Throwing Buddy: Solving Sensor Challenges Through Soft-Good Construction, Design, and Fabric Selection

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ABSTRACT

Wearable technology projects sometimes present complex problems, which are hard to solve through computer science solutions alone. Our interdisciplinary team met such a problem in the form of near infrared sensor noise due to fabric interference. We met the challenge through software/hardware solutions, but also strategic fabric selection and soft-good construction. This case study shows how incorporating everyone's expertise on an interdisciplinary team can afford solutions, which better accomplish the goals of a project than individual disciplines could alone.

Author Keywords
IR Absorption, IR Sensors, Soft Good Design, Fabric Selection

ACM Classification Keywords
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INTRODUCTION

When a software engineer works on a problem it would seem that his first solution would always be to alter the software. When a hardware expert faces a task, we can assume that if a sensor is not giving a desired effect then he would change the hardware. The same is true for designers of apparel and soft goods; their outcomes would be alterations in the form of the textile device. We know how important it is to "include the apparel design perspective in the successful design of wearable computing" [3]. This paper will describe a case study of interdisciplinary teamwork around building a wearable device for practice and training in pitching baseballs. The outcome shows the importance of incorporating wearable solutions from software, hardware, and design.

Project motivation and related work

The motivation behind the case study is a product called the "Throwing Buddy" www.coachesstudio.net. The original version of the throwing buddy uses a net attached to the hand, allowing for rapid reset of the ball while training. More importantly the net has red, white, and blue stripes helping teach and train correct hand positioning while throwing practice pitches (Figure 1). Coaches Studio, the creators of the "Throwing Buddy" asked our research team if we could instrument the non-electronic version of their wearable device to be able to determine pitch speed. When first presented with the challenge the software/hardware expert thought of IR break-beam as a solution, and the e-textile expert thought of creating a fabric to measure resistance change [2][4][7]. The ultimate design needed both sets of knowledge to find a working solution. We settled on Near Infrared (NIR) reflective sensing based on the small size and availability of pre-made sensors, as well as the high speed and low complexity of the sensing, but as you will see there were design solutions needed to make this selection work effectively.

Figure 1: Non-sensor version of "Throwing Buddy"

Design Process

IR reflective sensing works well for detecting the ball, as all baseballs should be made from similar white leather [8] and testing several baseballs showed they all reflect NIR nicely. Unfortunately, the netting manufactured to catch the baseball in the original "Throwing Buddy" was also reflective in the NIR range, and the NIR reflectivity sensors also detected this netting. Because the netting registered with the sensors it became hard to distinguish between the data created by the baseball and the data created by the netting.

The team first attempted to eliminate the netting problem by keeping the netting at a distance from the sensors. Using plastic strips, similar to a boning (a fabric term describing stiffening pieces incorporated in structural garments), to keep the fabric spread out during a pitch (Fig 2), but this turned out to be less effective than we wanted, bulky, and not durable enough for continuous training of fast pitching.

Figure 2: Plastic hoops incorporated in this prototype were incorporated to hold the NIR sensors away from the nylon netting.

Figure 3: Testing prototype made from vat-dyed cotton fabric that absorbs NIR.

The team next sought out alternative materials to use for the netting. It is important that the fabric be durable, abrasion resistant, and hydrophobic (to allow for ease of cleaning after practice). Because of this, like the original netting, the fiber type should be an acrylic or nylon. It also became important for the fabric to absorb NIR. Some materials and fabrics are designed to absorb NIR especially for military uses like camouflage [6][1]. But finding these fabrics available for purchase in a local fabric store is near impossible. Many vat dyed fabrics are also absorb NIR. One such fabric we were able to find was a black sulfur-dyed fabric. Vat-dying is used on natural fibers so we knew that it could not be used for the final product due to durability but we assumed we could use the fabric for prototyping (Figure 3). Initially these prototypes seemed to solve our issues, the sulfer-dyed denim was not interfering with the NIR sensors. Eventually another aspect of vat-dyed fabrics did start causing issues. Vat-dyes have a tendency to *crock* (which is the transfer of dye through friction/abrasion). After pitching with the vat-dyed prototype our white baseball turned dark blue and also started to absorb NIR (this is akin to having your raw denim leave blue marks on your white leather shoes).

