HEALTH INFORMATION SYSTEM WITH PRESSURE SENSING TOWARDS A BETTER CARE PLAN FOR PRESSURE ULCERS

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This declaration is made on August 07, 2021.

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Abstract

HEALTH INFORMATION SYSTEM WITH PRESSURE SENSING TOWARDS A BETTER CARE PLAN FOR PRESSURE ULCERS

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Keywords: Pressure Ulcer, Bedsore, Reposition, Health Information System, Pressure sensing

Pressure ulcers (bedsores) remain a major problem in health care settings as it causes severe complications. Therefore prevention at the early stage is more beneficial than treatments. Pathophysiological knowledge about pressure ulceration is incomplete as there is insufficient evidence supporting existing theories. Bedridden patients who cannot change positions on their own are prone to pressure ulcers. The efficacy of prevention methods like frequent patient repositioning and pressure redistributing support surfaces are challenged by recent systematic reviews against the higher face validity. The scarcity of detailed data is an obstacle to further research. Collecting long term data from various patients in different settings is challenging. This project delivers a health information system that collects data about pressure distributions, patient risk assessment and documentation of pressure ulcer occurrences. Patients, caretakers and doctors can be connected to the information system with mobile apps and pressure measuring mats. A low-cost solution forpressure measuring mat is introduced using the piezoresistive material Velostat. Thirty-two rows of copper strips are pasted on one of the neoprene sheets and sixteen columns on another. Then the Velostat sheet is sandwitched in between the two neoprene sheets. Perpendicularly intersecting copper strips work as a single cell. Altogether, 512 cells are produced. Pressure images from the mat are used to identify postures and locate ulceration points to obtain the pressure at these sites. We can control the cells and measure pressure with analogue multiplexers as the Velostat and two neoprene sheets operate as a sensor matrix. Measured pressure values are communicated to the information system through the internet. Two neural network models are used to identify the sleeping postures and segment ulceration points. The pressure at each ulceration point is stored separately.The information system facilitates personal risk assessment and ulcer documentation. The risk assessment scale is a development of existing systematic scales. Ulcer documentation is a modification of several existing guidelines. The mobile app works as a user interface and sends push notifications to caretakers informing patient reposition schedules. The complete system serves different functionalities to different parties. It will facilitate researchers as a database with descriptive data, doctors as a reporting system of patients' details and history, caretakers as

a tool to semi-automate reposition plan and guardians of the patients as a tool to supervise the caretakers.

Dedication

To our families, friends and teachers

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We express our sincere gratitude to our supervisor, Dr Pujitha Silva for his guidance, support, and commitment towards the success of this project. We are like to be thankful to Mrs T.L.K. Kumari, Technical Officer and Mr W.L. Kumara, Lab Attendant, Applied Mechanics Laboratory, Department of Mechanical Engineering, University of Moratuwa and Mr Ruwan Udayananda, the University of Moratuwa for helping us with the Universal Testing Machine and other laboratory equipment. We like to mention Dr Saman Piyadigama, Colombo East Base Hospital, who helped us develop ulcer documentation and localize it according to medical practices in Sri Lanka. We are especially thankful to Mrs Chathurani Dias, who supported us in various ways.

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Acronyms and Abbreviations

NPUAP - National Pressure Ulcer Advisory Panel
SOS - Save Oklahoma's Skin
NICE - The National Institute of Health and Care Excellence
SaaS - Software as a Service
API - Application Programming Interface
DTI - Deep Tissue Injury
UART - Universal Asynchronous Receiver-Transmitter
UTM - Universal Testing Machine
HTTP - Hypertext Transfer Protocol

1 Introduction

Pressure ulcers (also known as decubitus ulcers or bed sores) are a major problem in health care due to the high prevalence and high cost of treatment. Some ulcers do not heal for decades. If not properly managed, pressure ulcers may cause complications such as septicemia or even death. Early prevention of pressure ulcers is beneficial over curing. [1]

1.1 Literature Review

Prolonged external pressure into bony areas of the body causes pressure ulcers in bed-ridden patients. The prevailing pathophysiological understanding of pressure ulceration is highly incomplete. Several theories suggest that reduction of oxygen supply (under external pressure) to skin tissues causes cell death through an ischaemia-reperfusion cycle, which results in pressure ulcer formation. Another theory suggests that internal pressure on muscle tissues by bones causes ulceration. [2] None of these theories is empirically verified. Ischaemia reperfusion models describe ulceration as a phenomenon that starts at the skin and spread deep whereas the last theory describes it as a phenomenon that starts at muscle tissues closer to the bones and spreads in the opposite direction towards bones.

Reswick and Rogers studied the effect of pressure and time on cell death (Figure 1.2) in 1976 modelling ischaemia oriented theory.[3] There is no considerable improvement since then other than a few papers suggesting slight modifications. The few experiments that were ever conducted on reperfusion theory also provide inconclusive values. There is no satisfactory empirical research on internal pressure theory, although Deep Tissue Injury (DTI), a recently defined category of pressure ulcers, is specifically and widely believed to be a result of internal pressure from bones. [4]

The exact biomechanical impact of pressure on the human body (skin and muscles) is not yet known given that only a few unsatisfactory bio-mechanical models from research based on animal testing [5] and qualitative speculations without quantitative data are available [6, 7, 8]. There is no sufficient data on the mechanism through which external pressure causes an ischemia-reperfusion cycle. Furthermore, there is no quantitative empirical evidence for the effect of other proposed biomechanical factors such as shear, friction and moisture also.

Pressure ulcers are usually located in specific sites of the body such as back of head, shoulders, buttocks, knees, elbows, hips and heels (Figure 1.3). Pressure ulcers occur in four stages according to the NPUAP staging system (Figure 1.1), and there are specific

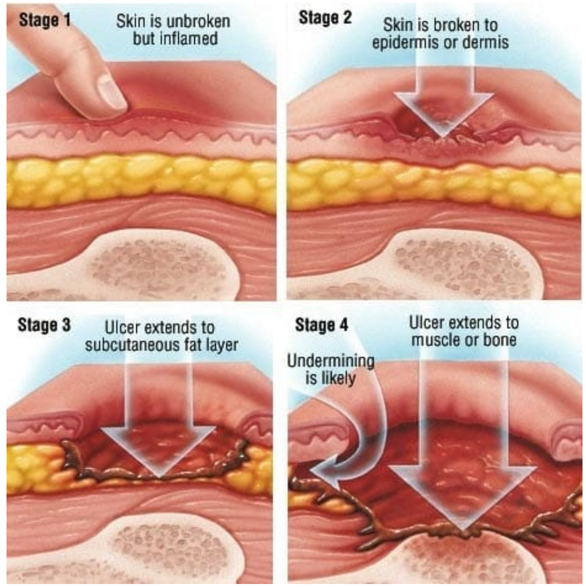


Figure 1.1: Stages I-IV of pressure ulcers according to NPUAP classifications. Image credits: https://www.nursinghomelawcenter.org/bed-sore-pictures.html

guidelines for treatment and management in each stage.[1] There is no empirical data available on how these factors affect different parts of the body and different types of bodies. No empirical data is available on the way that the healing rates or re-ulceration (re-ulceration is not prominent as in the case of diabetic foot ulceration) are affected by the pressure.

