Project Deliverable L : Final Report

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Abstract

During the fall semester of 2019, in GNG2101, group C1B took on a challenging project, The fall detection system. During 4 months, we worked toward one goal, which was to complete the project before design day and present the various results that were attained. In order to be successful, we had 3 different meetings with Bocar, our client from St-Vincent Hospital. From those interactions, we were able to get enough information to guide us with design criteria, constraints generation, prototype testing and many other different aspects of the design process. The present document will contain all the steps taken from the beginning of the project all the way up to its complete closure. Throughout the semester, many milestones, which were deliverables were completed and used to give us better tools to work on feasibility, conceptualization and implementation of the final product intended to solve the issue at the hospital.

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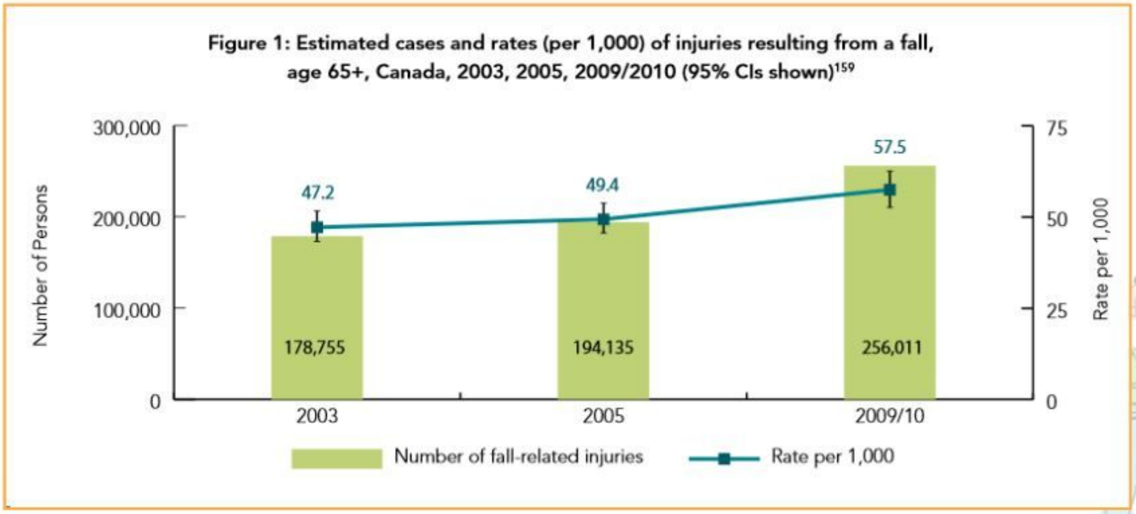
Introduction

Falling is a common occurrence in everyday life for anyone. Overtime, from a young age, we learn to fall less due to an increase in coordination and balance; this is especially important since an increase in age also results in an decrease in body flexibility and reformability. However, there are those who are not as fortunate to keep this full range of mobility, resulting in higher risks of falling and harming the body further. For hospital staff who are responsible these types of patients, a quick and accurate detection (and possible prevention) of a fall is imperative. That problem gets bigger and bigger due the fact that in Canada, for example, the aging population keeps increasing, causing those injuries due to falls to happen more frequently as shown in the graph below.



http://www.phac-aspc.gc.ca/seniors-aines/publications/public/injury-blessure/seniors_falls-chutes_aines/assets/pdf/seniors_falls-chutes_aines-eng.pdf

Figure 1: Rate of injuries resulting from a fall, age 65+, in Canada

Engineering Design Process

In order to completely finish the project, the engineering design process used was the IEDP(Iterative Engineering Design Process), due to the fact that it is one of the easiest process to use, and one that can easily be adaptable to any kind of situation that may be encountered throughout the development of the product. All the steps of the design process mentioned on the image below were realised. The first step, one of the crucial ones was the identification of the “Real” problem, which in our case, was unnoticed falls amongst elderly people at St-Vincent Hospital. Followed by that problem identification, a cyclic process of prototyping, testing, analyzing and refinement of the product were achieved. Furthemore, based on the results of testing the most recent iteration of the design, changes and refinements were made accordingly.

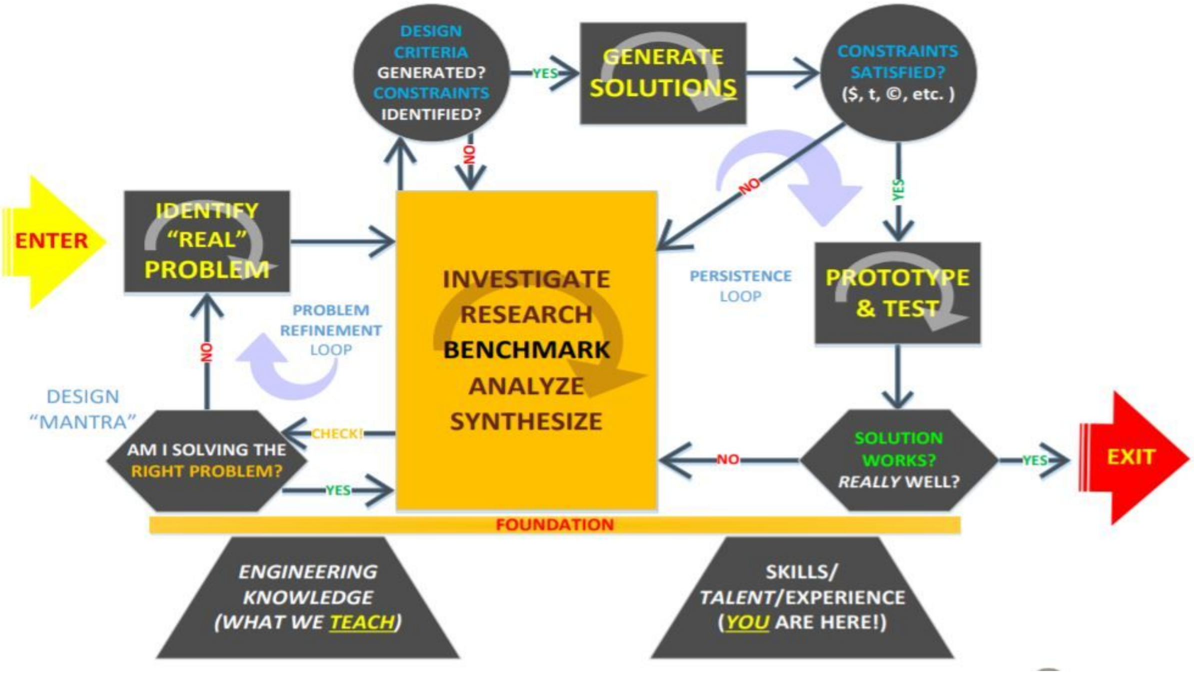

DESIGN CRITERIA GENERATED? CONSTRAINTS IDENTIFIED?
YES
GENERATE SOLUTIONS
CONSTRAINTS SATISFIED? ($, t, ©, etc.)
NO
NO
YES
ENTER
IDENTIFY "REAL" PROBLEM
INVESTIGATE
RESEARCH
BENCHMARK
ANALYZE
SYNTHESIZE
PERSISTENCE LOOP
PROTOTYPE & TEST
PROBLEM REFINEMENT LOOP
NO
DESIGN "MANTRA"
CHECK!
AM I SOLVING THE RIGHT PROBLEM?
YES
NO
SOLUTION WORKS? REALLY WELL?
YES
EXIT
FOUNDATION
ENGINEERING KNOWLEDGE (WHAT WE TEACH)
SKILLS/ TALENT/EXPERIENCE (YOU ARE HERE!)

Figure 2: Iterative Engineering Design Process

Need Identification and Product Specification Process

Need Statements

After the first meeting with the client, we had a better idea of what exactly the customer was looking for and what were some key aspects that he definitely wanted to see or have for the final product. All the information received can be seen in the table below, and all those points were fully used to achieve the final prototype.

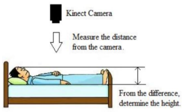
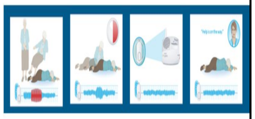
Need statements
1. The fall detection system is adaptable for use with patients who have varying degrees of mobility.

2. The fall detection system runs 24/7 providing a continuous analysis of the patient’s state.
3. The fall detection system sends an immediate alert to caregivers right after a fall is detected.
4. The fall detection system is affordable and is easily deployable
5. The system integrates with the patient or caregiver without disrupting routine/typical activities.
6. The system works with surrounding medical and hospital systems without modifying their behaviour.
7. The system detects falls such as slips, tumbles, buckles and rolls with a high level of accuracy and efficacy.

