Recent Advances in Ambient Intelligence and Context-Aware Computing

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A volume in the Advances in Computational Intelligence and Robotics (ACIR) Book Series

Information Science REFERENCE
An Imprint of IGI Global

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Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA, USA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

Library of Congress Cataloging-in-Publication Data

Recent advances in ambient intelligence and context-aware computing / Kevin Curran, editor.
pages cm
Includes bibliographical references and index.
ISBN 978-1-4666-7284-0 (hardcover) -- ISBN 978-1-4666-7285-7 (ebook) -- ISBN 978-1-4666-7287-1 (print & perpetual access) 1. Ambient intelligence. 2. Context-aware computing. I. Curran, Kevin, editor.
QA76.9.A48R43 2015
004.01'9--dc23
2014036868

This book is published in the IGI Global book series Advances in Computational Intelligence and Robotics (ACIR) (ISSN: 2327-0411; eISSN: 2327-042X)

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Chapter 3
A Camera-Based System for Determining Hand Range of Movement Measurements in Rheumatoid Arthritis

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ABSTRACT

Rheumatoid arthritis affects around 1% of the world's population. Detection of the disease relies heavily on observation by physicians. The effectiveness of these kinds of tests is dependent on the ability and experience and can vary depending on the observer. This chapter aims to investigate the use of Xbox Kinect camera for monitoring in rheumatoid arthritis patients as a cost-effective and precise method of assessment. A system has been developed that implements the Kinect sensor for usage in a hand recognition and digit measurement capacity. This system performs the tasks usually completed by a physician such as digit dimension monitoring and exercise observations. With the system being designed to be portable and easy-to-use, it is an ideal solution for both the physician monitoring patients in a clinic as well as posing a possible solution for patients wishing to monitor their own condition in their homes.

INTRODUCTION

Rheumatoid arthritis (RA) is a chronic disease that mainly affects the synovial joints of the human skeleton. It is an inflammatory disorder that causes joints to produce more fluid and increases the mass of the tissue in the joint resulting in a loss of function and inhibiting movement in the muscles. This can lead to patients having difficulties performing activities of daily living (ADLs). Treatment of RA is determined by physicians through x-rays, questionnaires and other invasive techniques. An example of this would be angle measurements taken using instruments such as tape measures or a dynamometer to measure grip strength. There is no cure for RA but clinicians

DOI: 10.4018/978-1-4666-7284-0.ch003

aim to diagnose it quickly and offer therapies which alleviate symptoms or modify the disease process. These treatment options include injection therapy, physiotherapy, manual therapy (i.e. massage therapy or joint manipulation) and drugs which can reduce the rate of damage to cartilage and bone. These treatments are assisted by patient education. Patients are shown methods of Joint Protection, educated in the use of assistive tools to aid in ADLs and shown altered working methods..

Solutions designed to facilitate and aid diagnosis of vulnerable patients – ones which are in chronic or debilitating pain, for example – face an array of unique requirements. Rheumatoid Arthritis affects around 1% of the population (Worden, 2011) and causes synovial joints in affected areas to become inflamed due to extra synovial fluid being produced. This can lead to a breakdown of the cartilage in the joints and can cause the bones in the joint to corrode. As a result, patients commonly exhibit deformation in their fingers and joints; as well as note regular and occasionally disabling pain (Majithia & Geraci, 2007). Typically, assessing patient mobility is a case of factoring in the patient attending their local medical practitioner for tests or treatment. This can become difficult however if a patient has limited mobility. For a patient who is suffering RA, it is possible that their disease is afflicting more than one set of joints in their body. Also, having the disease increases the risk of osteoporosis in the patient due to the nature of the disease and the medication they are required to take (Handout on Health: Rheumatoid Arthritis, 2009). In effect, this can mean that the patient would require home visits more commonly than a patient who is not suffering joint pain. Physicians required to visit the home of their patients in order to assess the current disease progression and possible treatments must have access to portable equipment. Therefore the equipment used must be mobile, easily set-up and be an inexpensive product. Portable low cost equipment does exist that aids treatment at home, however these methods have their own limitations that must be considered. The Jamar dynamometer has proven to be an inexpensive and reliable gauge of grip strength, providing data used in assessment. However, in patients with decreased mobility, a grip strength test would prove to aggravate their symptoms and increase levels of pain. This option is also open to false reading from patients not willing to exert their maximum grip strength due to the uncomfortable nature of the test (Richards & Palmiter-Thomas, 1996). There appears to be a lack of a measurement device that can record patients' treatment progression that is portable, cost effective and which has maximum consideration for patient discomfort level.

Healthy joints require little energy to move and the movement is usually painless. However for RA patients their joints have a thickened lining, crowed with white blood cells and blood vessels. Movement of affected joints not only causes bone erosion but also triggers the release of a chemical within the white blood cell causing a general ill feeling (Panayi, 2003). This secreted substances cause the joint to swell, become hot and tender to the touch while also inducing varying levels of pain. Increased swelling, triggered by the white blood cells response causes joint deformation. Severe joint deformity can render traditional methods, such as the manual devices mentioned earlier, ineffective. However it also presents limitations for the proposed advance methods currently being developed. The glove method requires the patient to fit their hand into a standard size glove. This method fails to address the fact that RA patients do not have standard joint movement; therefore maneuvering their hand into the glove could cause unnecessary pain and discomfort. Additionally a standard glove does not accommodate for joint deformity, especially not the extreme deformities that are symptomatic of RA. The difference in finger and joint size is also not considered. RA patients usually have symmetrical joint deformity, i.e. if there third knuckle on their right hand is affected then it is likely that the same joint on the left hand will be affected (Panayi, 2003). Expanding this example, if the same joint on both hands is swollen then the glove would either fit appropriately to the swollen joints or the surrounding joints. This increases result variability as hand movement cannot be standardised. In order for the glove method to accurately measure joint movement and limit discomfort a custom version would be needed for each patient. This would not be a viable option since the progression of RA would require patients to have multiple gloves fitted.

Current goniometric tests are not repeatable and are subject to human error (Condell et al., 2012). This can lead to adverse effects on the patient treatment. However, proposed solutions in the areas of glove-based measurements fail to address the fundamental issues like patient comfort and differing hand sizes. Moreover, the cost incurred with these solutions renders the systems impractical. In order to maximise patients comfort during testing, an external non-contact device is needed for RA patients. This is one of the proposed benefits of a potential computer based camera system. The patient would perform movement tasks but they would not be restricted by any outside materials. Movement would be recorded digitally aiding treatment analysis. The Kinect's versatility and cost effectiveness address accessibility issues. It would be a beneficial, portable piece of equipment that could be purchased by physicians and also patients. Therefore patients could carry out movement tasks daily; the results would be recorded by the camera and a computer. The data could then be assessed by the physician at a later date. A continual data supply would aid treatment planning and could also indicate differences in movement throughout the day. Providing a fuller grasp of movement functionally that is not currently assessed, due to the time restrictions of appointment allocations for patients.

The primary aim of this research therefore was to assess the viability of a camera-based software system for the real-time and historical measurement of hand movement and deformation in RA patients. Its development proposes a viable gain over current goniometric measurement methods. Existing methods and approaches to digitally measuring hand dimensions and movement have failed to address the key issues surrounding RA treatment. While these solutions seek to allow automatic and accurate measurement, many use non-commercial hardware and rely on proprietary software which can be very expensive. Similarly, these devices tend to be highly technical and require the supervision of a trained technician. The hand recognition and measurement system outlined here is a user-friendly alternative to current goniometric measurement methods. It will attempt to overcome challenges and limitations of other physical systems and establish the best solution to the common issues.

