Problem Statement/Research Question and Background

In order to invest in the user's long-term quality of life and physical wellbeing, we aim to design a system of products that approach wheelchair maintenance as a preventative measure against negative buildup. Part of this approach is aimed at preventing dangerous pressure sores from occurring, as this is caused by both the combination of excessive upholstery wear-and-tear and prolonged periods of sitting. By the integration of simple pressure sensors into a wheelchair at optimally predetermined locations, we can both mitigate upholstery sagging and pressure sore formation.

After interviewing Lori Bernhardt, PT, ATP, from Rancho Los Amigos National Rehabilitation Center, we learned that wheelchair maintenance is crucial to the user's physical health and wellbeing but is often forgotten and delayed until the user has already sustained significant, sometimes long-lasting, physical harm. One of the most important aspects of a wheelchair is to maintain and support a healthy and proper posture for the user. One study concluded that "a properly fitted wheelchair is the single most important factor in reducing repetitive strain injuries".[2] Deviation from ideal posture can lead to pressure sores, difficulty in manual propulsion from increased load on the upper limbs, discomfort and pain, and an increased risk of falls. This will clearly have a negative effect on one's quality of life, which is known to lead to a decreased participation in common daily activities and independence.[3] Among the many aspects of wheelchair configuration and fitment, the seat and backrest upholstery has a large and direct effect on the user's posture and comfort.

Due to the slow nature of seat and backrest upholstery degradation, the user adapts to resulting changes in posture and is often not aware there is a need to address this problem until significant physiological damage has already occurred. On top of upholstery degradation, tire pressure is an issue that can reduce one's mobility on a wheelchair without the user even realizing their tires are underinflated. Studies have found that around 35% of wheelchair users experience chronic shoulder pain and a large reason for this is due to underfilled wheelchair tires.[5] This issue, similar to upholstery maintenance, can be solved through the simple integration of pressure sensors, specifically into the nozzles of wheelchair tires to detect reduced tire pressure.

Upholstery and seat degradation can also be a major cause of pressure sores and patients with spinal injuries will typically not realize when these are forming in their lower body. Annually, $11 billion is spent on pressure ulcer treatment in the US, so devising any means of mitigating this risk will be able to allocate such medical spending to other means.[6] Through the integration of sensors, not only can we help ensure proper wheelchair maintenance is followed, we can notify users when they are at risk of developing pressure sores.

Methods/Approach/Solution Considered

To gain direction in our project, we conducted a lot of interviews with a variety of individuals from different backgrounds. We knew that we wanted to target wheelchair maintenance, but this is a very broad problem to attempt to solve. The people pictured below were integral in guiding us through the topic of wheelchair maintenance and provided us with the insight we needed to determine specifically which issues we wanted to tackle.

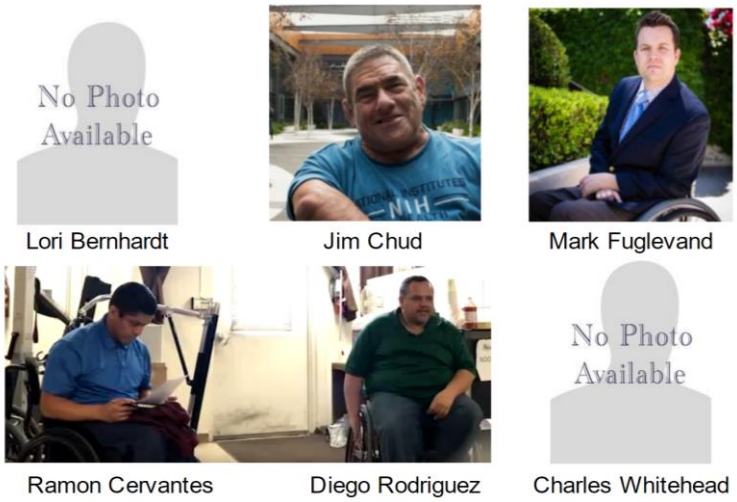

Figure 2. Everyone we interviewed during our visits to the Rancho Los Amigos National Rehabilitation Center. We interviewed Mark Fuglevand at Caltech.

Lori Bernhardt was instrumental in helping us understand issues with wheelchair degradation. She pointed us in the direction of upholstery sagging. Jim Chud and Mark Fuglevand helped us understand the market for such products - their insights allowed us to determine pricing for our products. Ramon Cervantes, Diego Rodriguez and Charles Whitehead gave us information that helped us design our product for better usability and functionality.

Initially, we thought about different ways in which one could fix the sagging of their seat upholstery quickly, easily, and by themselves. One way to do this involved rollers attached to the upholstery that can be turned to tighten the fabric when the user realized that the seat was sagging to dangerous levels. The design was very simple; the user would have to twist the rollers inwards to tighten the fabric. However, finding an elegant and practical design for this proved to be quite challenging and we realized our prototype may end up causing further issues than we hoped it would solve.

