DEVELOPMENT AND EVALUATION OF PROTOTYPE VIRTUAL REALITY TELEMEDICINE SYSTEM FOR ASYNCHRONOUS GAIT ANALYSIS

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Abstract

Various rehabilitation and diagnostic methods related to musculoskeletal injuries or diseases however, can be challenging to monitor and record over long time periods. Furthermore, patients in remote locations, which represent a substantial proportion, face additional time and cost limitations. Current gait analysis methods, although they provide a very detailed record of the patient's walking cycle, are few and located in major city based facilities. Telemedicine based systems are increasingly in demand as they offer cost benefits and wider accessibility. Our proposed system offers a novel, cost efficient motion capture method which could be deployed in remote location and record patient's gait which in turn can be presented to the specialist medical staff remotely through an analytical Virtual Reality environment for review.

1 Introduction

The need for telemedicine based systems for high quality care is on the increase. Governing bodies and healthcare professionals are seeking new methodologies to provide triage for patients remotely [1,2,3]. This transformation in delivery of care has been prompted due to strains on current healthcare resources. Global financial constraints and the increasing number of population have created the need for cost effective and efficient solutions for delivering high quality health care [4,5].

Gait related musculoskeletal diagnosis, rehabilitation and monitoring of injuries and pathologies through telemedicine system is a much needed intervention [6]. Such telemedicine system can provide triage and support patients living in remote, distal or rural locations and additionally lift the strain on hospital recourses by monitoring outpatients remotely [7,8]. Monitoring related to gait rehabilitation could increase with more regular input from patient with yet less use of the healthcare resources through the use of such asynchronous telemedicine system. To this much needed necessity we have developed a prototype system which enables health professionals to monitor patients and deliver triage utilising 3D captured visual and motion data. The motion data retrieved from the patient is simulated and recreated in a 3D virtual environment to be analysed by specialists and health professionals asynchronously. Additionally the system offers the means to communicate with local GPs and patients whilst monitoring and tracking patient's pathology and progression over time.

This paper will present the developed system, its functionality and complete interface, which enables gait data acquisition and remote analysis and monitoring of large variety of musculoskeletal pathologies related to gait. The paper will focus on the overall development process, many challenges tackled in the iterative process and the development methodology adapted for this system. Results of different approaches in acquiring data will be discussed and compared whilst looking at the impact on the quality of data retrieved in each process. The paper will conclude with a tentative plan to carry out user trials for patients located in distal and remote locations.

2 Current Gait Capture Issues

Gait analysis is the methodical study of human movement, using the eye and the brain of observers, improved by instrumentation for measuring body movements, body mechanics, and the activity of the muscles [7].

The purpose of Clinical gait analysis is to directly impact on the patient, whereas gait analysis research impacts on the discipline in general, contributing to the development of locomotion and kinematic studies. Clinical gait analysis should either aid in diagnosis or management of the patient pathology or assist in patient's rehabilitation and recovery. Therefore clinical gait analysis needs to be utilised in a patient's consultation.

Currently many techniques are being utilised in gait analysis to both assist clinical assessment and expanding the field by research. Professional motion capturing gear is a costly setup which necessitates a host of requirements. These include dedicated large space for lab installation, specialised optical sensors technology with marker suits and trained specialists to operate and retrieve usable data. Such laboratories are most commonly situated in urban cities at a designated facility which limits the patients having to travel to and back from the facility.

Figure 1: Different types of gait analysis equipment available at GCU gait analysis laboratory

Contemporary methods require physical presence of the patient, for a health professional to examine the patient's condition and locomotion. This can be a semi-subjective observational assessment by an expert or an objective method, where technology is employed to record, collect and analyse relevant data associated with the patient's gait in physical examination therefore limiting the triage for only those patients who can travel to the facility. This has created a need for a telemedicine driven gait analysis/ musculoskeletal diagnosis systems that could offer remote triage and allow both objective and semi-subjective means of gait analysis. Remote patient consultation can be supported if innovative technology can be employed for data acquisition with medical visualisation and virtual reality.