BACKGROUND

Measuring hand movement in this context refers to the ability of a given system to determine finger-digit movement in relation to the rest of the hand. Some methods may also allow for automatic detection and measurement of swelling and deformities of the hand. These characteristics are essential when tackling the development of a system aimed at assessing the symptoms and progression of an RA patient. When visiting their doctor, the patient will have their movements assessed in the areas where their RA is affecting them. The physician will check for the presence of finger-thumb drift, swan neck/boutonniere deformity, as well as Bouchard and Heberden nodes (Rheumatoid: Hand Exam, 2011). The examination consists of a patient placing their hand flat on a table (where possible – depending on patient discomfort) with their elbow and wrist resting flat. Using a goniometer, the physician examines (in degrees) extension, flexion, adduction and abduction of the proximal interphalangeal (PIP), metacarpopalangeal (MCP) and distal interphalangeal (DIP) joints of the fingers (Arthritis: Rheumatoid Arthritis, 2008). This determines thumb-index finger drift (position of index finger away from thumb) and palmar abduction (de Kraker, et al., 2009). The measurements are all documented in handwritten forms and are recorded to aid future assessments. These readings are all influenced by physician training and observations therefore they can vary between examiners.

Physical Goniometric Methods

Current goniometric methods for monitoring and assessing joint mobility and deformity are mostly analogue. Among the measures and practices used to establish the patient's disease activity are several self and physical assessments. These are essential for the continued treatment of RA in a patient, allowing the physician to determine joint-protection exercises as well as potential medicinal treatment in the form of anti-inflammatory and auto-immune medications. Measurements of a patients hand is recommended to be taken at regular visits to their doctor (Handout on Health: Rheumatoid Arthritis, 2009). These assessments can include hand measurements, blood tests (among other lab tests), and X-ray imaging of the affected hand.

A sphygmomanometer is used to assess a patients grip strength in their affected hand. This is achieved by inflating the cuff of the device to a standard pressure in a rolled manner, then having the patient grip the cuff in the palm of their hand. After the patient has squeezed the cuff, the physician can take a reading of pressure which can be used to indicate patient's grip strength (Eberhardt, Malcus-Johnson, & Rydgren, 1991). However, using the modified sphygmomanometer can proved misleading results. This instruments pressure gauge is activated when the patient squeezes the air filled compartment (Ashton & Myers, 2004). The limitation of this being that patients will larger hands will have artificially lower pressure readings than patients with smaller hands. This is due to the variance in pressure applied over the surface area (Fess, 1995).

The Jamar dynamometer is seen as a reliable alternative to the modified sphygmomanometer. It is a hydraulic instrument, functioning within a sealed system. It measures grip strength in kilograms or pounds of force (Ashton & Myers, 2004). Its versatility, simplistic functionality and cost effective features makes this method easily accessible (Fees, 1987). It has been found to provide accurate readings and the results are reproducible (Hamilton, Balnave, & Adams, 1994). This is an additional benefit the Jamar dynamometer has over its mechanical counterpart the Stoelting dynamometer. This mechanical method measures tension when force is applied to a steel spring and is not viewed as a reliable measurement (Richards & Palmiter-Thomas, 1996).

In assessing the patient's discomfort, the physician must rely on several questionnaires in order to gain an understanding of disease progression. The Stanford health assessment questionnaire, for example, is designed to assess the average morning stiffness the patient feels in the affected joints of their hands (Eberhardt, Malcus-Johnson, & Rydgren, 1991). This is measured and recorded in minutes and is used to gain an understanding of how long it takes for the patients joints to loosen and become supple again. Similarly, the patient is assessed on their experience of pain levels since their previous examination. This is done through a questionnaire in which they must evaluate their pain levels and discomfort over the preceding period. Another assessment of this form is comprised of several questions regarding ability and pain when performing ADLs. Commonly, the ADLs which are assessed include "dressing and grooming", eating, cutting and preparing food and general hand control over cups and jars (Eberhardt, Malcus-Johnson, & Rydgren, 1991). Patients are also assessed using the Visual Analogue Scale to measure their level of pain and discomfort. This consists of a line, marked on one side as "No pain" and on the other as "Worst pain imaginable" and patients are asked to mark a spot along the line which reflects the current feeling (Schofield, Aveyard, & Black, 2007). Similarly, a Health Assessment Questionnaire is designed to establish the patient's ability to perform daily tasks, with each question grading their capability using a "four-point grading system". This measures their "daily functionality level" (Fries, Spitz, Kraines, & Holman, 1980).

As a result of RA, joints in a patients hand and fingers can suffer bone erosion to varying degrees. In order to measure and document this, the patient will undergo radiographic tests in the form of X-ray imaging and MRI scans of the affected areas. This shows how the bones in the patients hand are affected and can be measured over a period of time to show disease progression and activity. Another method which has the potential to highlight key areas of bone-degradation and joint swelling is an ultrasound imaging of the affected hand. This offers a less invasive method of assessing bone density and level of swelling in the patient. However, Chen, Cheng & Hsu (2009) have shown that "prognostic value of MRI is not directly transferable to Ultrasound" and therefore it is, not yet, an adequate option for assessment.

Typically, several clinical tests are performed to establish the disease activity level; including urine, blood and other tests. From these tests, the patients Erythrocyte Sedimentation Rate and C - reactive protein results are established (DAS Booklet - Quick reference guide for Healthcare Professionals, 2010). In patients with rheumatoid arthritis, the C – reactive protein and ESR levels are used as a measurement and indication of inflammation in the patient's joints (Black, Kushner, & Samols, 2004).

Camera-Based Movement Detection

There are many options when attempting to determine a movement of a subject via camera-based methods. Providing a system with "computer vision" and allowing it to assess variables such as movement, size and depth of an object, is the goal in camera-based solutions. Some camera based-solutions require proprietary hardware, while others are able to utilise common devices and already existing technologies.

OpenCV is a cross-platform function library focusing on real-time image processing. The aim of this library is to supply an application with "Computer Vision", the ability to take data from a still or video camera and transform it into new representation or decision (Bradski & Kaehler, 2008). By taking pixel location and colour information, the library builds an image matrix which it uses to "see". OpenCV was originally developed and released by Intel. Since its release in 1999, the library has allowed a method of tracking motion within captured video and given developers the ability to discern movement angles and gestures. Also, in terms of utilising images and making a decision, here it refers to the ability for any given system to then automatically determine people or objects within a scene. Functions like this are possible with statistical pattern recognition, located within a general purpose Machine Learning Library (MLL) included in the library. This allows for implementation of many features including Object Identification, Segmentation and Recognition, Face Recognition, Gesture Recognition, Camera and Motion Tracking (Chaczko & Yeoh, 2007).

OpenCV is optimised to run on Intel-based systems where it finds the Intel Performance Primitives. Bradski & Kaehler (2008) note that while the library consistently outperforms other vision libraries (LTI and VXL), its own processing is optimised by about 20% with the presence of IPP. The OpenCV library works well with installed camera drivers to ensure that it functions with most commercially available devices. This allows developers to create applications and rely on non-proprietary, widely available camera equipment. Therefore cost and development become a lot more practical for potential developers. Furthermore, in relation to potential environments and scenarios in which applications may be deployed, utilising existing cameras and commonly available devices means that applications can be implemented in a wide array of locations.

The Prosilica GC1290 system is a product designed to facilitate the measurement of a hand for patients with RA (GigE Vision for 3D Medical Research, 2010). Designed by threeRivers 3D, the device is intended to monitor the joint swelling in a hand by recording changes in the volume of the patients joints. A metal frame (80cm high, 60cm wide and 40cm deep) houses a total of four cameras and scanners. Two 3d laser scanners project patterns and grids onto the patient's hand which is then returned in order to create a 3d representation. The laser scanners are equipped with a monochrome camera in order to record this image and identify the laser grid. A colour camera picks up a standard image and is used to monitor joint deformation, while a thermal imaging camera detects joint inflammation. There is also a device intended to measure thermal information located near the hand rest; this is used to provide reference information: ambient room temperature, patients general thermal information.

