

**Implementing an Accurate, Real-Time Motion Estimation Algorithm within the Field of Cardiovascular Image Processing**

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# ABSTRACT

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# **CHAPTER 1: INTRODUCTION**

## 1.1 BACKGROUND TO THE PROJECT

Within the medical image processing study area, an issue of paramount importance is the necessity of fast and accurate analytical data which can be derived from patient data, for the purposes of this project an example area of study selected was a simple velocity estimation calculation which estimated the velocity of the muscle movement of a patient’s heart between frames of a DICOM image. As such, the implications of this statistical analysis are the need for real-time image processing techniques, such that the velocity calculation can be calculated as accurately as possible without the burden of expenditure of time and memory efficiency lost to serial processing.

Imperatively, the motivation behind this project is to investigate how the ultrasound image representation for patients can be algorithmically analysed to produce additional data that can be used to further describe a patient’s condition, the algorithms of which would be based on the motions detected between frames of the ultrasound image for a particular patient. This data can then be used to calculate the velocity of the muscle movement of the heart during the cardiac cycle, which could be used for demonstrating the competence of a patient’s heart.

Previous research in this area of study indicates that techniques such as speckle-tracking echocardiography may be used to monitor the displacement of speckles representing the myocardium, research also suggested it could be used for the strain measurement of the longitudinal, circumferential and the radial of the myocardial function during the cardiac cycle (Pavlopoulos et al., 2007). In addition to this, similar research papers investigating the analysis of ultrasound images suggest that the clinical efficacy of the algorithmic calculation for the muscle movement of the heart during the cardiac cycle is largely dependent on how fast and accurate the block-matching motion estimation algorithm operates (Mondillo et al., 2011). The algorithm in question needs to be a fast real-time processing algorithm capable of processing an image in a speed of 52 frames-per-second, so another paper suggests that a possible way for accomplishing this fast real-time block-matching motion estimation algorithm is through the implementation of parallel processing through the graphical processing unit (GPU) as opposed to serial processing the ultrasound image through the central processing unit (CPU) (Massanes et al., 2011).

In summary, the motivation of this project will be to investigate and develop a fast-real-time block-tracking motion-estimation algorithm that is capable of analysing an ultrasound image to produce additional muscle movement velocity data, which in turn can be used to deliver a more informed diagnosis or prognosis for a patient, for example it could be used as a possible method to project the competency of a patient’s heart. It is imperative that the algorithm that will be capable of ‘real-time’ processing the image, as a requirement of the image analysis will be to ensure that the algorithm will be able to process the image at a constant speed of 52 frames-per-second (FPS).

## 1.2 PROJECT AIM AND OBJECTIVES

Predominantly, the aim of this project was to investigate and produce a fast, real-time block-matching motion estimation algorithm that was capable of analysing ultrasound images for patients that suffer with cardiac-related illnesses. This algorithm will be quantifying the speckle-pattern data that represents any movement from the myocardium during the cardiac cycle, the data of which will be used to calculate the average velocity of the muscle movement and provide additional data that can be used to help to further diagnosis or prognosis of a patient in a time efficient manner. Explained below are the objectives, which upon completion, will help to accomplish this aim:

* A key aspect of being able to achieve this is by accurately and efficiently extracting the relevant image data from the ultrasound image, which will be supplied as a digital imaging and communications in medicine (DICOM) image. Therefore, the initial objective of this project will be to investigate all aspects of the DICOM image format and establish how it can be manipulated and used effectively for the proposed project.
* Part of the aim for the proposed project is to develop an algorithm that is capable of tracking and calculating the velocity of the muscle movement based on the data extracted from the ultrasound image. This will be done by dividing each frame of the DICOM image into a series of equally sized blocks and then utilising the block-matching motion estimation algorithm for the motion estimation algorithm so the system can track the total displacement of each speckle representing the myocardium between each frame of the DICOM image, which subsequently can then be used for assisting with the diagnosis and prognosis for patients with cardiac-related illnesses.
* Imperatively, the parallel algorithm needs to be compatible with any patients being diagnosed for a cardiac-related illness, the implication of this being that the proposed algorithm must be developed in such a way that a fast, accurate muscle movement velocity estimation calculation can be derived regardless of any differing qualities each patient’s heart may be perceived to have.
* The system will currently only be able to run under a serial architecture without concern for the speed of the algorithms, so the system will need to be converted under parallel architecture where the calculations and processes for the algorithms can be completed concurrently.

However, it was made apparent later in the project lifecycle that the initially proposed aim and objectives were too ambitious, with the prominent issue being proclaimed as the inability to produce both a serial and parallel implementation of the proposed system with the proposed amount of project resources.