Table 1: A set of prioritized customer statements turned into need statements

Benchmarking

To be able to build our product, we decided to take a look at what was previously done and how those products work, and checking if some of those products had some of the requirements or all of the requirements that we were trying to fulfill. Therefore, the following products and descriptions were retrieved from reports provided by previous teams who have attempted to create a solution for the fall detection system for Saint-Vincent Hospital (SVH).

	Alarm with a magnetic cord 	Pressure mat 	Blood pressure monitor 	Depth detector  Kinect Camera Measure the distance from the camera. From the difference, determine the height.	Sensor-based device 
The device prevents the fall	This device prevents the fall by having a rope attached to the patient's garment and	This device tries to prevent the fall of a patient when it detects a considerable	This device tries to prevent falls of patients by calculating the arterial pressure,	This device attempts to prevent the fall by using a depth sensing system that is	This device works with sensors in a powerful microprocessor placed around the neck of the

	that triggers when the patient falls and the magnet at the other end of the rope detaches from the speaker of the alarm	change of weight when the patient has fallen	indeed, when a person passes from a sitting position to a standing up position or during falls, the arterial pressure of the individual increases considerably, which triggers an alarm	hooked to the ceiling above the patient's bed, that gets triggered when the patient approaches the camera (then gets up from his bed eventually)	patient and a box serving as an alarm. The microprocessor records all day long data on the patient when he is lying down, sitting or standing and detects falls by processing this data
The device doesn't send false alarm	This device seems very easy to remove, it is possible that some sudden movements during the night or during the day can cause false alarms	The disadvantage of this device is that it will send a huge number of false alarms even when the patient hasn't fallen at all, caused by a variation of weight of the patient when trying to be more comfortable for example	This device should not limit false alarms according to the way it is programmed, to make sure, tests and investigations have to be conducted continuously	This device does not make a false alarm, depending on the product's efficiency or sensors	This device seems to be quite effective according to user comments but it depends on the company that produces the dispositif
The device doesn't restrain the patient	the device does not restrain the patient as there is only one hooked rope that can easily come off	There are no restraints simply because the device is placed under the patient	This device does not restrain the patient as it looks like a small bracelet or watch attached around the	This device is attached to the ceiling,in order to not get in the way of the patient,therefore, it will not be a restraint for the patient	This device is a necklace, it won't restrain the patient because of its size and weight

			patient's wrist		
The device warns the caregivers	The device can warn nurses with an alarm of 70 to 85 decibels	This device can send a powerful signal to the nurses after the patient fell	This device can send a powerful signal to the nurses when it detect an high heart rate	This device can send a powerful signal to the nurses when it detect a difference in the hight	This device can send a powerful signal to the nurses when the device calculate a fall detection
Cost	About 60 $ per alarm	This system doesn't last too long, usually it has to be replace simply after being used once. About 50$ per alarm	About 70 $ per alarm	About hundreds of dollars	About 50 $ per month
Durability	Depends on the materials used	Not very durable due to the fact that it can only be used once	durable device due to the fact that it is waterproof	Depending on the materials used	Depending on the company that manufacture this device
The device can't be deactivated by the patient	This device should not be disabled because it is in the back of the patient having difficulty with movement but it is possible to manually unhook the rope or cut it	This device can't be deactivated by the patient while it's being hanged on the bed or on a chair	This device can't be deactivated by the patient unless the patient try to hard to deactivate the system and the patient can remove the device from his hand very easily	This device can't be deactivated by the patient or accessible for the patient	This device can't be deactivated by the patient but the patient can remove the device very easily

Table 2: A list of product used to develop our benchmarking

Metrics

The ten items in the following table are measures that will be used to evaluate the performance of the product solution space.

Metrics #	Needs #s	Metrics	Imp	Units
1	3, 7	Time to detection of fall	1	s
2	1, 7	Accuracy [true positives/(all positive detections)]	1	%
3	1, 5, 6	Mass of product	1	kg
4	1, 5, 6	Volume of product	2	m^3
5	1, 5, 6	Length of product	2	m
6	1, 5, 6	Width of product	2	m
7	2	Run time over single ‘cycle’	3	s
8	2, 5, 6	Electrical power Required	4	w
9	4	The cost of the product	1	$
10	4, 6	Product Implementability	2	subj.

Table 3: A list of Key metrics

Target Specifications

For each of the ten measures provided above, a range of specific desired quantities are assigned based on client interview.

Metrics #	Metrics	Desired Value Range	Units
1	Time to detection of fall	< 5	s
2	Accuracy [true positives/(all positive detections)]	> 96	%
3	Mass of product	< 0.75	kg

4	Volume of product	< 800	cm^3
5	Length of product	< 10	cm
6	Width of product	< 5	cm
7	Run time over single ‘cycle’	> 21, 600	s
8	Electrical power Required	< 10 > 3	w
9	The cost of the product	< 70	$
10	Product Implementability	-	subj.

Table 4: A set of Target Specifications

For each of the value limits specified in the table above, it is implicitly provided that there is an optimal value. However, since this optimal value cannot reasonably achieved or known for all metrics, the range is provided. Take eg. cost; the optimal cost is $0, but this is not reasonable, of course.

Conceptual Designs

Based on customer needs we had to clarify core functionality by breaking down required product functions into smaller basic sub-functions, identifying external sub-system boundaries.

Saint Vincent’s Hospital is looking for a product that helps accurately and quickly detect (and ideally prevent) falls when a caregiver is not present.

- The fall detection system is adaptable for use with patients who have varying degrees of mobility.
- The fall detection system runs 24/7 providing a continuous analysis of the patient’s state.
    - The device is scanning/monitoring the patient
- The fall detection system sends an immediate alert to caregivers right after a fall is detected.
- The fall detection system is affordable and is easily deployable.

  - The cost is further explained in the BOM

- The system integrates with the patient or caregiver without disrupting routine/typical activities.

- The system works with surrounding medical and hospital systems without modifying their behaviour.

- The system detects falls such as slips, tumbles, buckles and rolls with a high level of accuracy and efficacy.

The following 12 ideas were identified as potential concepts from the team. The ideator is listed within square brackets, and the list is sorted by team member's name.

- Sensor pad jacket/vest (reacts/alerts when there's an impact with the ground)
- Walkie talkie (fall monitor)
- A necklace that alerts the caregivers when pulled
- Better handles and railings around the room/bed + warning signs ("Use the handles in order to prevent a fall")
- Customizable impact sensor clothing
- Cushion mats that prevent injuries and inform caregiver
- Robot that grabs person before falling
- Accelerometer + belt
- Spiderman weblike grapple that catches patient that falls
- Auto-inflating vest that reduces injury from falls
- Camera that tracks falls using object recognition
- Soft floor + Pressure Detection

As the suggestions provided aboved overlapped, it was not necessary to evaluate each concept individually; rather, some ideas were consolidated for the study. Additionally, criteria of evaluation were also not considered entirely individually. Take for example the length, width and volume of product (which directly correlate to patient comfort); these three metrics were combined into the metric called "Geometry of Product." For the purposes of comparison, this is sufficient and arguably more efficient.

Selected criteria	Auto-inflating Vest	Accelerometer+ Belt	Sensor pad jacket/ vest	Necklace that alerts care givers	Improved handles and railings around the bed	Customizable impact sensor clothing	Object recognition camera	Robot that grabs person before falling	Cushion mats that prevent injuries and inform caregivers	Spider-Man weblike grapple that catches patient that falls	Soft floor+ Pressure Detectors
Detection Time	2	1	1	3	5	1	1	2	3	5	2
Accuracy	5	1	1	3	4	1	3	2	2	2	2
Mass of product	2	2	2	1	1	1	0	5	0	0	3
Geometry of Product	2	1	1	1	1	1	1	3	1	3	2
Electrical Power Required	1	1	1	1	0	1	3	2	2	0	2
Production Cost Estimate	2	2	2	2	3	2	4	5	2	2	2
Product Implementability	2	1	1	1	1	1	1	5	2	2	1
Total	16	9	9	12	15	8	13	24	12	14	14

Table 5: Decision Matrix for Generated Concepts

The high-level, abstract, functional decomposition is portrayed by the diagram provided below. In general, any fall detection (or prevention) system must follow the states outlined in the graphic provided. In the case of a fall prevention system, the state named “alarm on” would also act as the state that handles the mechanisms of prevention.

All of the solutions above are ranked on a scale from 1 to 5, 1 being the best and 5 being the worst. A “0” only means that the concept doesn’t require that component at all and therefore doesn’t have a significant impact on the overall product implementability. Based on the total of all the columns,the best solutions are the one with a total less than 10.

From the analysis and comparison done above, the three leading concepts all had a similar theme. As such, they are all listed as promising solutions that the team believes will eventually become the final, implemented prototype.

