Image Analysis Software to the Early Detection of Pressure Ulcers
— Individual Project Background Report —

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Contents

1 Introduction **3**

2 Background **4**
2.1 Pressure Ulcers 4
2.2 Related Research 4

3 Progress **7**
3.1 Overview of Project 7
3.2 Specifications 8
3.3 Plan 9

A Software Engineering Methodology **15**

Chapter 1

Introduction

Pressure ulcers (PU) have been defined as an area of localised damage to the skin and underlying tissue caused by pressure, shear, friction or a combination of these factors (European Pressure Ulcer Advisory Panel). Pressure ulcers are not only costly affecting a significant proportion of the population, but are associated with increased mortality.

According to the staging description of PU revised by International NPUAP- EPUAP Pressure Ulcer, in pressure ulcer stage I, Skin is not broken but is red or discolored or may show changes in hardness or temperature compared to surrounding areas. When you press on it, it stays red and does not lighten or turn white. The redness or change in color does not fade within 30 minutes after pressure is removed. And most importantly, A pressure sore at this stage can be reversed in about three days if all pressure is taken off the site.

They occur when unrelieved pressure, typically over a bony protrusion, initially causes blood to pool at the site. Blood vessels are constricted and the skin is starved of oxygen and other nutrients. If not diagnosed and relieved of pressure early, the skin or even underlying tissue and bone may ulcerate. With an aging population, incidence is likely to increase.

Early detection is thus key to avoiding pressure ulcers and the subsequent treatment costs, with several non-invasive techniques, including image processing and analysis, recently being developed for this purpose.

A study conducted by the U.S. Centers for Medicare and Medicaid Services (formerly Health Care Financing Administration) reported that the proportion of black and Hispanic patients developing more serious Stage III and IV pressure ulcers was over twice that for white patients [15]. This suggests difficulty in early detection of pressure ulcers in patients with darkly skins, which requires more accurate and efficient image process algorithms to enhance the image distinguished by the medical staff.

The aim of this project is to explore the feasibility of using non-invasive techniques for the early detection of pressure ulcers. Emphasis will be placed on exploring a range of image processing and image analysis techniques and develop an practical non-invasive image-based pressure ulcer detection software.

Chapter 2

Background

2.1 Pressure Ulcers

A pressure ulcer (PU) is any lesion caused by unrelieved pressure resulting in damage of underlying tissue [30]. Pressure ulcers are areas of localized tissue destruction caused by compression of soft tissue between a bony prominence and an external surface for a prolonged period of time [5]. Unrelieved pressure and shear are the most important contributing factors in the pathogenesis.

In UK, nearly 700,000 people are affected by pressure ulcers each year, across all care settings, including patients in their own homes, with the most vulnerable of patients aged over 75. Around 186,617 patients develop a pressure ulcer in hospital each year [8]. Given the aging of the population, PU are likely to become a problem of increasing proportion in the near future [3].

Pressure Ulcers are associated with significant economic burden, and costs continue to rise [16]. The cost of treating a pressure ulcer varies from £1,064 to £10,551. Costs increase with ulcer grade because the time to heal is longer and because the incidence of complications is higher in more severe cases. The total cost in the UK is £1.4 £2.1 billion annually (4% of total NHS expenditure) [4]. Pressure ulcers cost \$9.1 -\$11.6 billion per year with 2.5 million patients in the US. Cost of individual patient care ranges from \$20,900 to \$151,700 per pressure ulcer [19]. Pressure ulcers are not only costly, but are associated with increased mortality.

Therefore, these consequences highlight the value of the early detection of pressure ulcers. If pressure ulcers are detected in the early stage, simple care of the tissue can allow the skin to remain intact and heal without scarring or the need for surgical intervention.

According to the staging description of PU revised by International NPUAP- EPUAP Pressure Ulcer [9], stage I PU presents as Intact skin with non-blanchable erythema of a localized area usually over a bony prominence. Discoloration of the skin, warmth, edema, hardness or pain may also be present. Darkly pigmented skin may not have visible blanching. And Stage I may be difficult to detect in individuals with dark skin tones due to increased melanin content.

2.2 Related Research

Main issues regarding proper characterization of skin lesions consists of image acquisition, the image processing and analysis, the feature extraction, and the classification methodology [20]. Major advantage of using computer is that patients do not have to undergo many painful diagnosing techniques. Moreover it speeds up the procedure of diagnosis of the disease according to the processed images of skin. There are several previous studies to show what techniques are used to improve the early detection of pressure ulcers.

