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Final Project Report: Beanie Baby Monitor

Process, Testing, and Iteration

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I. Motive

Parents are often concerned whether the amount of crying of their newborn baby is considered ‘normal’. We see this especially in new parents who are unsupported by, perhaps, their own parents or nannies, who may have more experience with young children. Additionally, during the critical period between birth and eight weeks, crying can be indicative or symptomatic of other disorders and diseases. Yet, there is little to no proper data collection about what constitutes normal crying except for the record keeping done by parents themselves and the professional experience of pediatric doctors. Our team was tasked by Dr. Amy Gelfand, a neurologist at the UCSF Pediatric Department, to design and prototype a device to tackle these issues in an innovative manner.

II. Brainstorming and design selection

During the first meeting with Dr. Gelfand, she envisioned a wearable prototype that transmits data wirelessly, is able to differentiate between crying and ambient sounds, and has a long battery life. Dr. Gelfand had many goals and it was a challenge to figure out what she actually wanted, to convince her of better alternatives to achieving her goals, and to deliver a product to the best of our ability, resources, and time. After the initial brainstorming and research, we explained to our client that the main achievable goal for the time being is to create a wearable prototype that records baby crying.

The brainstorming process began with a list of twenty different ways of incorporating a recording device into a baby wearable. Using a Pugh chart, we compared these ideas to a traditional baby monitor, which is only capable of audio transmission, based on the following design criteria: cost, ease of use/maintenance, baby friendly, and size/weight.

The first criterion of cost is important because we want to create an affordable device that would be available to many people. Then, ease of use/maintenance is important to consider for parents, since they would be responsible for putting the device on the baby and cleaning it. Furthermore, our client emphasized the importance of a baby friendly device. This criterion deals with the device’s safety, comfort, and appearance. The client requested that the material used does not cause irritation or abrasion on a baby’s sensitive skin and that the device does not look too electronically complex. Finally, the size/weight of the device are related to its comfort. It cannot be too heavy or bulky for an infant to wear.

Based on the selection criteria and the scoring of the design concepts, the top idea was a beanie device. The beanie is made from 100% organic cotton so the comfort and safety of the baby is certain [1]. The beanie also has an elephant design so it is baby appropriate. Finally, the beanie can be stretched and expanded to accommodate the normal range of baby head sizes (32-38cm) [2]. Attached to the beanie are velcro pieces where a Raspberry Pi Zero W, a small microphone, and a heart rate sensor are fastened. Thus, the parts are easily removable and the beanie can be washed. The total beanie weight with the sensors will be about 51g so it is very light for a first prototype. Even though our client had initially a set vision of creating an anklet device, we had to convince her why a beanie is better. The main differentiating factor was that a beanie would be closer to the baby’s mouth, or closer to the source of crying, thus yielding less noisy data than would an anklet.

From the brainstorming process, we learned that a client may have a vision for a product but may not know what is involved in creating that product. It is the engineer’s job to explain the processes and recommend the best methods for creating the product. We also learned that when creating a device, it is important to consider the ecosystem of a device. We need to design for the customer, or baby in this case, and for those interacting with the device, the parents.

III. Anatomy

Since the device is incorporated on a beanie, it will have a prolonged contact with the babies' sensitive scalp and skin. The elastic part ensures the beanie stays in place but will apply a constant pressure to all sides of the head for prolonged periods of time. Babies have weak skulls with unclosed sutures and fontanelles (Fig. 1.1) and if the band compresses the skull, it may cause some deformation [3]. Furthermore, a baby's skull and spine may be impacted due to the added weight of the sensors, especially when the baby is picked up. Finally, part of the device is a heart rate sensor placed on the elastic band, over a baby's superficial temporal artery (STA) (Fig. 1.2). The PPG sensor must be placed directly on top of this artery with a low pressure to minimize noise in the readings.