- Sensor Pad Jacket/Vest
- Accelerometer + Belt
- Customizable impact sensor clothing

Due to the similar nature of the projects chosen to be best amongst all options, a combination and substitutions of these concepts was primarily used to develop the eventually chosen concept. The process is captured by the following, customized table.

The table works by noting the major components that each of the narrowed concepts entailed and assigning a status of being kept or being discarded for the final concept.

Concept Name	Concept Component	Status
Sensor Pad Jacket/Vest	Vest	Discarded
	Force Sensor Pad	Kept
	Computation Element (microcontroller)	Kept
Accelerometer + Belt	Accelerometer	Discarded
	Computation Element (microcontroller)	Kept
	Belt	Discarded
Customizable impact clothing	Impact Sensor	Discarded
	Customizable Clothing	Kept
	Computation Element (microcontroller)	Kept

Table 6: Description of Features Kept & Discarded

To summarize: The solution to the client's desire for a non-intrusive product that helps track falls of patients is a line of clothing with cleverly integrated force sensing pads from which data will be collected and analysed for the detection of a falling event - upon which a caregiver will be informed. This solution provides a simple implementation to a difficult problem and also allows for future improvements in truly meaningful, and perhaps unexpected ways.

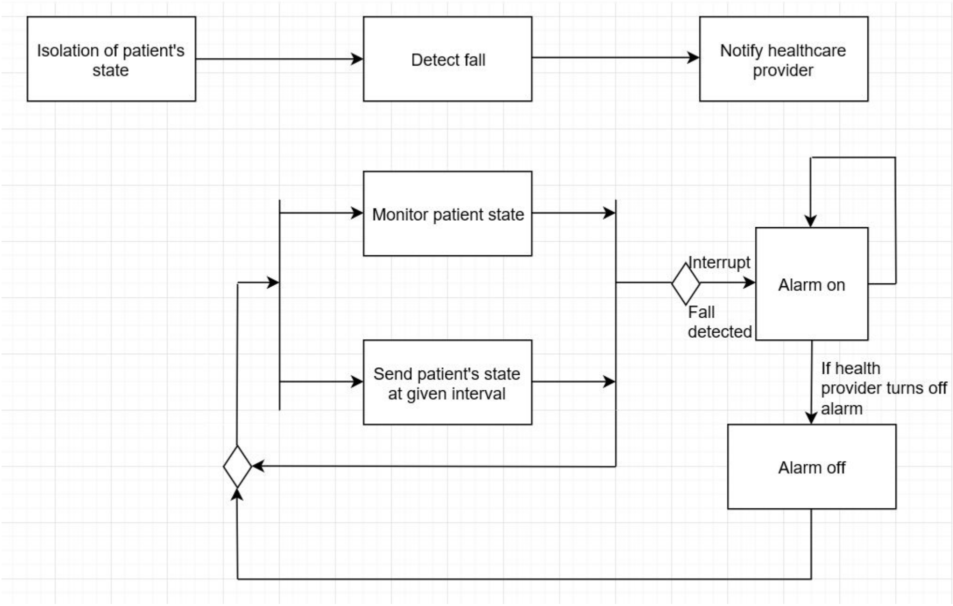

Isolation of patient's state
Detect fall
Notify healthcare provider
Monitor patient state
Send patient's state at given interval
Interrupt
Fall detected
Alarm on
If health provider turns off alarm
Alarm off

Figure 3: High-level functional decomposition

The chosen concept's hardware can be quite easily visualized from the following diagram:

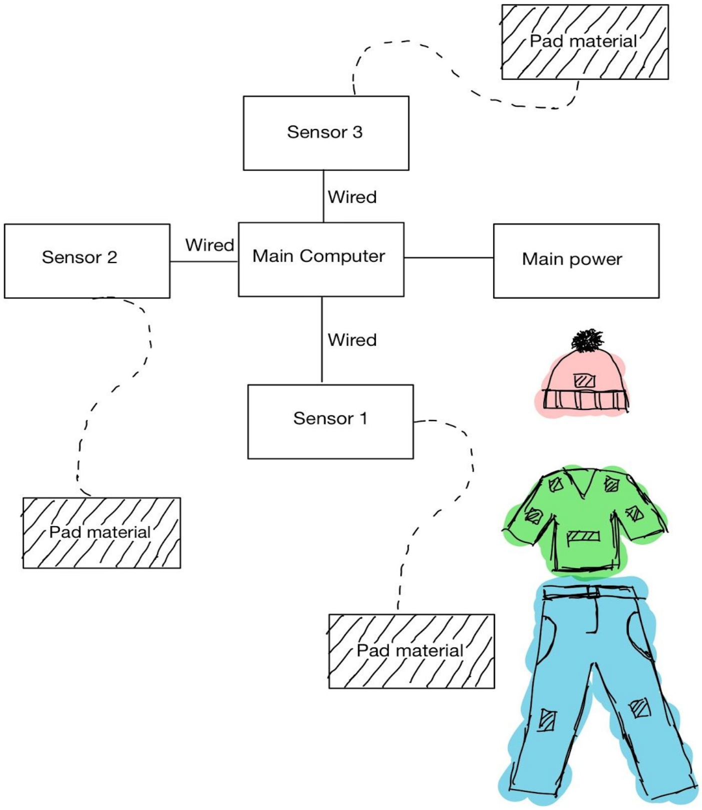


Figure 4: Representation of the chosen concept

The diagram is only meant to provide the reader of this document an idea of the concept and does not provide any details of implementation. Furthermore, the number of sensing pads on clothing will be a topic of optimization and research. To achieve the most accurate results, these pads will be strategically placed to improve the odds of positive detections, while reducing the odds of false positives.

In reality, what the client truly wants is an effective fall prevention product. However, with the constraints of resources (particularly financial and temporal) a successful project in that domain is difficult; but, a good step in that direction is an accurate fall detection platform that further testing, via implementation, can be performed. For that reason, the chosen solution is ideal in the context of both the course requirements and the client's desires. The following two lists specify the benefits and drawbacks.

Benefits

- The patients are able to wear a fashionable clothing piece without the addition of further discomfort
- In case the fall detection alarm goes off after a fall has been detected, it will not interfere with the system already implemented at the hospital
- Once the hardware is implemented and calibrated, different algorithms can be eventually tested for better fall detection rates

Drawbacks

- Doesn't prevent falls in any way
- The simple hardware may mean that some types/mechanisms of falls are not accurately captured

Project Planning and Feasibility Study

The overarching plan of this project will follow the natural flow of prototype development. The three major prototypes and their intentions are listed first.

Prototype 1 - Conceptual

The intention of the first prototype will be to test the comfort levels and visual appeal of the eventual product. Furthermore, the prototype will provide a gauge of the level of difficulty of hiding/protecting the electrical components that will eventually be in place (such as wires and piezoelectric discs). From these findings, the team will be able to vary the materials used for the final prototype - to increase both comfort, by reducing restrictive constructions, and increase product lifetime.

The required materials for this prototype are provided in the BOM table relating to “Prototype 1” later in this document.

Prototype 2 - Functional

The second prototype will allow for a primary testing of the functionalities required of the final product. That is, all of the sensing pads will be assembled and hooked up to the main computing unit. A choice of main computing unit can be decided by integrating different choices at this stage. This prototype is what the team is calling a “Flat product.” That is to say that while none of the exteriors are implemented, the electrical system is almost fully connected in the way that it is supposed to be. This allows for iterative loops of software design as well as testing complex relations between the sensor readings and the desired outputs of monitoring patient states.

The required materials for this prototype are provided in the BOM table relating to “Prototype 2” later in this document.

Prototype 3 - Final

The final prototype is referred by the team as a “Client hand-off.” This is the prototype that resembles a final product the most. In other words, the “Flat product” will be transformed into the final prototype by adding all exteriors. In this case, those exteriors are attaching the pads to clothing, to create the initial clothing lineup. This prototype will be handed off to the client for further testing on their end as well as be used for demonstrations.

The required materials for this prototype are provided in the BOM table relating to “Prototype 3” later in this document.