Image processing and computational techniques have been applied in different aspects of wound diagnosis. Some aspects involve wound-area identification, which has been tackled with different techniques such as contour detection with histogram segmentation, active contours modelling, region growing, clustering approaches or skin texture models.

Cula and Kristin developed two models for use in skin texture recognition. Both models are image-based representations of skin appearance that are suitably descriptive without the need for prohibitively complex physics-based skin models, which take into account the varied appearance of the skin with changes in illumination and viewing direction [6].

Tim D. Jones and Peter Plassmann used an active contour model is presented that models the contour using piecewise B-spline arcs and uses the minimax principle to adaptively regularize the contour according to the local conditions in the wound image. The model makes use of the existing manual delineation process in order to initialize the solution and is shown to reduce the effect of the inherent variations upon the repeatability and consistency of area measurements in many cases.[10]

Karkanis presented an approach to the detection of tumors in colonoscopic video. It is based on a new color feature extraction scheme to represent the different regions in the frame sequence. This scheme is built on the wavelet decomposition. The features named as color wavelet covariance are based on the covariances of second-order textural measures and an optimum subset of them is proposed after the application of a selection algorithm. The proposed approach is supported by a linear discriminant analysis procedure for the characterization of the image regions along the video frames. The whole methodology has been applied on real data sets of color colonoscopic videos. The performance in the detection of abnormal colonic regions corresponding to adenomatous polyps has been estimated high, reaching 97% specificity and 90% sensitivity [11].

Some approaches focus on detecting the different tissues existing in the wound, by using diverse segmentation methodssuch as histogram thresholding, watersheds, mean-shift smoothing, region growing, classification or graphssometimes combined with machine learning strategies.

Dimitrios I. Kosmopoulos investigated how a tool for automated pressure ulcer stage classification can be integrated into an asynchronous telemedicine system aiming to increase efficiency and monitoring capabilities for large volumes of patient data. The deployment requirements, the internal architecture as well as the employed techniques are outlined. Furthermore, the initial processing results are provided to demonstrate the feasibility of automated classification of pressure ulcer regions in various grades [12].

Francisco Veredas proposed a hybrid approach based on neural networks and Bayesian classifiers is used in the design of a computational system for automatic tissue identification in wound images. Specific heuristics based on the wound topology are designed to significantly improve the results of the classification. This method obtains high efficiency rates from a binary cascade approach for tissue identification. Results are compared with other similar machine-learning approaches, including multiclass Bayesian committee machine classifiers and support vector machines [27].

Hazem Wannous and Sylvie Treuillet introduced the key steps including color correction, merging of expert labeling, and segmentation-driven classification based on support vector machines. The tool thus developed ensures stability under lighting condition, viewpoint, and camera changes, to achieve accurate and robust classification of skin tissues. Clinical tests demonstrate that such an advanced tool, which forms part of a complete 3-D and color wound assessment system, significantly improves the monitoring of the healing process. It achieves an overlap score of 79.3 against 69.1% for a single expert, after mapping on the medical reference developed from the image labeling by a college of experts [29].

Hazem Wannous and Yves Lucas focused here on tissue classification from color and texture region descriptors computed after unsupervised segmentation. With a multiview strategy for tissue classification, relying on a 3-D model onto which tissue labels are mapped and classification results merged. The experimental classification tests demonstrate that enhanced repeatability and robustness are obtained and that metric assessment is achieved through real area and volume measurements and wound outline extraction [28].

Erythema can be detected with relatively simple and low-cost imaging and image enhancement techniques at pressure ulcers stage I, which was suggested by Prabhu Jude Rajendran. They used CLAHE algorithm and the preliminary results clearly indicate that the enhanced images exhibit higher contrast and make the pressure ulcer site more conspicuous to the examiner [22].

Jon Leachtenauer research group used a non-contact imaging-based method to detect Stage I pressure ulcers over a wide range of melanin levels. Two approaches were explored: the first used broad and narrow band visible spectrum imaging, and the second used near infrared (NIR) imaging. The results are presented together with results of numerical analysis of different erythema indices derived from the visible spectrum images [13].

A study at the University Hospital of University of Sao Paulo revealed a pressure ulcers incidence of 39.8% [23], and the evolution of healing process is followed by measuring PU using simple measures, tracing, photographs or image analysis by a computational system, which is sup ported by softwares Motic and AutoCAD [17].

R.Guadagnin, R. de S. Neves et al initially captured images by digital camera. Each image was separated in the images that correspond to blue, green and red bands. They then performed convolution on each image with a 9x9 mean mask with Idrisi Software to remove distortion due to texture peculiarities as it may happen that due to texture peculiarities isolated points distort parts of the images that belong to healthy skin, pressure border or pressure core [24].