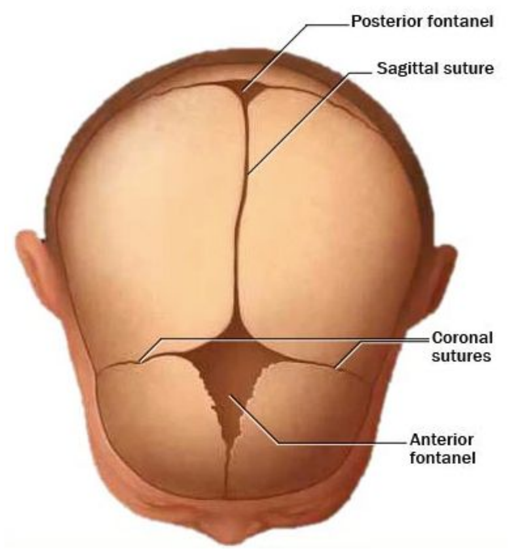

Fig. 1.1 A baby skull with unclosed suture and fontanelles

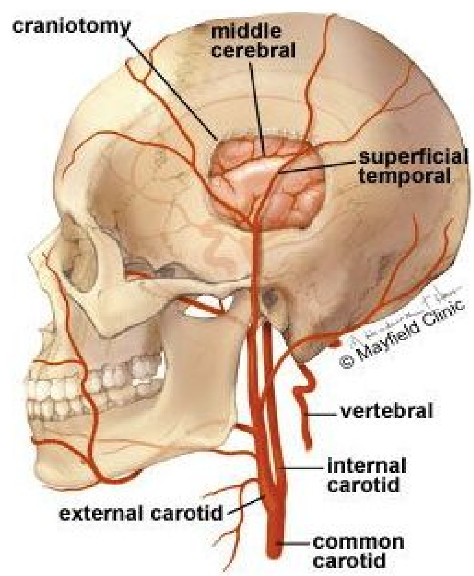

Fig. 1.2 The position of the superficial temporal artery

IV. Estimated joint/tissue loading

A newborn baby has weak motor skills and neck muscles [4]. Assuming that newborns are always lying down or held by a parent's hand supporting their head, any muscles and joints in the head and neck are neglected as they do not play a major role in holding the beanie in place. Also, since the device is light, the forces applied from the sensors on a newborn's head are negligible. The only major forces of concern to the baby's safety are the forces applied by the beanie's elastic band to the superficial temporal artery (Fig. 2). We assume that there is no net force acting on the beanie as confirmed by the figure.

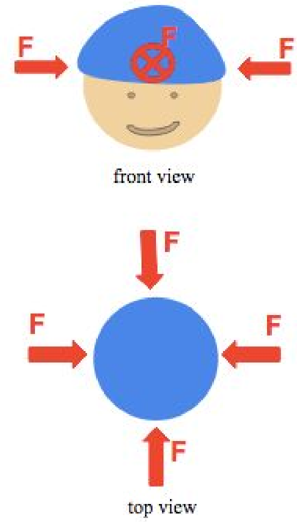

Fig. 2 Free body diagram of forces from the band on a baby's head

To find the forces, we assumed the band acts as a spring governed by the equation $F = k\,\Delta x$ and we considered the maximum pressure that can be applied by the elastic to a baby's head before causing a pressure ulcer (4.13 kPa) [5]. Thus the force applied to a baby's superficial temporal artery due to this pressure would be:

$$F = P\,x\,A$$
$$F = (4.13\ kPa)(0.03\ m)(0.356\ m) = 44.1\ N$$

where A is the surface area of the elastic band under which the force is acting. Finally, in the biomechanics assignment, we determined the spring constant k experimentally by measuring the band's displacement by adding a known weight. The displacement as a result of the calculated force and k ($51.3\ \frac{N}{m^2}$) would be:

$$\Delta x = \frac{F}{k}$$
$$\Delta x = 0.860\ m$$

It is not expected that the beanie will stretch to ~1 m, so blood flow will not be blocked in the superficial temporal artery and the occurrence of pressure ulcers is extremely unlikely.

V. Prototyping

After the brainstorming process, it was clear that a beanie was the most desirable accessory in which to embed our design. We ordered three beanies from Amazon for the initial prototype. For our looks-like prototype we used cardboard in the place of the heart rate sensor, the microphone, and the Raspberry Pi (Fig. 3). We sewed velcro onto the lid of the beanie and glued velcro to the other side of the three cardboard pieces for attachment purposes. At this point, we did not really have an idea for the attachment mechanism - only that we knew it had to be detachable so that the beanie could be washed. We also sewed thread around the hat from one cardboard piece to another to mimic wiring. In the works-like prototype, the Raspberry Pi microcontroller connects to the microphone through an ADC because it only has digital inputs (Fig. 4). The microcontroller then connects to a computer with the USB to TTL serial converter so it does not need a monitor and keyboard. From this set-up, we were able to record crying sounds.

