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Stereo Vision Based Therapeutic Massage Evaluation System

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***Abstract*—This paper focuses on therapeutic massage evaluation based on displacement of markers attached to the patent's back as well as masseur's hand. The arrangement of markers plays also an important consideration, since the trajectory of monitored markers must be suitable to compare the massaging skills of different persons. Since the movements to be measured are of high frequencies the sampling rate of the measurement must be high enough to capture all the motion details. During the experiments a synchronized high speed stereo camera system has been used.**

Index Terms— **stereo vision, massage, evaluation, detection, markers.**

I. INTRODUCTION

This work is related to camera based evaluation of specific human motions being in strong relation with some motion related dieses as well as therapies such as massage for example where all motion details plays significant role. By capturing these motions the motion related dieses can be detected or the skills of the person performing the therapy can be evaluated. In order to capture such motions various aspects must be considered and must be taken into account during the measurement. Nowadays many solutions have been proposed and developed for capture the movement of various objects. Let us first mention some well-known and extensively applied motion capture techniques: perhaps the most popular and most simple approach is based on attaching markers to the target and tracking them by two or more cameras. Although this approach is simple its robustness is outstanding and thus is highly welcome in many areas such as entertainment, medicine, sport, etc. In relation to these systems many type of markers have been developed such as magnetic markers [4], gray level markers offering higher accuracy measurement [2], On the other hand there are techniques which do not require markers to be present, they can operate in markerless environment, as well. These approaches are more complex and computationally more expensive. In addition usually they are less accurate and less robust than their marker based counterparts. For instance in [8] authors have proposed an approach for recovering 3D human body pose from single images and monocular image sequences. As already mentioned, motion capture techniques are welcome in many application, let us focus on applications related to the field of medicine. First of all let us emphasize some concrete areas where the motion and positioning plays significant role. In [5] author deal with a camera based positioning system and its calibration to aid the positioning of patients for radiation therapy. In [6] authors investigate proper movements in a physical therapeutic scenario. In [7] the authors developed a wireless body sensor platform for real-time monitoring of day-to-day activities. A soft wearable motion sensing suit aimed for biomechanics measurement is proposed in [9]. This paper deals with the problem of how to evaluate the efficiency and thus the skills of the person performing healing massage based on visual tracking and reconstruction of the hand movements. The concept is similar to those used by motion capture techniques; however in case of therapeutic massage movements the accuracy as well as the sampling rate are of key importance. This is because the frequency of therapeutic movements usually covers a wider range of frequencies, nevertheless even a small motion (few millimeters) may have significant impact on the efficiency of the therapy. In addition (as the results reflect – see later) the characteristics of small high frequency motions may considerably distinguish the professional therapeutic person from the amateur. Due to above reasons the accuracy of the measurement is crucial. Such accuracy usually cannot be offered by commonly used motion capture systems. Nerveless besides tracking the motion of some markers (attached to the hand of the therapeutic person) the shape of the targeted surface as well as some designated key points on the body must be considered. By using a specific arrangement of markers also the force by which the surface of the body is pushed can roughly be estimated. However this latter topic is a subject of a further research. The paper is organized as follows: In section II the basic concept of the approach is described, section III deals with calibration and cameras synchronization issues, in section IV the experimental results can be followed and finally conclusions are reported.

II. SYSTEM DESCRIPTION

In the followings let us describe the proposed measurement system illustrated in Fig. 1. It consists of a high-speed synchronized stereo camera pair, circular as well as line markers attached to the patient. Circular markers are attached also to the hand of the therapeutic masseur. By tracking these markers using the stereo camera system and considering the shape of the threated area the efficiency of the therapeutic massage can effectively be evaluated. The obtained data are suitable to compare the therapeutic skills of masseurs, and thus for supporting the improvement of their skills considerably. The measurement process consists of four main parts, i.e. system calibration, synchronization of cameras, setup of markers and tracking markers. In the followings let us focus on these problems.

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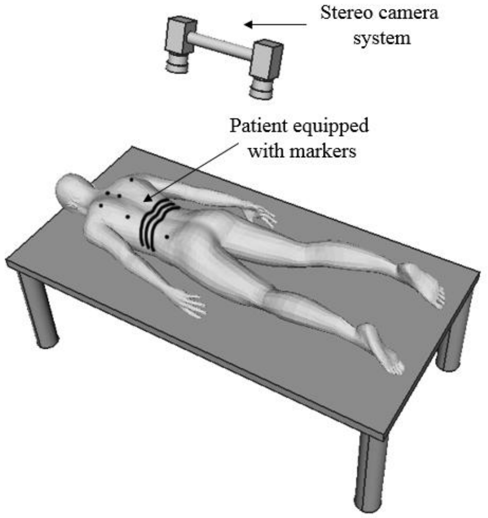