Fabric Selection

After having difficulty with the vat-dyed fabric we needed to find a fabric, which we could use but which we could also get in limited quantities in a quick turn around. Many of us who work in wearable electronics have faced this moment of walking into a fabric store knowing the sales associates are going to have no clue as to the technical properties of the fabrics they sell. How can we expect a fashion and apparel expert to also know the electrical properties of the fabrics on the shelf? We took a cue from Rehmi Post's triboelectric testing paddle [5] which he created to test the ability of fabrics to make a static charge.

Our team created a handheld device to test (Figure 4) the NIR absorption of fabrics and took our testing device with us to the fabric store to find those fabrics, which might work for our project. The device consisted of a microcontroller development board and one of the sensors we planned to use, mounted in a case to eliminate outside light and hold the sensor facing the test material at a distance of 1cm. The microcontroller read from the sensor both with the IR LED on and off, took the difference, and simply reported a long-running average over USB CDC protocol. This was then displayed on an Android device using a simple USB terminal, making the entire testing device portable.

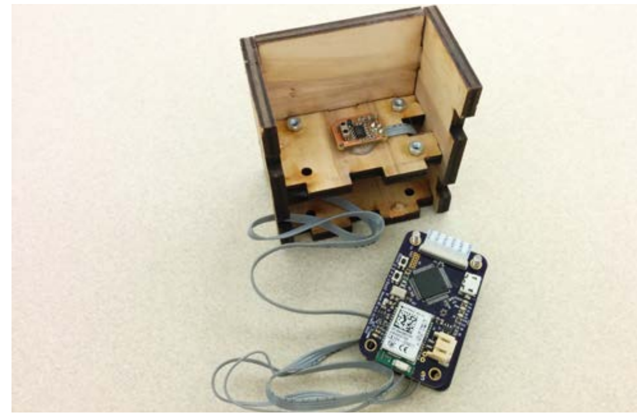

Figure 4: NIR absorption fabric testing device.

Upon taking our testing device to the fabric stores, as well as testing materials already on-hand, we found that some wools and polyesters seemed to absorb limited amounts of NIR. Out of approximately 200 candidate fabrics tested in reseller stores, only a few stood out as being most absorptive: a cotton with an unknown screened-on black ink, a cotton/elastomer denim mix ("stretch" denim), and two black acrylics manufactured by Sunbrella for outdoor upholstery and umbrellas.

The cotton with screened-on black is a bit of a mystery, and highlights the difficulty of determining the manufacturer of fabrics. The cotton/elastomer mix denim is likely also dyed with a sulfur dye due to the mixed materials, which happens to make it more IR absorptive than other dyed cottons. The Sunbrella fabrics are acrylic, and are likely solution-dyed with something specifically chosen for UV resistance, and in this case, also absorbs all visible and NIR light. Notably, not all Sunbrella fabrics absorb NIR - testing of several dozen showed that only the "Canvas Black" 5408-0000 and "Raven Black" 5471-0000 performed well.

These acrylic fabrics were the right choice for our prototype, but direct testing was necessary to locate them.

Because the Sunbrella fabrics are solution dyed (the dope or liquid plastic is dyed in solution before being extruded into fiber) this means that as the fabric will also keep its NIR absorption characteristic as they abrade.

Sensor selection

Another challenge with our reflective NIR sensing was that we needed to be able to sense a high-speed ball, while having some immunity to ambient NIR light. We used the standard trick of taking pairs of samples from the NIR light sensor - one with the IR LED on, and one with the IR LED off - and using the difference to eliminate the effect of ambient NIR.

The first issue is that we needed our IR light sensors to react fast enough to record a ball passing at upwards of 30 m/s. With sensors spaced at 45 mm, this meant that we needed to sample at approximately 20 KHz to see a one-sample shift for a 1 m/s speed difference. We initially used phototransistors for our IR light sensors, but found them to be too slow when detecting small changes in reflected light.

We decided upon using photodiodes (Avago HSDL - 9100) due to their faster response time. While PIN photodiodes are faster to respond (6 µs), they typically allow much less current through than a phototransistor (on the order of 10 µA). Because our phototransistors are on the ends of cables running from the wrist to the sensors, this very low current takes too long to charge the parasitic capacitance of our wires. To get around this, we built a transimpediance amplifier built from an op-amp to amplify the current flowing through our PIN photodiode. The complete sensor board is shown in figure (Figure 5).