1.1.1 Pressure Ulcer Prevention

The main pressure ulcer prevention strategy which is strongly recommended by health care authorities is frequent patient repositioning. This strategy was popularized after the end of World War II by Ludwig Guttmann, based on face validity. [9] Caretakers should turn the patients into a different sleeping posture for every 2 h (This duration was Guttmann's ad hoc recommendation).

The absence of high-quality research evidence supporting the efficacy of repositioning was discussed in a Cochrane systematic review published in 2014 [10] (and updated in 2020 [11]). Research does not show a significant advantage of 2 h repositioning over alternative periods or no-repositioning. Currently available data are low certain and not sufficiently reliable to provide a conclusion. Existing studies do not consider biomechanical facts explicitly. Recently some researchers castigated the repositioning strategy for side effects such as disturbance to sleeping patterns, negative impact on dementia patients and back pain of caretakers.[12] Recently, NICE guidelines increased the period from 2 h to 6 h for normal patients and 4 h for patients in the high-risk category. [13] Standard guidelines do not recommend altering repositioning plans according to existing ulcers, and there is

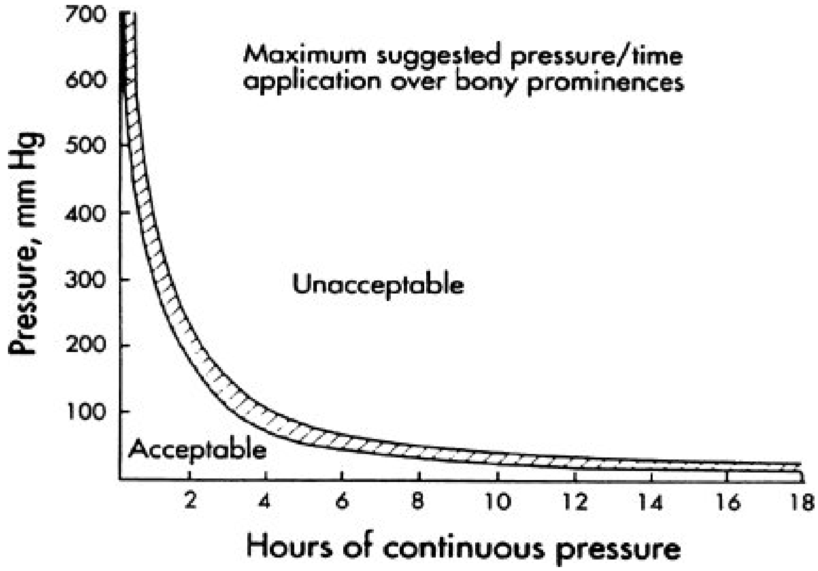


Figure 1.2: Reswick and Rogers' pressure time cell threshold graph.

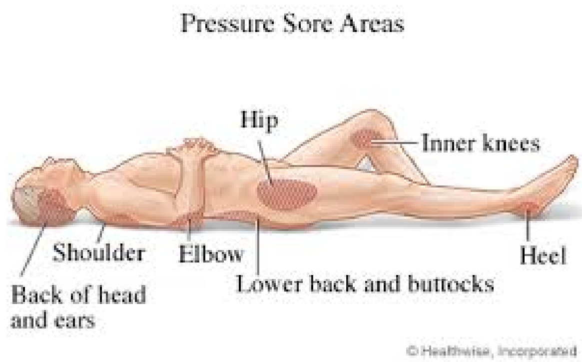


Figure 1.3: Common sites where ulceration occurs.

no research ever conducted in that area. The efficacy of other proposed prevention strategies including the use of pressure redistribution surfaces also is not supported by research, contrary to the availability of a wide range of products in the market. [14]

1.1.2 Personal Risk Assessment and Documentation

There are several patient risk assessment indicators including Braden and Waterlow scales. [15] The importance of a systematic scale for risk assessment is often emphasized overusing clinical judgement alone. Clinical evidence on the efficacy of these tools is still insufficient and uncertain.[16] Proper documentation is of crucial importance in modern health care. There are several paper-based or electronic documentation systems for pressure ulcers. According to studies, the purpose of existing documentation systems is not met with ulcer prevention and care.[17] The patient repositioning plans are rarely documented. There are no records of biomechanical data. Existing electronic documentation systems are desktop applications that store records inside a single end-user device. The recent advancement of mobile, web, IoT and cloud technologies are not yet employed for pressure ulcer documentation.

1.2 Requirement of A Health Information System

Ajami and Khalegi discussed the importance of a wireless sensor network for pressure monitoring.[18] There is need for a sophisticated Health Information System (HIS) that supports not only remote pressure monitoring and electronic documentation but also important utilities to optimize care plan such as posture detection, ulceration point (the specific areas of the body which are more prone to ulceration) detection, pressure/risk estimation, repositioning schedule calculation and carer notification. Although there are several implementations addressing subsets of the above tasks already, constructing a health information system from a holistic point of view is a novel concern. Such an information system should network patients, caretakers, guardians and doctors together and generate, collect, store, analyze and interpret data for better care planning. Because pressure ulcer is a grey area of medical research, the information system should work as a tool to investigate biomechanical and clinical details of bed-ridden patients. Another requirement is to facilitate semi-automation of patient care through care plan optimization like reposition schedule calculation and carer notification system. The wide availability of mobile technology paves the way to a flexible and more sophisticated reporting system. Integrating low-cost pressure sensing equipment into the information system provides the opportunity to monitor and collect data for long periods and widen the scope of research, including the majority of ulcer-prone patients that reside in household settings. Reduction of the cost will facilitate research into pressure ulcers in developing countries.

1.3 Previous Research

There is little research into pressure monitoring equipment for bed-ridden patients. Most of the research is based on pressure measurement posture detection and pressure image segmentation. Some research considered automatic patient repositioning by actuators. [19, 20] The contribution of the researchers of the University of Dallas has considered a wide range of aspects that are related to the pressure ulceration phenomenon. [21] These researchers paid attention to the biomechanics of pressure ulceration. But this is before 2014, the year several systematic reviews were published questioning the efficacy of prevention methods. Therefore the limitations to their study are not apparent in their original papers. They purposely conflate data related to different theories, scenarios and settings to achieve final results. Therefore their results are considerably dependent on ad-hoc assumptions and speculations from indirect data. In this research, we adopted some of their results (Appendix I) for our purpose as the best available solution evaluating the limitations.