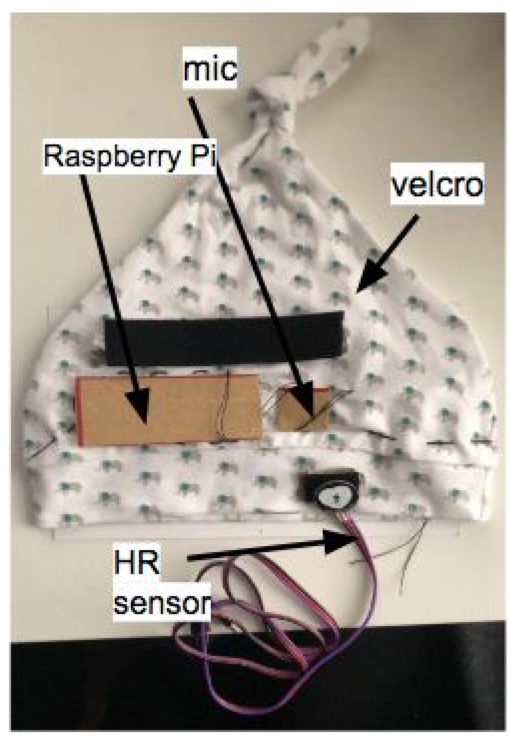

Fig. 3 Looks-like prototype

During the prototyping process, we discussed with our client the needs of doctors, parents, babies, and hospitals to fully comprehend what the device ecosystem was. Without the ability to talk to parents and more doctors, we were unable to check our design criteria on potential users. However, Dr. Amy Gelfand gave us invaluable advice on exactly when and how our device would be used. Trying to balance the needs of the parents, babies, and doctors, all which interact with the device on different scales, forced us to think outside the box on many occasions and to think about our device from as many different angles as possible.

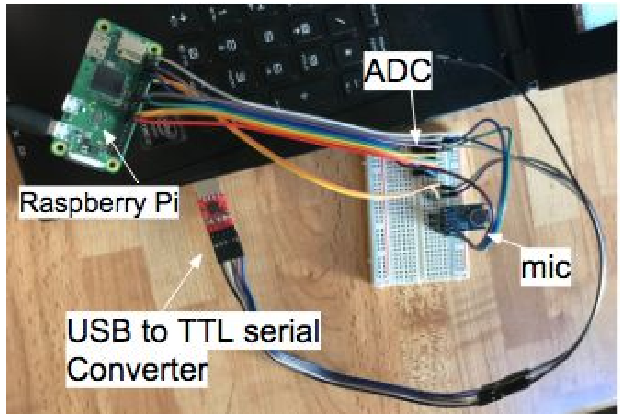

Fig. 4 Works-like prototype

VI. Testing

To test the device functionality, we used a microphone to record the crying of a few babies. We were able to measure and visualize the intensity of the sound coming into the microphone in real time (Fig. 5). Additionally, we saved the data for post processing if needed. The device also converts the raw audio data into a frequency spectrum using *Fast Fourier Transforms*. From this data, a trained data scientist would be able to create a machine learning algorithm to parse through as much data of crying babies as possible so that it would be able to recognize crying sounds from other sounds.

From testing the device, we realized that a complicated machine learning algorithm is necessary as a future step for the device. Without this, it is impossible to differentiate baby crying from other sounds. As shown in Fig. 5, the crying curve of one baby varies significantly from the crying curve of another baby. However, if thousands or millions of babies were used instead of just three, an ML algorithm would allow a computer to find identifying characteristics that allow it to differentiate sounds. Unfortunately, we did not have access to any babies to test the sound recording on, so we used previously recorded baby crying audio sources.

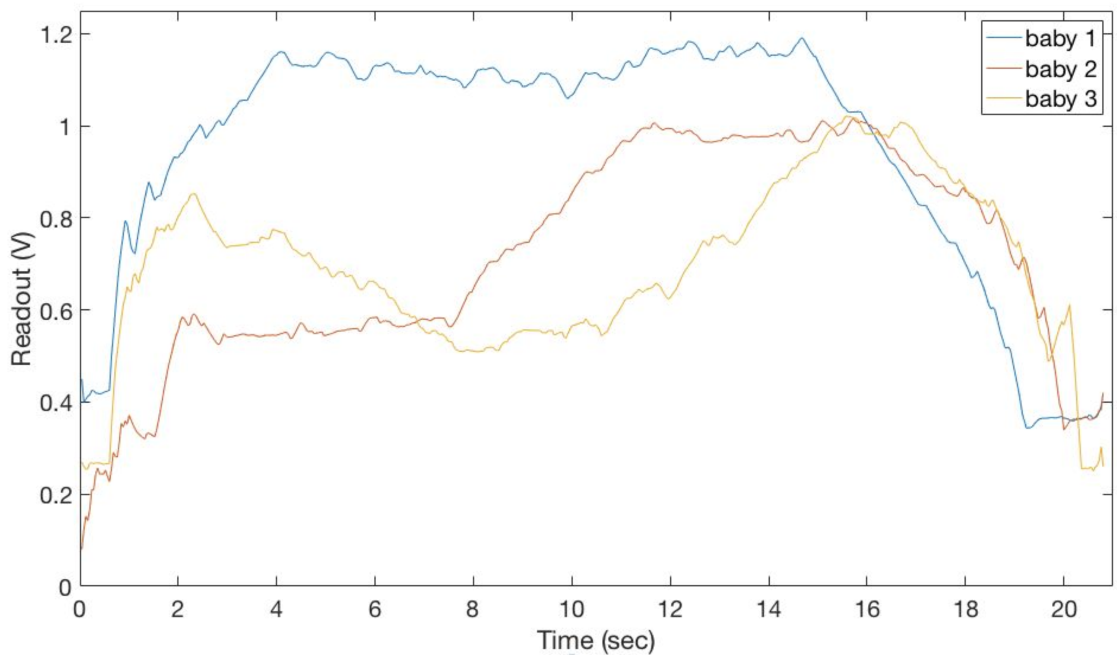

Fig. 5 MATLAB plot of 3 different, smoothed baby crying curves (span=150)