All data taken from the device is recorded and displayed in real time in order to minimise problems such as motion blurring because of hand movement. This data is then processed by proprietary software packaged with the device to display this information (at 32 frames per second) to the patient and the physician. The software system used is also deployable to all major operating systems (GigE Vision for 3D Medical Research, 2010). With the range of information gathered by this device, it would allow physicians to gather very specific and relevant information on a patient; and process it in a relatively short period of time. Similarly, using a device which outputs measurements on a patients hand standardises the procedure and readings; making them more assessable. This is because the information gathered by the device is statistical and provides a quantitative assessment of disease progression. Furthermore, this limits human error in measurements taken and does not rely on the physicians judgement. The Prosilica system does have some drawbacks, however. Since the device is bespoke it is not commercially available but is designed for medical use. This results in the device requiring direct contact with the manufacturer. This also has an adverse effect on the affordability of the device. The device itself is relatively large, consisting of the aforementioned cameras and frame. While the device could be suited for use in a doctor or physician's office or surgery it would not accommodate home visits and physician mobility. In cases where a physician is required to perform a home visit to the patient, it is not feasible that the device could accompany them due to size and associate cost.

Glove-Based Systems

As an alternative to current goniometric methods, there have been many investigations into glove-based technologies. These aim to assess a patient's finger and joint movement in order to aid in diagnosis and treatment of RA. Existing glove-based solutions, use varied methods of reading joint mobility and tension. Among the technology used are sensors using magnetic technology, electrical resistors and contacts or LEDs with flexible tubes (Dipietro, Sabatini, & Dario, 2008).

Previous research into the use of glove-based technologies has shown the 5DT Data Glove to be among the most accurate versatile gloves available (Condell, et al., 2010). It utilises fourteen fiber-optic sensors; with two sensors per digit and one sensor for each knuckle on the patients hand. It also has a tilt sensor mounted on the back of the hand to measure the orientation of the patient's hand. The sensors on the glove work by measuring light travelling through the sensors. As the patient moves their hand, the stress on the sensor changes, altering the amount of light passing through the receiver.

The glove is produced by Fifth Dimension Technologies and allows for accurate measurement of hand/finger movements; passing the information via USB to either the bundled software or software developed to utilise specific aspects of the glove. To accomplish the creation of custom software to utilise the glove, it comes with a cross-platform SDK in order for developers to make better use of the data they are able to collect. However, this glove is only beneficial if the hand to be tested is always going to be either the left or right hand of a patient. Since the glove is designed to fit only one side of the patient, a new glove must be used should the measurements being taken be desired from the other hand. Furthermore, if the measurements are to be taken from a patient with a different sized hand than the glove which is available, a more suitable one must be found.

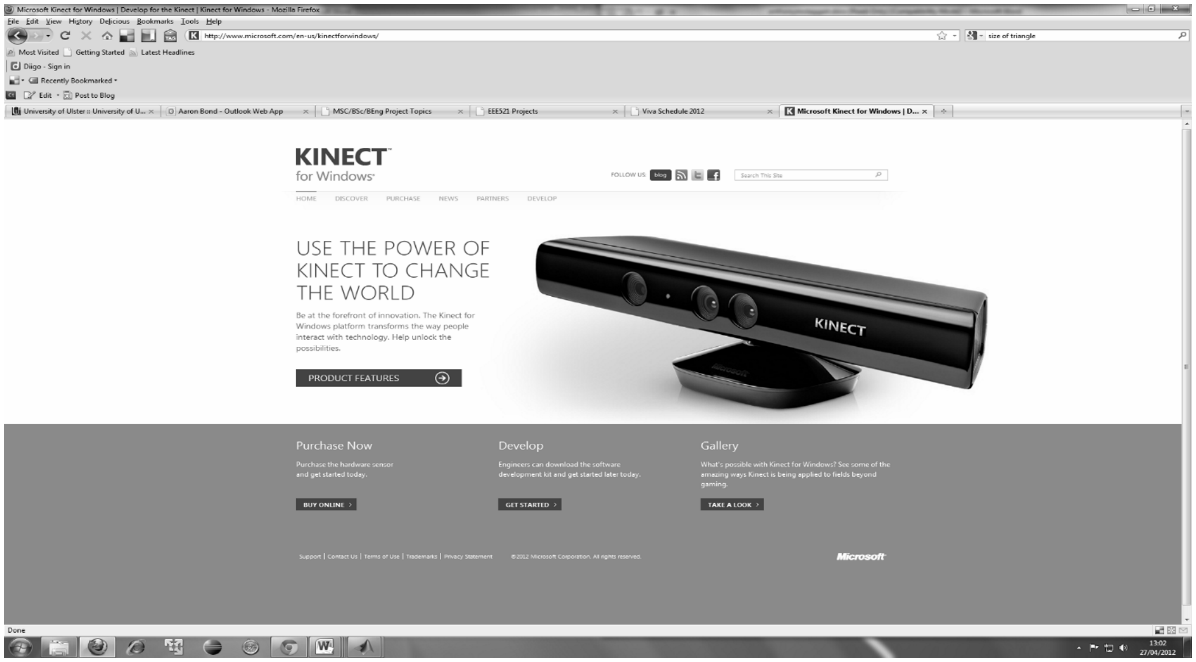
Dipietro et al. (2008) also found that the most accurate results were read from the device when the cloth of the glove fit the patients hand well. Were the cloth too tight, the glove would restrict movement in the patient and give readings which were more extreme than the actual movements. However, if the glove material was loose on the patient, readings were not representative and were less than the actual movements. While the glove allows for highly accurate information readings from the patient's hand; it has some problems which are intrinsic to its design. Gloves like this one are designed to measure hand movements and gestures while the software has been designed to incorporate that use into hand assessment tools for RA patients. One of the main symptoms of RA is hand and finger deformation along with "peri-articular osteopenia in hand and/or wrist joints" (Arnett, et al., 1988). Combined, this results in limitations to hand movements and articulation. Thus, the finger and wrist articulation which is needed in order to manoeuvre the hand into a glove can become painful and difficult.

USING THE KINECT

A Kinect Sensor is the medium chosen to receive the images of the subject's hand. The Kinect is currently available in two models; the "Xbox 360 Kinect" and the "Kinect for Windows". Both models are functional with a Windows-based PC and can utilise the Kinect SDK released by Microsoft. The Kinect for Windows has been modified to allow for readings to be taken much closer to the device than allowed by the Xbox 360 version. This ensures a greater accuracy of data taken from the subject. For the purpose of this design the software will be designed to work with both the Kinect for Windows and the Xbox 360 Kinect; allowing users to utilise whichever is more accessible with the knowledge that Kinect for Windows readings will be more accurate at closer ranges. The Xbox Kinect was used due to affordability and accessibility of the device. However, all code produced can run on both platforms as much of the business logic which handles transferring information from the device to the development computer is achieved through drivers and image-processing libraries like the Kinect SDK. This abstraction allows for maximum versatility in the system.

