, we could identify the trend is reasonable because at night and noon, our girl was sleeping and hence there is little movement at that period. In contrast, in the morning and afternoon, our girl plays, leading to a big relative motion amplitude at that time.

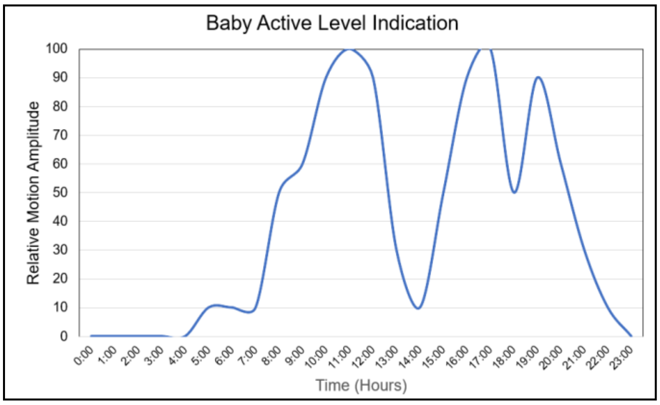


Fig. 18. Data Accuracy Test – Active

We also fed the motion data from the home server into Matlab to get a 3D motion map during the time period (Figure 19). When applying the technique to real life, the dense lines indicate that the baby is moving in a limited space whereas the sparse lines indicate that the baby is exploring new areas. When the baby is taken away by unknown people, the motion data can help indicate the speed and direction that the baby is moving.

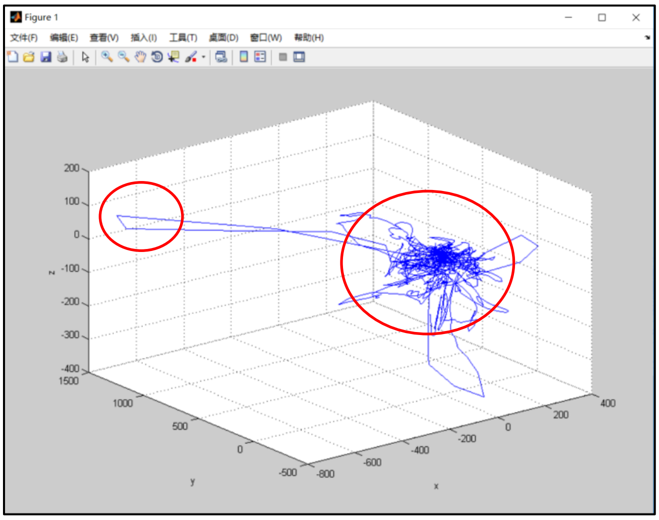


Fig. 19. Processed 3D Motion Data by Matlab

4.4 IoT device Battery life test

We were also keen to know how long the device will work since it is an important parameter to parents and they would like to know if the device is robust or not. Since we have already chosen a button cell, we designed a test to check the battery life. In our test, we considered three conditions, which are continuous, intermittent and idle. "Continuous" means that the data was transmitted to the home server every second. "Intermittent" means that the data was transmitted to the receiver on an hourly basis. And "idle" means the there is no data streaming at all. Our test results are listed in table 3.

TABLE 3 Battery Life Test

Streaming	Battery Lifetime	Remark
Continues	7days	Real-time streaming to App/PC
Intermittent	10days	Connected to a device but intermittent data streaming
Idle	30days	Connected to App/PC but no streaming

If the parents need more battery life, they may turn off the sensors, reduce sampling frequency, and use intermittent transmission.

5 Project Management

Our team members demonstrated their capabilities and were able to work together and remain in good shape despite several setbacks during this year. A major impact occurred when one of the important team members dropped the project.

Basically, the initial trigger point of our project was achieved properly and the FPR goals as proposed in MDR were accomplished accordingly.

In this project, Yun Shi was in charge of the Android app design including establishing the connection between the wearable device and mobile phone, GUI design, and alarm system implementation. He was also responsible for designing the project website, final report/ presentation slides/ demo day poster preparation and data analysis.

Kiran took responsibility for the wearable design. He also implemented the interface between the wearable device and the Android app, which enables the raw receiving function in the app.

6 Conclusion

BabyGuard is a working system that can help parents to actively monitor a baby's physical status. The monitoring device is less expensive than others (See Table 4 for cost) and yet, it is easy to implement. Due to its accurate data detection and instant alarm triggering function, BabyGuard is a highly suited product for babysitting. This system has the potential to be upgraded in the future, i.e., studying the activity pattern of a baby and setting a baseline for motion monitoring.

TABLE 4 Cost

Item	Cost
Bluetooth Low Energy Device	￥300
Button Cell	￥5
Android Device	￥2000 (Testing)
Personal Computer	￥4000 (Testing)
TOTAL COST	￥305 (US$45)

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