2 Methodology

An information system architecture that supports care planning of pressure ulcers requires certain basic functionalities such as

- capturing biomechanical data of the body
- Analyzing those data
- collecting risk assessment data
- providing platform to report and document ulcers
- networking related people
- planning schedules.

Therefore our information system architecture is supported by pressure-sensing mats and mobile apps. Some standard risk assessment scales, ulcer documentation formats are added to the system with appropriate modifications. Additionally, scalability, flexibility and cost-effectiveness are two other important characteristics of such a system. Our initial scope was to build a pressure sensing mattress system that is capable of recommending optimal repositioning strategies based on biomechanical data. As there are no proper evaluation criteria to assess pressure ulcer prevention and the existing biomechanical and pathological research in pressure ulcers are inconclusive, we constructed an information system that provides a platform to investigate pressure ulceration phenomenon while providing a tool for care planning by digitizing processes currently done in paper or not done in any systematic way. Existing theories can be used in our system to improve care planning within their limitation.

2.1 Expected Deliverables

1. Low-cost sensor panel to measure magnitude and duration of pressure at the point of contact
2. Information system architecture for continuous pressure monitoring, ulcer documentation and risk assessment.
3. Posture and ulceration point detection by pressure maps to enhance repositioning plan.
4. Mobile App based notification system alarming caretakers about repositioning time

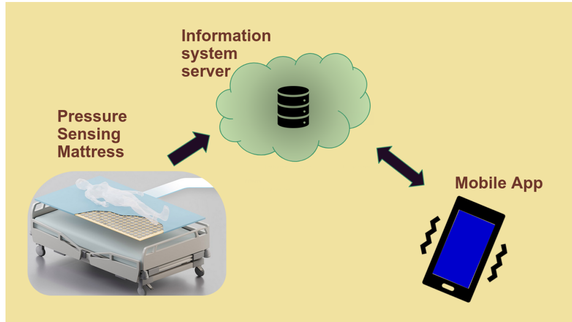


Figure 2.1: Component diagram

2.2 Components and Functionality

There are three main components of our solution. (Figure 2.1)

- Information System (Server and Backend)
- Mobile App
- Pressure sensing matress

The information system provides basic components of authentication, and data storage for pressure data, personal risk assessment data and ulcer documentation. It is consist of another supplementary sub-component for machine learning models. The information system provides a RESTful API for mobile app clients and pressure sensing mats. App and pressure sensing mat can send and retrieve relevant information from the information system. The mobile app provides a user interface for patients/guardians, caretakers and doctors to interacts with the system.

The pressure mat consists of a sensor panel developed by a substrate of piezoresistive material Velostat®. The sensor readings are processed one cell by one in the ATMega32® microcontroller and send to the information system using a NodeMCU/ESP8266® via WiFi and the internet. The information system is capable of integrating other available commercial pressure sensing mattresses without any change of their structure.

In the central server of the information system, these pressure data will be filtered and stored. The sleeping postures and ulceration points are identified by these data and pressure at these points is saved in a separate table using Neural Network Models.

There is a notification system that sends notifications to the caretakers of patients instructing the repositioning plan. (Functional block diagram is shown in Figure 2.2)

2.3 Information system back-end

Information system backend is written in Python using the enterprise level full stack web designing framework Django® and hosted in Heroku® cloud platform. As the database

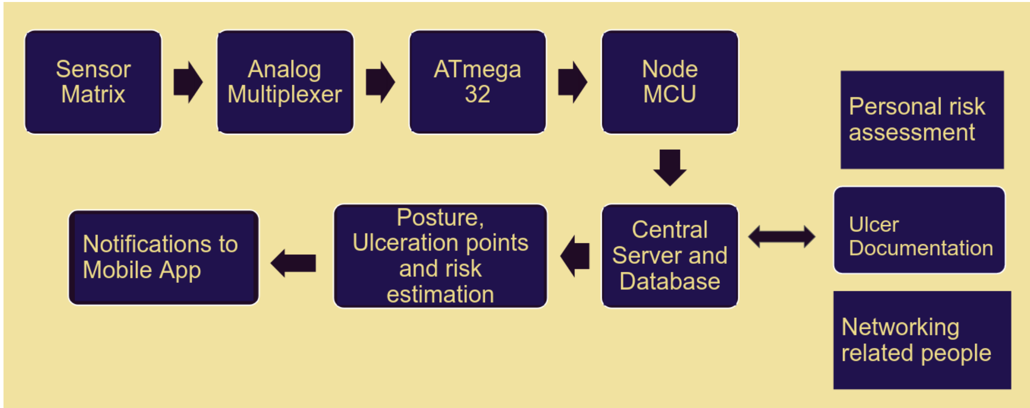


Figure 2.2: Functional block diagram

management system, we choose Postgresql which is a SQL based relational database management system. All the static media files are stored in Cloudinary ® (a SaaS for media files). APIs are created from the django-rest-framework library and Firebase® is used to communicate with mobile apps with push notifications.

The web application is considered on Django apps (sub-modules) for each main functionality.

1. Authentication and User Profiles
2. Social connection handling
3. Pressure data
4. Personal Risk Analysis
5. Ulcer Documentation

Neural network models are build and trained using Tensorfow® and Keras® libraries and hosted in Heroku® using popular python backend microframework Flask®.

2.3.1 Authentication and Authorization

There are user accounts to authenticate the users and there are three user groups as doctors, caretakers and patients. These roles and accounts are used to authorize access to particular components. Users have permission to update their personal information, caretakers can update their risk assessment data and doctors can update ulcer reporting documentation as well as risk assessment data. Even later data is only accessible to caretakers or doctors who are assigned to relevant patients. Token authentication is used to authenticate access.

To create an account a user is requested to add his username and password and thereafter he has to use that username and password to log in. Users can update their profiles with basic details and profile photos.

2.3.2 *Social Networking*

All doctors, caretakers, patients can see each other in search lists. The connection between the users is established via request and confirm mechanism. There are send, show, accept, reject, delete functionalities for a request. Doctors and caretakers can only access the data of a patient only if they have been connected to the particular patient. Users can remove others from their connection list.

2.3.3 *Pressure data*

Pressure data sent from pressure mats are stored in the database via the central server. These data are further analysed with Neural Network Models to find ulceration points. Pressure data is stored in the format **lx, ly, x, y, p, n** format.

Here,

lx : Number of cells over x axis of the mat

ly : Number of cells over y axis of the mat

x : x coordinate of the current cell

y : y coordinate of the current cell

p : Pressure at the (x,y) cell

n : frame number (Reading complete mat is a one frame)

This format supports sending measurements of cells one by one therefore we can capture even a partial reading. This format does not restrict the resolution to a particular value we decide so changing lx and ly of the request any available pressure sensing mattress can be integrated without any structural change of the system.

