



**A VISUAL TRACKING RANGE OF MOTION
ASSESSMENT SYSTEM FOR LOWER LIMB JOINT**

by

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LIST OF ABBREVIATION

ACL	Anterior Cruciate Ligament of knee joint
Ave	Average
BMI	Body Mass Index
cm	Centimetre
CDC	Centres for Disease Control and Prevention
CL	Confidence Limit
CV	Coefficient of Variation
DOF	Degree of Freedom
EGM	Electrogoniometer
EXT	Extension
FLEX	Flexion
GUI	Graphical User Interface
LD	Left Deviation
MBS	Marker-based System/ Solution
MCL	Medial Collateral Ligament of knee joint
<i>Mild_EGM</i>	Mild injury measured by Electrogoniometer

<i>Mild_VTS</i>	Mild injury measured by Visual Tracking System
<i>Mild_UGM</i>	Mild injury measured by Universal Goniometer
MLS	Marker-less System/Solution
Mo	Moderate
<i>Mo_EGM</i>	Moderate injury joint flexion measured by Electrogoniometer
<i>Mo_VTS</i>	Moderate injury joint flexion measured by Visual Tracking System
<i>Mo_UGM</i>	Moderate injury joint flexion measured by Universal Goniometer
MPE	Mean Percentage Error
MRI	Magnetic Resonance Imaging
N	Normal
<i>N_EGM</i>	Normal joint flexion measured by Electrogoniometer
<i>N_VTS</i>	Normal joint flexion measured by Visual Tracking System
<i>N_UGM</i>	Normal joint flexion measured by Universal Goniometer
NTDB-NSP	National Trauma Data Bank – National Sample Program
OA	Osteoarthritis
Pat ID	Patient Identification
PE	Percentage Error

QTM	Qualisys Manager Track System
ROM	Range of Motion
RD	Right Deviation
RDM	Relative Difference of Mean
RDS	Relative Difference of Standard Deviation
TKR	Total Knee Replacement
TL	Transverse Ligament of knee joint
SD	Standard Deviation
SE	Standard Error
Sev	Severe
<i>Sev_EGM</i>	Severe injury joint flexion measured by Electrogoniometer
<i>Sev_VTS</i>	Severe injury joint flexion measured by Visual Tracking System
<i>Sev_UGM</i>	Severe injury joint flexion measured by Universal Goniometer
UGM	Universal Goniometer
vs.	versus
VTS	Visual Tracking ROM Assessment System / Visual Tracking System

Sistem Penilaian Pengesanan Penglihatan Pelbagai Gerakan Sendi Tungkai Bawah

ABSTRAK

Ketepatan ukuran pelbagai gerakan (ROM) pada sendi tungkai bawah adalah penting untuk diagnosis tahap keterukan kecederaan sendi tungkai bawah. Ia adalah penting untuk membantu doktor perubatan dan ahli fisioterapi untuk menentukan rawatan dan latihan pemulihan yang diperlukan oleh pesakit kecederaan sendi tungkai bawah secara khususnya. Sistem pengukuran perubatan yang semasa seperti Universal Goniometer (UGM) mempunyai peleraian yang sebesar 1° menyebabkan ralat pemerhatian; manakala Electrogoniometer (EGM) terdedah kepada kedudukan sensor yang tidak tepat dan terlepas apabila bergerak kerana kekurangan sifat-sifat mekanikal. Oleh itu, Sistem penilaian pengesanan penglihatan ROM (VTS) bagi sendi tungkai bawah ukuran dicadangkan. Tujuan penyiasatan ini adalah untuk membangunkan satu kaedah untuk mengukur ROM sendi tungkai bawah dan memeriksa ROM yang diperolehi antara VTS dengan EGM dan UGM untuk mengukur sudut sendi tungkai bawah. Terdapat tiga eksperimen utama yang telah dijalankan iaitu, Experiment Pengesanan, Ujian Klinikal dan Kajian Kes Klinikal. Eksperimen pengesanan dilakukan pada sistem pengesanan penglihatan yang dibangunkan sebelum digunakan pada subjek manusia yang sebenar untuk memastikan prestasi sistem dan keselamatannya. Sistem ini telah diuji di bawah perubahan keamatan cahaya, jarak kamera, sudut ketinggian kamera dan lokasi penanda untuk menentukan keadaan operasi yang optimum. Dalam ujian klinikal, terdapat dua ujian yang akan dijalankan iaitu Ujian Kawalan Sihat dan Ujian Subjek Cedera. Penemuan seramai 20 subjek kawalan sihat telah membuktikan bahawa sendi tungkai bawah kiri dan kanan manusia adalah serupa (keserupaan 99.80% ~ 97.64%) bagi subjek yang sihat. Perbandingan antara VTS, EGM dan UGM mendapati bahawa ketepatan bagi setiap dua sistem yang dibandingkan dengan yang lain adalah sangat berbeza bagi VTS vs. EGM dan EGM vs. UGM. VTS vs. UGM menghasilkan ketepatan tertinggi bagi semua pergerakan sendi dibandingkan dengan VTS vs. EGM dan EGM vs. UGM; ketepatan itu adalah 99.46% untuk perlenturan lutut kiri. Di samping itu, sejumlah 70 orang subjek yang cedera (termasuk sendi buku lali, sendi lutut dan sendi pinggul) telah menjalani ujian subjek cedera untuk membandingkan tahap keterukan antara penyakit dan ketiga-tiga sistem pengukuran. Dalam ujian subjek yang cedera, VTS memberikan pekali perubahan (CV) dibandingkan dengan EGM dan UGM untuk pelenturan lutut bagi kecederaan sederhana adalah 2.45%. Oleh itu, VTS berupaya untuk memberikan pengukuran ROM yang paling tepat. Perbezaan relatif untuk sisihan piawai (RDSD) yang terkecil yang diberikan oleh VTS vs. EGM semasa kecederaan parah pelenturan pinggul adalah 1.05%. VTS vs. UGM memberikan RDSD yang paling kecil disbanding dengan VTS vs. EGM dan VTS vs. UGM ringan vs. normal (semua pelenturan), sederhana vs normal (untuk pelenturan lutut dan pelenturan pinggul) dan parah vs. normal (perlenturan lutut). Penggunaan VTS untuk kajian kes klinikal ditunjukkan untuk memantau ROM semasa pemulihan Pengantian lutut palsu keseluruhan (TKR) dan penormalan kembali proses daripada 5 orang pesakit perempuan. Hasil kajian kes klinikal menunjukkan bahawa VTS menyediakan pengukuran ROM lebih tepat dengan serakan yang kecil dibandingkan dengan kedua-dua UGM dan EGM. Tambahan pula, VTS umpan balik dikumpulkan daripada 20 orang doktor perubatan. Umpan balik Ini menunjukkan bahawa VTS boleh digunakan untuk menggantikan UGM atau EGM dalam penilaian ROM. Kesimpulannya, sistem

