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Design and development of a system for analysis of movement of the hand and wrist

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ABSTRACT

Range of motion of the joint of the hand is necessary to do a quantitative functional evaluation. Mechanical goniometry is the typical procedure to measure finger joints, but this method has several problems; instrument, subjective examiner-dependent, tedious and high time consuming. In this paper, we present the design of a 2D-images prototype video-based movement analysis system to measure the joint of the hand and wrist in space including three perspectives. The instrumentation is centered on glove with markers, each placed on proximal and distal phalanges of the fingers and also the wrist. Hand images are acquired using three digital cameras, a card video and they are processed with Vision Builder. The GUI was designed in LabVIEW platform and its specifications get clinical requirements. The examiner may make quantitative, easy and trustworthy evaluation kinematic of the hand. He can take reliable values because they are between literature ranges. Then, he can do his treatment, surgical and rehabilitation decisions in an objective way. The video-based system to measure the hand's joints represents a good tool to substitute the manual goniometer.

Key Words: Abduction, adduction, goniometry, joint, phalanges, ROM.

RESUMEN

La medición del rango de movimiento de las articulaciones de la mano es indispensable para realizar una evaluación funcional veraz; y la goniometría mecánica es el medidor estándar en la clínica. Sin embargo; presenta varios problemas especialmente debido al propio instrumento, por la anatomía del paciente, es altamente dependiente de la destreza y experiencia del examinador y es muy tedioso porque requiere mucho tiempo de exploración. En este trabajo presentamos el diseño de un sistema de análisis de movimiento de la mano a través de imágenes 2D en tres vistas. La instrumentación se centra en un guante compuesto de marcadores colocados en cada articulación de los dedos de la mano así como en la muñeca. Las imágenes se capturan con tres cámaras digitales, una tarjeta de video y son procesadas con el software Vision Builder. El sistema ha mostrado su confianza, ya que las lecturas obtenidas están dentro del rango de valores hallados en la literatura. El examinador puede realizar evaluación cuantitativa, fácil y veraz de la cinemática de la mano y decide sus procedimientos terapéuticos, quirúrgicos y de rehabilitación de una manera más objetiva. El sistema representa una excelente herramienta de medición para sustituir el goniómetro manual.

Palabras clave: Abducción, adducción, articulación, falange, goniometría, ROM.

INTRODUCTION

Range of motion (or ROM), refers to the distance and direction a joint can move between the flexed position and the extended position. Limited ROM refers to a joint that has a reduction in its ability to move.

Temporal invalidity is granted to the worker when he is unable to carry out his work due to the presence of some pathology or industrial accident. With regard to occupational accidents that occurred during 2007 Mexican Institute of Social Security (IMSS) reports that hand injuries occupied 37% of lesions[1]. Diagnostic, treatment and hand rehabilitation programs are very important to decrease the days off work.

The reduced motion may be a mechanical, injury or diseases problem with the specific joint and impair function and the ability to perform usual daily activities. The functional evaluation ROM of the joints of the hand is crucial to avoid long-term disability and return to work among patients who have an industrial accident.

There is a set of clinical tests to evaluate the functionality of the hand that include; anatomic inspection, measurement of range motion for flexion and extension of the proximal and distal interphalangeal joint also the radiocarpal articulation or wrist joint[2]. For example, the wrist may be media-line or half-position among flexion and extension[3].

Abduction and adduction positions are measured in relation to the line axial of the hand. The fingers are put together and touch each other in adduction and for abduction all the fingers are separated in arcs of 20° approximately.

Table 1 shows some standard arc of mobility of the fingers for metacarpophalangeal (or MCP), proximal and distal interphalangeal (or IP) articulations as well as abduction and adduction amplitudes to achieve daily life activities described by Hume[4] and Velázquez[5].

Table 1. Range of motion.

Articulation	Index	Finger Middle	Little
MCP	70°	80°	95°
Abduction-adduction		5 - 160°	
IP proximal		36 - 86°	
IP distal		20 - 61°	

The main device to measure ROM in the joints of the hand is the mechanical goniometer[6] which uses a stationary arm, protractor, fulcrum, and movement arm to measure angle from axis of the joint[7]. This manual device currently not only is tedious and high time consuming clinical inspection but also impractical in the case of severely disabled hands and measuring subjective examiner-dependent.