2.3.4 *Machine Learning*

There are two machine learning models to analyze pressure data. One is to identify posture and the other is to identify ulceration points. Since the ulceration occurs in these particular sites it is important to identify pressure at those locations. To locate these points on the pressure mat and to identify repositioning we should find postures of the patient from pressure data. We used a dataset from the University of Dallas to train the neural networks and we used data preprocessing and augmentations to improve the model. There are 13 people in 18 postures (5 major postures supine, left yearning, right yearning, left fetal, right fetal

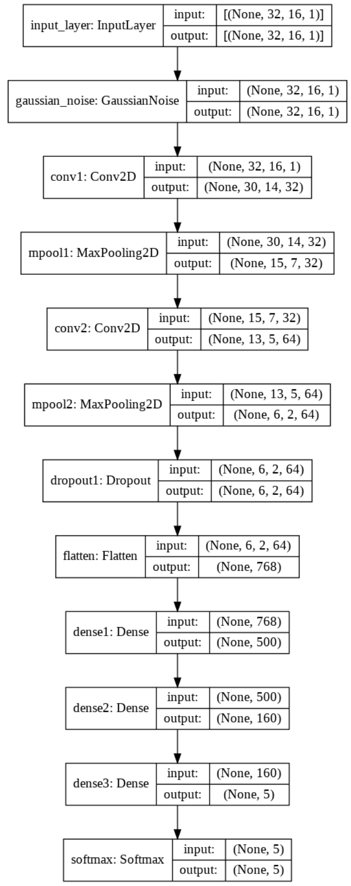


Figure 2.3: Neural Network architecture of the posture detection model. When pressure image is given the model identifies the sleeping posture

and there slight variations with rolling angle and using pillows as wedges.) There is a collection of pressure distribution measured by a commercial pressure measuring mattress for 2 mins which is roughly 120 frames for each. The resolution is 64×32.

Posture Detection Model

The posture detection model is a sequential model with several convolution and pooling layers (Figure 2.3) before the final dense layers. When the input pressure image is given the model outputs the corresponding name of the sleeping posture.

Validation The dataset was divided into a training and holdout set such that data from 9 persons for train and data from 4 persons for the holdout.

preprocessing The pressure images are resized to 32×16, Gaussian noise of variation of 0.08 is added and finally, Gaussian filter of variation of 0.5 is applied. This adding extra noise is supposed to regularize the neural network to work in more realistic environments with low-cost pressure mattresses.

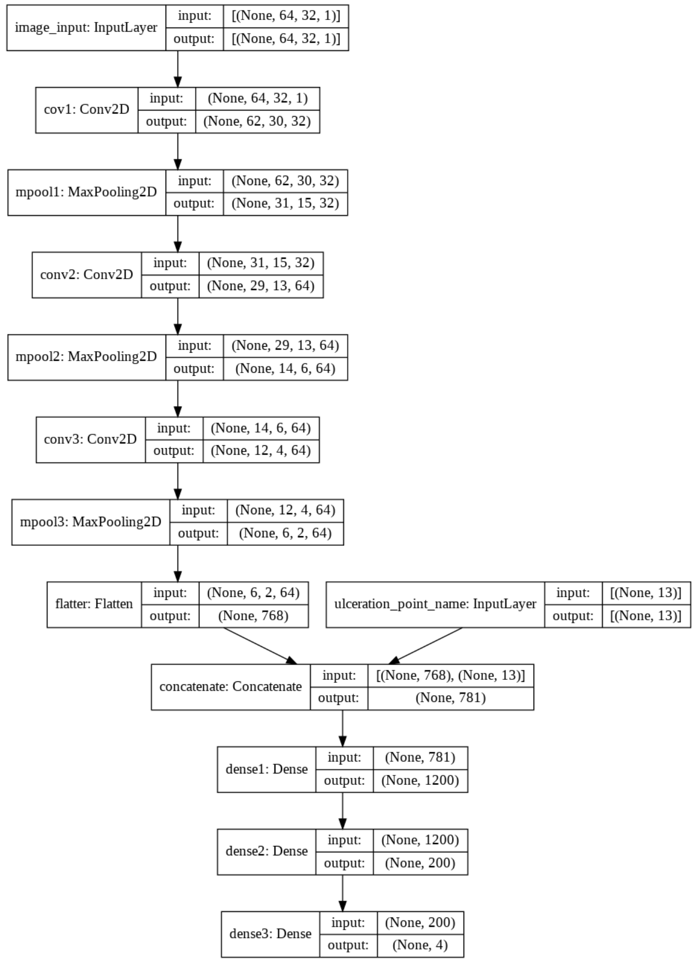


Figure 2.4: Neural Network architecture of the model for ulceration point detection. When the pressure image and the ulceration points we consider is given the model provides parameter of the bounding box for that particular site.

Data Augmentation Pressure images are rotated in random angles between -150 to -150 and Gaussian Noise of variance of 0.1 is added.

The 5 labels for supine, left yearning, right yearning, left fetal and right fetal are one-hot encoded.

The neural network provided 92.45% holdout set accuracy.

Ulceration Point Detection Model

The same dataset was used to train the neural network model for ulceration point detection. We manually created bounding boxes for ulceration points using the annotator tool Labelbox®. Then we preprocessed images likewise in the previous model. The four parameters (two coordinates of the upper left corner of the bounding box, height and width)

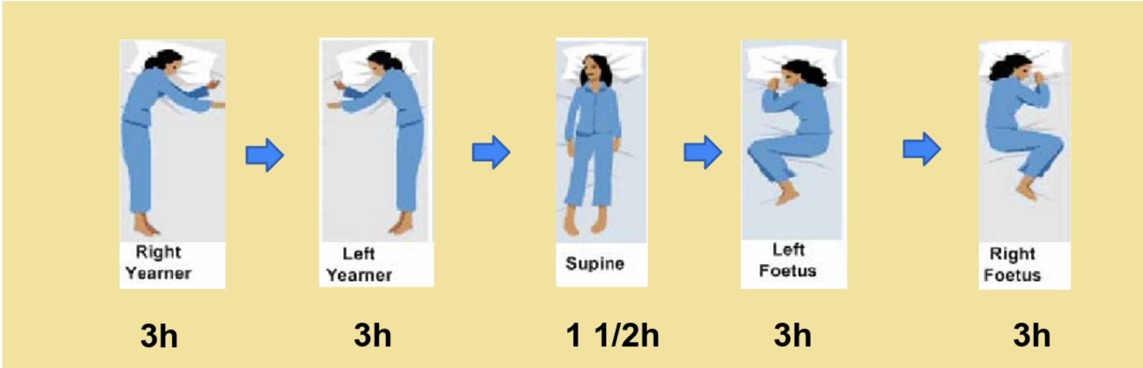


Figure 2.5: Schedule for reposition.

were used to train the model with a mean squared error loss function. There are two inputs to the model.(FIgure 2.4) The pressure image and the name of the ulceration point we consider (one-hot encoded). Then the model outputs four parameters for the bounding box.