We then designed prototypes to fix the backrest sagging. Our plan was to integrate a tightening mechanism very similar to that of a ratchet strap. When excessive sagging of the seat occurred, we would simply crank the ratchet a few times to tighten the back and restore the upholstery to normal. While the ratchet straps did tighten in a way that would correct posture, we noticed a significant amount of bending on the two vertical frame members of the backrest - the bars that typically lead directly to the handgrips. We thought that this could be easily fixed if we added a support member between the frame members to prevent them from bending inwards towards each other. However, adding an additional structural member to the wheelchair frame not only adds unwanted cost and weight but also could present unforeseen problems with other wheelchair accessories and the collapsibility of a wheelchair.

Part of the issue with our designs above is they didn't detect any wear-and-tear of the wheelchair components and instead placed this responsibility on the user. Users will often go months without realizing their upholstery is sagging to dangerous levels. This is capable of causing pressure sores, so developing a product capable of detecting this is vital. Our initial thoughts centered on looking for ways to use body heat to change the color of a liquid crystal and notify the user that their seat is sagging. This would prevent the need for developing a complicated electronics system, instead relying on basic physical and chemical properties of

thermography crystals. These liquid crystals could be set to change color within certain very small temperature changes. Our idea was to manufacture these crystals such that they would "turn on" when coming in contact with the body of a wheelchair user. However, after testing the liquid crystal to see how fast heat would conduct from one end to another, we decided the solution was too slow and impractical. Also, the possibility of false positives seemed too likely.

Description of Final Approach and Design

In the end, we decided to use a simple and reliable LED circuit with a switch as our main prototype. If a person's seat sagged too much, their back would press against the switch turning the LED on and notifying the person that their seat is sagging. Switches were placed on fixtures around the chair that could lead to pressure sores of sagging when undetected. These switches would turn on a simple LED light that was attached to a display board, indicating what parts of the chair were facing sagging (i.e mid-seat, mid-femur, lower-back and upper-back). These switches acted as placeholders for what would eventually become sensors in our final product.

During our interviews, we learned that wheelchair users want others to view them as independent people and as completely separate entities from their wheelchairs. They do not want their wheelchair detracting away from who they are as individuals, which often meant keeping their wheelchairs as simple as possible. This meant they often chose to use inconspicuous wheelchairs that weren't overly flashy or well equipped. Furthermore, in our interviews with members of the Rancho Los Amigos community we noticed that a lot of people generally didn't want to deal with problem. Infact, many were willing to pay money to get their chair fixed. So we shifted our efforts towards component degradation detection. We initially placed our LED in a location that was far too obvious and would draw lots of unwanted attention to the user. We needed to figure out a way to hide it from others but still make it noticeable to the user. Thus, we decided to put the LED and the battery together in a single handheld interface that the user could put wherever they wanted. They could also change the battery quickly and easily if need be. We did this by putting most of the circuit on a single breadboard with wires extending from the breadboard to a switch that was attached to the back bar.

As a next step, we are integrating proper pressure sensors to tell the user how much the seat was sagging as opposed to a binary output that just told you whether or not it was sagging. In order to do this, the pressure sensors would be capable of changing the LED intensity as more pressure was applied to the sensor.

We are also incorporating pressure sensors into the cushion and tires of the wheelchair. The pressure sensors for the seat will be easily attachable and removable via simple clamps, ensuring they remain fixed at a proper location in order to reduce any false readings. The tire pressure sensors are simple caps that mount onto the nozzles of the tube very inconspicuously and return a pressure reading to a Bluetooth receiver. A threshold level will be set that will notify the user when tire pressure has dipped too low. We are designing a display and an app to let the user know when upholstery maintenance, additional tire pressure, and pressure sore alleviation stretches are necessary. The cushion sensors consist of a flat mat embedded with sensors that, with the other upholstery sensors and tire pressure sensors, are connected to either a display or a mobile application via Bluetooth. The latter option assumes the user has a smartphone with Bluetooth and Android or iOS capabilities. If the user does not have a smartphone, then

purchasing a display will also be an option.

(A) **(B)**

Figure 2. Simple prototype

Above was our very first and very simple true prototype. The transparent seat symbol in the outer cover, seen more clearly in Figure 2, would light up in a particular location depending on what switch was tripped during excessive sagging. The tire pressure sensors and seat cushion pressure sensors, along with the Bluetooth transmitter, were not yet completed for this prototype, so they were not integrated into this display. The next step for the display can be seen below.

Figure 3. Render of current design

The display above would be far smaller than the above prototype so that it is capable of fitting into the user's pocket. It would be far more compact and wireless so that it would be more portable. If the user desired, it could be clipped to his/her keys, bag, wheelchair, etc. so it can be kept track of with easier. The plan in the coming weeks is to integrate more complex display abilities into the handheld device. Risk of pressure sore development along with low tire pressure warning symbols will be integrated into this handheld device, notifying the user when to perform a stretch or when maintenance on a tire is due.