* The DICOM images that are supplied for the algorithm may contain an element of noise throughout the distribution of speckles, thus this may provoke a distortion in both the motion detection with each kernel as well as the overall average velocity estimation calculation. Thus, a further objective of this project was to process each frame of a DICOM image such that the majority, if not all, of the noisy pixels distributed throughout the image are removed, this in turn would promote the overall efficacy of the results obtained by the algorithm by significantly improving the accuracy of the motion estimation algorithm.

# **CHAPTER 2: LITERATURE REVIEW**

## 2.1 CARDIOVASCULAR IMAGE PROCESSING

overall efficacy of the results obtained by the algorithm

could allow in-depth analysis for systolic and diastolic dynamics for a variety of different cardiac illnesses, this research paper argues that speckle-tracking is predominantly accurate for the quantification of the longitudinal, circumferential and radial strain of the heart. (mondillo)

Ultrasound is a medical imaging modality suited for many applications as the image acquisition is real-time, thus it is commonly utilised for surgical applications such as cardiovascular diagnosis as it is capable of offering a light, inexpensive, non-ionizing method to image the surgical field and quickly update the pre-operative planning. To this end, Fontes et al (2011) also argues that the methodology of processing the image must subsequently be capable of real-time processing, as it can be observed to be a crucial aspect within a surgical application such as cardiovascular image processing.

Rosenzweig et al (2011) explores the possible implications of using parallel processing for an ultrasound image by processing an image and comparing the capabilities of using only the CPU and using both the graphics processing unit (GPU) and the central processing unit (CPU) to process an acoustic radiation force impulse (ARFI) image, monitoring any small displacements that may have been caused within the muscle tissue. As a result of this study, Rosenzweig et al (2011) argue that the time required for processing the data was significantly reduced when the image was parallel processed using both the GPU and the CPU as opposed to serial processing with just the CPU.

In a similar study, Massanes et al (2011) suggest that current applications that require real-time motion estimation algorithms often use parallel designs for very large scale integration (VLSI) devices, but are usually costly, difficult and time consuming to develop. This study evaluates the block matching motion estimation algorithm with a full search on the frames of a surveillance video of 720 x 480 pixel resolution at 30 frames per second, under both a serial programming architecture and a parallel programming architecture. At the outcome of the project, Massanes et al (2011) argue that an implementation of the block matching motion estimation algorithm with multiple GPU cards provided a significant speedup in comparison to the speed of the algorithm when implemented with the CPU by up to several orders of magnitude.

## 2.2 SPECKLE TRACKING ECHOCARDIOGRAPHY

One critical aspect of the proposed project is to establish a solution which is capable of identifying new locations for specific features within an ultrasound image as accurate and precisely as possible, for example the new location which the cardiomyocytes may have expanded or contracted during the cardiac cycle. Static B-scan ultrasound images, such as the DICOM images involved for this study, can be utilised in such a way that the speckles tracked on a frame of an ultrasound image can be used to describe details and features of an object contained within the image, for example any speckle patterns that may be reflecting from the myocardium or the cardiomyocytes.

Mondillo et al (2011) advocates that speckle tracking is a technique is fundamentally based on the analysis of speckles during the cardiac cycle, whereby single speckles are merged into functional units, in this case kernels, which can be argued to be representative of the peculiar displacement of the speckles between two frames of a sequence of images. To this end, it is argued that each kernel could constitute as a unique ultrasound fingerprint which could be tracked and quantified between each frame of the ultrasound image throughout the entire cardiac cycle, whereby Mondillo et al (2011) argues that the motion of the speckles could be estimated by comparing kernels between two frames of the ultrasound image. The motion data estimated would subsequently provide a means for calculating the clinically useful analytical metrics such as the displacement, displacement velocity, strain and the strain rate of the selected myocardial segments and left ventricle rotation.

Similarly, Notomi et al (2005) investigates the validity and effectiveness of utilising the speckle displacement in the ultrasound images to establish a rotational velocity from the left ventricular and the left ventricular torsion of a heart,

Furthermore, a shortcoming of the speckle tracking echography technique implies that a patient who may have abnormal decorrelation scores could lead to the speckle tracking data not accurately representing the muscle movement and consequently lead to less reliable results being produced with the speckle tracking imaging technique (Notomi et al., 2005).

On the other hand, a limitation of this technique is that any speckle-pattern that is being measured must remain constant during the cardiac cycle and not be subjective to motion distortion, as any minor differences will modify the extracted speckle values and consequently produce less accurate results for the calculated velocity of the muscle movement. While it could be argued that this speckle-tracking technique is more subjective to data distortion than the Doppler technique, the improved lateral resolution of speckle-tracking with a high-quality ultrasound image can enable the shallower segments of the heart to be tracked more accurately (Pavlopoulos et al., 2009) and could be used to produce a more accurate velocity calculation of the muscle movement observed in an ultrasound image.

