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Human Motion Analysis with Ultrasound and Sonomyography

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Abstract— **Skeletal muscle is an important tissue of human body, and its contraction can control and regulate body motions, which plays a key role in the human movement. With the development of computer and human motion analysis, the muscle activities are involved into the whole human motion analysis. Currently, muscle assessments in human motion analysis are commonly performed using surface electromyography (SEMG). However SEMG cannot be applied to measure all muscles because its access to deep muscles is very limited, which restricts its application. Sonomyography (SMG), which represents the real-time change of muscle architectural parameters obtained using ultrasound imaging, is an alternative noninvasive method to quantify the muscle dynamic activities during human motion. It is gradually becoming a reliable research and clinical tool and playing increasingly important role in the functional assessment of muscles. In this study, a human motion analysis system with ultrasound and sonomyography which could provide objective data about muscle architectures and their change during muscle contraction in real-time was developed. Preliminary tests were conducted on a normal subject, and the feasibility was demonstrated.**

I. Introduction

Human motion analysis is a highly interdisciplinary field and has a wide range of applications. Human gait is the pattern of movement using human limbs. Unlike other biometric traits, gait has the advantage: unobtrusiveness [1]. The gait is also difficult to hide or fake because different gaits can be distinguished by differences in movement patterns influenced by functions of their entire muscular-skeletal structure, although all humans follow the similar walking pattern. Most of previous researches focused on the kinematics and kinetic characteristics of the gait and motion, which had various limitations and was not easy to obtain the essence of the motion, such as skeletal muscle activity. However, skeletal muscle is an important tissue of human body, and its contraction can control and regulate body motions [2]. Some biomechanical models have been developed to understand the complex muscle activity during motion [3-6]. During normal activities, skeletal muscles produce forces by various contractions, such as isometric, isokinetic, isoinertial, isotonic and eccentric contractions. Furthermore, limb kinematics is relatively invariant in various modes of locomotion, while the muscle activity patterns required to produce kinematics pattern can vary considerably. So the above conventional measurements failed to consider this aspect of the "real" gait cycle.

Surface electromyography (SEMG), the electrical signals generated by muscles during contractions [7-9], is the first and most frequently used bio-signal to measure the muscle activity by evaluating the electrical activity during human locomotion. Nonetheless, SEMG has its own limitations, such as sensitive to motion artifacts, difficult to differentiate signals from neighboring muscles, difficult to evaluate deep muscle, etc.

The biological and bioelectrical characteristics of muscles are closely related to the structure, such as the thickness of muscles, fascicle length, pennation angle, and cross-sectional area. It is now well established that the knowledge of a muscle's architecture is about the geometric arrangement of the fascicle within the muscle, primarily described by its muscle architecture parameters (MAP), fascicle length, pennation angle, muscle thickness and cross-sectional area, which was highly related to muscle function during motion [10-14]. Sonomyography (SMG), which represents the real-time change of muscle architectural parameters obtained using ultrasound imaging, is an alternative noninvasive option to measure the muscle activities under different contractions. SMG is relatively new and few related researches have been reported in this area. In a previous study, Zheng et al. (2006) used SMG to describe signals representing the dimensional changes of muscles during contraction [12]. Their system was successfully developed to continuously record different type of signals including ultrasound, force, torque, joint angle and SEMG and to obtain the dynamic architecture information of the muscles from both 2-dimensional B-mode ultrasound images and 1-dimensional A-mode signal.

Guo et al. (2008) used 1-dimensional SMG with A-mode ultrasound signals and a single-element ultrasound transducer to detect thickness changes in forearm muscles during contraction and demonstrated that 1-dimensional SMG can be reliably performed and that it has the potential for skeletal muscle assessment and prosthesis control [13]. Although the research about 2-dimensional SMG with B-mode ultrasound on the muscle activity during human locomotion is very limited due to the cumbersomeness of the probe and complexity of 2-dimensional ultrasound images, there are still some progresses about the skeletal muscle activity monitoring using B-mode ultrasound together with gait analysis systems in recent years. Lichtwark and Wilson (2006) combined ultrasound imaging and CODA motion analysis system to assess the length changes of the gastrocnemius medialis muscle fascicle along with those of the elastic Achilles tendon during human locomotion under different incline conditions [14]. Lichtwarka et al. (2007) also made the investigation on the muscle fascicle of gastrocnemius during walking and running with the CODA motion analysis system and B-Mode