The Kinect is a device which facilitates the translation of real-world objects and motion into 3d representations. The basics of the device were initially developed by PrimeSense, who later sold the technology to Microsoft. The device utilises a number of sensors in order to accumulate input which can be compiled into a digital representation. It has one camera which allows for input in the infra-red (IR) spectrum which returns a depth map. This map is transmitted from an IR transmitter located next to the IR receiver and consists of a projection of dots onto the target area[1]. Also, the sensor contains a third camera which receives standard RGB (human spectrum) input in order to gain a colour image of the target area. The colour input camera receives information at a resolution of 640x480 pixels while the IR receiver gathers input at 320x240 pixels. Both cameras run at 30 frames per second. The field of view on the depth image is 57.8 degrees (Limitations of the Kinect, 2010). The device also contains a microphone array for receiving sound input (which can allow

Figure 1. Microsoft Kinect for Windows



voice recognition and commands). This consists of 4 microphones placed along the bottom of the Kinect. Lastly, the Kinect features a motorised base. This base allows for targeting of the sensor bar; adjusting its position to acquire the best perspective of the target space. This base allows for manoeuvring allows for a total alteration of 27 degrees vertically in either direction. All of these features of the Kinect make it capable of processing an area to determine distance to an object as well as colour and audio ambience.

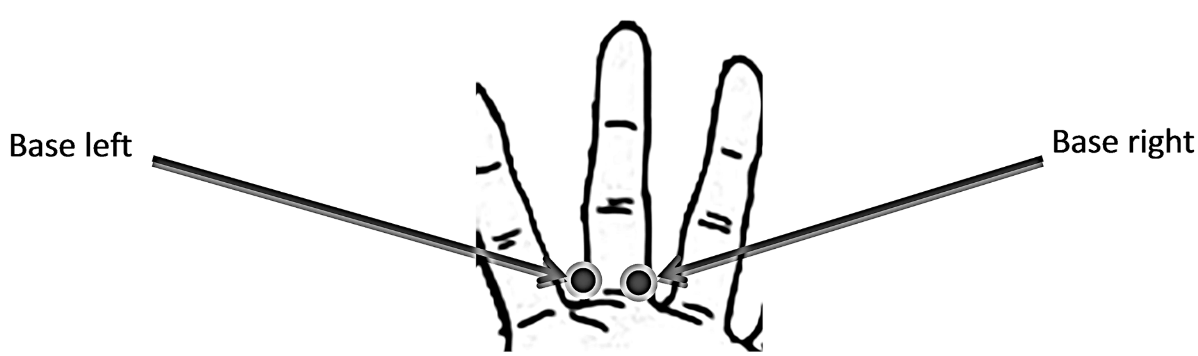
While a standard camera with computer vision software may be able to determine objects in a space, it can become difficult if there is a lack of colour differentiation between the object and the surrounding space. Tölgyessy & Hubinský (2011) assert that with the extra cameras and sensors, performing tasks such as image segmentation becomes a lot easier, especially with the distance threshold which can be assigned to the input. This allows unwanted background data to be filtered out and reduces the noise in the input. Microsoft has also released an SDK which contains drivers and other files associated with producing an application utilising the Kinect. The SDK allows for the device to be used with a Windows 7 operating system and supports C++, C# and Visual Basic programming languages. Along with access to the raw sensor information the Kinect is gathering, the SDK also allows for skeletal tracking (identifying humans and human gestures) via bundled libraries (Ackerman, 2011).

One of the main advantages of the Kinect is the accessibility of its hardware. The Kinect is a relatively advanced device allowing for computer vision. By combining advanced hardware with a commercial price-point and making an SDK available, Microsoft have allowed developers to capitalise on the capabilities of the device at relatively low cost. This promotes its use in varied environments since maintenance and cost are comparatively small when regarding other advanced computer vision utilities. The device is mobile too. The Kinect sensor was designed and built for home use, making it reliable in many conditions. For optimal functionality, the device requires standard room lighting. It requires that the room be lit well enough that the standard RGB camera can pick up information but also not so bright that the IR patterns become indistinguishable (Carmody, 2010). A downside of the system is that for accurate readings, the subject must be at least the minimum distance from the device. This minimum distance for the Kinect sensor is 0.6m and the maximum range is variable between 5m – 6m (Limitations of the Kinect, 2010). However there is an inexpensive add-on for the Kinect which acts as a zoom lens, reducing the minimum distance required. We utilised Connector/NET to integrate a C# system with web-based MySql database implementation. This was the preferred option of database technology as the web-based data access allowing remote tests feeding back to a centralised database and hand readings are never stored locally but on a web server. The system only measures hand data when all 5 fingers are present and readable by the program. This ensures accuracy since the hand has to be properly oriented in order for the fingers to be recognised.

We establish a single finger width as shown in Figure 2. This process ensures that each finger examined by the system is assigned to a relevant local variable and thus can be analysed and stored based on which part of the hand object it belongs to. Employing this method will also mean the readings from the fingers are as accurate as possible no matter the orientation of the hand.

The system uses several supplementary software frameworks in order to receive and analyse information from the Kinect sensor. The Kinect sensor reads the scene and this image and depth information is passed from the Kinect to the OpenNI framework via a set of 64bit PrimeSense drivers. The CandescentNUI implemented in the main C# program then accesses the OpenNI data stream and constructs it into usable objects for use by the hand recognition system. The graphical user interface (GUI) is constructed using Visual Studio 2010's designer and XAML code. The type of interface created is a Windows Presentation Foundation (WPF) project which allows for efficient form navigation in the form of XAML "pages" which can be linked to and navigated away from. This layout allows the system to retain a sense of being light-weight and efficient since the pages are only loaded as-and-when they are needed and are not causing too much background processing. Furthermore, the GUI is developed in such a way as to be approachable and easy to navigate for any user since a main objective of this project is to test viability of patient home-use. The Connector/NET addition to the C# project which allows integration with MySQL also facilitates quite functional MySQL statement writing. We set the maximum depth range for the Kinect sensor to receive data as 900mm; this is chosen because at ranges close to and above 900mm, with an image resolution of 640x480 pixels, hand and contour information

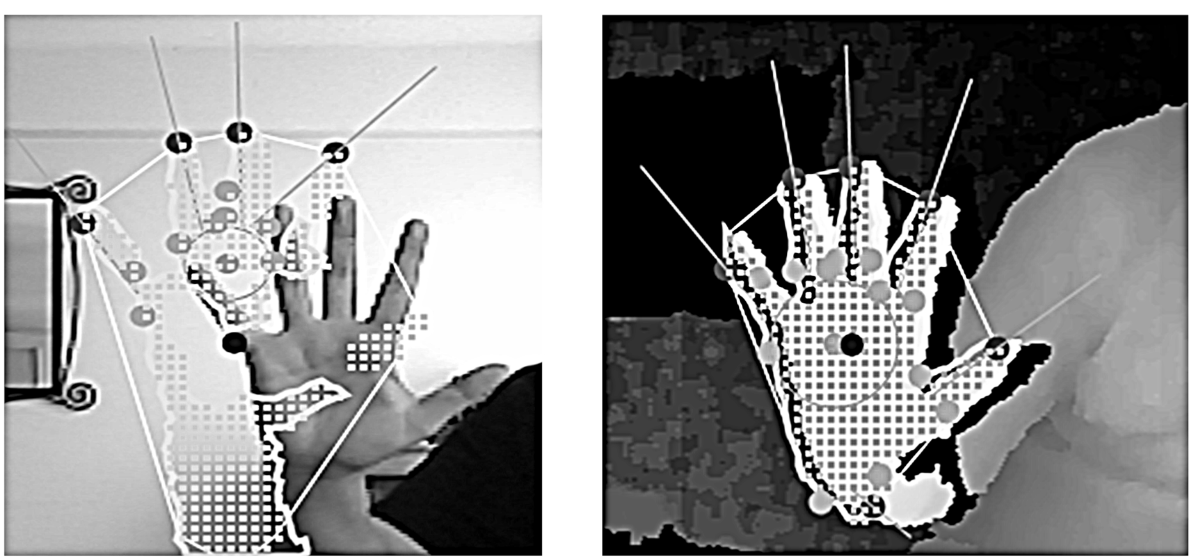
Figure 2. Finger width measurement process



becomes very difficult to establish and the integrity of the data is questionable. The CandescentNUI code which is used for the majority of the hand recognition returns detailed information back to the recognition interface. In the system, a listener is set up to handle new frames of information being returned from the Kinect sensor. In order to give feedback to the user of the computation that is being performed on the image data being received, we add a raw data window which contains much of the pertinent information involved with the hand recognition. This window may be presented in either RGB (full color) image format or a black and white depth interpretation of the data. For the purposes of this system, it is more effective to show the depth data since it gives a better idea to the user of the location they need their hand to be in order to achieve optimal readings as shown in Figure 3. Now, when the depth data is being analysed by the system we can automatically pass it forward to the interface of the system in order for the user to observe the changing depth and finger recognition information.