2.3.5 Scheduling

Usually, 2 h recommendation period for any posture is used and there is no particular order of posture order. However, the researchers of the University of Dallas tried to find a repositioning schedule based on pressure distribution. Unfortunately there risk assessment metric is based on data from closely related research for slightly different problems and their final result is dependent on ad-hoc assumptions they used. (Appendix I)

In summary, if we put the outline of their research in perspective it states that the supine posture is the riskiet as both sides of the body are subjected to pressure. Although a side of the body is subjected to more pressure in a left or right posture that is a complete relieving phase for the other side of the body. Although we hesitate about the validity of their arbitrary risk metric and ad-hoc assumption we decided to use their result and recommend a repositioning plan as follows. (Figure 2.5)

1. Right Yearning - 3 h
2. Left Yearning - 3 h
3. Supine - 1.5 h
4. Left Fetal - 3 h
5. Right Fetal - 3 h

The left and right postures should be alternatively applied but we do not distinguish between yearning and fetal. As these intervals are below the range of NICE guidelines it could be justified to use these intervals.

2.3.6 Personal Risk Assessment

We considered two existing personal risk assessment scales Braden scale and the Waterlow scale. The information system captures data relevant to both scales and calculates corresponding metrics.

The personal risk assessment forms contain the following data and are expected to be filled by a health care professional (a doctor or a nurse).

Assessed By : The doctor or the caretaker (nurse) assessed personal risk

Gender : Male/Female

Age : Age of the patient

Weight : Weight of the patient (kg)

Height : Height of the patient (cm)

These details should be filled as 1,2,3,4 according to the Braden scale guideline.

Sensory perception : Ability to respond meaningfully to pressure-related discomfort

Moisture : Degree to which skin is exposed to moisture

Activity : Degree of physical activity

Mobility : Ability to change and control body position

Nutrition : Usual food intake pattern

Friction and Shear

An explicit definition of 1,2,3,4 level for each category is given in the Braden scale guideline (which is showed by an information box in the mobile app.)

According to the total score, the patients are classified into four risk categories.

Severe risk	≤ 9
High risk	10 - 12
Moderate risk	13 - 14
Mild risk	15 - 18

These are some other important risk factors (Yes/No binary options).

- Diabetes mellitus
- Peripheral vascular disease
- Cerebral vascular accident
- Hypotension
- Hypoalbuminemia
- Incontinence
- Venus thrombosis

2.3.7 Ulcer documentation

Documenting existing ulcers is an important concern. Treatments are based on proper documentation. This includes basic details related to the wound, surrounding skin and conditions of the patient. We adopted basic components from NPUAP (National Pressure Ulcer Advisory Panel) guidelines and the SOS (State of Oklahoma) toolkit to prepare our documentation pattern. We discussed the current state of pressure ulcer documentation with a medical practitioner in Sri Lanka and remove over-complicating components from these two guidelines. Then we add several additional components and alter the terminology to make it compatible with the medical terminology used in Sri Lanka. Some of the components we introduce here are not currently documented in Sri Lanka.

Reported by : The doctor that reports the ulcer

ChangeAddDelete : The updated date (automatically filled)

Site : Ulceration points

Stage : Stage I,II,III,IV, DTI (Deep Tissue Injury), Unstaged (NPUAP classification)

Duration : Duration (days)

Length : Length of the ulcer (mm)

Width : Width of the ulcer (mm)

Depth : Depth of the ulcer (mm)

Margin : Regular, Irregular

Edge : Sloping, Punched out, Rollout, Everted

Edge color : Color of the edge of the ulcer

Underminings : (Yes/No)

Sinus tracts : (Yes/No)

Floor : Healthy, Granualation Tissue, Slough, Necrotic, Eschar, Epithelial (Multiple selection)

Discharge : Serous, Purulent, Serosanguineous, Other

Discharge amount : Small, Medium, Heavy

Surrounding skin : Warm, Thickend, Hyperpigmented, Hypopignmented, Gangreous, Itching, Swelling (Multiple selection)

Skin sensation : Good, Impaired

Regional lymph nodes enlarged : Yes/No

Smell : Yes/No

Pain : Yes/No

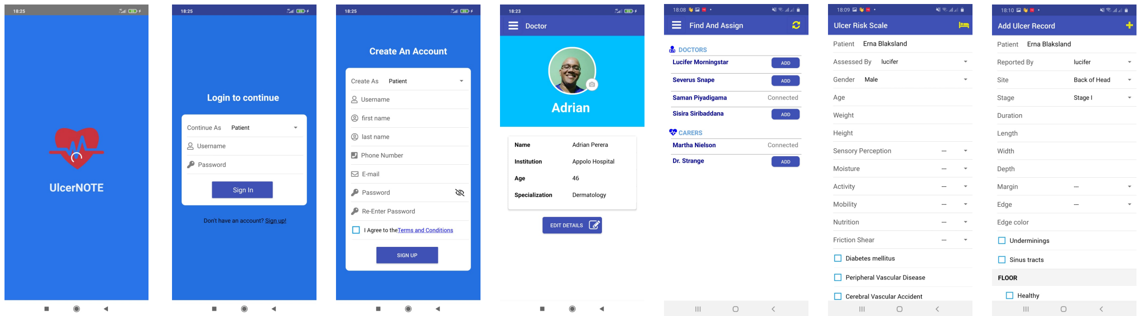
Progress : Improved, No change, Stable, Decline

Image : Image of the ulcer

2.4 Mobile app

Mobile app provides a user interface for basic functionalities of the system. This includes,

- Login
- Profile update
- Search other users
- Handle social connections
- Register mattress
- Personal Risk Assessment
- Ulcer documentation



(a) Loading (b) Login (c) Register (d) Profile (e) Search (f) Risk (g) Report

Figure 2.6: User interface of mobile app.

- Notification

Notifications are sent 5 mins before the reposition and another at the moment reposition is planned. The next posture and the period in that posture are given with the notification. If the patient is not turned at the specified time then other notifications are sent three times with a 5 min interval.

2.5 Pressure Mat

There are two different methods to create a pressure mat. The first method is to combine a large number of sensors and the second method is to develop a single substrate of pressure sensing material into a sensor panel. The first approach is manufacturable complexity. Therefore we selected the second approach. Velostat® is a low-cost piezo-resistive material that is used for similar applications. [22, 23, 24] Selection of piezoresistive material over piezo-capacitive material reduce the complexity of the sensor interfacing. Resistance can be measured by constructing a voltage divider.