## 2.3 BLOCK-MATCHING MOTION ESTIMATION ALGORITHM

Another significant aspect of this project is the consideration of the approach in which the speckles are tracked between frames of an ultrasound image, furthermore the strategy which is undertaken for comparing and establishing the new location of a speckle. Effectively, a block-matching algorithm usually operates by dividing the pixels representing a particular frame in a sequence of images in a series of equally sized macroblocks, the algorithm then iterates through each pixel within the image and compares each macroblock of pixels with candidate macroblocks in a subsequent frame in a sequence of images using a similarity criterion. At the outcome of this algorithm, the resulting output should present an accurate depiction of the new location of a particular pixel which the algorithm believes the pixel may have traversed to, subsequently providing an estimate of the total displacement for each pixel which can be used to describe the overall motion between two frames in a sequence of images.

An effective and efficient motion estimation algorithm can be considered as a vital module in other fields of study and applications, for example a motion estimation algorithm could be argued to be the most important module in a typical video encoder. Huang et al (2006) seeks to further explore and compare the extensive possibilities for motion estimation techniques for video sequences and proposes that the key aspects of fast algorithms can be classified into a total of six different categories: reduction in search positions, simplification of matching criterion, bitwidth reduction, predictive search, hierarchical search and a fast full search. As such, this study proposes that the sum of absolute differences (SAD) matching criterion regards all of the pixels in the current block and a candidate block, however Huang et al (2006) proposed that the computational effort of this comparison could be reduced by performing a subsampling scheme, whereby only every second pixel within the macroblock is considered for displacement estimation in both the horizontal and vertical directions. Overall, this study claims to have yielded a speedup of approximately a factor of four while still estimating the motion with minimal error.

However, in a study surveying possible approaches for estimating the image velocity in ultrasound image sequences, Boukerroui et al (2003) investigates possible implementations for a block-matching motion estimation algorithm and compares possible similarity measures which would be utilised when comparing each of the macroblocks.

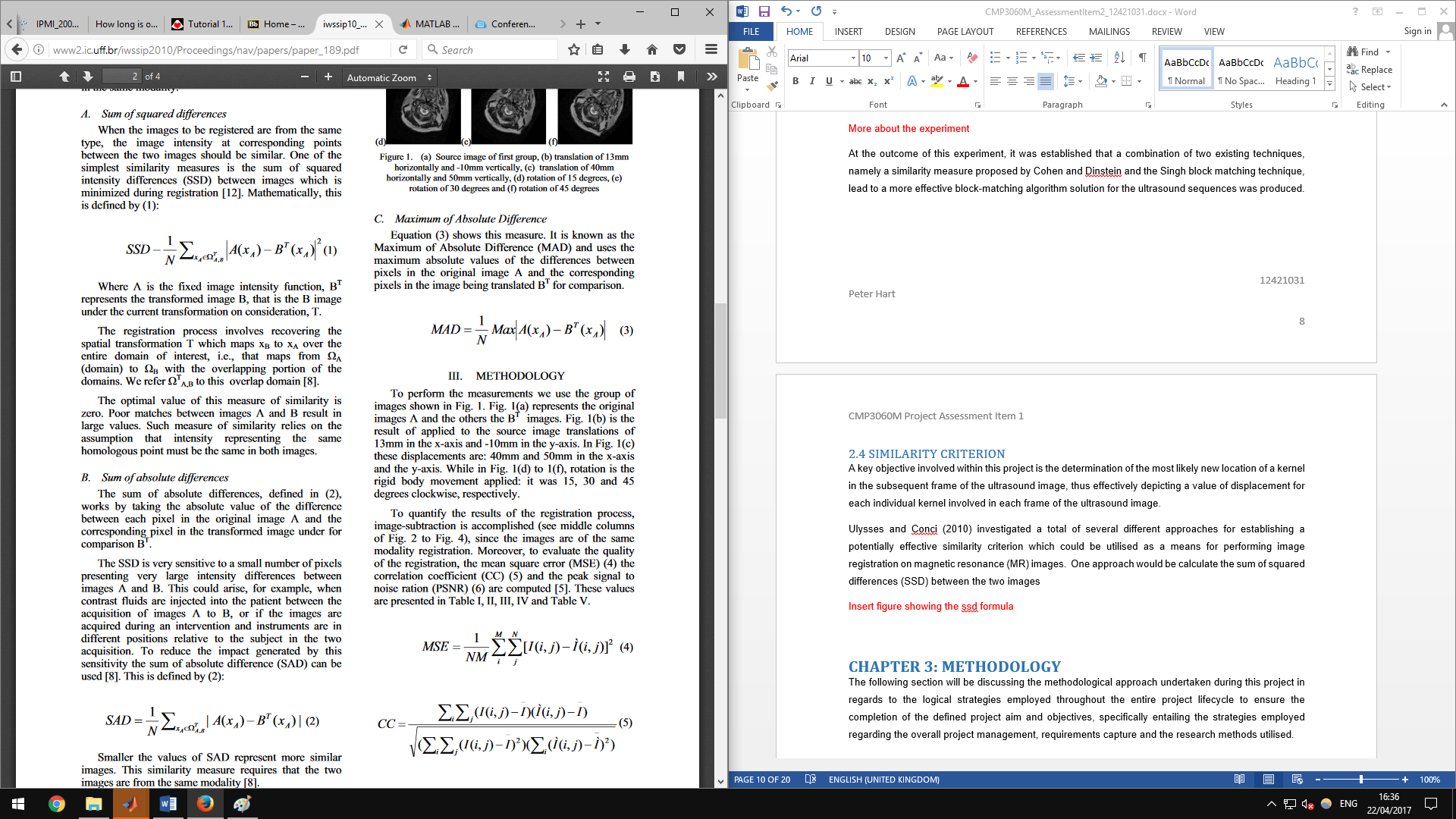
In this study, a Singh block matching approach operates somewhat differently to the previously discussed block-matching approach whereby the velocity estimation is calculated based upon the only the component of velocity normal to intensity edges on the image, however Boukerroui et al (2003) argues that this approach loses an amount of accuracy in the calculation as the search region of the algorithm is discrete, thus the calculation is limited by this discretion. In contrast, this study proposed that a more reliable estimate for the velocity could be calculated by using a smoothness constraint and an appropriate confidence measure. Boukerroui et al (2003) claims that the velocity at each pixel is unlikely to be completely independent of the velocity of its neighbours, and as such the velocity of each pixel could be refined based on the velocity values of the neighbourhood of velocity values.