The location of the cluster information and finger information overlays align much better with the depth data than with the RGB. This is due to the location of the two cameras which receive this information being located slightly separately apart. The data generated by Candescent allows for the hands on screen to be enumerated and for each hand to have a number of "finger" elements. Within these objects numerous pieces of position and depth data are accessible. In order to establish which finger the data is associated with, we must first determine which finger is which in the hand object. To achieve this, a method utilising the logic of finger position on the X axis is used. This code is run for each finger. This code is utilised in the case of the left hand being presented as the thumb in that context would be the digit located furthest along the X axis. This is run for each digit and as it is assigned, it is removed from the hand object; allowing the system to re-enter the hand object and assign any unassigned fingers. Each finger has a "BaseLeft" and "BaseRight" property as well as a "FingerPoint". Each of these objects has an X, Y and Z (depth) value. It is from these that we are able to determine dimension data and whether the users hand is positioned correctly for optimal readings to be taken. Optimal position for

Figure 3. Sensor depth data and RGB with finger recognition



readings is determined by taking the Z value for the left-most digit and Z value for the right-most digit and comparing them. Using this method we can establish horizontal tilt of the hand and can formulate an algorithm which will alert the user if their hand is positioned too far skewed on the X axis.

We compare the left-most and right-most digits and use a threshold of 4% +/- each other to allow for some tilt of the hand. This has been assessed to be the most effective range since it allows enough range of movement that the hand does not feel stiffened in order to be read but maximises the integrity of the hand data. This is especially important in this project since it is quite possible that a sufferer of rheumatoid arthritis will have difficulty orienting their hand to an exact location in order for the system to assess it. Using this method, the user is afforded quite a lot of freedom of movement. The base left and base right values of an individual finger may have different Y axis values since the hand can be tilted to many different orientations and the system will still detect it and analyse the data. To overcome this, the finger width must be determined by using Pythagoras' theorem to determine the distance between the two points.

As seen in Figure 4, the distance on the X axis between the two points can be determined as "B". When the distance on the Y axis is also determined we can use it as "A" and find "C" through Pythagoras' theorem: $c^2 = a^2 + b^2$. A similar method is implemented in order to determine the height of a given finger. Since the finger can be oriented in a number of different fashions (similar to Figure 4the Y value of the finger point is not an adequate reference to the height of the finger from its base. For this reason, the Pythagorean theorem is again utilised in the following fashion detailed in Figure 5.

Since we have already established finger width, we can half it and use it to determine a base value for a triangle. By taking getting the difference between the "BaseRight" and "BaseLeft" values we can construct a base line for the triangle to be used for the Pythagorean theorem. The "B" line referred to in this code snippet is the straight line distance between the lower part of the triangle and the top; effectively giving the second side of the triangle. The "*Math.Abs()*" function here is the method for returning an absolute value which is part of the Math library of C#. The purpose of this is to always return the difference between the

Figure 4. Finger width Pythagoras Method

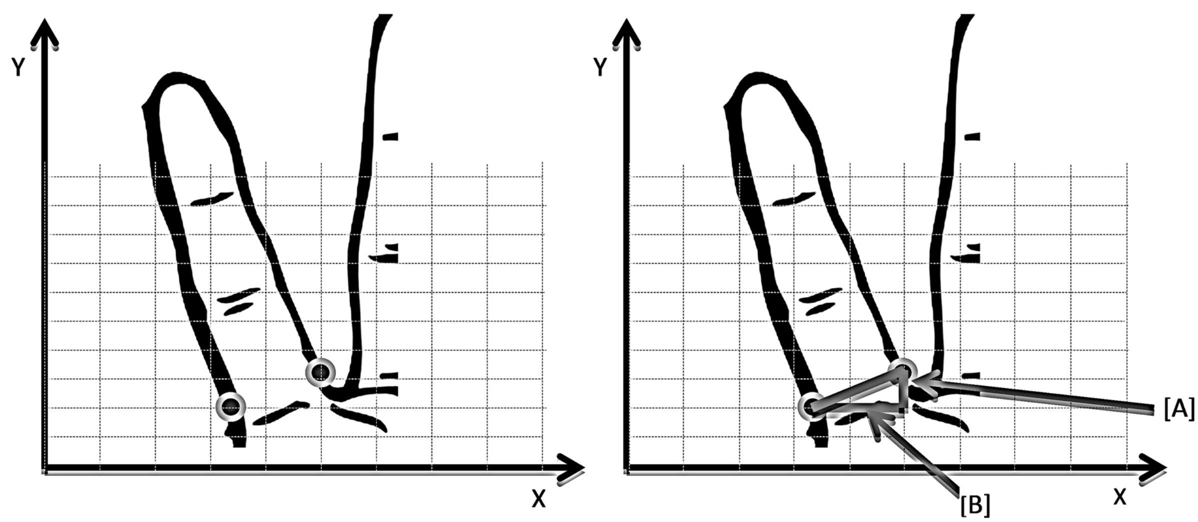
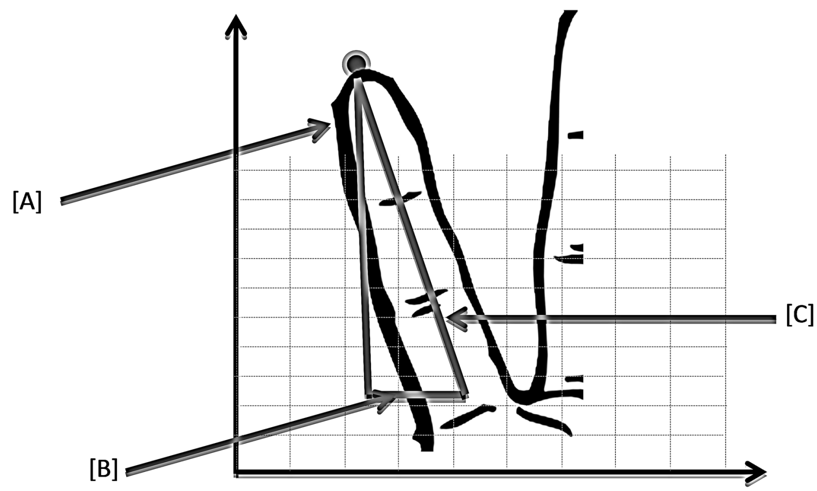


Figure 5. Finger height measurements



two values, instead of a negative value which may happen if the hand is presented in an orientation other than that which the system was intended to handle. The system can return the height of the finger, no matter the orientation of the hand. If the hand in an ideal orientation, the distance from base to tip on the Y axis would be suitable for determining the finger's height. However, since the fingers can be oriented at many angles diverging from the palm of the hand, this function utilises the midpoint of the finger to construct a triangle to use the proven method noted above. The midpoint is constructed by adding the two co-ordinate values of the "BaseLeft" and "BaseRight" and dividing it by 2. From here the triangle is created in a similar fashion to that utilised above.