Fig 1: Illustartion of the measurement environment

A. *System Calibration*

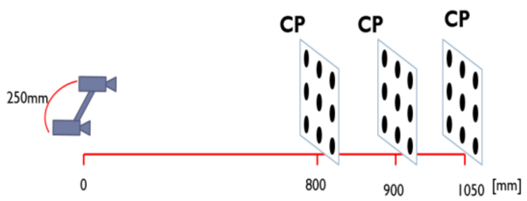

Fig 2: Arrangement of calibration planes (CP) and cameras

Camera calibration belongs to the most crucial tasks in high precision 3D measurement. This process is responsible for accurate estimation of camera parameters. The accuracy of estimated parameters may be influenced by the applied calibration method, number of calibration points. As calibration method the Direct Linear Transformation (DLT) has been used. Although this method requires precise setup of calibration planes it offers promising accuracy when the target falls into or near the volume formed by shifting the calibration planes along the depth axis. During experiments as calibration pattern a white plate has been used consisting 9 circular markers (see Fig. 2). The elements of the projection matrix can be obtained as the least square solution of the following system of equations:

$$\mathbf{Ab} = \mathbf{0}, \tag{1}$$

Where

$$\mathbf{A} = \begin{bmatrix} X_1 & 0 & X_2 & 0 & \dots & X_n & 0 \\ Y_1 & 0 & Y_2 & 0 & \dots & Y_n & 0 \\ Z_1 & 0 & Z_2 & 0 & \dots & Z_n & 0 \\ 1 & 0 & 1 & 0 & \dots & 1 & 0 \\ 0 & X_1 & 0 & X_2 & \dots & 0 & X_n \\ 0 & Y_1 & 0 & Y_2 & \dots & 0 & Y_n \\ 0 & Z_1 & 0 & Z_2 & \dots & 0 & Z_n \\ 0 & 1 & 0 & 1 & \dots & 0 & 1 \\ -x_1X_1 & -y_1X_1 & -x_2X_2 & -y_2X_2 & \dots & -x_nX_n & -y_nX_n \\ -x_1Y_1 & -y_1Y_1 & -x_2Y_2 & -y_2Y_2 & \dots & -x_nY_n & -y_nY_n \\ -x_1Z_1 & -y_1Z_1 & -x_2Z_2 & -y_2Z_2 & \dots & -x_nZ_n & -y_nZ_n \\ -x_1 & -y_1 & -x_2 & -y_2 & \dots & -x_n & -y_n \end{bmatrix}^T \tag{2}$$

Where the X_i, Y_i, Z_i values stand for the 3D coordinates of the ith calibration marker, while x_i, y_i are the coordinates of its projection in the image plane of the camera to be calibrated.

$$\mathbf{b} = [b_{11}\ b_{12}\ b_{13}\ b_{14}\ b_{21}\ b_{22}\ b_{23}\ b_{24}\ b_{31}\ b_{32}\ b_{33}\ b_{34}]^T \tag{3}$$

Where b_{ij} stand for the elements of the projection matrix. During the calibration process the calibration pattern consisting circular markers was set to three different positions each shifted by 100 mm along the depth axes as depicted by Fig. 2. The location of the first calibration plane must be set based on the distance between the patent's back and the camera system which was about 900 mm. This is because the accuracy of the measurement is higher inside the volume formed by calibration points.

B. *Synchronization of Cameras*

When measuring high frequency motions by cameras, it is important to ensure that each frame pair corresponding to the left and right cameras is captured simultaneously. For this purpose cameras equipped with external trigger input have been used offering precise synchronization. The square wave signal has been generated by an external circuit.

C. *Marker Arrangement and Detection*

In order to capture all motion details during a therapeutic massage, the body of the patient as well as the hand of the masseur is equipped with circular and line markers. The primary purpose of circular markers is to ensure the detection of specific deformations of body parts affected by the massage. On the other hand the line markers attached to the body of the patient are used to measure the characteristics of the curvature of the patient's back as well as to estimate the applied pushing force based on the deformation of line patterns. Fig. 3 and 4 illustrate the displacement of markers on the surface of the patient's body and masseur's hand, respectively. In order to evaluate the massage, the movements of the masseur's hand together with the relative displacement of markers attached to the patient's back are considered. These motions significantly differ when comparing beginners with professional masseurs. During the experiments the patient clothing as well as the masseur's glove was one colored quipped with markers (see Fig. 3). This ensures fast and robust marker detection by simple thresholding. In order to easily distinguish between markers attached to the hand of the masseur and that of the body circular markers with different radiuses have been used.