At the outcome of this experiment, it was established that a combination of two existing techniques, namely a similarity measure proposed by Cohen and Dinstein and the Singh block matching technique, lead to a more effective block-matching algorithm solution for the ultrasound sequences was produced.

## 2.4 SIMILARITY CRITERION

A key objective involved within this project is the determination of the most likely new location of a kernel in the subsequent frame of the ultrasound image, thus effectively depicting a value of displacement for each individual kernel involved in each frame of the ultrasound image.

Ulysses and Conci (2010) investigated a total of several different approaches for establishing a potentially effective similarity criterion which could be utilised as a means for performing image registration on magnetic resonance (MR) images. One approach would be calculate the sum of squared differences (SSD) between the two images,



## 2.5 SEARCH STRATEGIES

# **CHAPTER 3: METHODOLOGY**

The following section will be discussing the methodological approach undertaken during this project in regards to the logical strategies employed throughout the entire project lifecycle to ensure the completion of the defined project aim and objectives, specifically entailing the strategies employed regarding the overall project management, requirements capture and the research methods utilised.

## 3.1 PROJECT MANAGEMENT

As previously discussed, the intended outcome of this project is to deliver a velocity estimation algorithm that would be suitable for integration within the application of cardiovascular image processing, whereby doctors and surgeons may be able to use the data obtained from proposed solution to help with the diagnosis or prognosis of a patient.

### 3.1.1 PROJECT PLAN

The time and task management of the project was pre-planned in the form of a project plan framework referred to as a Gantt chart, Wilson (2003) argues that Gantt charts provide an effective means for displaying important information and useful for implementing interactive approaches to scheduling in a project.

Effectively, the Gantt chart for this project was designed to outline a schedule for the deliverables of the project, allocating an amount of time for key tasks involved during the development under a one-week granularity. This Gantt chart was designed in reference to the preliminary risk assessment and contingency plans (see chapter 3.1.3) that were undertaken, allocating a higher proportion of time towards tasks which could be considered as a higher risk of failure in comparison to other tasks of the project (see Appendix I.).

WORK BREAKDOWN

### 3.1.2 SOFTWARE ENGINEERING MODEL

There are many possible approaches which could have been chosen as the methodology for the management of this project, however the methodological approach which is selected must be justifiably robust and capable of delivering a high-quality solution at the outcome of the project. To ensure that the solution is developed efficiently, the following section will be exploring various software development methodologies and how they could potentially be integrated into the management of this particular project as well as discussing the chosen methodological approach for this project.