The information received from the Kinect can be variable at different distances over a period of time; i.e. at 50cm over a period of 30 frames there may be a variance of around 10% in the information received due to a combination of the hand detection algorithm and the method wherein the Kinect senses depth data. To overcome this, a sampling method for the data has been implemented. By sampling data retrieved from the fingers over 10 frames it was found that the variance decreased in readings. The level of accuracy this provided was determined to be adequate on the testing device (Xbox Kinect sensor) and would be more than enough on the more powerful Kinect for Windows device.

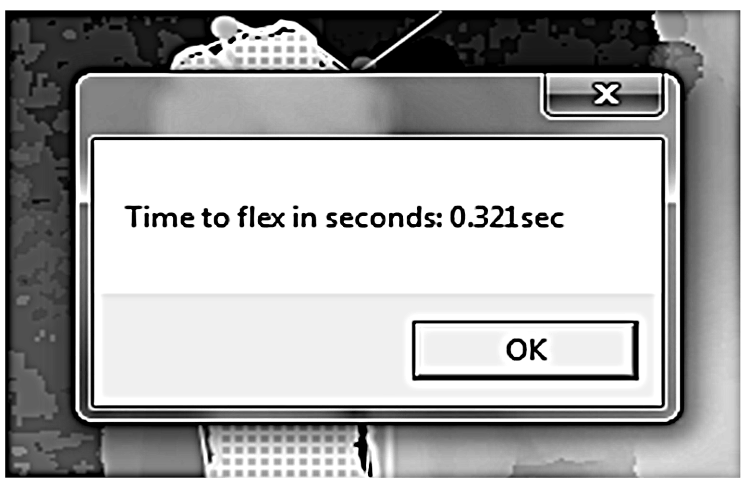
EVALUATION

The user can utilise the system to perform and monitor exercises in their hands. The data recorded from these exercises is potentially useful to a physician and is therefore recorded to be viewed at a later date. The exercises performed can be on either hand, (which the user must specify before proceeding) and includes determining maximum flexion on the finger muscles. This is assessed by the user stretching their hand to full extension, the system beginning a timer and then prompting the user to flex their fingers inward again.

Figure 6 shows the hand recognition working even when no fingers have been found. This allows for the exercise code to check for the presence of the fingers at extension and when they have not been found it but the hand is still visible it establishes that the full hand has been clenched into a fist. The time taken to perform this exercise as well as the maximum range of motion is

Figure 6. Hand at full flexion

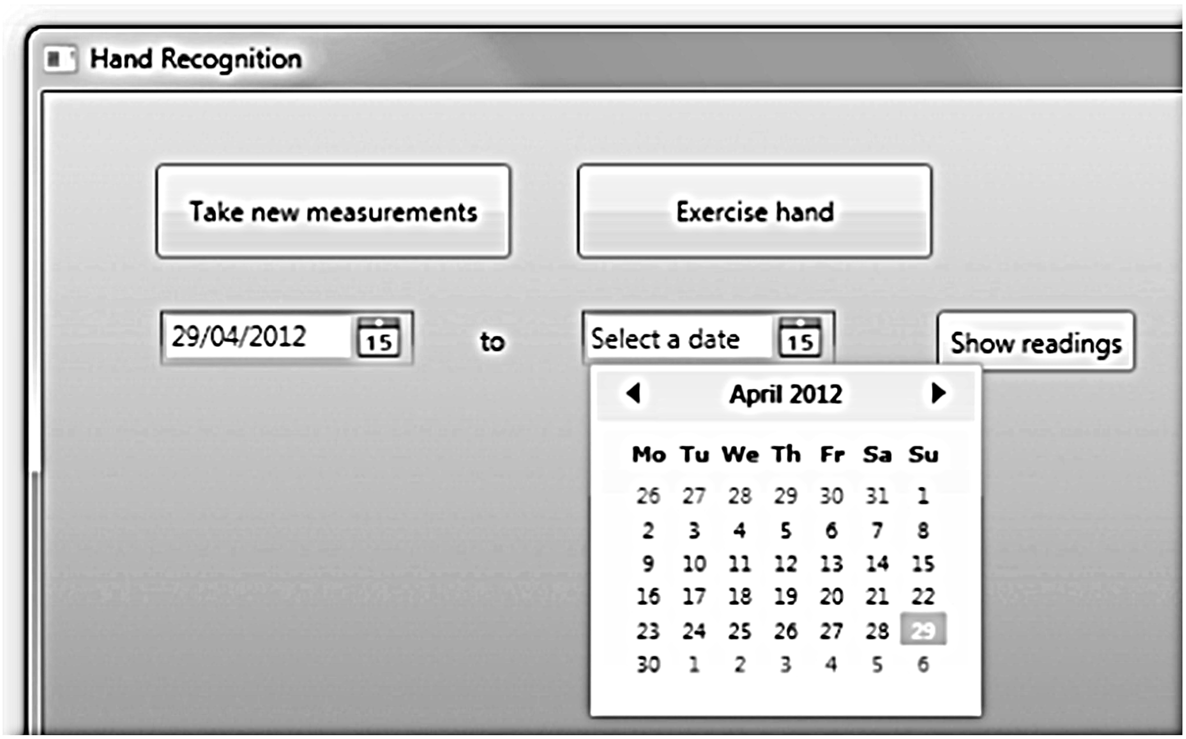
Figure 7. Exercise time taken message box



potentially useful in establishing a treatment plan for the patient and is stored with the rest of the user's information in the database.

The main landing screen after login is shown in Figure 8. The "Begin Test" button shown in this page will start the finger measurement process. Before it starts the functions necessary to measure the hand, several checks are performed to make sure that the system is accepting all the necessary data. Firstly, it will establish whether or not the user has selected a "Hand to test" so that the fingers on the hand can be correctly identified later. After, the system can begin to show information to the user in the form of the raw depth image previously shown in Figure 3. From here, the finger recognition and dimension determination begins. When the data is constructed by the system it is displayed on screen for the user (see Figure 10).

Figure 8. Main interface



Tests were performed to assess the real-world dimensions of the digits on each finger independently and then compared these to the readings output by the system. The tests were then performed at optimal range, too close to the sensor and then far way to determine the scale of results depending on distance to the sensor. The system was used to determine height and width of digits on a specified hand. To compare this set of results, physical measurements were taken of each digit using a ruler. These results were tabulated as "expected" results and measured against results output by the system. The results of these tests are put together as a series of graphs in order to visually display the effect of range on the data taken from the sensor. The first set of results, measuring the width of digits on the right hand, is shown in Figure 10.

As can be seen the results from this test, system readings vary only slightly at the optimum range