Now that the three prototypes have been explicitly stated, the desired timeline for the project can be fully defined; it is provided here in table format (but which can also be provided in the form of a gantt chart if desired by the client):

Task No.	Task Name	Task Description	Task Owner	Prerequisite Tasks	Task Deadline
1	PD C	Conceptual design + Project plan	Milestone	-	Feb 3rd
2	Circuit Diagram	Fully develop the diagram specifying all electrical components and connections	Vanessa	-	Feb 8th
3	Initial Software Design	Develop state and activity diagrams for the required software	Karim/Andre	-	Feb 8th
4	Prep for Prototype 1	Gather all required materials for first prototype	Manit	-	Feb 6th
5	Build Prototype 1	Assemble the conceptual prototype	All members	4	Feb 8th
6	PD D	Detailed Design + Prototype 1	Milestone	5	Feb 10th
7	Presentation Preparation	Create the slidedeck for progress presentation	Vanessa	5, 6	Feb 10th
8	PD E	Project progress presentation (in lab)	Milestone	7	Feb 11th
9	Collection of Fall Data	Collect data on fall mechanisms from online datasets	Karim	-	Feb 13th
10	Analysis of Fall Data	Achieve first pass list of major body positions where sensor pads would be most effective	Manit	7	Feb 15th

11	Prototype 2 Prep	Gather/order all required materials for first prototype	Vanessa	2, 3, 6	Feb 15th
12	Business Model Prep.	Write up the business model	Andre	1	Feb 23rd
13	Build “Flat Product”	Connect all electrical components together	Vanessa Manit	11	Mar 1st
14	PD F	Business model	Milestone	12	Mar 3rd
15	Implement Software	Write all software necessary to perform functions	Andre/ Vanessa/ Manit/ Karim	13	Mar 6th
16	Test “Flat Product”	Test all functionality of prototype 2	Andre/ Vanessa/ Manit/ Karim	15	Mar 8th
17	PD G	Prototype II and customer feedback	Milestone	16	Mar 10th
18	Prep Economics Report	Write report describing economic study in detail	Manit/ Karim	-	Mar 15th
19	Prep Video Pitch	Record and edit 1 min video	Vanessa/ Andre	17	Mar 15th
20	Final Prototype Prep	Order and gather all components needed for final prototype	Karim	17	Mar 15th
21	PD H	Economics report + 1 min video pitch	Milestone	18, 19	Mar 17th
22	Build final prototype	Turn the implementation from “Flat Product” into final product	Andre/ Vanessa/ Manit/ Karim	20	Mar 22nd
23	Test Final Prototype	Test all functionality of prototype 3	Andre/ Vanessa/ Manit/ Karim	22	Mar 28th
24	PD I	Design day presentation (w Judges+ clients)	Milestone	23	Mar 29th

25	Final Demonstration Prep	Develop the final demonstration	Vanessa/ Karim	23	Mar 31st
26	Final Presentation Prep	Create slide deck for final presentation and practice	Andre/ Manit	23	Mar 31st
27	PD M	Final presentation with final prototype	Milestone	25, 26	Mar 25th or Apr 1st
28	IP and Patent Prep	Complete required tasks for PD J	Andre/ Vanessa/ Manit/ Karim	23	Apr 5th
29	PD J	Intellectual Property, Patent/Creative Commons Search	Milestone	28	Apr 5th
30	Final Report Prep	Write final report	Andre/ Vanessa/ Manit/ Karim	27	Apr 12th
31	PD L	Final report	Milestone		Apr 12th

Table 7: Ideal and desired timeline for the complete execution of the product

The following Bills of Materials (BOM) are provided for each of the three prototypes discussed in the project plan.

Prototype 1 : Conceptual, Low Budget						
Item No.	**Item Name**	**Description**	**Quantity**	**Unit Cost [$]**	**Extended Cost [$]**	**Cost to Team [$]**
1	T-shirt	One of the most simple clothing items that will be developed in the initial line	1	$15	$15	$0
2	Toque	Another potential clothing item that will be developed in the initial line	1	$20	$20	$0

3	A132412-DS-ND	24 AWG Copper wire	25 ft	$0.5064	$12.66	$0
4	Analog for Sensor - G1S Plywood	3mm thick Cardboard/plywood cutouts that will mimic the piezoelectric plates that will eventually be used	1 board [24in x 48]	$17.20	$17.20	$0
5	Double Sided Tape	Used to temporarily attach the pad material to clothing	1 Roll	$5.80	5.80	$0
6	Pad Material	Likely thin nylon or scrap fabric laying around somewhere	To make 4 pads	-	-	-
Totals					$70.66	$0

Table 8: BOM for the first prototype

Prototype 2 : Functional, Low Budget

Item No.	Item Name	Description	Quantity	Unit Cost [$]	Extended Cost [$]	Cost to Team [$]
1	Arduino Nano	Main computing element candidate I	1	$15.02	$15.02	$15.02
2	Arduino Uno	Main computing element candidate II	1	$35.99	$35.99	$0
3	A132412-DS-ND	24 AWG Copper wire	25 ft	$0.5064	$12.66	$0
4	Piezo Discs	27mm piezoelectric discs with leads attached	1 bundle [12 pcs]	$6.95	$6.95	$6.95
5	Double Sided Tape	Used to temporarily attach the pad material to clothing	1 Roll	$5.80	5.80	$0
6	Pad Material	Likely thin nylon or scrap fabric laying around somewhere	To make 4 pads	-	-	-
Totals					$76.42	$21.97

Table 9: BOM for the second prototype

Prototype 3 : Functional, Full Budget

Item	Item	Description	Quantity	Unit	Extended	Cost to

No.	Name			Cost [$]	Cost [$]	Team [$]
1	T-shirt	One of the most simple clothing items that will be developed in the initial line	1	$15	$15	$15
2	Toque	Another potential clothing item that will be developed in the initial line	1	$20	$20	$20
4	Sewing Thread	To stitch the pads onto clothing in a more permanent fashion for client delivery	1 roll 200 yards	$6.40	$6.40	$6.40
5	Arduino Nano	Main computing element candidate I	1	$15.02	$15.02	$0
6	Arduino Uno	Main computing element candidate II	1	$35.99	$35.99	$0
7	A132412-DS-ND	24 AWG Copper wire	25 ft	$0.5064	$12.66	$0
8	Piezo Discs	27mm piezoelectric discs with leads attached	1 bundle [12 pcs]	$6.95	$6.95	$0
9	ESP8266 Esp-01 Serial Wireless Wifi Transceiver Module	Wifi module for main computing element to coordinated with a centralized computer upon which notifications of a fall element will appear	1 bundle [4 pcs]	$12.48	$12.48	$12.48
6	Pad Material	Sheets of flannel	1 meter roll [48in width]	$7.99	$7.99	$7.99
Totals					$132.49	61.87

Table 10: BOM for the third prototype

Totals for All Prototypes	
Prototype ID	Cost to Team [$]
Prototype 1	$0
Prototype 2	$21.97
Prototype 3 [Final - hand off to Client]	$61.87

Total Cost to Team	$83.84

Table 11: Total for all prototypes

The feasibility of the chosen solution is presented through the five TELOS factors method below:

Technical (T)

The mechanisms of falling are wide and not easily detectable to a certainty. In the clinically ill or elderly, the rate of falling and corresponding consequences are high, even just due to a physiological nature. For this reason, the product must achieve a high rate of detection to help caregivers provide the highest quality of care. Technically, this means that every component chosen must perform within certain tolerances/ranges. The feasibility of achieving these ranges is directly related to the expertise present on the team and the available resources, which of course include time and cost. The following lists present all available resources (and their magnitude):

- Expertise of Team
  - **Karim : Chemical Engineering Student**
    - Experience with sequence optimization and 3D modeling
  - **Vanessa : Electrical Engineering Student**
    - Experience with electrical circuits and low-level microcontrollers
  - **Andre : Software Engineering Student**
    - Experience with writing fully integrated and industry grade software
  - **Manit : Electrical Engineering Student**
    - Experience with physics based modeling and simulation

- Facilities
  - “Maker” Ecosystem
    - Brunsfield - provides tools and some materials for machining
    - Makerspace - provides 3D printing facilities and materials
    - MakerLab - provides meeting location and simple tools
  - SITE + CBY
    - Computers with software
      - Solidworks
      - Ansys
      - MatLAB

- Other Important resources
    - Time
        - 7 weeks from submission date
        - 12 productive person-hours in total per week
        - 84 productive person-hours in total
    - Financial
        - $100 for final product prototype
    - Scrap Material
        - Access to many recyclable material from “Maker” Ecosystem
            - Plywood
            - Scrap metal

From a forward looking perspective, the following steps are likely required to :

- Steps Required for Completion of Project (not entirely ordered)
    - Develop system specifications based on requirement specifications
    - Conduct a survey of available (COTS) central processing computers that will act as the gateway between sensing pads and notifying method
    - Conduct a survey of available (COTS) pressure/impact sensors
    - Literature review of topics in segmentation of digital events, mechanics of falling, statistical analysis of common impact points and comfort/fashion
    - Determine components based on a system development approach
    - Design of robust software to provide ease of use and adaptability
    - implement designed system
    - Implement designed software
    - Test and validate all functionality while also developing an appropriate demonstration for the client
    - Document process and client facing manuals/instructions.

Based on the lists provided, the feasibility of the project on a technical basis is covered. To elaborate, taking every item in the list of required steps matches an item, or derivative thereof, in the list of available resources. More specifically, all forms of expertise are present, the required actions and materials can be formed within the facilities available and the time and finances to develop the prototype are sufficient.