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ultrasound [15]. Aggeloussis et al (2010) examined the reproducibility of fascicle length and pennation angle of gastrocnemius medialis (GM) during human walking by using the VICON motion analysis system with ultrasound [11]. The above study required to extract the muscle architecture parameter manually and failed to consider the impact of probe orientation and position because there is no method available to obtain the dynamic change of muscle architectural parameters automatically. Nevertheless, the SMG is gradually becoming a reliable research and clinical tool and playing increasingly important role in the functional assessment of muscles with the ability to detect muscle activity at different depths and locations.

The objective of this study was to develop a human motion analysis system with ultrasound and sonomyography. The system required to realize the automatic muscle architectural parameters extraction from ultrasound images and incorporated the information of probe position and orientation.

II. Materials and Methods

A. Construction of Human Motion Analysis System with B-mode Ultrasound

The system required to combine the SMG measurement with the kinematics measurement and the SEMG measurement. As shown in Fig. 1, the system mainly consisted of four parts: kinematics measurement system, ultrasound measurement instruments, EMG measurement device and a control circuit board for synchronization. The motion capture system, VICON, provides a mature vision-based human motion analysis for accurate kinematics measurement. Moreover, the VICON MX system (VICON, Los Angeles, U.S.A) can provide the hardware interface for the external analog signal, such as EMG. Therefore, the VICON MX was chosen to collect the 3-dimensional kinematics data in this study. The BTS TELEMG multi-channel electro-myographic system (BTS, Milano, Italy), which could realize the wireless and portable measurement for the SEMG to monitor muscular activities, was selected as the third-party device of the VICON MX system. The post-processed SEMG signal was treated as an external analog input by the VICON MX system and stored in the VICON database. Furthermore, the Hitachi EUB-8500 ultrasound scanner (Hitachi, Tokyo, Japan) was adopted as SMG measurement instrument. Besides, a custom-built control circuit board with an infrared Light Emitting Diode (LED) was developed to synchronize the ultrasound images with the data from the VICON system.

Custom-designed software programmed by Microsoft Visual Studio 2005 was developed for controlling synchronization signal via custom-built synchronization device and capturing ultrasound images via a video capture card (NI-IMAQ PCI/PXI-1411, National Instruments Corporation, Austin, TX, USA) at the same time. During data collection, the B-mode ultrasound image was displayed on the software interface in real time. Ultrasound images were collected at 25 frames per second and saved for further off-line analysis.

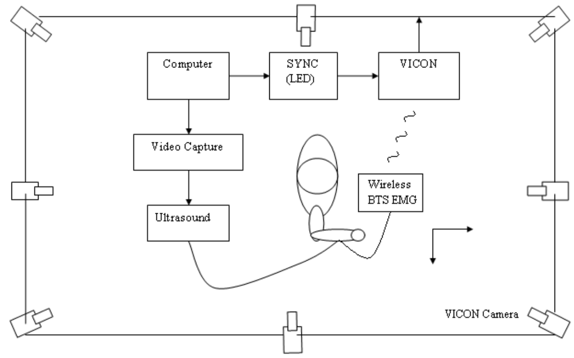

Figure 1. Measurement system of human motion analysis with B-mode ultrasound

B. Measurement Protocol

The following flow chart (Fig. 2) represented the brief procedure about how the data were collected for human motion analysis with ultrasound. A total of 4 movement patterns, including elbow flexion extension, wrist rotation, knee flexion extension and ankle rotation, were chosen to verify the human motion analysis with SMG measurement. Before the experiment, the retro-reflective markers were attached on the subject based on the motion type and the number of body segments. There are different marker set systems available, such as the Plug-In-Gait marker set, Helen-Hayes marker system, Cleveland-Clinic marker set etc. The marker set system may influence biomechanical models and feature of kinematic measurement. The Plug-In-Gait marker set was adopted to attach retro-reflective markers on the human subject in this study because it is the default system used by the VICON. After the experiment, the VICON software was used to discard the unwanted frames of SEMG and kinematics data based on the external infrared LED signal. Besides, SMG measurement was only stored when the synchronization signal was triggered. All the candidate data was exported as the input of the custom-built data analysis program for further analysis. Moreover, the ultrasound probe was able to be secured to the different positions for the same movement pattern. Custom-designed data analysis program can incorporate and align these SMG measurements to realize SMG measurement of different muscles for the same movement pattern in this study.