2.5.1 Calibration of Material

The relationship between pressure and resistance of Velostat was evaluated as follows. A piece of 1’ × 1’ Velostat was sandwiched between two copper plates and Neoprene sheets to create an individual sensor and the resistance was measured over ascending and descending force. Universal Testing Machine (Figure 2.7) was used to apply pressure over the Velostat. The same test was conducted for two layers of Velostat. Although the sensitivity becomes double the impact of hysteresis is higher for two layers. The test was confirmed with deadweight as the pressure from the UTM was unstable in the case of 2 layers of Velostat. (Figure 2.8)

2.5.2 Communicating Pressure Values

The ATMega32 microcontroller powers up each column one by one through analog multiplexers with 5V and measure the voltage of each row (in a voltage divider with a fixed

Figure 2.7: Universal testing machine

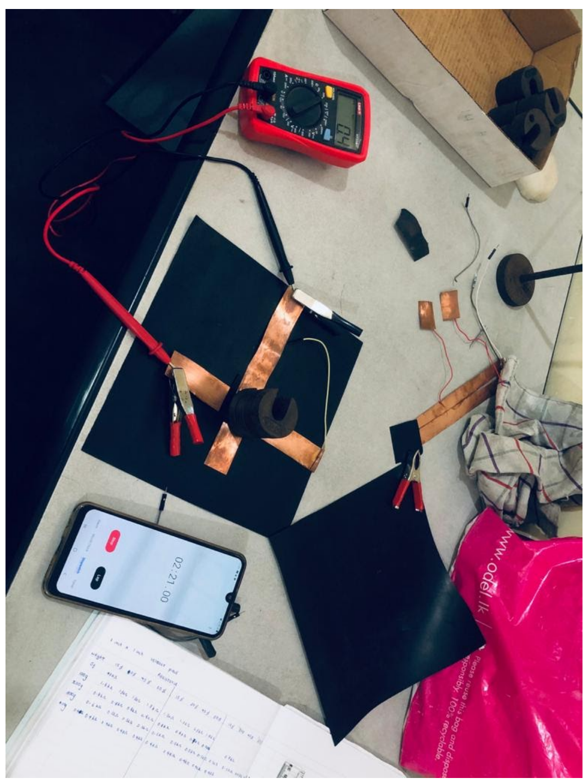


Figure 2.8: Measuring with deadweight

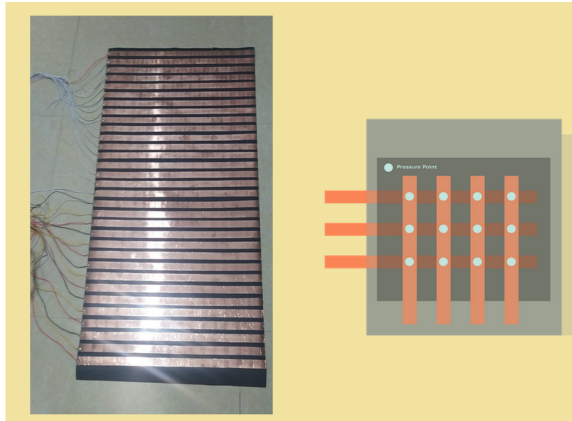


Figure 2.9: Pressure mat

resister) via analog multiplexers with the in-built analog to digital converter, map it to the corresponding pressure value and communicates the measurement to ESP8266 module via UART communication. A baud rate of 9600 was applied and it was sufficient as pressure measurements are not required in a very high frame rate. The ESP8266 module sent pressure data to the information system server via the HTTP API endpoint.

2.5.3 Preparing Mat

Velostat sheet was sandwiched by two Neoprene sheets each one contains a set of parallel rows or columns of copper tapes. Each column is attached to the output channels of an analog multiplexer and each row are attached to the input channels of two multiplexers that works as one multiplexer in the combine. One neoprene sheet contains columns and the other neoprene sheet contains rows therefore when the Velostat sheet was sandwiched by them such that the copper tapes touching the velostat, the columns and rows are perpendicular. The points where the columns intersect the rows act as a pressure sensor. Therefore this setup funcions as a two dimension pressure sensor array with a sensor at each cross point. (Figure 2.9)

Columns are powered one by one using the analog multiplexer and the voltage is measured over a voltage divider choosing each row by other multiplexers.

Neoprene acts as an insulator to build the copper wire grid. All rows are weakly pulled down according to previous research which shows it reduces cross-talk effects (by analysing combined effects).[25]

2.5.4 Sensor reading processing and communication

The communication between ATMega32 and ESP8266 is via UART and then the WiFi router sends it to the server. (ESP8266 module communicates with the WiFi server via WiFi)

3 Results

The relationship between resistance and pressure is non-linear (as expected for Velostat). Comparing the curves under ascending and descending forces it can be seen that hysteresis effects are tolerable. (See Figure 3.1) Comparing two layers of Velostat (3.2b) against one layer (3.2a), it was revealed that the time for a stable result was longer in the case of two layers, although the sensitivity improved in the former case. Therefore one layer of Velostat is appropriate for the pressure mats.

3.1 Frames of Pressure Mat Readings

The frames from the pressure mat are mapped with the colour scheme Jet and Gaussian interpolation is used to get the final output. Since there were huge difficulties for a proper and careful calibration in the overall pressure mat we could not get highly satisfactory results. But the mat detected areas corresponding to high pressure approximately. A more satisfactory image was obtained for feet when standing on the mattress. (Figure 3.3) Disks each weighs 1.25 kg were used to calibrate parts of the mattress.

3.2 Neural Network results

When a pressure image is sent to the server, the posture detection model detects the posture. Then particular ulceration points are active for that posture. Providing the pressure image and naming these ulceration points as the input, bounding box parameters can be obtained. All five postures are classified correctly, and bounding boxes are marked appropriately as in the figures (3.4).