Economic (E)

This project presents a special challenge to heavily consider the economics of a hospital ecosystem. The patients are likely elderly and may not have a wide pool of financial resources to draw from - on that point, the hospital also doesn't have this. For that reason, the following cost and economic analysis is provided here.

Economics is a game of cost management. Therefore, the first step is to consider the total cost of this project. The budget restrictions are of $100; in other words, the total cost of this project from the point of view of the team is $100. An assumption can be made that the product cost will be approximately 60% of this amount due to prototyping and other activities. Therefore assuming the final product costs less than $60, the following, and likely naive, analysis can be conducted.

The success of this project is based ultimately on the client's ability to implement and further expand upon the designed product. The calculations below show an approximated cost of implementation for SVH.

Number of Patients Considered for Implementation: [per year]	20
Base Cost per Patient: [assumed]	$60
Maintenance Cost per Patient: [approximately required every 6 months]	$5 per pad replacement
Number of Pad Replacements Per Patient:	4
Total cost: [over a 20 year lifespan]	$32000

Or in other words, a total cost of about $1600 per year; for a hospital, this is a very reasonable number to spend for an additional item in the medical technology category of their budget. Of course, these costs would also likely be offset by patient medical or health insurance itself. The exact business plan for this project is not yet determined, but the simple analysis conducted shows the potential of multiple avenues of business methodologies resulting in success.

An important note is that it is expected that an entirely new technology will make this product obsolete within 20 years. Therefore, the analysis was conducted over that period of time.

With these potential of market success, the project is deemed economically feasible: for both the team as well as the client.

Legal (L)

A hospital is an organization like many others, with one major exception: the medical laws and regulations that one must adhere to. Issues of upholding confidentiality and integrity of medical equipment and systems must be carefully considered and followed. While these laws and regulations are vast in both quantity and complexity, the client provided some guidelines that the team can follow.

The first is to never tamper with equipment that is present. That is, the solution must not need to integrate with onsite equipment, including the existing call system. This is for reasons pertaining to liability and the lack of time to ring up any contract that gets around such liability. The second major guideline is to not interfere with any hospital routines. Following these two major guidelines, the project is sure to avoid any issues facing legality.

Operational (O)

The operation of the team is intrinsically varied due to the nature of studentship. The group has agreed to meet once per week to get caught up and make major decisions. However, meetings with vague or undetermined agendas tend to end up unproductive. On top of this, course schedules will likely throw off any schedule the team makes. Knowing and understanding this is powerful. In this way, every timeline will have fairly large margins of cushioning between task completion and deadline date.

Furthermore, there are only about seven weeks before the final deliverable needs to be presented - not a lot of time. Therefore, the team will keep this in mind every week, when working towards the end goal.

Scheduling (S)

The table below presents the timeline of the project deliverables. A brief discussion of this timeline follows.

Deliverable	Delivery Date
PD C: Conceptual design + Project plan	Feb 3rd 2019
PD D: Detailed Design + Prototype 1	Feb 10th 2019
PD E: Project progress presentation (in lab)	Feb 11th 2019
PD F: Business model	Mar 3rd 2019
PD G: Prototype II and customer feedback	Mar 10th 2019
PD H: Economics report + 1 min video pitch	Mar 17th 2019
PD I: Design day presentation (w Judges+ clients)	Mar 29th 2019
PD M: Final presentation with final prototype	Mar 25th or Apr 1st
PD J: Intellectual Property, Patent/Creative Commons Search	Apr 5th 2019
PD L: Final report	Apr 12th 2019

Table 12: Milestones for all the different deliverables

From the table, each major deliverable for this project occurs approximately one week after it's predecessor. While the number of deliverables for a project of this nature seems excessive, the timeline is not unreasonable. However, it may be the case that some, less important (for the overall success of the project in the eyes of the client), deliverables may suffer from a dip in quality to achieve them.

A Quick Dig into the Science of Falling

In order to implement the sensors used for our project, we decided to study in the detail the science of falling. We discovered that there are specific parts of the body that we're most likely to hit whenever we're falling. For the final prototype, we developed and were able to build a network of 4 sensors on half of the piece of clothing used for the final product, placed on the wrist, the chest, the back and the shoulder, parts that have a high probability of being hit, as shown in the image below.

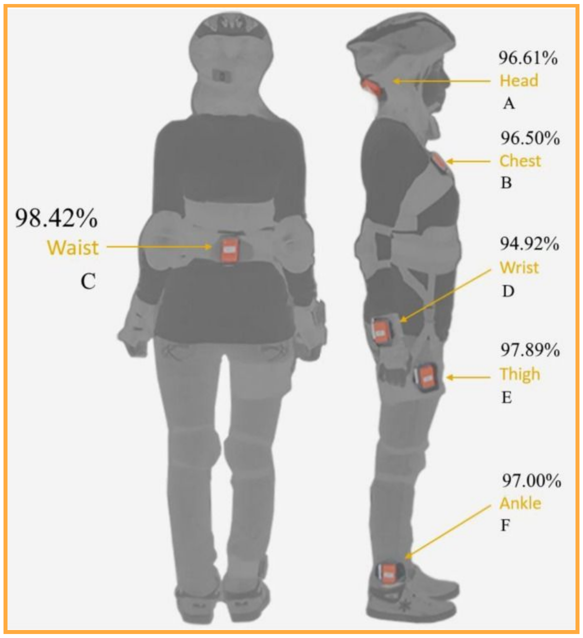


Figure 5: High risk body parts more exposed to being hit after a fall

This is only one of the many studies performed on the topic of fall mechanism characterisation. By using the extensive data collected by numerous researchers, the product can be improved iteratively in the following way: it has been mentioned that the hardware used for the chosen concept is simple and prone to many errors. However, it does have the benefit of being fully modular and software upgradable. When better, more robust algorithms of fall detection have been tested and are ready to deploy, they can be easily integrated for the product(s) developed under The Fall Collection.

In this way, the product is potentially ever improving and the problem of fall detection can become one of large data analytics and even, dare we say the words, machine learning.

Prototyping, Testing and Customer Validation

Prototype I

Using these sketches as a template, the prototype was implemented with limited resources. Photos of the physical prototype are provided here:

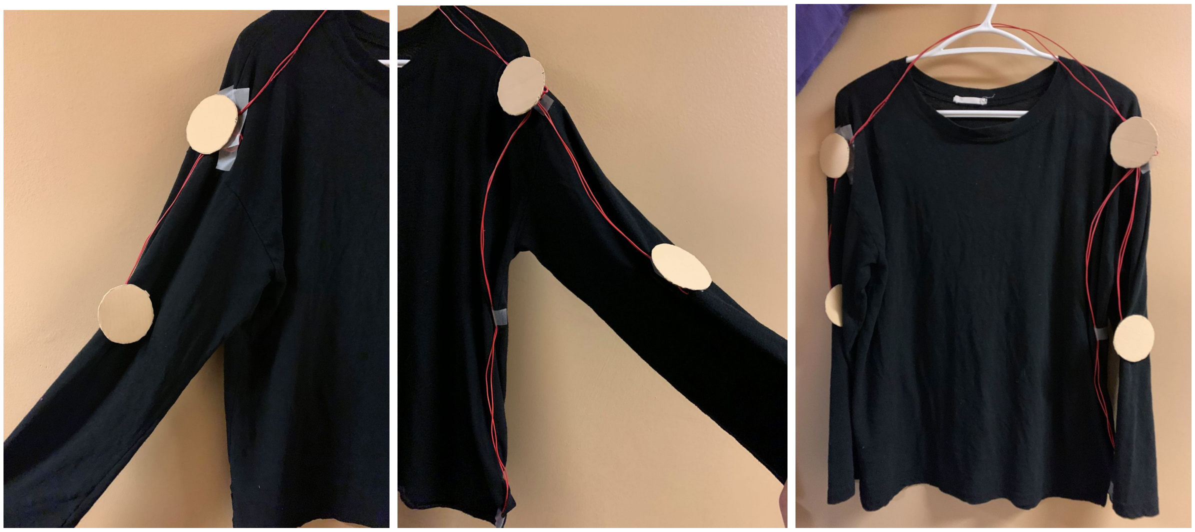


Figure 6: Visual Implementation of Non-Functional Prototype

Testing:

Even with this simple non-functional prototype, much was discovered. These discoveries are given in the table below.

Level of comfort	
Expected results	Actual results

The device doesn’t restrain movements and is comfortable.	The first prototype is comfortable, however movements are still limited due to the wires therefore, arrangement of the wires is needed in order to achieve that freedom of movements while keeping comfort to the highest level.

Table 13: Results of Testing Non-Functional Prototype

In further prototyping we must consider trying and using different materials to ensure the comfort and durability.