D. *Algorithm of motion evaluation*

In this section let us describe how the motion of tracked markers is considered during the evaluation process. As already mentioned, markers attached to the patient's back and those attached to the masseur's hand must be considered together. The below algorithm has been proposed for evaluating the masseur's motion and its efficiency:

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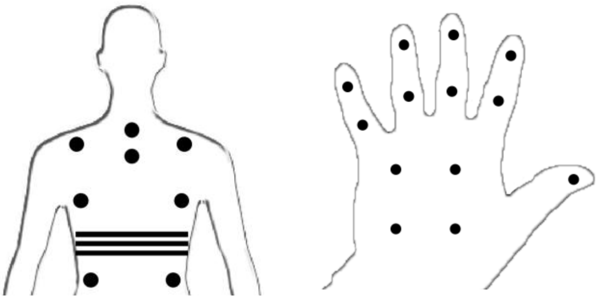
Algorithm 1 Massage Evaluation System

Calibrate cameras by DLT method
Setup trigger input according to the required frame rate
Acquire synchronized stereo image pairs
Start offline processing
Detect circular markers by thresholding
Based on the size of markers perform separation. Small markers correspond to hand of the masseur while larger ones to the patient
Let N_b and N_h stand for the number of markers attached to the body and that of the hand, respectively.
Estimate the image coordinates of marker centers.
Let $\mathbf{m}_{i,1b}(t) = [x_{i,1b}(t), y_{i,1b}(t)]$ and $\mathbf{m}_{i,2b}(t) = [x_{i,2b}(t), y_{i,2}(t)]$, $i = 1..N_b$ denote the image coordinates of the ith marker at time t corresponding to the 1st and 2nd camera, respectively.
for all $\mathbf{m}_{i,1b}(t)$, $\mathbf{m}_{i,2b}(t)$, $i = 1..N_b$ **do**
    Estimate the 3D location of each marker based on triangulation.
    $\mathbf{M}_{i,b}(t) \leftarrow Triangulate(\mathbf{m}_{i,1b}(t), \mathbf{m}_{i,2b}(t), \mathbf{P}_1, \mathbf{P}_2, \mathbf{d}_1, \mathbf{d}_2)$, where $\mathbf{P}_1$ and $\mathbf{P}_2$ stand for the perspective projection matrices, while $\mathbf{d}_1$ and $\mathbf{d}_2$ the lens distortion coefficients of the 1st and 2nd camera, respectively.
end for
for all $\mathbf{m}_{i,1h}(t)$, $\mathbf{m}_{i,2h}(t)$, $i = 1..N_h$ **do**
    Estimate the 3D location of each marker based on triangulation.
    $\mathbf{M}_{i,h}(t) \leftarrow Triangulate(\mathbf{m}_{i,1h}(t), \mathbf{m}_{i,2h}(t), \mathbf{P}_1, \mathbf{P}_2, \mathbf{d}_1, \mathbf{d}_2)$, where $\mathbf{P}_1$ and $\mathbf{P}_2$ stand for the perspective projection matrices, while $\mathbf{d}_1$ and $\mathbf{d}_2$ the lens distortion coefficients of the 1st and 2nd camera, respectively.
end for
Compose various subsets of body marker indexes and corresponding weights, i.e. $B_j = \{\{i, w_{i,j}\} \mid i \in \{1, 2, ..., N_b\}, 0 \leq w_i \leq 1\}, \sum_{1<i<N_b} w_{i,j} = 1$, for all groups B_j.
Similarly, for hand marker indexes $H_k = \{\{i, w_{i,k}\} \mid i \in \{1, 2, ..., N_h\}, 0 \leq w_i \leq 1\}, \sum_{1<i<N_h} w_i = 1$, for all groups H_k.
Based on groups created in the previous step calculate the weighted average of corresponding trajectories.
Compare the trajectories corresponding to different masseurs



(a) (b)

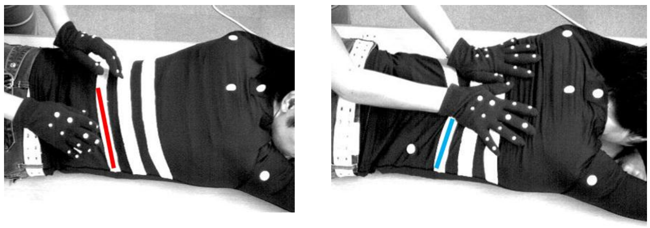
Fig 3: Displacement of markers used during experiments. Patient's back (a), Masseur's hand (b)

During the measurement different marker combinations with different weights were considered. As the results reflect the main characteristics of the measured trajectories strongly depend on the skills of masseurs. During the experiments nine masseurs including professionals as well as students have been evaluated based on the measured trajectories of markers. Markers being arranged as illustrated in Fig. 3 can offer information about the shape of the hand as well as body. Although the main aim of this paper is to show how the trajectory of markers – in case of massage like movements – can accurately be measured by synchronized stereo cameras and how the measured high frequency motions differ in case of professional and beginner therapeutic masseurs. As it can be followed in the upcoming section, the measured frequencies and trajectories corresponding to the motion of certain markers are suitable to identify the level of massaging skills.