VII. Design Assessment

Our device was essentially a first generation prototype of what we hope will be an incredibly helpful product for parents. Consequently, our device records and saves audio, but it does not recognize crying noises. Additionally, the device needs to be attached to a monitor and keyboard for live data display; however, it can record data wirelessly. Our looks-like and works-like prototypes are currently very far apart from each other, given that the works-like is controlled by a Raspberry Pi microprocessor, and is far too large to be worn by a baby with its peripherals.

With more product development, we believe that the final device will function as a comfortable, customizable beanie that can fit most baby heads. The electronic components will be small enough to fit into pockets within the beanie without causing discomfort. At the same time, the electronics will be large enough for users to easily remove and handle when washing the beanie with other clothing. Furthermore, the device will record the baby's heart rate in addition to crying and send the raw data to an application on the user's phone wirelessly. The application, which will serve as the post-processor of the recorded signals, will use both the baby's heart rate and the audio data to recognize when and how often the baby cries. In this design, the bulky microprocessor will be replaced by individualized components to record and send data. This will be displayed in an elegant user interface that will help users keep track of their babies during the first few weeks after birth. This will also help users show doctors their babies' crying tendencies, so doctors can diagnose relevant conditions more accurately.

One of the first aspects we would improve in future iterations is the quality of the microphone and signal processing. By physically and digitally filtering out noise from the collected signal, the post-processor will analyze the original signal much more easily. Furthermore, improving the signal to interference ratio will help clean up the collected signal.

Both of these additions will allow our device to detect a crying baby more accurately. As the components of the works-like prototype are finalized, they will be integrated into a looks-like prototype that can be worn by test subjects.

Comparable methods are particularly limited in variety, including baby monitors, such as Netgear's Arlo Baby, the D-link EyeOn Baby, and the Konig IP Baby Monitor, as well as diaries kept by the baby's caretaker, a more traditional method. Our benchmarking reference was a traditional baby monitor, because it is commonly used to notify parents if their baby is crying. Although they are normally used only when the parent is not in the same room as the child, modern baby monitors can easily be used to record crying babies. The Arlo model records high definition video, air temperature, and audio, while saving data through cloud-based technology and transmitting data to any smartphone via an application. These features are accompanied by a rechargeable battery, along with more active abilities meant to help the parents remotely interact with the baby [7]. But the most comparable feature is the alert mechanism, which notifies the user if motion is seen in certain areas, or a certain level of audio is recorded. Such a device performs nearly all the functions of our device, including audio recording, data collection, and storage. But the process by which the device recognized crying is arbitrary and the frequency of the baby's crying episodes are not recorded anywhere. Our device will be able to record such information and make it a better fit for the specific need discussed above.

VIII. Client Feedback

Even though we were not able to show our client, Dr. Amy Gelfand, our prototypes, we were able to describe to her our brainstormed ideas. She saw pictures of what we had been working on and although she had little to say about the sensors and the electronics, she was very happy about the idea of sensors on the outside of a beanie. We talked through some design concerns we had to address in the works-like prototype but she seemed excited about our efforts.

IX. References

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[4] BabyCenter. “Baby Milestones: Head Control.” *BabyCenter*, 9 Oct. 2018, www.babycenter.com/0_baby-milestones-head-control_6579.bc.

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[6] “Superficial Temporal Artery to Middle Cerebral Artery Bypass Graft.” *Pinterest*, www.pinterest.com/pin/222013456610653465/.

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X. Appendix A

Member Contributions:

- Shoba: Contributed to the report and presentation. Contributed ideas and drawings to the brainstorming. Built the looks-like prototype.

- Mace: Design and testing of electrical and software components of device. Contributed to the report and presentation. Researched parts for device. Contributed ideas and drawings to the brainstorming.

- Shahad: Contributed to the report and presentation. Contributed ideas and drawings to the brainstorming. Helped with the looks-like prototype and made the demo day presentation poster.

- Fayyad: Contributed to the report and presentation. Contributed ideas and drawings to the brainstorming. Helped with figuring out the device biomechanics.

- Roshan: Contributed to the report and presentation. Contributed ideas and drawings to the brainstorming. Helped with figuring out the device biomechanics.