3.3 Simulation of pressure-time behaviour on ulceration points

When ulceration points are located, the pressure of these points can be calculated. We simulated temporal behaviour and repositioning using the dataset by the University of Dallas. Repositioning considerably shifts the pressure distribution and the pressure values are almost stable in a particular posture. (Figure 3.5)

3.4 Implementation

The information system `http://prevelcer.herokuapp.com`

App React native based app

API documentation `https://documenter.getpostman.com/view/13647586/TVmHDeox`

Neural Network Models `http://prevelcernn.herokuapp.com`

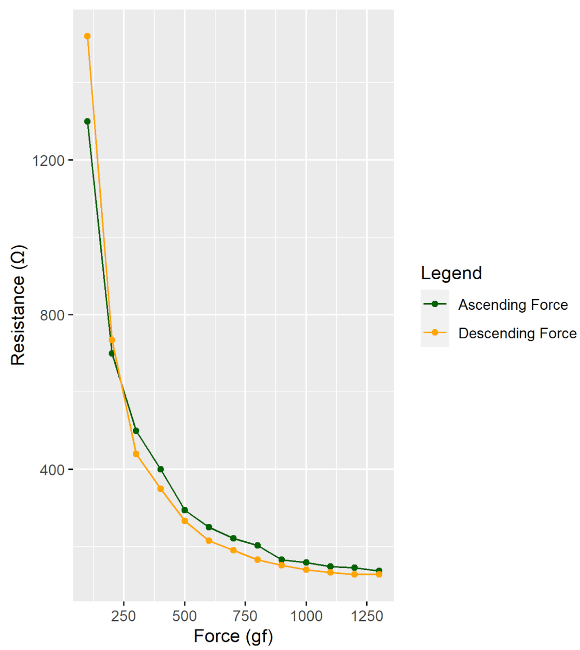
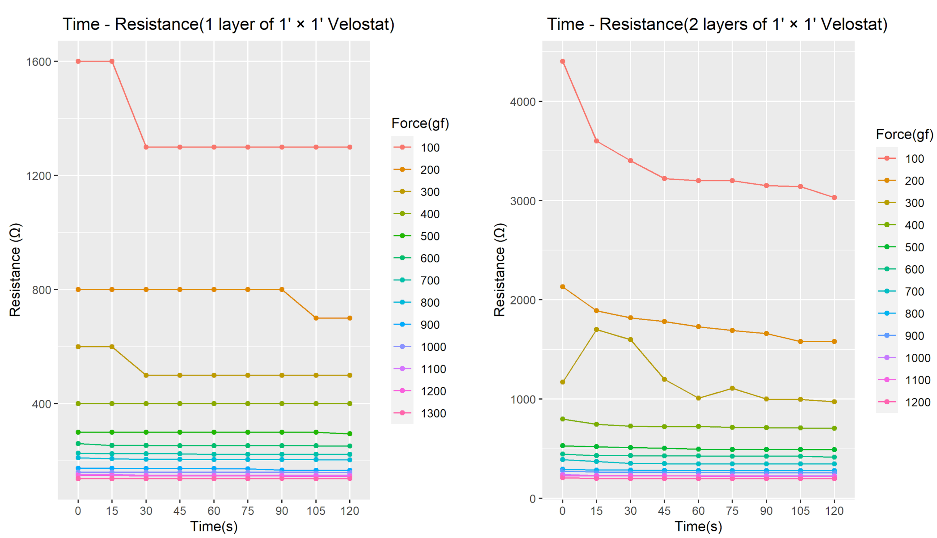


Figure 3.1: Resistance vs Pressure for Velostat



(a) One layer of Velostat (b) Two layers of Velostat

Figure 3.2: Time for stable resistance value was higher in the case of two layers than one layer

Figure 3.3: Pressure mat frames

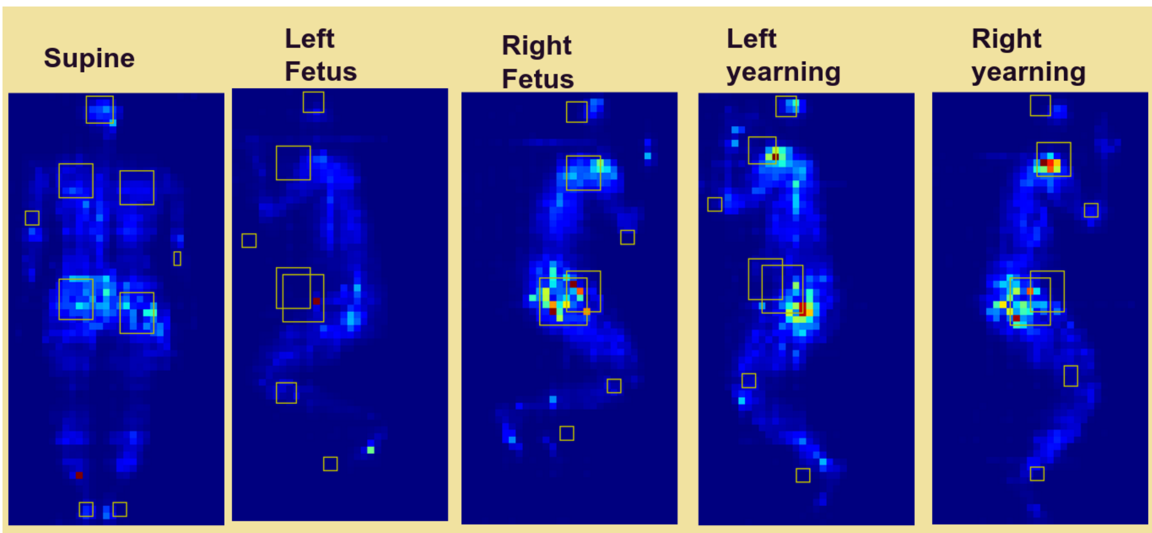


Figure 3.4: Neural Network result

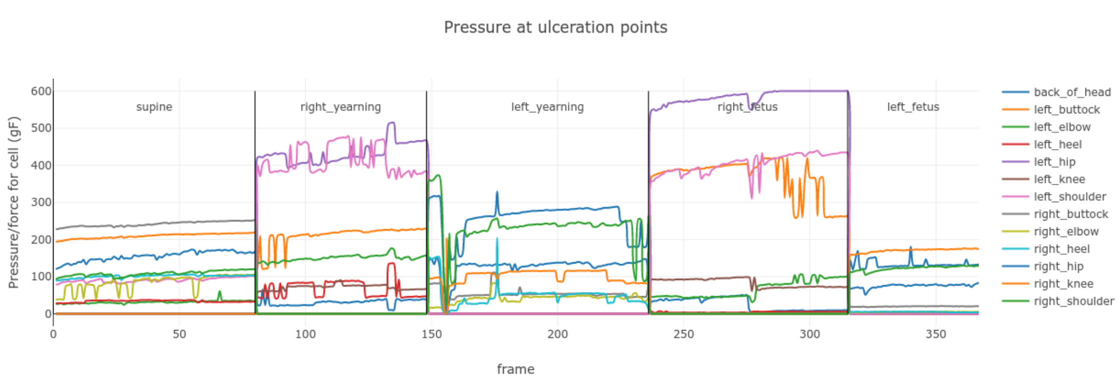


Figure 3.5: Simulation.