Although, today there are several systems to assess the movement of the human body the most of them are directed to gait study to treat individuals with conditions affecting their ability to walk and hand analysis does not exist or its evaluation is very limited[8].

Another mechanisms are sensor gloves-based which have not been widely integrated into clinical practice, because of their technical constraints, such as accurate measurements (stability of the sensor signal, repeatability of movements), facilities to be applied (comfortable during donning, doffing and using), rapidly calibrated, feasibility in use (available for left and right hands as well as different sizes)[9].

Chiu et cols have used video-based motion analysis systems to evaluate fingertip motions in hand injury patients[10]. However, when they want to measure three or more fingers it presents some problems of visibility and repeatability[11]. Other researches are directed towards demonstrating the validity of video motion analysis for measuring finger flexion and extension[12] with multiple cameras[13] and in real time[14].

This paper presents the design and development of a prototype to measure of the movement of the hand in space (hand's kinematics) based on acquisition of three views. The system must make possible to show all joint fingers and for clinical use in surgical and rehabilitation treatment.

METHODOLOGY

Anatomic requirements

Three views are proposed to fully analyze of the hand. The frontal view used to measure the angles of the fingers: a) little-ring, b) ring-middle, c) middle-index, d) index-thumb and the wrist in abduction and adduction position. For left view, the movements to be measured are flexion and extension of the wrist, and the IP distal, IP proximal, and MCP movements of the index and the middle finger. The last view is the right face, in which it is measured the IP distal, the IP proximal, and the MCP movements of the little and the ring fingers.

Prototype design

a) **Design of vision image.** The first stage consists of the image acquisition software as well as the development and glove design considering the type, size and shape of the markers. Markers are crucial to get reliable measurements of ROM hand including flexion, extension, abduction, and adduction joints. Images and video are acquired by mean of NI PCI-8252 (three ports) card video and the Vision Builder™ AI 3.6 application is used to process the information (to calculate the angles of the fingers and wrist)[15]. Three 60 fps (640 x 400 pixel) digital cameras are programmed to get three views.
b) **Calculation of the ROM measures.** Vision Builder and LabView have a tool kit for detecting reference markers to obtain the ROM measure; ROI (Region of Interest) detection, optical filters threshold (for identifying object bright) and geometric calculus (angles).
c) **Design of the scenario with controlled light.** A reference XYZ frame located on dark room to control light, is designed to guarantee the trustworthiness of the measurements. Scenario is a quasi-circumference structure of 2 m in diameter and 60 cm in height, wrapped with black textile and has six light bulbs (daylight led lights) in six equidistant points (60°) on the top to produce a uniform light to center of the scenario, where the hand is positioned over an ergonomic support. At the same time, three cameras (C1, C2 and C3) are installed with separations of 90°, 80 cm from the center and the height is adjusted according to the long arm of the subject (Figure 1).
d) **Design of the graphic interface.** The Graphical User Interface (or GUI) is developed in LabView™ platform[16]. Among its main characteristics; it has to be user friendly, shows the measurements in a clear fashion, handles the patient's data to export them to EXCEL format for further statistical and graphic analysis.

Figure 1. Scenario with mechanical mannequin hand.

System test

This stage provides feedback to user on what it intends build and evaluates the integration of components and modules.

Validation

The system is validated using a mannequin; measures must be within range literature. These results also are compared with a human hand.

RESULTS AND DISCUSSION

The first white glove was designed for a right hand medium size, with black markers put in the selected joints. The size markers range is 0.25 cm^2 to 1.21 cm^2 and two geometric shapes (round and square) were selected. The size variation permits great precision for different position of each object and to avoid confusions and to distinguish points of the fingers and wrist to make real measurements.

The camera detects and discriminates the position of the articulations depending on the position of the selected camera and of the objects. A filter is used to detect black objects and predetermined size. The size parameters are adjusted and determined a minimum and maximum area and the objects will be screened. Once the points are marked, it is selected the type and angle of measurement. Figure 2 shows the glove in a frontal view for the measurement of the abduction and adduction of the fingers.

The first test of the system was carried out with a pre-designed mechanical mannequin hand that simulates the movements of the hand, with this mannequin it possible to avoid alignment and calibration troubles and to get precise measurements. A forearm ergonomic support was designed to make sure the replication of the readings when a human hand is used. This support is made of black nylon; it is adjustable in the wrist very easy to fasten, ambidextrous, and it has a magnetic base to facilitate its position.