Figure 9. Finger measurements results

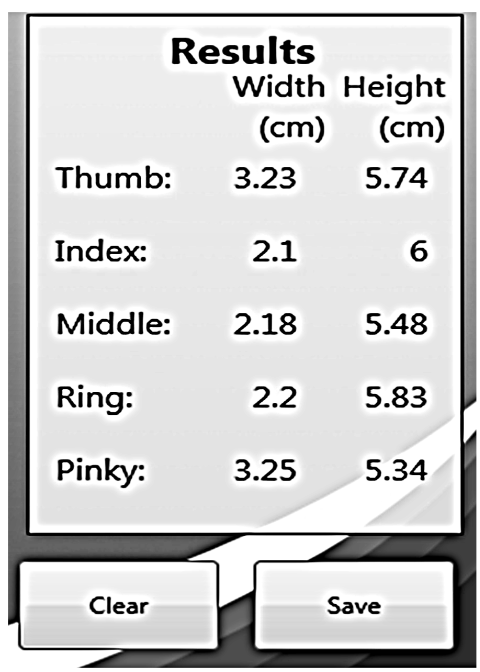
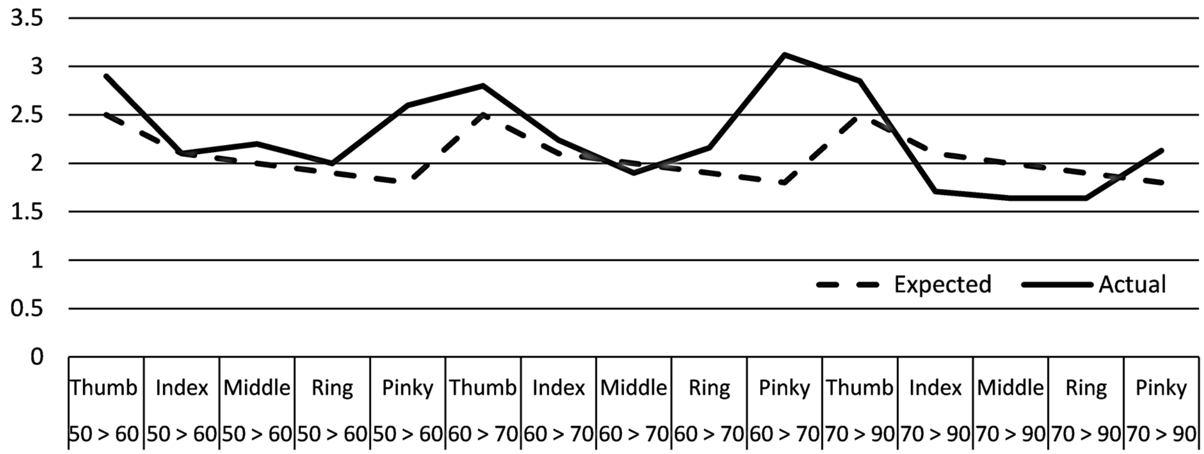


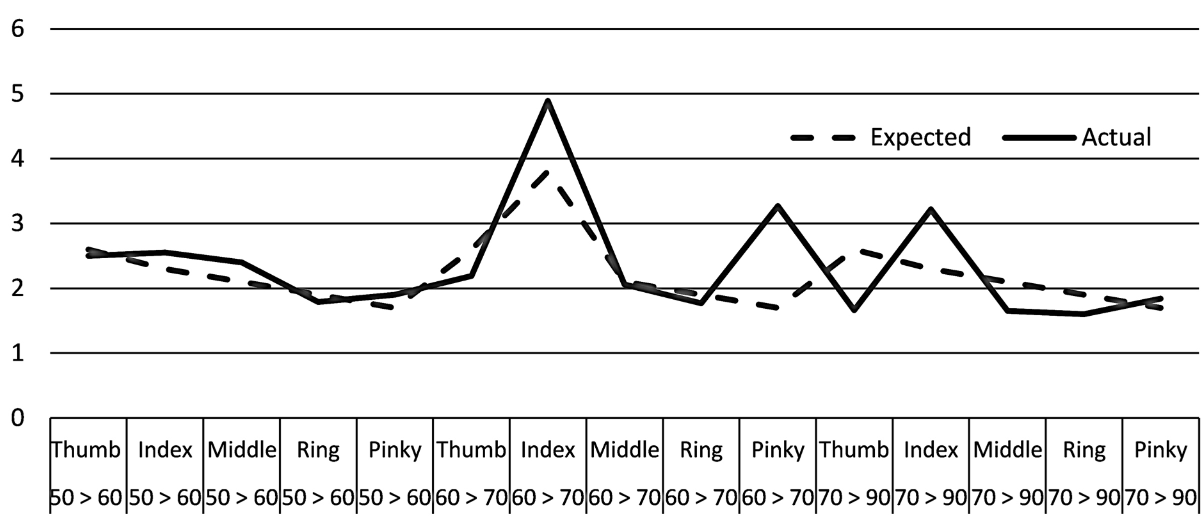
Figure 10. Width of digits on right hand



of 50 > 60cm from the sensor. With some outliers, the readings remain consistent until outer limits of range at ~80cm. Furthermore, as a result of this test it can be determined that most variance occurs within the recognition of the pinky finger on the right hand. The results of this test remained more constant than were initially expected to be. Consequently, this adds to the integrity of the data at all readable ranges from the Kinect sensor. Next tested was the width measurements taken of the left hand. Once again, the physical measurements of the left hand were taken and compared against the width measurements established through the system. The variation of these results is shown on Figure 11.

Variation in these results is similar to the results shown on the right hand. As can be seen, at optimal range the data interpreted by the system is very reliable. With the distance between the sensor and hand increasing, so does the level at which the results fluctuate. Once more, the readings are most varied in the mind range (60 > 70cm). This was found to be true of the readings for the widths on the right hand also. When the variations in the

Figure 11. Width of digits on left hand



digit widths had been determined, the next step was to compare the results of the finger height measurements. This was done by measuring the fingers on each hand in a similar fashion to what the system is intended to do. By taking the centre point of the digit then using a ruler to go from base to fingertip, a physical, real-world value was determined. This value was then laid out in a table and used for comparison with system-generated values. First tested was again the right hand. Similar to the width tests, the hand was placed at different distances from the sensor to test effects of distance on reading accuracy. The values from the right hand are shown in Figure 12.

While the variance in width measurements remained relatively consistent throughout the distance tests, finger height measurement showed much more varied results. As seen in these results; at optimal range, digit height is established very accurately. However, these tests prove that for digit height, distance is a very important factor.

These tests must be compared with the results of the left hand testing in order to be substantiated. Figure 13 shows the results of these tests.

Through this second set of height results, we can determine that the behaviour of the first test is replicated. As the distance from the sensor increases, the data variance increases. This variation becomes very high at the extreme ranges such as 70 > 90cm and renders information invalid.

From these tests we can determine that the optimal range for the Kinect when finding digit height falls between 50 > 60cm distance from the device. Figure 14 shows this range in a visual diagram. Within a range of 0 to 50cm, the information from the Kinect sensor is not efficient enough to rely in for accurate data. At 50cm the data becomes usable and reliable for accurate readings. However, as the distance from the Kinect increases, the data becomes less and less accurate; finally resulting in the data being unusable again.

The ability for the system to determine individual fingers was tested. The aim of this test was to ensure that the system can pick up a hand without needing to identify finger elements (i.e. a fist). It was also used to test if the system can pick up a hand showing only a sub-set of fingers (i.e. a raised index finger). To accomplish these tests, the measurement process was run with the right and left hand testing scenarios. Through this raw data window we can determine when the hand has been recognised by the system as it overlays a cluster image on the raw data. Furthermore, when a finger has been recognised, a "fingertip point"