Hairong Qi et al. describe a custom geometric correction method to restore the image from the misalignment distortion and present a binary tree-based generic demosaicking algorithm to efficiently estimate the missing special components and reconstruct a high-resolution full-spectral image. They used this new method for early detection of pressure ulcers, particularly so for dark pigmented skin to show how the geometric correction and demosaicking algorithms successfully reconstruct a full-spectral image from which apparent contrast enhancement between damaged skin and the normal skin is observed [21].

Jean-Franois Deprez proposed a 2D ultrasound elastography based on ultrasound imaging to address the challenging problem of pressure ulcer early detection. This was able to detect a subepidermal layer, helping to differentiate between pathological and healthy regions [7].

Chapter 3

Progress

A Medical Bsc student used linear normalisation, global histogram equalisation and contrast limited adaptive histogram equalisation to enhance image, and the videos were processed through eularian colour magnification. The findings in that report have confirmed that image processing can be used to improve image contrast and subsequently aid in the detection of erythema. This applies to all skin colours [18].

This report will using his findings and test more image process algorithms and implement them to the software. In the meantime, using MATLAB image process toolbox to test the algorithm is necessary to implement them to the software quickly.

Due to the skin color diversity, it requires multiple algorithm for different skins and individuals. Skin colors are important for a broad range of imaging applications to assure quality and naturalness. This report will discuss the impact of various metadata on skin colors in images. The software will be implemented by the refined skin color models from framework improve the accuracy of skin detection.

Besides, except image process tools implemented in the software, it also includes basic image draw tools as a windows desktop application to improve the user interaction, such as:

- File: Open an image, Save, and Exit.
- Editor: Undo, Redo, Copy, Paster, Reset (Reset the image to the original One)
- View: Initial Size, Zoom In, Zoom Out, Fit to Screen, Right Rotate, Left Rotate
- Adjustments: The image enhancement is in the Adjustments tools part
- Help: Helper, and About PUimage

3.1 Overview of Project

Basically, the pressure ulcer image processing software works as followed:

- Medical staff create an accountant in the database of PUimage software, and login to initial some basic settings;
- The user (medical staff) get the patients' skin image data in some frequency (like per week, depending on patients' situation), upload to the software;
- Using Image adjustment tools to analyse the image, store results in the database;
- Update the skins' evaluation diagram. It is useful to monitor the patients' evalution;
- Until the pressure sore of the patient is reversed.

The software is described in Figure 3.1.