Furthermore, another possible approach would be to manage the project using agile management, this approach advocates developing the solution in multiple small development lifecycles, subsequently delivering the solution in small increments as delivering one final solution at the outcome of the project in comparison other methodologies. To this end, this approach enables a methodological approach which is justifiably flexible and adaptable to change during the project lifecycle, as a project using this methodological approach could possibly develop, evaluate and iterate through a project lifecycle until a desirable outcome of the project is achieved.

On the other hand, a limitation of this advantage is the potential issue of excessive expenditure of project resources, namely allocation of project time, which would become an increasingly more prominent issue as a result of the iterative project lifecycles.

Another possible approach for managing the project would be a Waterfall methodology, this largely operates by designing the development model for the project as a single cycle of development processes which are inferred from a set of unmodifiable requirements that are specified by the client at the start of the project. However, a significant disadvantage for the inclusion of this type of model is that it introduces a high amount of risk and uncertainty into the project plan, this primarily being the difficulty and limitation of regressing to previous stages of the project to make some form of improvement or amendment. As a consequence, key features such as the block-matching motion estimation algorithm would not be able to be tested until the later stages of the project lifecycle and would leave less opportunity for the solution to be improved, this could imply possible issues with the effectiveness and efficiency of the developed motion estimation algorithm if it hasn’t been rigorously tested and consequently consistently improved throughout the entire project lifecycle. Thus, it could be argued that this in turn would imply that a significantly less robust and lower quality solution to be developed in comparison to other software engineering models.

In conclusion, in order to select a methodological approach would be appropriate for this project, the deliverables of this project need to be considered. As such, one of the key factor considered was the issue of the desire to build the project completely before being tested and delivered, or if the project should be tested and re-built with new features or requirements in a series of iterations. A fundamental aspect of this project is to be able to deliver a real-time, accurate motion estimation algorithm capable of estimating cardiovascular motion within an ultrasound image, as such the methodological principles followed during this project were those adhered from the agile approach, whereby the project lifecycle was largely executed through the use of small, consecutive software development lifecycles. While it can be argued that the waterfall methodology advocates the concept of delivering the project in a potentially more timely manner as the solution would not need to be consistently tested at various stages of the project, an agile approach ensures that the quality of the solution delivered at the outcome of the project will be rigorously tested and capable of providing meaningful and effective data in later stages of the project.

To adhere to selected agile philosophy, the each version of solution would be tested using black-box and white-box testing approaches at the completion of each iteration of the project lifecycle, this allowed opportunity for the current version of the solution to be reviewed which could be subsequently acted upon in the next iteration of the project lifecycle. For example, during milestone two of the project plan, it was established that the current version of block-matching motion estimation algorithm was not achieving the intended results and was subsequently incorrectly estimating the motion present within the ultrasound image. This can be considered as a significant issue in the project, as the quality of the block-matching motion estimation algorithm is at the core of the solution which would negatively affect the final results if ignored. However, an agile approach to this project allowed the issue to be methodologically managed at the start of the subsequent project lifecycle iteration by adapting the plan and requirements of that iteration, whereas in comparison this improvement would be difficult for inclusion with a waterfall methodology. This in turn allowed the project to deliver a thoroughly improved solution as a consequence which would be capable of producing more significant and accurate data which could be used as a representative of the velocity of the heart muscle contraction and expansion between frames of the ultrasound image.