Figure 3 shows the GUI designed in LabView™, in which demographic data are displayed, the user may select a ROM protocol, can analyze the whole hand or choose a particular finger.

When a protocol is selected, the user defines the finger (thumb, index, middle, ring, little) or wrist, the type of movement (flexion, extension, abduction, adduction), the interest joint (IP distal or proximal, MCP) and the system immediately picks out the appropriate camera to be used and shows its ROM measurements. The demographic data are captured by the user and the information is automatically saved on a video-ROM database which was designed for this purpose. Figure 4 shows a view of the left-side camera, which measures the movements of the ring finger, the little finger, and the flexion and extension of the wrist.

Finally, Table 2 shows the measurements taken with this video-based system for MCP, DIP, PIP, adduction and abduction of five finger joints; they are matched with those found in the literature.

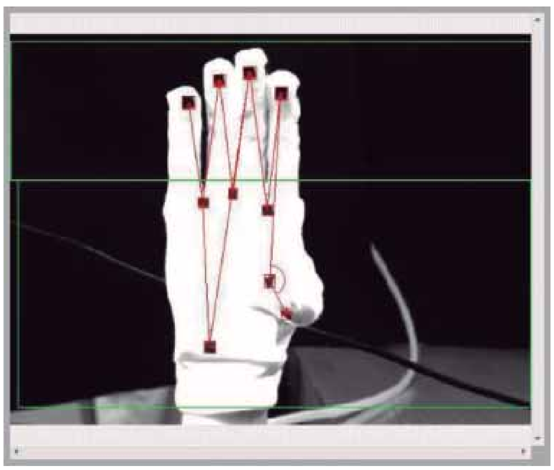

Figure 2. White glove with markers in frontal view.

CONCLUSIONS

Although, the glove design and the management of the cameras were very difficult, it was possible to control the reflections and unwanted items by mean of white glove with markers size-geometry-based. Measurements of all the joints of the hands can be acquired using three views, simultaneous and automatically. The glove is easy to put on, is no user-depend and has a quick calibration procedure. The lectures were got using no only a mechanical hand mannequin with simulated movements but

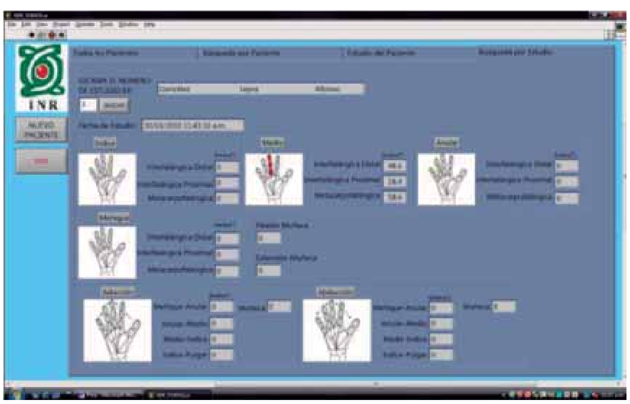

Figure 3. GUI application for the ROM study.

Figure 4. Measurements of the ring and little finger of the mechanical mannequin.

Table 2. Measurements of the angles of the fingers.

Joint	Finger				
	Thumb	Index	Middle	Ring	Little
MCP			59°	81°	46°
Adduction	118°	77°	79°	54°	
Abduction	1.1°	1.7 °	1.4 °	1.4°	
IP proximal			23 °	79°	26 °
IP distal			38 °	74 °	61°

also healthy subjects. The measurements are reproducible, repetitive and match the ones found in the literature.

The system collects angular data (MCP, IP proximal and IP distal joints, also flexion and extension of the wrist as well as adduction and abduction) corresponding to its actual movement. The GUI interface has been adapted to user clinical requirements; also it is possible to program modifications, upgrades and settings. Data can be imported into EXCELL database for future assessments kinematics of the hand and statistical analysis.

The video-based system to measure the ROM hand can represent a good tool to complement functional hand evaluation for designing treatment, making surgical decisions and monitoring patient rehabilitation, because the measurements are automatic recorded, are reproducible, their resolution up 1 ° and low time consuming. The next project will be incorporate kinematic analysis.

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