3 Proposed System Rationale

Adhering to the above, this work aims to develop a prototype telemedicine system that supports Musculoskeletal Diagnosis, Gait analysis, rehabilitation and offers an asynchronous virtual consultation.

Notably the system will use off-the shelf equipment in order to reduce significantly the implementation costs (Figure 1). As such, the proposed system utilises, 2 Xbox Kinect sensors to record data remotely.

The Kinect data is recorded and processed before being utilised in the developed Telemedicine based virtual reality gait analysis application (TVRGA- APP). It has to be noted that the nature of this application requires a minimum of 3 meters by 3 meters of capture space. The intended users for the particular application are primarily health professionals and clinician who specialise in the area of biomechanics, human kinematics, gait analysis and rehabilitation. However the data collection system, i.e. motion capture is designed to be used also by non computer specialists. As such additional effort has been invested towards the development of a simple and efficient interface. The system will allow the health professionals to visualise and analyse the data submitted by the patients asynchronously. Additionally the patient could also utilise the system, as it offers information to the patients to help them understand the pathology and anatomy related to their injury although the latter would be more for education and visualisation purposes.

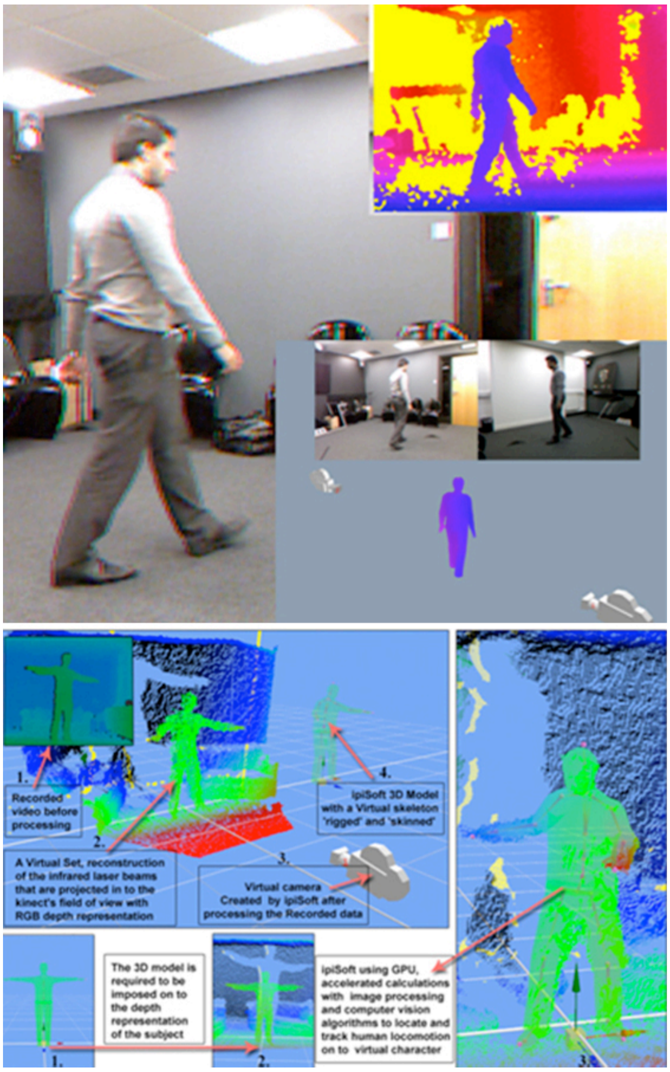

Figure 2: Patient movement is being recorded using two Xbox Kinect's and is processed in a virtual environment using off the shelf hardware and software.

The proposed system offers two options where it can be set-up: either the patient's home or the patient's local General Practise. Patients that are familiar with the particular or similar technologies could potentially install and use the system in their homes. Alternatively the system could be installed in an array of GP practices across the UK, therefore facilitating the patients that do not feel comfortable to use this application on their own.

The data can be collected locally by health professionals working at the general practise. The data can be submitted and transmitted through a secure internet connection to the Data Processing Centre, where the data is cleaned, optimised, mapped and transferred into a telemedicine Virtual Reality Application. The application data is then forwarded to a gait analysis specialist who can analyse the data, make a diagnosis and give advice (see figure 2). Additionally the application data is sent back to the General Practice or the patient for educational purposes as visualisation of pathology could aid understanding and enhance rehabilitation compliance.