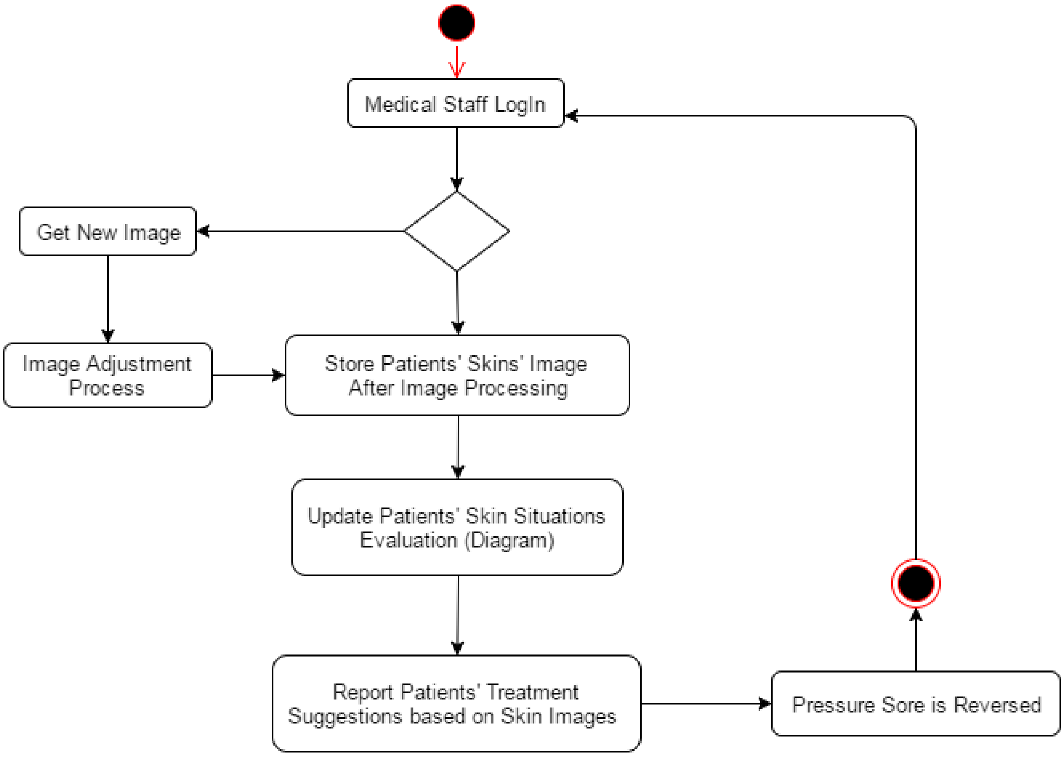


Figure 3.1: Project Activity Diagram

3.2 Specifications

Main high level essential requirements of the software proposed by the professor include the creation of a component, that is responsible for analyze the skin images, as well as the medical staff and patients database. Table 1 demonstrates the low level specifications derived from the aforementioned requirements by applying the simplified version of van Lamsweerde's KAOS goal-oriented model, questioning how and why a particular requirement is applied. Table 3.1 is grouped by a particular component of the software and includes a relevant risk levels.

3.2.1 Requirements

External interface Requirements

- User interfaces A first-time user of the mobile application should see the log-in page when he/she opens the application. If the user has not registered, he/she should be able to do that on the log-in page. Every user should have a profile page where they can edit their e-mail address, phone number and password, and their patients' database.

- Software interfaces The mobile communicates with the mobile phone in order to get image information , and with the database in order to get the information about the user and hospital location and related information.

Functional Requirements

Details are updated the table.

Performance requirements

The requirements in this section provide a detailed specification of the user interaction with the software and measurements placed on the system performance.

- Image Process Algorithm Performance Efficient multiple image processing is based on data training performance.
- Application memory The amount of Operate System memory occupied by the application
- Software Availability and Internet Availability The availability of the system when it is used and connecting to the Internet.
- Security If an admin tries to log in to the web portal with a non-existing account then the admin should not be logged in. The admin should be notified about log-in failure

Table 3.1: Specifications Table

Component	Description	Risk
User Login	Creating an interface to Login into the system	L
User Input Info	Creating a user interface that allows the user to input the users' information as well as his or her patients' related information	L
Windows applicaitons Function	File: Open an image, Save, and Exit	L
Windows Image Editor	Editor: Undo, Redo, Copy, Paster, Reset (Reset the image to the original One)	L
Windows Image Viewer	Initial Size, Zoom In, Zoom Out, Fit to Screen, Right Rotate, Left Rotate	L
Image Adjustment Tools	Implement multiply image processing algorithms and user choose suitable parameter for different individuals	L
Image Difference Evaluation Diagram	Create a patients treatment changes based on the timeline	L
Database	Development of a database in place of hash table storing relevant data	L
Software Support	Extension of the software to support multiple computer system and exploring the possibility of support on mobile devices	H

3.3 Plan

I have already broken the project down into three main parts: modelling, implementation and evaluation. Modelling will focus on image process algorithms. In the implementation phase, the model is transformed in computer code and implemented into the software. During modelling and implementation are sufficiently far along that the code is producing results, then the evaluation stage can begin and results can be analysed. Although separate they are not independent. For example, difficulties in implementation may require a rethink in the model, the implementation must include code that stores results for evaluation and evaluation of results may lead to changes in the model. Most of the progress so far has been on modelling and so I shall focus on it for this chapter.

3.3.1 Methodology

System Boundaries

Main components of the programs will be developed using C++ language. The reasoning behind such is Dlib, which is a modern C++ toolkit containing machine learning algorithms and tools for creating complex software in C++ to solve real world problems[14]. Moreover, C++ with OpenCV library is usually popular for performance critical image processing applications. Written in optimized C++, the library can take advantage of multi-core processing

[2].

The possible challenge that could arise is the lack of previous experience in Image Process, as well as a number of solutions that could be adopted to develop a complicated analysis and management system. To ensure the refactoring of the code is kept to minimum, thorough research of the languages and available tools will be conducted prior any development takes place.

Development Techniques

Due to schedule constraints and lack of previous development experience, the development process will take place iteratively [25]. Such approach allows for creation of mini-projects, which appears to be less risky than a spiral model in the instance where additional features would not be possible to implement.