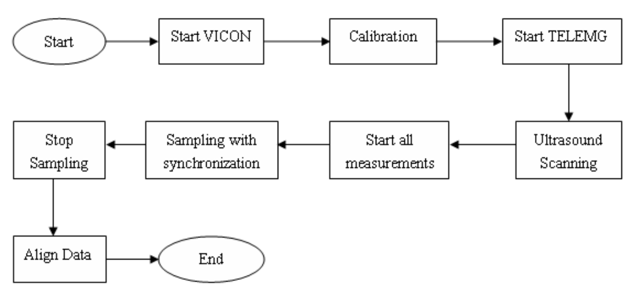

Figure 2. Flowchart of the data collection

A wide linear probe was usually chosen to scan muscle which provided the B-image with maximum 60 mm in width. The ultrasound probe required to be attached on the subject steadfastly during human motion. Besides, the enough ultrasound gel was applied on the region of measurement to fill the gap between the probe and the skin so as to reduce the artificial effect of ultrasound images caused by human motion, such as shadow. Furthermore, the placement and orientation of ultrasound probe are the important factors that influence the B-Mode ultrasound images of the muscle structure, and then impact the measurement accuracy of the SMG [16]. In this study, the probe secured with lightweight foam and Velcro straps was attached with retro-reflective markers to provide additional 3-dimensional position information for the ultrasound probe and muscle ultrasound images (Fig 3). This was used to align the plane of visualization and enhance the accuracy of muscle architecture measurements.

C. Data Analysis

Custom-designed data analysis program with user-friendly interface programmed by Microsoft Visual Studio 2005 was developed to display and process all measurement including kinematics, SEMG and SMG in the same interface. All features were extracted from these measurements, which can be used for actual motion analysis in future. The kinematics mainly provides the pattern of movement, and the EMG and SMG mainly provide the information about muscle activity. One normal subject with signing informed consent form was evaluated with using this motion analysis system.

III. RESULTS

In this study all movements were performed repeatedly within 1 minute. All features of kinematics measurement, such as angle and velocity, were extracted on the basis of Plug-In-Gait marker set. The muscle architecture parameters were extracted from B-mode ultrasound images. Before feature extraction, the B-mode ultrasound images were enhanced with Speckle Reducing Anisotropic Diffusion (SRAD) [17] because ultrasound images are known with low signal-to-noise ratio, low contrast and high amounts of speckle. There were mainly two strategies applied to process SMG measurement: texture based analysis and feature based analysis.

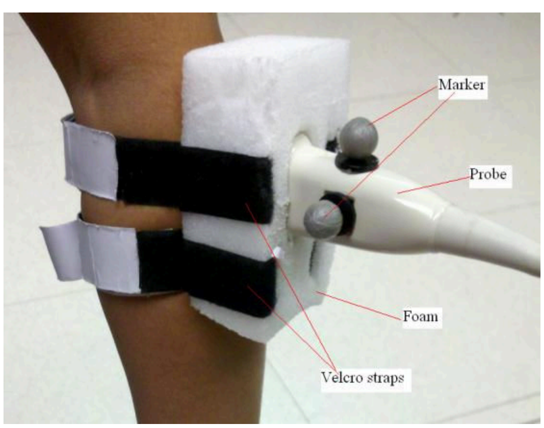

Figure 3. Probe attached retro-reflective markers and secured with lightweight foam and Velcro straps

- Texture based analysis utilized the texture information of ultrasound images. The displacement of region of interest could be tracked with normalize cross correlation or optical flow algorithm. Furthermore, the globe texture orientation of region of interest could be extracted on the basis of gradient information. Moreover, the optical flow map could be applied to analyze the muscle movement pattern and trend.
- Feature based analysis extracted the lines and edges directly from ultrasound images, which was usually applied to extract pennation angle, which is the most dominate line feature in the muscle ultrasound image. The Revoted Hough Transform (RVHT)[18] and Revoted Radon Transform [19] were conducted to extract the lines in this study.