Prototype II

In order to present the aspect of our second prototype, here are the images/pictures showing the sensors and all the connections currently in place.

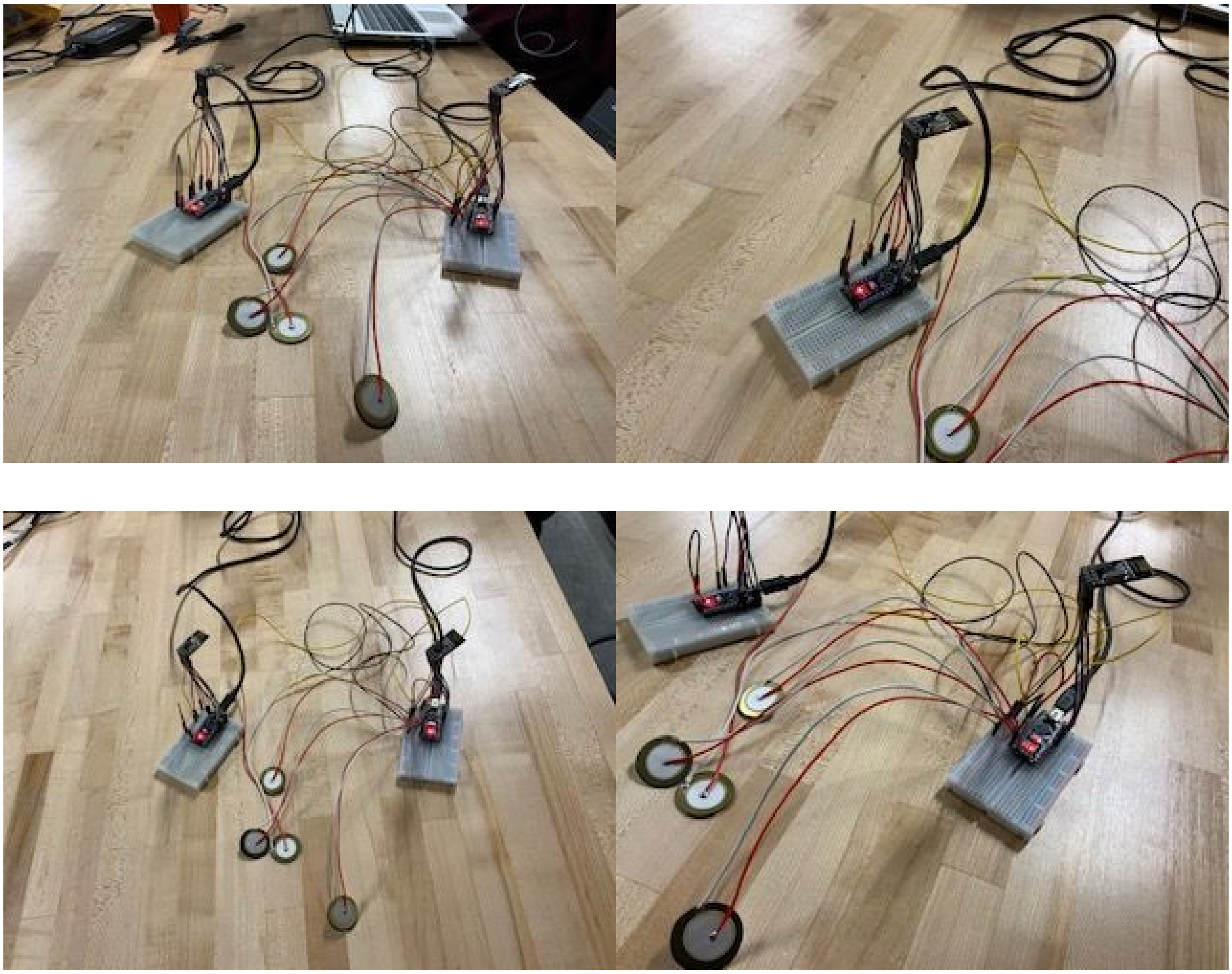


Figure 7: Development of second prototype

Following the development of our second prototype, three different tests were conducted and divided into objectives, procedures, expected results and actual results,everything can be seen in the table below.

<u>Testing:</u>

Prototype testing				
Test	**Objective**	**Procedure**	**Expected Results**	**Results**

Test 1	Test the sensitivity of the piezo sensors	Connect the sensors to a multimeter and hit them to see how they react and how sensitive they are	The sensors should be able to be accurately display a certain amount of voltage depending on the force of the impact	The sensors work just as expected. With small impact, the sensors are able to measure from 1 up to 2 volts and with bigger impacts, they can read and pick up to 3 volts.
Test 2	Remote communication using radios	By sending messages(data) from the transmitter side to the receiver side and observing if the message is fully received without a delay	Both sides(transmitter and receiver) should interact with each other pretty quickly and send information without any interruption and/or delay	The remote communication is successfully established and the messages are sent continuously without any sort of delay
Test 3	Test multiple pads at the same time to see if they all work perfectly	Connect 4 sensors to the transmitter side and hit each and every single one of them or even more simultaneously	The sensors should all work at the same time and each one of them should be able to pick up its own individual set of data	Everything works as expected, the sensors can individually send information to the receiver when hit

Table 14: Set of different tests conducted on the second prototype

Prototype III

Based on prototype I and II, a final prototype was developed, a prototype that combined all the aspects of the previous two, ensuring comfort without limiting its capabilities and can be seen below.

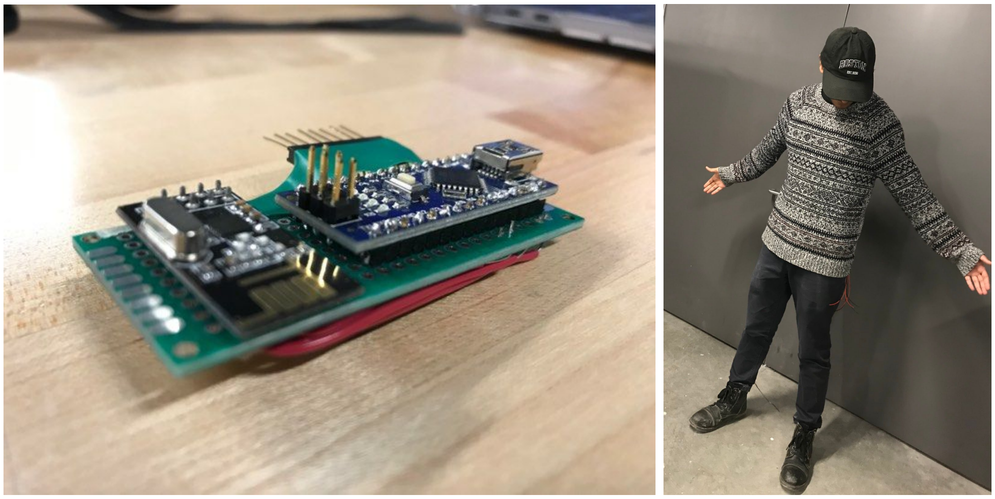


Figure 8: Final prototype

This fully integrated, demonstration prototype was displayed at design day and both praise and feedback were received. The functionality remained nearly identical between the second and third prototype. Further testing was done on the radio communication as well as battery life time. Neither tests recorded any substantially surprising results, and hence are omitted from this report.

As mentioned previously, and as will be discussed again shortly, this prototype does not only hail useful for demonstration purposes, but also as a technological or research platform for future algorithm development and data collection on the mechanisms of falling.

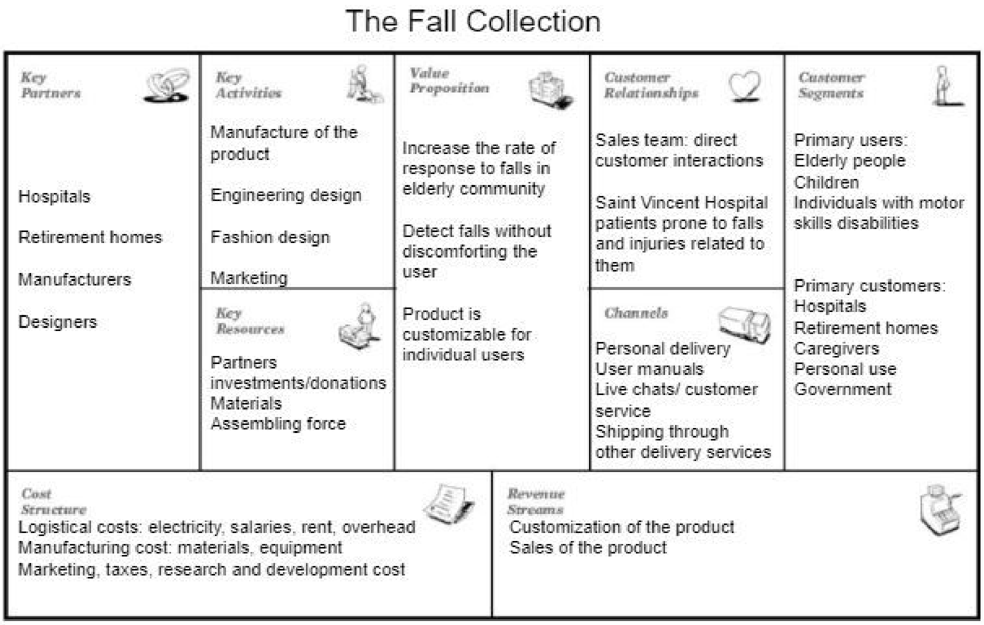
Business Model

The prime functionality of the initial product is the ability to detect falls in patients, therefore not only it will benefit people living in long term healthcare facilities but can also be used for a more personal use. With this in mind, the list below provides important assumptions:

- Having a high fidelity detection and data collection method for falling will allow, in the future, for further development of fall prevention products (which is of course the ideal end goal)
- Fashion/comfort is an important factor in buying wearable technology of any kind - hence, focussing on this aspect will allow the business to expand into wider markets (than just patients at the hospital)
- As healthcare is a federal/governmental responsibility, they will wish to buy and implement this product (if the product works well) in facilities hence expanding customer segments
- The scale production of this product will be cheap as the price of the material and manufacture will be low. Therefore the major cost for the business will be administrative/logistical

The feasibility of the product and business rely on these four major assumptions. In general, the sales of the product rely on assumptions 2 and 3, while the development depends on assumptions 1 and 4. However, seeing as the product is definitely desired by the healthcare industry, the risk of failure from misguidance of assumptions is minimized. Therefore, the team is confident supporting this business as a feasible prospect.

Based on the assumptions made above, a Business Model Canvas was developed and can be seen below.



The Fall Collection

Key Partners

Hospitals

Retirement homes

Manufacturers

Designers

Key Activities

Manufacture of the product

Engineering design

Fashion design

Marketing

Key Resources

Partners investments/donations
Materials
Assembling force

Value Proposition

Increase the rate of response to falls in elderly community

Detect falls without discomforting the user

Product is customizable for individual users

Customer Relationships

Sales team: direct customer interactions

Saint Vincent Hospital patients prone to falls and injuries related to them

Channels

Personal delivery
User manuals
Live chats/ customer service
Shipping through other delivery services

Customer Segments

Primary users:
Elderly people
Children
Individuals with motor skills disabilities

Primary customers:
Hospitals
Retirement homes
Caregivers
Personal use
Government

Cost Structure

Logistical costs: electricity, salaries, rent, overhead
Manufacturing cost: materials, equipment
Marketing, taxes, research and development cost

Revenue Streams

Customization of the product
Sales of the product

Figure 9: Business Model Canvas of the product

Economic Analysis

For this section, a list of variables, fixed, direct and indirect costs associated with our business based on the manufacturing and sales of our product was developed and a clear distinction between price and cost was established. It’s important to know that prototyping and higher-volume manufacturing costs were more likely going to differ. The classification of all these costs can be seen in the table below.

DESCRIPTION	CLASSIFICATION
Financing cost	variable, indirect cost
Tax	variable, indirect cost
Rent	fixed, indirect cost
Production material	variable, direct cost
Material	variable, direct cost
salary	fixed, indirect cost
Depreciation	variable, direct cost
Overhead	fixed, indirect cost
Electricity	semi-variable, indirect cost

Table 15: Costs classification of the product

The following lines describe a theoretical income-expense report for an initial three years. The dollar values listed are in 1000s of dollars. Ie. a reported value of $300 refers to an actual value of $300000.

Sales:		$1000
Cost of Goods Sold:	-$350	
Gross Profit on sales:		$650
Operating Expenses:		
Marketing Expenses:	-$150	
General & Admin Expenses:	-$120	
Depreciation:	-$60	

Total Operating Expenses:	-$330
Operating Income:	$320

As the report does not need to include tax, and it is assumed that there is not interest on the initial loans, the report ends on operating income. Therefore, over the course of three years, it is expected that the total operating income is a total of $320000. This is a reasonable value considering the demand of the product as well as typical costs of running such a business. Furthermore, this value leaves ample rooms to pay interest, taxes, account for a contingency and spend more on R&D.

Furthemore, by using a Net Present Value analysis, we were able to determine the break-even point for our product.The assumptions made here are that the cost of goods are the only important factor for the NPV analysis due to the unknown nature of the other overhead costs. Additionally, the entire investment was provided at the very beginning.

Initial investment	$350000
Price of one unit	$50
Break-even point	$\frac{\textit{inital investment}}{\textit{unit price}} = \frac{\$350000}{\$50}$ = 7000 units

Therefore, it can be said that the business will break even after 7000 complete units sold. To make this analysis simpler, no other aspect of the business was considered (such as providing service to repair broken units or providing replacement sensor pads, etc...).

For the development of this economic analysis, assumptions were made based on the mean squared average value of manufacturing costs, customer market research conducted supplementing the initial demand curves produced during the research phase on this project.

A list of assumptions are provided below:

- Minimum Annual Return Rate:	10%
- Cost of manufacturing entire clothing item:	$25
- Cost of manufacturing replacement sensing pad:	$3

- No risk factors that would fluctuate prices within next three years
- Demand increases over time for product if no supplied solution

- Fixed business expenses are constant per year for the next three years
- Market for the proposed solution exists
- Marketing effectiveness remains constant over three years for a fixed input cost

While some of these assumptions may not hold true, the consequences are minimized using this set.

Parting Remarks & Allusions to the Future

Falling is easy; detecting these falls is not! In this report, an overview of the development of a simple, yet potentially effective means of combating the increasing problem of injuries due to falls was provided.

Falling, especially at an elderly age, has a significant likelihood of reducing quality of life. For this reason, a solution must be found to prevent these falls or reduce the chance of injury. The first step to prevention is detection. Detection in itself is difficult; for that reason, it is necessary to continue researching the topic. Following this line of thought, this project focused on developing a product that could help detect falls in the almost immediate term and also that could act as a technology platform for researchers studying the mechanisms of falling. This product was also developed to maximize comfort and be adaptable to individual client's fashion sense all while achieving an extremely cheap unit and maintenance price.

In addition to the design work done for this project, the implementation via prototypes was provided. This is in hopes that a future team can continue to the development of this product to the point of use at the original client location, St. Vincent's Hospital in Ottawa.

To conclude, the official description of the developed product is provided: *The Fall Collection is a line of clothing that cleverly (and cheaply) allows for the detection of various slips, falls, and tumbles to help aid in a quick recovery: all without compromising comfort or fashion.*

Bibliography

Figure 1. Rate of injuries resulting from a fall, age 65+, in Canada, retrieved from http://www.phac-aspc.gc.ca/seniors-aines/publications/public/injury-blessure/seniors_falls-chutes_aines/assets/pdf/seniors_falls-chutes_aines-eng.pdf

Figure 5.High risk body parts more exposed to being hit after a fall, retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5017327/?fbclid=IwAR2-nqogf753WuX5O_U9ON_SjnyEg5E7fELxfqy3TwMxcsUo-TKz8EIG6F8

Figure 12. Electrical Schematic of Sensor Pad and Signal Conditioner,in Appendix I, retrieved from https://www.ti.com/lit/an/sloa033a/sloa033a.pdf

Appendix I: Preliminary & Potentially Useful Snippets

Signal Conditioning Aside

As this is the major criteria for success from the client, this is presented as the detailed design of the system. The team will focus development efforts on getting this sensor pad to be as functional adaptable as possible to allow for future development of clever software for more accurate detection of falls.

The results of the detailed design study is best presented in the form of the following electrical schematic.