### 3.1.3 PRELIMINARY RISK ANALYSIS AND CONTINGENCY PLAN

The following section presents an acknowledgement for all of the risks that have been considered to be significantly relevant to the project represented as a risk matrix. However, it should be noted that the following risk matrix only prioritises risks that are specific to this particular project and will not be considering the handling of common risks such as the failure of hardware and equipment. It should be noted that the risk quotient has been calculated by: *impact level x risk likelihood*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Risk Description** | **Risk Likelihood** | **Impact Level** | **Risk Quotient** | **Contingency Plan** |
| The provided ultrasound image of the patient’s heart may not load into the system as intended, which would lead to it being impossible for any velocity data to be calculated from the ultrasound image. | 0.3 | 7 | 2.1 | Assuming that the issue lies with the quality of the ultrasound image that was supplied, the original ultrasound image data will be securely destroyed and a request for a different copy will be made.  However, this concern will be passed onto the supplier of the ultrasound image if the issue is still unresolved. |
| The developed object-tracking algorithm may not work on all examples of the patient data and may fail to be compatible with any subsequent DICOM images that are provided for additional patients. | 0.4 | 6 | 2.4 | The issue however may result from the fact that the ultrasound image was recorded from ultrasound hardware than the other DICOM images, so the amount of scan lines may be marginally different.  In this case, debugging time can be saved by testing the developed algorithm on further examples of patient data and could be made compatible with the existing algorithm by managing the speckle-tracking quantification calculation to consider the potential change in scan lines and handle this particular ultrasound image separately. |
| The allocated time for a particular task may overrun, for example there could potentially be a delay with the development or implementation of the object-tracking algorithm. Thus, this small delay would delay later tasks and would further delay the entire project, presenting the risk of not being able to complete the project for the planned deadline. | 0.6 | 5 | 3 | Contingency time will be built in within the project plan and will be utilised as additional time in the event that particular objectives for the project take a longer amount of time to complete than originally intended. As a result, this makes the likelihood of the project not being completed on-time for the intended deadline significantly less likely. |
| The confidentiality of the ultrasound image data from each patient may become compromised and susceptible to unauthorised access. | 0.3 | 9 | 2.7 | All work done for the project in regards to the patient’s DICOM image will be done in a confidential workspace and will not be shared with any member of the public. |
| Ineffective storage could risk unauthorised access to any ultrasound image data that has been supplied by the patients. | 0.3 | 9 | 2.7 | The patient data will be stored securely in a password protected and encrypted zip folder on a separate external hard drive, where the naming convention for the relevant files and folders will not relate to patient’s personal data. |
| A patient may decide to withdraw any ultrasound image data that they shared for the purposes of this research project. | 0.3 | 8 | 2.1 | The original ultrasound image data will be securely removed from all data storage locations and further ultrasound image data will be gathered from a different patient that will agree to the University of Lincoln ethical research guidelines. |
| The diamond search block-matching algorithm is incompatible with the intended project or it isn’t as fast as three step search or four step search. | 0.2 | 4 | 0.8 | As research suggested that the diamond search block-matching algorithm would likely be the most suitable algorithm in regards to the algorithmic efficiency, contingency time will be allocated for debugging any issues within the algorithm itself.  However, if one of the alternative algorithm implementations is consistently found to be more efficient in comparison to the diamond search algorithm, then another implementation will be selected. |
| The complexity of the developed block-matching motion estimation may be too high for it to be adapted to use parallel processing as opposed to serial processing, and may be difficult to complete within the project timescale. | 0.4 | 7 | 2.8 | Assuming that the allocated contingency time is not enough to accommodate the issue of converting the algorithm from using serial processing to parallel processing, the parallelisation of the algorithm is considered as a STRETCH objective and therefore may not be completed within the proposed timescale of the project. In the event of this, the production of the developed algorithm under a parallel processing architecture will be proposed for further research and this project will conclude results based on the findings discovered within the serial processing architecture. |

## 3.2 RESEARCH METHODS

As previously elaborated, the fundamental aim of this project was to implement an accurate motion estimation algorithm that provides the necessary capabilities for integration within the application of cardiovascular image processing, whereby the proposed solution could arguably provide doctors and surgeons with further means of diagnosis and prognosis of patients with cardiovascular illnesses. Depending on the outcome of the proposed solution, this project could help contribute towards providing more accurate data which could arguably be considered as more representative of a patient’s health condition when regarding the ultrasound image diagnosis or prognosis.

To develop a solution which would be capable of accomplishing the pre-determined aim and objectives of this project (see chapter 1.2), quantitative primary results data were collected by quantifying the results obtained when testing the developed solution on a total of twelve, anonymous, randomly selected ultrasound images of patients diagnosed with cardiovascular related concerns. This data will be observable data which can be examined and statistically analysed in regards to elapsed time and its ability to estimate appropriate velocity values for the muscle movement present between frames of an ultrasound image in real-time, these results will be plotted in the form of velocity plot over the entire cardiac cycle recorded in each example cardiovascular ultrasound image that was provided. These results will then be compared between each patient to assess the effectiveness and efficiency of the solution’s ability to deliver towards the objectives and aim of the project (see chapter 1.2).

# **CHAPTER 4: SOFTWARE DEVELOPMENT PROCESS**

The following section will entail a more in-depth discussion regarding how the project was managed at prominent stages of the project lifecycle, further exploring what software development processes were employed and their desired impact on the overall management and delivery of the project.

## 4.1 DESIGN

As previously discussed, the intention behind the completion of this project was to employ an accurate and reliable motion estimation algorithm which would be capable of estimating the velocity of the cardiomyocytes within an ultrasound image as the myocardium contracts and expands during the cardiac cycle, as such an imperative characteristic to be noted in order to accomplish this is to ensure that the solution is capable of determining the motion of speckles within the ultrasound image in real time. The following section will be exploring the fundamental design processes employed throughout the design stage of the software development lifecycle of this project, specifically entailing how the solution was tailored towards accommodating the previously discussed aim and objectives of this project.