The lines extracted with using RVHT and Revoted Radon Transform were most dominant fiber in ultrasound images. Fig. 4 and Fig. 5 show the preliminary results of the pennation angle extracted with feature based analysis. By contrast, texture orientation represents the overall direction of the region of interest in ultrasound image. Fig. 6 show the result of texture orientation with texture based analysis.

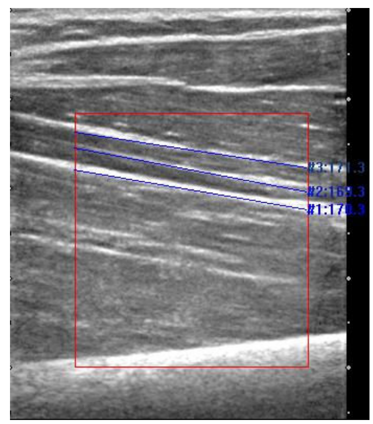

Figure 4. Angle detected with RVHT

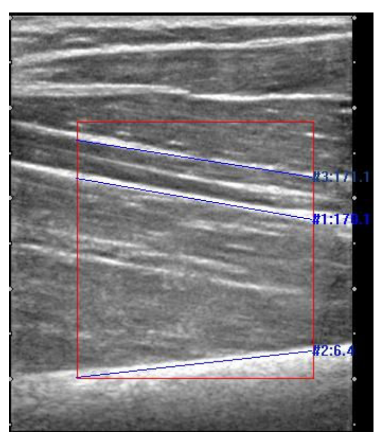

Figure 5. Angle detected with Revoted Radom Transform

The feasibility and performance of the sonomyography togother with other biosignals was evaluated. Fig. 7 show the kinematics features, SEMG, and SMG features together. It demonstrated that the SMG features can be automatically extracted and have great potential to be applied in the motion analysis.

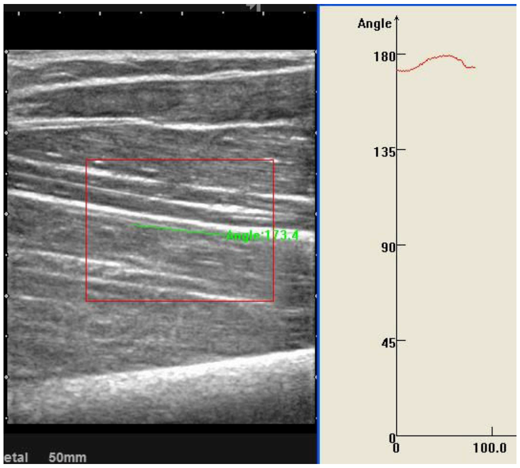

Figure 6. Texture orientation with gradient information

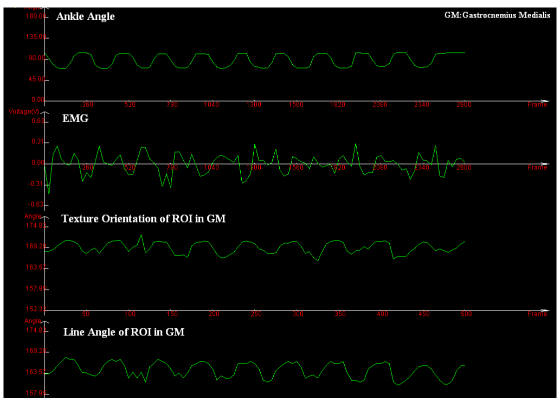

Figure 7. Features extracted from kinematics, SEMG and SMG

IV. CONCLUSIONS

In this study a human motion analysis system with ultrasound and sononmyography was developed. The feasibility of integration of ultrasound images with conventional motion analysis has been demonstrated. The SMG could be automatically extracted from the ultrasound images as an input of whole human motion analysis system. The stabilization of the probe position was also considered in this system. Further experiments will be conducted in order to estimate efficiency and accuracy of the whole motion analysis system. Furthermore, ultrasound image processing algorithm will be improved to provide more robust analysis result. Moreover, the imbalance of trunk muscle with low back pain will be studied with this system.

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