4 Discussion and Conclusion

Pressure ulceration is yet an incompletely explored territory. Previous engineering research on pressure ulceration tried to make strong conclusions ignoring scarcity of evidence. As the existing prevention strategies including reposition were strictly challenged since 2014, it is unwise to make bold moves. Therefore we primarily focused on providing a platform for researchers to explore the phenomena while using available knowledge for better care plans. In addition, low-cost pressure measuring mat was introduced to promote research in developing countries.

Although there are several applications for digitized ulcer documentation or pressure monitoring, they are standalone software that was expected to be run on a single machine. We introduce a cloud-based central network that will be helpful to collect data in one place. Previous engineering applications did not introduce mobile phones into ulceration care planning. The wide popularity of smartphones has transformed the nature of the problem.

When the bounding boxes are marked, two inputs (pressure image and the label of the particular ulceration point is) given to find relevant bounding box parameters. It is considerably different from usual image segmentation models that predicts all the bounding boxes at once or classify bounding boxes. (Similar trick is commonly used with transformers)

The terminology in ulcer documentation is localized to Sri Lanka and some new items were added as an improvement.

As all parts of the system are loosely coupled, any part can be integrated or used for other related applications.

As future work, textile production techniques can be applied to the pressure mat to build a commercial product. Live streaming of pressure images can be added to the app. If a sufficient amount of pressure and ulcer documentation data are available, researchers can investigate the exact relationship between pressure and pressure ulceration to find a better prevention strategy.

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Appendix I

Ulceration risk of pressure-time relation

Based on pressure-time cell death experiment, this equation shows the higher threshold of constant pressure at a certain time T

$$P(T) = \frac{P_{max} - P_{min}}{1 + e^{\lambda(T - T_0)}} + P_{min} \tag{4.1}$$

Here,

$$\begin{aligned} P_{max} &= 31kPa \\ P_{min} &= 8kPa \\ \lambda &= 0.15min^{-1} \\ T_0 &= 95min \end{aligned}$$

(These values are based on experiment expect for T_0 which is arbitrary)

Following equation shows the maximum safe time (T_{max}) for particular pressure value.

$$T_{max}(P) = \begin{cases} \infty & P < P_{min} \\ 0 & P > P_{max} \\ T_0 + \frac{1}{\lambda}\left(\frac{P_{max} - P_{min}}{P - P_{min}} - 1\right) & P_{min} < P < P_{max} \end{cases} \tag{4.2}$$

The risk of the particular pressure value is given by this equation

$$\delta R = \frac{\delta t}{T_{max}(P)} \tag{4.3}$$

Cumulative risk is calculated in the following way.

1. Sum risk when pressure is greater than P_{min}.

2. Set total risk to zero when pressure becomes lesser than P_{min}.

This risk estimation algorithm is adopted from Ostabbas et al [21].

According to this risk metric it is shown that supine posture has higher risk. It further shows that the supine will generate same risk as left or right postures with half of period.

Appendix II

Schematic of the pressure mat

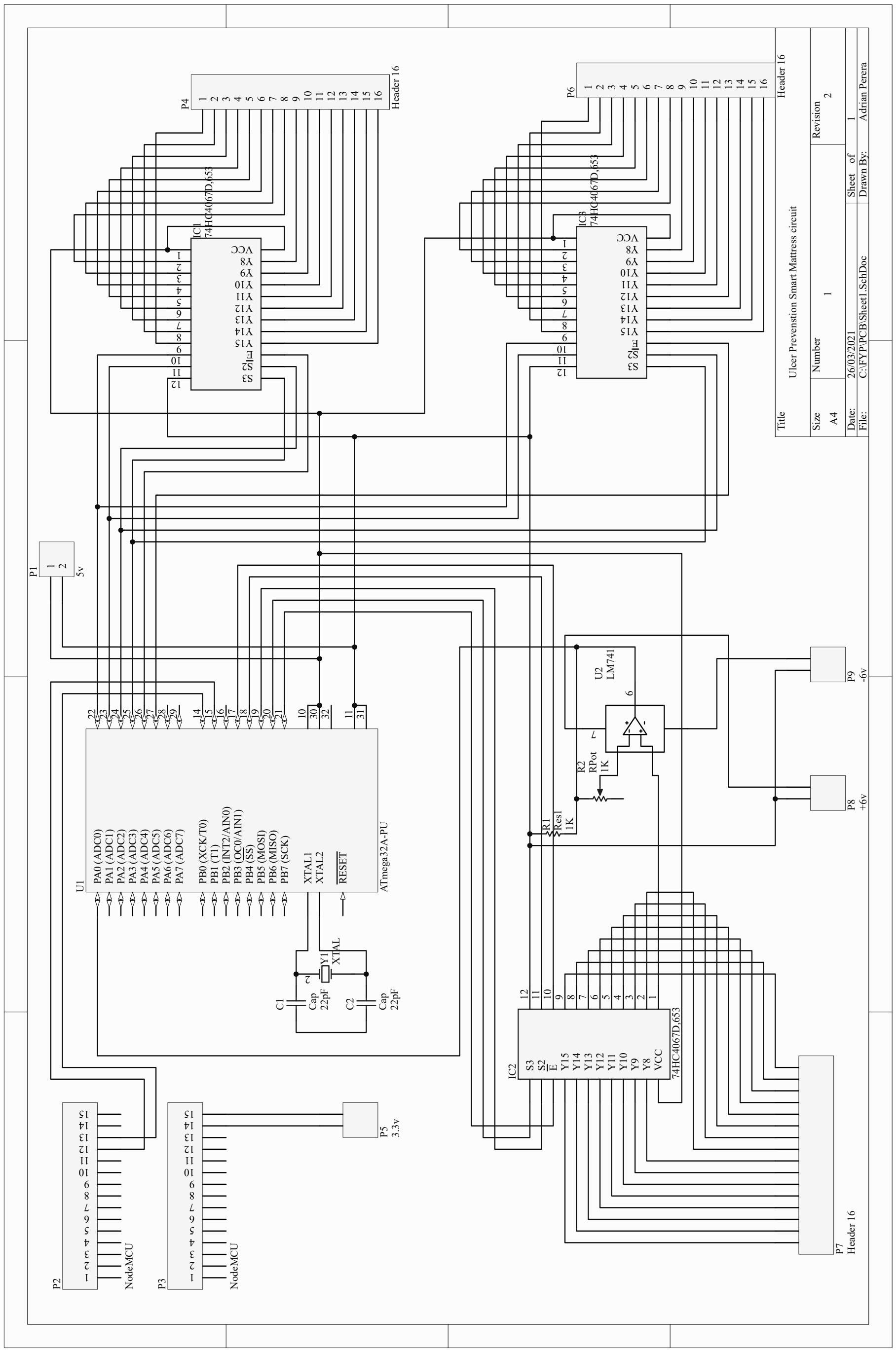

Figure 4.1: Schematic Diagram.