### 4.1.1 BLOCK-MATCHING MOTION ESTIMATION ALGORITHM

One fundamental problem which was required to be solved for this project was to establish a means for accurately depicting the amount of movement that may have occurred between two frames of the ultrasound image, to inherently establish a value which can be argued to be representative of the total distance the cardiomyocytes contracted between frames of the ultrasound image. As such, research undertaken within the literature review of this project indicated that one approach for accomplishing such an objective would be to implement a search algorithm in the form of a block-matching motion estimation algorithm in combination with the speckle tracking technique.

In a recent study (Mondillo et al, 2011) suggests that speckle patterns observed in an image can be used as a representative as an identifier of different features within the image, and in turn was proposed that these speckle patterns could be utilised as a comparator between two frames of an image. To this end, this project utilises a technique referred to as a block-matching algorithm which is used for measuring the similarity between two similar images or segments of images in regards the pixel data (Shi and Sun, 2000).

This algorithm operates by iterating through each pixel within a frame of the ultrasound image at a pre-defined step size, whereby the speckle pattern of each pixel is established by the neighbourhood of pixels surrounding the currently selected pixel, effectively forming a macro block of pixels. This macro block of pixels is then loaded into a kernel matrix and compared with the macro blocks of pixels in the subsequent frame of the ultrasound image, searching through all macro blocks within a defined search window (see chapter 4.1.2) and comparing against each one to establish which macro block in the subsequent frame is justifiably the most similar to the currently selected macro block from the original frame of the ultrasound image through the use of a similarity criterion (see chapter 4.1.3). As claimed by Boukerroui et al (2003), the velocity at each pixel is unlikely to be completely independent of the velocity of its neighbours, so the velocity of each pixel is refined based on the velocity values of the neighbourhood of velocity values to produce a more resourceful outcome for the motion estimation.

### 4.1.2 SEARCH STRATEGY

As previously discussed, a fundamental part of the design for the block-matching motion estimation algorithm was the consideration for search strategy, specifically in regards to search window inferred when searching through a frame of the ultrasound image for most similar macro block in the subsequent frame of the ultrasound image in respect to the currently selected macro block of pixels from the original frame. As such, the search strategy that will be enforced for this particular project will be the utilisation of a fast search technique, whereby the number of candidate macro blocks which the block matching motion estimation algorithm will be comparing will be significantly lower than the total of candidate macro blocks that would be apparent through the full search technique. In respect to this particular project, a focus within the project aim is to accomplish a block-matching motion estimation algorithm that is capable of real-time processing a cardiovascular image in the format of an ultrasound image, as such a fast search technique will compress the search window to a smaller area of pixels surrounding the selected pixel from the original frame, thus enabling a much more efficient result to be obtained.

### 4.1.3 SIMILARITY CRITERION

To enable the comparison, a kernel is established which embodies the concept of taking the currently selected pixel and its neighbours from a frame of the ultrasound image and using it as a reference kernel when searching and comparing this kernel with multiple kernels within a search window of the subsequent frame of the ultrasound image, attempting to locate the kernel which can be argued to be the most likely new location of the currently selected kernel.

However, an issue of vital importance that was presented was how the algorithm could determine which kernel within the search window could be characterised as being the most similar, and incidentally the most viable, kernel in regards to the currently selected reference kernel. The implications of this decision made by the algorithm being that it will determine the accuracy and reliability of the final velocity value output estimated between two frames of the ultrasound image, hence a sum of absolute differences (SAD) metric was calculated between the currently selected reference kernel and a kernel within the search window of the block-matching motion estimation algorithm.

### 4.1.4 NOISE REMOVAL

One objective of this project which could be considered as a key asset for the aim of the project to be fulfilled was the consideration of noisy pixels which are inherently present throughout all of the ultrasound images.

The noise present in the ultrasound images was conducted in a total of two different ways, the first being through the application of an image segmentation technique. For the purposes of this project, the only pixels that need to be considered for the velocity estimation are pixels which are representative of the cardiomyocytes within the ultrasound image, thus the inclusion of further pixels within the velocity estimation would be unnecessary and can be considered as noise for the algorithms.

As a result, the developed solution pre-processes each frame and converts the ultrasound image to a binary image, effectively segmenting the cardiomyocytes away from the remainder of the image. The resultant binary image can then be utilised as a mask for flagging noisy motion vectors, whereby only pixels that describe the cardiomyocytes within the ultrasound image will be considered for the algorithm and flag any subsequent noisy motion vectors.