Moreover, the project will be adopting the Agile ideology [26] with Scrum framework, because of more flexible model of Scrum over XP, and a greater suitability for smaller, as in this instance, development teams. As far as the version control system is concerned, the distributed approach as opposed to centralized will be adopted due to the flexibility it offers and the option to work on several features simultaneously. Although it is believed that distributed model could be more difficult to maintain and prone to merge conflicts [1], previous experience with the Git-based software, along with daily meetings should reduce such risks to minimum. Moreover, the project repository will be hosted at the Github, providing with an opportunity of immediate support in case of unexpected issues with the system.

3.3.2 Implementation

The process of implementing the image process methods into computer code must be broken down into smaller tasks. This will also include basic windows menu design, image adjustment methods, database setting, are appropriate to use. This project is more than producing a software but I consider it as a significant portion to be software engineering. As such I will layout briefly how I plan to follow good practices.

Image Process Algorithm

The software will provide a comprehensive set of reference-standard functions for image processing, analysis, visualization, and algorithm development. The user can perform image analysis, image enhancement, noise reduction, geometric transformations, and image registration.

Version Control

I will keep my code (including all the reports) under version control using Git. Git is very useful to use on individual projects since it does not require setting up a server for repositories unlike centralized version control systems such as Subversion. Using Git also allows me to backup my code on Github where anyone can follow my progress if they want, `https://github.com/Shanshan-IC/MscProject`. For instance the source for this Latex document can be found at `https://github.com/Shanshan-IC/MscProject/Backgroundreport`.

MATLAB

The software will be implemented image processing algorithms based on data test results on MATLAB image process toolbox.

OpenCV

The software will be developed by Visual Studio 2012 with OpenCV. OpenCV (Open Source Computer Vision Library) is an open source computer vision and machine learning software library. OpenCV was built to provide a common infrastructure for computer vision applications and to accelerate the use of machine perception in the commercial products.

Database

In the middle of stage, the software will be implemented the database to help nurses and doctors to store patients' skin analysis data and monitor the progress during the detection stage.

Test Driven Developement

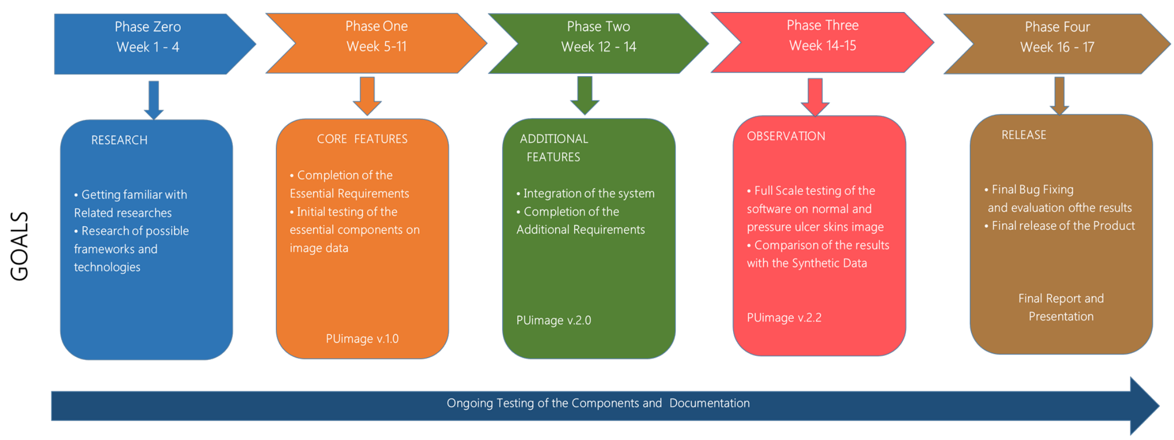
Test-driven development is an advanced technique that uses unit tests to drive the design of software. The suite of unit tests provides constant feedback that each component is still working and act as documentation that cannot go out-of-date.

3.3.3 Evaluation

In order to evaluate all the image process methods, it is necessary to decide first what should be considered as successful outcomes and then how these should be measured. For example, different images taken from nurses gains better effect results using different algorithm and why, and as a whole, which might be measured as the best solution for analysis, setting it as default.

3.3.4 Proposed Schedule

Due to selected iterative model, the scheduling strategy consists of the division of the project development into one research phase and four goal-oriented phases [1]. Each phase is inclusive of the technical group meeting for the ticketing purposes, as well as the ongoing testing and documentation. Moreover, a follow-up meeting with the professor will take place after the completion of each phase to ensure all the requirements were met as expected.



The proposed schedule may be subject to possible changes based on the outcome of the meetings or general alterations of requirements.

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