Cost

Like all manufactured goods, production will carry large marginal costs. The below table

assumes the purchase of 10,000 units

Item	Cost
LED Light (x10)	$2.50
Assorted Hardware	$0.60
Force Sensitive Resistor (x10)	$20.00
9V Battery (x1)	$1.20
BreadBoard (x1)	$3.71
Frame Mounting Clamp (x4)	$4.99
Acrylic Sheet (18t" x 18") (x1)	$4.00
Adafruit Feather 32u4	$8.90
Microcontroller	$1.85
Tire Pressure Sensor	$20.00
Total Cost per Unit (including display)	**$67.75**
Total Cost per Unit (excluding display)	**$61.54**

With these costs we estimate a price of around $90. We must be careful not to price the product too low otherwise insurance may set a lower price as a ceiling for the coverage.

Significance

It seems that there is a distinct lack of monitoring and assessment of wheelchair users' posture and comfort, in fact, "there currently is no documented measure of wheelchair assessment for residents in nursing homes,"[2] which is a large portion of the wheelchair user population. A product to monitor, detect, and notify a wheelchair user when the seat and backrest upholstery has degraded to a level that will soon become harmful, allows the user to become conscious of the need to address and change the upholstery as a preventative measure against physical harm and discomfort. This product can be extended to incorporate a variety of sensors, such as tire pressure sensors, to monitor numerous components of the wheelchair and thereby act as a good way to ensure that no health problems arise as a result of the wheelchair itself.

This concentrates the majority of the overall pressure directly on the ischial tuberosity as well as the coccyx. These pressure centers are a leading cause of discomfort and pressure sores.

Certain seat cushions, such as the PRS PURAP Seat Cushion, do a great job at spreading out this pressure and reducing the likelihood of pressure sores. However, the PRS PURAP Seat Cushion costs $110, which can be a significant expense for a simple cushion. Cushions are also one of the first components to be worn down on a wheelchair, so needing to replace this item regularly would be very costly. If we can develop a cheaper system of sensors that notifies the wheelchair user when areas of concentrated pressure have been present for an extended period of time, the user can then adjust his/her position in the chair to alleviate the pressure and prevent pressure sores all while continuing to use their current, cheaper seat and cushion.

There is also a need for tire pressure sensors, as many users often do not realize when their wheelchair is running on a flat. During our interviews, many medical professionals and wheelchair users complained that flat tire detection was something that was not effectively accounted for with wheelchairs. Wheelchair users would require far more energy to move their wheelchair and not realize why. This could increase the risk of shoulder or other upper-body injury. Once air was applied, however, wheelchair users are always amazed at how much easier it is to propel themselves in their chair. This issue is very similar to the issue of upholstery degradation. Wheelchair users are unaware that their chair is in need of maintenance and by the time they do realize the issue, it is too late and significant damage may have already occurred.

Beyond just the potential benefits wheelchair users may gain out of our project, we have also learned many valuable lessons during our research phase and design phase. While conducting research, we learned a lot about how wheelchair users hope to be viewed in everyday society. Hearing about how much long-term wheelchair users value their independence made us realize the importance of our project. Our project would allow wheelchair users to handle their own maintenance without heavily relying on their local seating center. We also learned the importance of keeping one's wheelchair as discreet as possible; many users will go as far as removing their backrest and armrests since they believe these items make their chairs far too clunky. Thus, we learned that we needed to keep our design as discreet as possible, in order to stay in line with the demands of the individuals. These are fundamental practices that many product designers and engineers must follow, so being able to implement them in such a practical means has been incredibly beneficial to our learning.

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Works Cited

1. Medola, Fausto Orsi et al. "Aspects of Manual Wheelchair Configuration Affecting Mobility: A Review." *Journal of Physical Therapy Science* 26.2 (2014): 313–318. *PMC*. Web. 7 Mar. 2017.

2. Gavin-Dreschnack D, Schonfeld L, Nelson A, et al. "Development of a Screening Tool for Safe Wheelchair Seating." Advances in Patient Safety: From Research to Implementation (Volume 4: Programs, Tools, and Products). Rockville (MD): Agency for Healthcare Research and Quality (US); 2005 Feb.

3. Gavin-Dreschnack, D. "Effects of Wheelchair Posture on Patient Safety." *Rehabilitation Nursing*. 2004 Nov-Dec;29(6):221-226. PubMed, PMID: 15598002

4. eTechTom, "Wheelchair Repair Part 2." *Youtube*. Youtube, 7 Dec 2012. Web. 14 January 2017.

5. Girls on Wheels, "Wheelchair Maintenance: Cleaning Casters." *Youtube*. Youtube, 12 July 2016. Web. 14 January 2017.

6. Sen, Chandan K., PhD. "Human Skin Wounds: A Major and Snowballing Threat to Public Health and the Economy."*Conference Management Toolkit - Login*. HHS Public Access, 10 Nov. 2010. Web. 8 Apr. 2017.