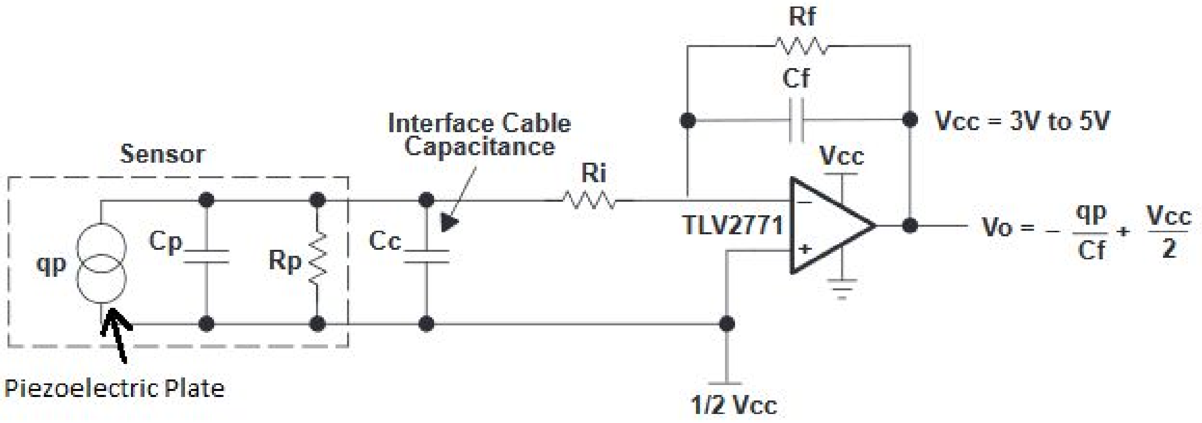


Figure 10: Electrical Schematic of Sensor Pad and Signal Conditioner

As the signal conditioner will exist close to the central computing unit (as opposed to close to the sensor pad), a capacitance enabled signal conditioner is designed using the high slew rate, rail-to-rail operation amplifier, TLV2771. In essence, the signal from the piezoelectric plate will be amplified to match the full range of the analog to digital converter (ADC) on board the main computing element. As such, the output from the signal conditioner, Vo, will connect directly to the ADC of the main computing element.

Initial Sketches of Concept

Presented here are the initial concept sketches developed during the ideation phase of this project.

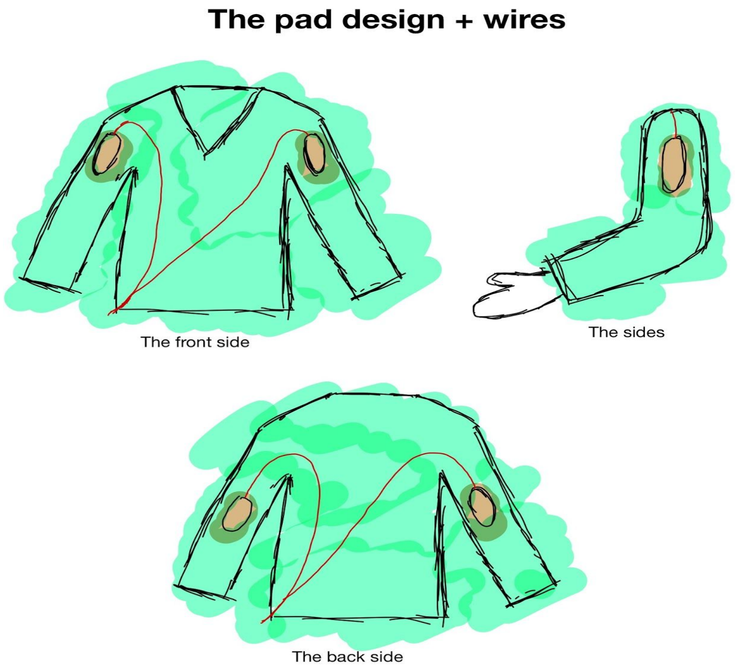


Figure 11: Concept Sketches for The Fall Collection

While they are not accurate, they are a good reminder of the simplicity of the idea.

Appendix II: Demonstration Code

Base Station Code

```
#include <SPI.h>
#include "RF24.h"

RF24 myRadio (7, 8);

struct package
{
  bool alert = 0;
  float probabilityOfFall = 0.0;
  bool hitsOrNots[4] = {0, 0, 0, 0};
};

typedef struct package Package;
Package data;

byte addresses[][6] = {"0"};

void setup() {
  // put your setup code here, to run once:
  Serial.begin(115200);
  delay(1000);

  pinMode(2, OUTPUT);


  myRadio.begin();
  myRadio.setChannel(115);
  myRadio.setPALevel(RF24_PA_MAX);
  myRadio.setDataRate( RF24_250KBPS ) ;
  myRadio.openReadingPipe(1, addresses[0]);
  myRadio.startListening();
}

void loop() {
  // put your main code here, to run repeatedly:
  if ( myRadio.available())
```

```
{
    while (myRadio.available())
    {
    myRadio.read( &data, sizeof(data) );
    }
    Serial.println("Rec");
    Serial.print(data.hitsOrNots[0]);
    Serial.print(data.hitsOrNots[1]);
    Serial.print(data.hitsOrNots[2]);
    Serial.print(data.hitsOrNots[3]);
    Serial.println("");

    //Implementation with all 4 sensors based on different combinations

    if (data.hitsOrNots[1] == true) {
    //data.probabilityOfFall = 25.0;
    if (data.hitsOrNots[2] == true) {
    data.probabilityOfFall = 50.0;
    }
    }

    if (data.hitsOrNots[2] == true) {
    //data.probabilityOfFall = 25.0;
    if (data.hitsOrNots[0] == true) {
    data.probabilityOfFall = 50.0;
    }
    }

    if (data.hitsOrNots[3] == true) {
    //data.probabilityOfFall = 25.0;
    if (data.hitsOrNots[0] == true) {
    data.probabilityOfFall = 50.0;
    }
    }

    if (data.hitsOrNots[3] == true) {
    //data.probabilityOfFall = 25.0;
    if (data.hitsOrNots[1] == true) {
    data.probabilityOfFall = 50.0;
    }
    }
```

```
      Serial.println(data.probabilityOfFall);

      if ((data.probabilityOfFall >= 50)){
      digitalWrite(2, HIGH);
      delay(100);
      digitalWrite(2, LOW);
      }

      if ((data.probabilityOfFall >= 50)){
      digitalWrite(2, HIGH);
      delay(100);
      digitalWrite(2, LOW);
      }
      if ((data.probabilityOfFall >= 50)){
      digitalWrite(2, HIGH);
      delay(100);
      digitalWrite(2, LOW);
      }
      if ((data.probabilityOfFall >= 50)){
      digitalWrite(2, HIGH);
      delay(100);
      digitalWrite(2, LOW);
      }

      data.probabilityOfFall = 0;
  }
}
```

Sensor Network (Wearable) Code

```
#include <SPI.h>
#include "RF24.h"

RF24 myRadio (7, 8);

int sensorPins[4] = {A0, A2, A4, A6};
int peizoVals[4] = {0, 0, 0, 0};
int peizoPrevVals[4] = {0, 0, 0, 0};
int peizoDiffVals[4] = {0, 0, 0, 0};
```

```
struct package
{
  bool alert = 0;
  float probabilityOfFall = 0.0;
  bool hitsOrNots[4] = {0, 0, 0, 0};
};

typedef struct package Package;
Package data;

byte addresses[][6] = {"0"};

void setup() {
  // put your setup code here, to run once:
  Serial.begin(115200);
  delay(1000);
  myRadio.begin();
  myRadio.setChannel(115);
  myRadio.setPALevel(RF24_PA_MAX);
  myRadio.setDataRate( RF24_250KBPS ) ;
  myRadio.openWritingPipe( addresses[0]);
  delay(1000);
}

void loop() {
  // put your main code here, to run repeatedly:
  myRadio.write(&data, sizeof(data));

  peizoVals[0] = analogRead(sensorPins[0]);
  peizoVals[1] = analogRead(sensorPins[1]);
  peizoVals[2] = analogRead(sensorPins[2]);
  peizoVals[3] = analogRead(sensorPins[3]);

  peizoDiffVals[0]=peizoVals[0]-peizoPrevVals[0];
  peizoDiffVals[1]=peizoVals[1]-peizoPrevVals[1];
  peizoDiffVals[2]=peizoVals[2]-peizoPrevVals[2];
  peizoDiffVals[3]=peizoVals[3]-peizoPrevVals[3];

  for(int i=0;i<4;i++){
      peizoPrevVals[i]=peizoVals[i];
  }
  //After we implemented the other sensor, we'll come back and add more stuff to those if statements
  if(peizoDiffVals[0]<=-10 || peizoDiffVals[0]>=10){
      data.hitsOrNots[0]=true;
  }
  else{
      data.hitsOrNots[0]=false;
  }

  if(peizoDiffVals[1]<=-10 || peizoDiffVals[1]>=10){
      data.hitsOrNots[1]=true;
  }
  else{
      data.hitsOrNots[1]=false;
  }

  if(peizoDiffVals[2]<=-10 || peizoDiffVals[2]>=10){
      data.hitsOrNots[2]=true;
  }
  else{
      data.hitsOrNots[2]=false;
  }

  if(peizoDiffVals[3]<=-10 || peizoDiffVals[3]>=10){
      data.hitsOrNots[3]=true;
  }
  else{
      data.hitsOrNots[3]=false;
  }

  Serial.print("\nPackage:");
  Serial.print(data.hitsOrNots[0]);
  Serial.print(data.hitsOrNots[1]);
  Serial.print(data.hitsOrNots[2]);
  Serial.print(data.hitsOrNots[3]);
  Serial.println("");
  delay(10);
}
```