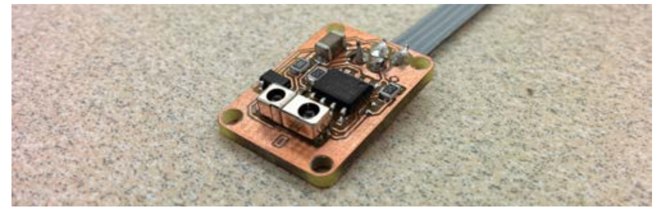

Figure 5: Complete NIR reflection Sensor Board.

Soft good construction

Finally even though the selection of the new sensors and the NIR absorption properties of the newly found Sunbrella fabric helped with much of the sensor noise issues we faced in prototyping, we also made a few construction changes to the “Throwing Buddy” which should aid in good data collection. The seams of the original “Throwing Buddy” left the fabric with a tendency to lay flat and close together. By inverting the seams the stiffness of the fabric has a tendency to stay open and apart (which is great for keeping the sensors at a distance from the opposite side of the netting)(Figure 6).

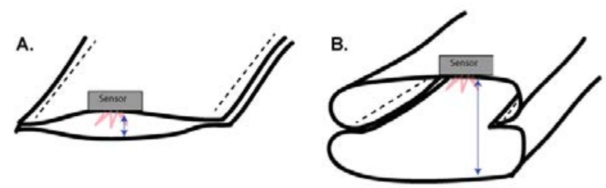

Figure 6: Fabric sewn in the original “Throwing Buddy” was constructed in a way that tended to make the sensor closer the fabric on the opposite side (A), where as by changing the seam the sensor naturally stays further away.

We also decided to only use the Sunbrella fabric in the portion directly across from the sensors. In this way the Sunbrella fabric absorbs the NIR but does not obscure the baseball and allows for all the original training techniques to continue to be utilized even in the sensor embedded version (Figure 7).

Figure 7: Current Prototype

Discussion

Through the combination of hardware, software, fabric selection and soft good construction techniques our team was able to create a prototype that reliably senses a baseball pitch. Notice in figure 8 how (each NIR sensor is a different color) by time stamping the sensor activation the speed of the ball can be determined. The speed of the ball relative to the sensors can easily be found by looking at the times between the pulses and dividing by the distances between the sensors.

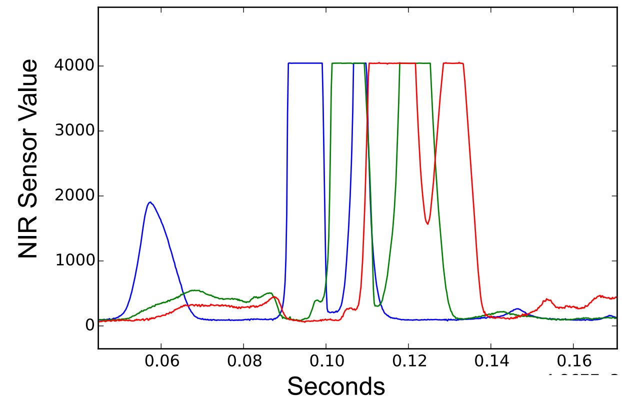

Figure 8: Graph of NIR sensor values recorded as the ball passes each of the sensors.

The graph in figure 8 shows the NIR reflectivity data from a baseball pitch. At 0.06 s, as the fabric is moving before the ball is released, it is picked up by the sensor, but at a lesser level due to the high NIR absorption. At time 0.09 s, one can see the first of the three sensors are triggered. The sensors each have a positive pulse with a negative pulse in the middle. The negative pulse is caused by the ball coming in direct contact with the sensor and totally blocking the NIR LED. As the graph shows we were able to reduce the interference with the NIR sensors.

This case study should stand as a testimony to listening and incorporating all voices on an interdisciplinary design team. By valuing all voices on the project team, software/hardware engineering and apparel design we were able to work together to create a solution that works better than any solution we could have individually accomplished.

Future work

This initial functional prototype will go on to be tested in user studies and eventually find its way into production as a consumer product.

ACKNOWLEDGMENTS

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