pengesanan penglihatan penilaian ROM adalah sistem pengukuran yang paling sesuai digunakan dalam menilai ukuran ROM pesakit untuk mengenal pasti aras keterukan sendi tungkai bawah.

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A of Visual Tracking Range of Motion Assessment System for Lower Limb Joint

ABSTRACT

Accurate range of motion (ROM) measurement of lower limb joint motion is important for assessing the severity of human lower limb injuries. It is essential for assisting the medical doctor and physiotherapist to determine the suitable treatment and rehabilitation exercises that are required for lower limb injury patient specifically. Current medical measurement systems such as Universal Goniometer (UGM) has a large resolution of 1° which may cause to have observation error while Electrogoniometer (EGM) is affected by the inaccurate sensor's position and detachment when moving due to its mechanical properties limitation. Thus, a visual tracking ROM assessment system (VTS) for lower limb joint measurement is proposed. The purpose of this investigation was to develop a method to quantify a ROM of the lower limb joint and examine the ROM obtained between the VTS with EGM and UGM, for the measurement of lower limb joint angles. There were three major experiments conducted i.e., Validation Experiment, Clinical Test and Clinical Case Study. Validation experiment was done on the developed visual tracking system before being applied on the real human subject to ensure the system performance and safety to be acceptable. The system had been tested under the several of light intensity level, camera distance, camera elevation angle and markers location to determine the optimum operating condition. In clinical test, there were two tests carried out; they were Healthy Control Test and Injured Subject Test. A total of 20 healthy control subjects' findings proved that the left and right lower limbs of human were similar (99.80% ~ 97.64% of similarity) for the normal healthy subjects. Comparison between VTS, EGM and UGM found that the accuracy for each two systems compared to each other was significantly different for the *VTS vs. EGM* and the *EGM vs. UGM*. The *VTS vs. UGM* produced the highest accuracy for all the joint motions compared to *VTS vs. EGM* and the *EGM vs. UGM*; it was 99.46% for left knee flexion. In addition, total of 70 injured subjects (included ankle joint, knee joint, and hip joint) had undergone injured subject test to compare its severity level between illness and three measurement systems. In the injured subject test, VTS yielded the smallest coefficient of variation (CV) compared to the EGM and UGM for Knee flexion for moderate injuries which was 2.45%. Thus, VTS was capable of giving the most compact ROM measurement. The smallest relative difference standard deviation (RDSD) was given by *VTS vs. EGM* during severe hip flexion injuries which were 1.05%. The *VTS vs. UGM* yielded the smallest RDSD compared to *VTS vs. EGM* and *VTS vs. UGM* mild vs. normal (all flexion), *moderate vs. normal* (for knee and hip flexion) and *severe vs. normal* (knee flexion). The VTS was applied in a clinical case study to monitor the ROM of 5 females Total Knee Replacement (TKR) patients during TKR recovery and rehabilitation process. The clinical case study results show that VTS provided more accurate ROM measurement with small dispersion compared to both UGM and EGM. Additionally, the feedbacks of the VTS were collected from 20 medical doctors. These feedbacks indicated that the VTS could be used to replace UGM or EGM in ROM assessment. As conclusion, visual tracking ROM assessment system is the most suitable measurement system to be used in assessing the patient's ROM measurement to identify its lower limb severity level.