System functionality

In order to further reduce the cost of the proposed system, it was developed in Unity 3D. It offers a host of interactivity, that enables health professionals and clinician's to interact with the virtual data-set and offers tools that aid in confidently analysing and monitoring patient's gait and their rehabilitation progress. The system offers a variety of interactive tools that could be accessed by the user within a full real-time interactive virtual space as depicted in figure 3.

As such, the user can observe and study the motion, analyse the patterns and angles in flexion, extension, abduction, adduction, lateral and medial rotation of knee, ankle and hip for both legs. The produced information could be compared with previous records of the same system and contrasted to main facilities motion capture data. Data visualisation is presented both in form of graphs for each joint and angle, in addition to 360 degrees viewing capacity of the actual recorded gait. The musculoskeletal information is further enriched with highly detailed 3D anatomical information that could be accessed during the VR motion. The provided anatomy and pathology information has been verified by specialised medical practitioners from the relevant fields such as orthopaedic surgeons, radiologists and GPs [5].

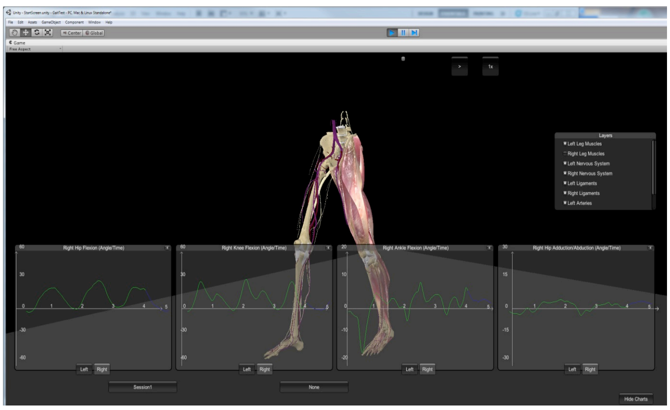

Figure 3: Screenshot of Real-time VR gait analysis application

4 Evaluation & Results

Preliminary evaluation of the system was undertaken through interactive sessions with 20 users. The evaluation contrasted the existing high fidelity motion capture and gait analysis system to the proposed system. In order to gather the same motion sequences, both systems recorded data simultaneously. Additionally subjective feedback was acquired through pre and post questionnaires aiming to identify the usability acceptance of the system. Notably, comments related to the educational value of the associated factual information of the proposed application are beyond the scope of this paper and will not be further analysed here.

The gait analysis results produced by the prototype system were promising. Elaborating further, the proposed system captured the required gait analysis angles and motion patterns in acceptable detail in comparison to the high fidelity dedicated motion capture system. The latter is using 8 cameras with Infra Red (IR) emitters and reflective markers attached on the user's body, with recording speed of 120 fps. In contrast, our proposed system is markerless and relies upon the triangulation of points between the 4 cameras and the 2 IR emitters of the 2 Kinects with recording speed of 30fps. Although technologically inferior, our system could offer comparable results on the points of interest as illustrated in figure 4. As such the proposed system can provide clear and usable information for telemedicine purposes and for rehabilitation progress monitoring, alleviating the existing workload of the specialised facilities.

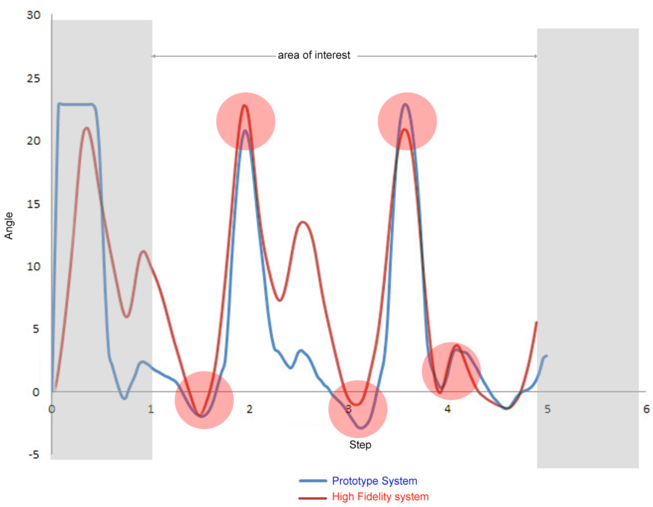

Figure 4: Comparative motion graph between high fidelity motion capture and proposed motion capture system.