Consequently, the inclusion of noisy motion vectors, which abnormal values as a result of the presence of noise, can subsequently lead to the output of the algorithm to be distorted and produce a significantly less accurate estimation. To counter this issue, an average motion vector value was estimated and subsequently compared with each motion vector that was observed in each region of the ultrasound image, this data was then utilised to determine which motion vector values could be considered as noisy motion vectors based on the angle difference between each motion vector and the estimated average motion vector.

This was predominantly accomplished by calculating a tangent value based on each motion vector and the estimated average motion vector, such that if the tangent value was estimated to be larger than a threshold value it would be flagged as a noisy motion vector and will be ignored in the final velocity estimation calculation.

## 4.2 DEVELOPMENT

In contrast to the previous section of the report, this section will be discussing how the original design of the solution was adapted and possibly improved during the development stage of the project.

### 4.1.1 BLOCK-MATCHING MOTION ESTIMATION ALGORITHM

The original design of the block-matching motion estimation algorithm entailed optimising the solution by utilising a search strategy which depicted a strict search window surrounding the currently selected block of pixels which the algorithm could operate on, however this was later improved during development stages of the project by enforcing a full search as opposed to a fast search. This change in design allowed the block-matching motion estimation algorithm to operate a more effective search technique, where it was guaranteed to find the most likely new location of a group of pixels if the search window was expanded to being the entirety of the image. It can be argued that this design improvement for the solution is implemented at the cost of processing efficiency, as this version of the solution will notably require a significantly larger amount of computational resources and expenditure due to the significant increase of candidate macro block which the algorithm now has to operate on. However, this design improvement was retained in the final version of the solution as this technique was noted to being considerably more compatible for the parallelisation of the algorithm as it is possible for the estimation to be achieved independently for each block in the current frame of the ultrasound image.

### 4.1.2

## 4.3 EVALUATION

# **CHAPTER 5: CONCLUSION**

# **CHAPTER 6: REFLECTIVE ANALYSIS**

The following section will entail a critical reflection regarding the processes following and the efficacy of decisions made during the course of this project, specifically regarding their impact on the project and what lessons may have been learned as an outcome.

While the end solution produced at the outcome of this project could be considered as effectively accomplishing a number of the established objectives pre-allocated at the start of the project, it unfortunately fails to fully fulfil the original intended aim of the project as the final version of the solution was developed under a serial programming architecture as opposed to a parallel programming architecture. A direct consequence of this is the limitation of not being able to observe the estimated velocity data in real-time, instead producing a considerably slower version of the solution in comparison to the speed which the program could have theoretically accomplished, as claimed by Massanes et al (2011) and Rosenzweig et al (2011). Incidentally, one factor which could be argued to have contributed towards this issue in the project is the methodological approach which was selected and subsequently follower throughout the full lifecycle of this project, whereby a large portion of the project management was inherently inspired by the principles defined by an agile methodological approach to software engineering. As previously discussed, the principles of the agile methodological approach towards software engineering projects advantageously allowed the software development processes of this project to be undertaken through a series of iterations of small lifecycles, this in turn enabled the opportunity for consistent feedback to be acquired during the testing stage at the end of each project lifecycle and allowed for weaknesses in the solution to be established and improved upon in the subsequent iteration. However, while it can be observed that this methodological approach would enable a theoretically higher quality and therefore more effective solution to be solution at the outcome of the project, this methodological approach can also be observed as being a shortcoming for the management of this particular project. This is largely due to the fact that the development of some features involved with the project required more development time than initially anticipated, for example more time was consistently added for the improvement of the block-matching motion estimation algorithm to ensure a high quality solution was created, however this subsequently lead to less time being allocated for later stages of the project. In summary, as this project had a strict deadline enforced, it could be argued that the project may have benefitted from a slightly different methodological approach which was tailored more towards development speed as opposed to a quality focus, for example a waterfall methodology.

However, if a time constraint was less of an issue with this project, one improvement that would factor into the management of the new project would be more time allocated towards the development of the solution within a parallel computing architecture, particularly as one previously described shortcoming faced with this project was the issue of too much time being allocated towards the development and improvement of the solution under a serial programming architecture. In hindsight, this would be avoided if the project management had adhered to a more realistic project plan, whereby a higher proportion of the project development time would be focused more on the parallel version of the solution. This stage of the project plan was underestimated in regards to development difficulty and time required, and as such development on this feature became extremely difficulty due to time constraints caused by the excessive development time expended on the serial architecture version of the solution.

Further explore the real-time implementation of the motion estimation algorithm

Test with other search strategies to further gratify results

As previously discussed, the time management of the project was largely operated through the means of a Gantt chart document which represented the entire project plan.

Advantage of gantt chart in regards to this project

# **CHAPTER 7: REFERENCE LIST**

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# **CHAPTER 8: APPENDIX**