Figure 12. Height of digits on right hand

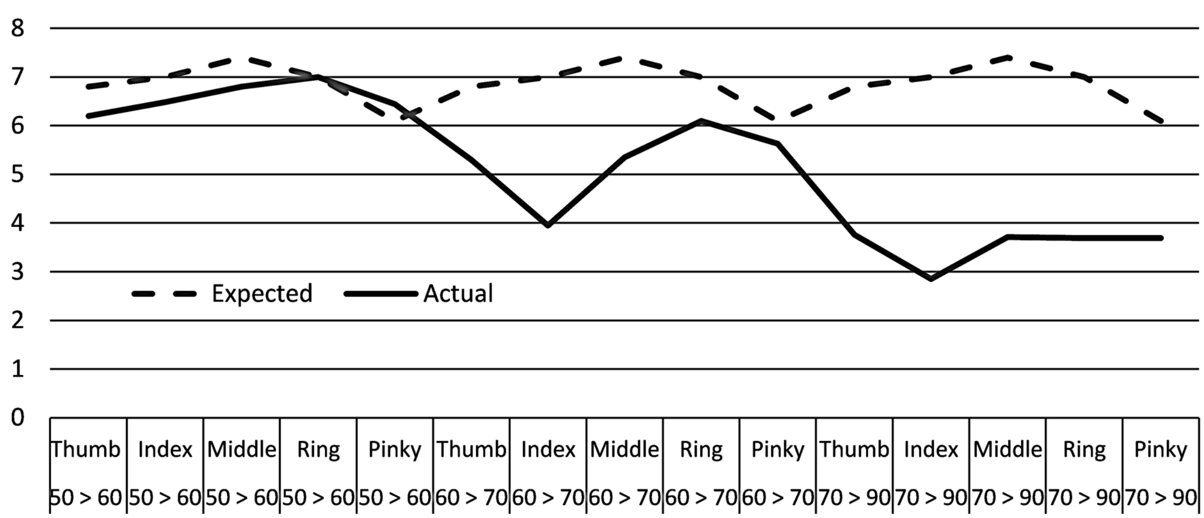


Figure 13. Height of digits on left hand

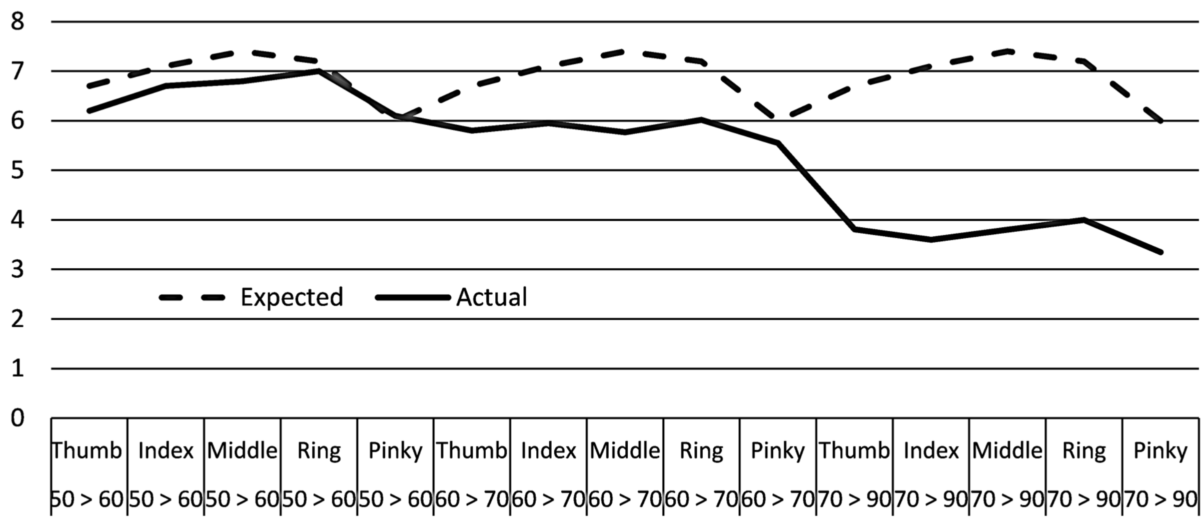
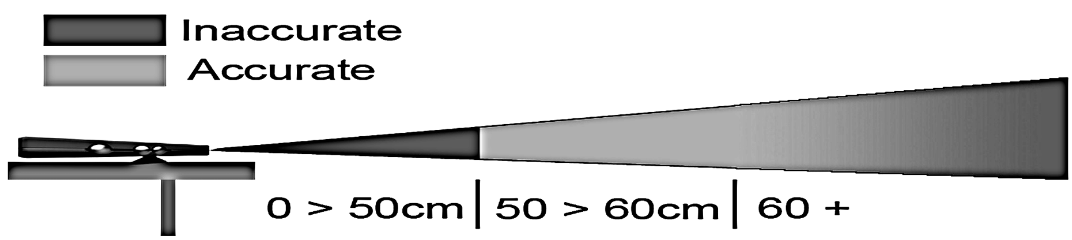


Figure 14. Kinect optimal range



is added to the overlay. By monitoring this when the sensor is presented with a hand clenched into a fist and a hand which presents only the index and middle fingers, we can assess whether the system will work with only partial readings. It was found that the system could determine that a hand is present even without all of the fingers showing. This functionality is utilised in the hand exercise section to establish the time a user takes to complete tasks. This testing validates the readings returned by the exercise section of the system.

The system was also tested in a number of adverse conditions such as poor lighting and range diversity in user location (too close, too far from sensor). In terms of these requirements the system performs well. Since the Kinect itself works with infra-red light rather than standard image recognition, it is functional in very dimly lit scenarios. The only adverse condition in terms of lighting is when the Kinect sensor is introduced to a room with direct sunlight which can interfere with the infra-red recognition. Similarly, the system has been developed in such a manner that the range of user motion is accounted for programmatically; handling poor hand orientation on-the-fly where possible and displaying notices to the user otherwise.

CONCLUSION

The detection of progress in the treatment of Rheumatoid arthritis relies heavily on observation by physicians. The effectiveness of these kinds of tests is dependent on ability and can vary depending on the observer. The adoption of a camera based system is a step towards providing a less subjective analysis of the range of movement in patients. We outlined here a system which integrates an off-the-shelf Kinect sensor for usage in a hand recognition and digit measurement capacity. This system repeats common tasks usually completed by a physician (or specialised nurse) such as digit dimension monitoring and exercise observations. Measurements taken include digit width and height as these can be accomplished different distances from the Kinect and in varied environmental conditions. Physicians can also monitor patients over time without requiring multiple appointments where the measurements are taken manually. Ultimately, the system shows that it is possible to use a Kinect-based solution in many scenarios which call for regular observation of a patient with RA. With the system being designed to be portable and easy-to-use, it is an ideal solution for both the physician monitoring patients in a clinic as well as posing a possible solution for patients wishing to monitor their own condition in their homes.

Next we hope to monitor the resting angles of joints in the hand and comparing to the fully flexed angles of joint movement. While the system handles patient exercises and provides useful data; this could be extended to accommodate the treatment plans provided by a physician. The user could perform joint flexion and extension exercises day to day and over a period of time the physician could build a model representing their range of movement. This would be benefit to a patient as it would result in a full documentation of their condition, rather than the physician taking measurements weeks apart at different appointments.

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KEY TERMS AND DEFINITIONS

Cloud Computing: Cloud computing describes a new supplement, consumption, and delivery model for IT services based on Internet protocols, and it typically involves provisioning of dynamically scalable and often virtualized resources.

Kinect: The Kinect is currently available in two models; the “Xbox 360/One Kinect” and the “Kinect for Windows”. Both models are functional with a Windows-based PC and can utilise the Kinect SDK released by Microsoft.

Multitenant Architectures: Many companies share the same infrastructure within the Public Cloud, and the term given to this is Multitenant Architectures.

OpenCV: OpenCV is a cross-platform function library focusing on real-time image processing. The aim of this library is to supply an application with “Computer Vision”, the ability to take data from a still or video camera and transform it into new representation or decision.

Quality of Service: This is a measure of network performance that reflects the network’s transmission quality and service availability. QoS can come in the form of traffic policy in which the transmission rates are limited which guarantees a certain amount of bandwidth will be available to applications.

Rheumatoid Arthritis (RA): RA is a chronic disease that mainly affects the synovial joints of the human skeleton. It is an inflammatory disorder that causes joints to produce more fluid and increases the mass of the tissue in the joint resulting in a loss of function and inhibiting movement in the muscles.

Router: A device or setup that finds the best route between any two networks, even if there are several networks to traverse.

Sphygmomanometer: A sphygmomanometer is used to assess a patient's grip strength in their affected hand. This is achieved by inflating the cuff of the device to a standard pressure in a rolled manner, then having the patient grip the cuff in the palm of their hand.

ENDNOTES

[1] Night Vision with Kinect Nightvision Infrared IR http://www.youtube.com/watch?v=-gbzXjdHfJA&feature=related.