Furthermore the user's feedback was in favour of the prototype system as it is presented below by a part of the questionnaire as presented in figure 5. In particular, users were inclined to use this method in future for both rehabilitation and diagnosis purposes. Furthermore due to the simplicity of the system it was deemed easy to use and straight forward in contrast to the existing high fidelity systems.

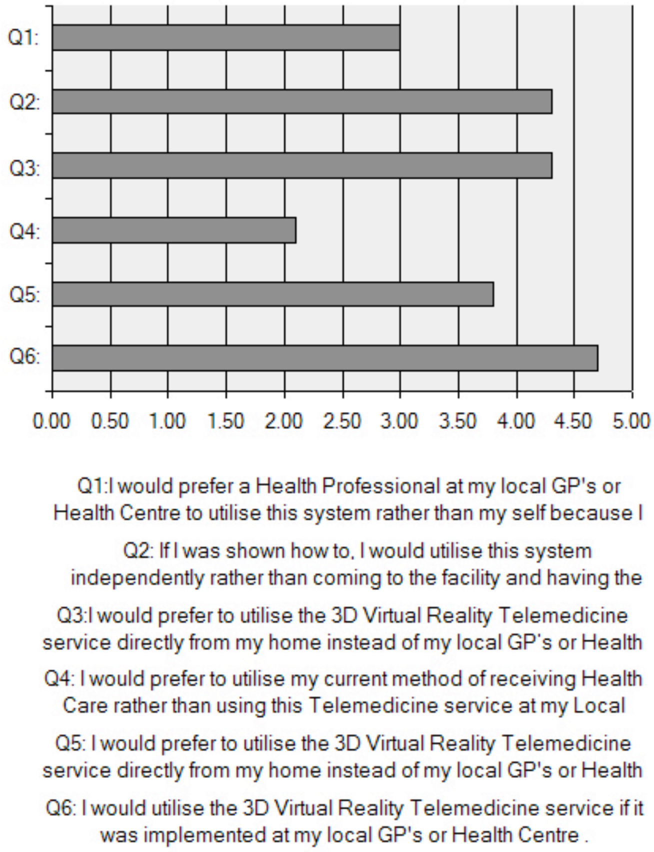

Figure 5: Average score ratings of the subjective feedbacks derived from the user preference

In an nutshell, the system's performance and usability suggests that the prototype could offer significant assistance to the current gait analysis methods and medical practitioners particularly in cases that the system needs to be deployed quickly and in non-specialised environments. Such application could find use also for medical support units that operate in different disaster areas across the globe.

4 Conclusions

Overall this paper discusses the challenges involved in the development process of the Virtual-Reality Telemedicine System for Asynchronous Gait Analysis. The proposed interface has been evaluated with the use of both quantitative and qualitative methodologies. The derived results are promising as the vast majority of the users enjoyed the experience. The system offered comparable results to higher fidelity systems. As such it could be used for particular rehabilitation monitoring and diagnosis activities complementing the existing high end systems.

Our tentative plan of future work aims to expand the context and interactivity of the system so as to enable a larger number of users and test the systems in remote locations, such as the Scottish isles. Furthermore, we seek to increase the accessibility of the system and the speed of the asynchronous data analysis and visualisation. Additionally the prototype VR application entertains the use of Virtual Reality for educating and informing patients of their conditions. As such we would aspire to increase the existing database of 3D models and related pathologies. The latter will further assist the General Practitioner doctors and enhance their explanatory capacity towards the patients. Consequently we plan a second series of system trials which will further inform our thinking and design of interface tools.

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