III. EXPERIMENTAL RESULTS

During the first experiment the massaging technique of a professional therapeutic masseur and that of 8 students has been measured. The baseline of cameras was set to 250 mm. In Fig. 4 some captured moments of the massage can be followed. One may easily recognize the deformation of line markers depending on the pushing force and the direction of hand's movement (see Fig. 5).

Fig 4: Some key frames captured during the massage



(a) (b)

Fig 5: Illustration how due to pushing force the line marker is deformed. (a) no force applied, (b) deformation of line markers due to applied force.

A. *Evaluating the Trajectories Drawn by Markers*

The evaluation was based on trajectories measured by the stereo camera system as already shown in the previous section. First of all let us show the motion of the hand as well as the trajectory of a virtual point composed as the mean of four markers attached to the hand of the masseur. By considering the trajectories of more markers being attached to the hand and to the body more detailed skill comparison might be performed. Here let us focus only on the mentioned virtual

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marker. As the data reflect (see Figs. 6-15) there are significant differences between the skills of students and that of the teacher. These differences clearly appear in the measured frequencies as well as amplitudes of markers. Although in this experiment only one virtual marker which corresponds to the center point of the hand (the mean of the four markers attached to the hand) has been evaluated, even in this case the level of skills can clearly be distinguished. For instance from Fig. 8 it can be recognized that one of the students has skills being very close to that of the teacher. On the other hand the skills of the other students are of lower level, i.e. the highest frequency is almost half or less than that of the teacher.

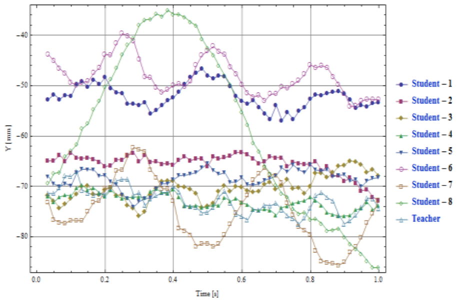

Fig 6: Trajectory of markers along Y axes

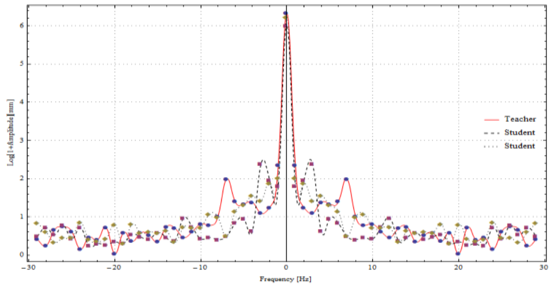

Fig 7: Spectrum corresponding to student-1, student-2 and teacher

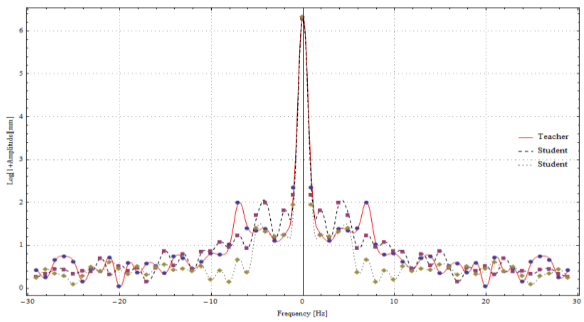

Fig 8: Spectrum corresponding to student-3, student-4 and teacher

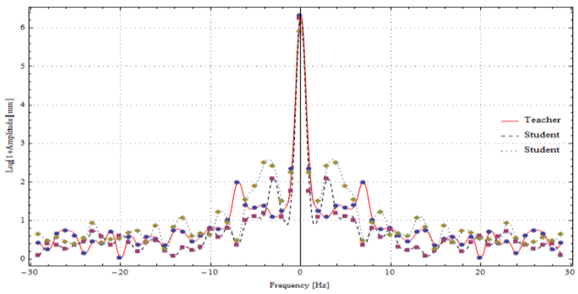

Fig 9: Spectrum corresponding to student-5, student-6 and teacher

In Table 1 and 2 the highest significant frequency together with the corresponding amplitude can be followed in case of students (S1-S8) and the teacher (T). In order to perform more detailed evaluation or skill ranking a fuzzy rule based can be designed by taking into account all the measured data together with the relationships between the trajectories of markers attached to the hand and to the body. However it represents a subject of a further research.

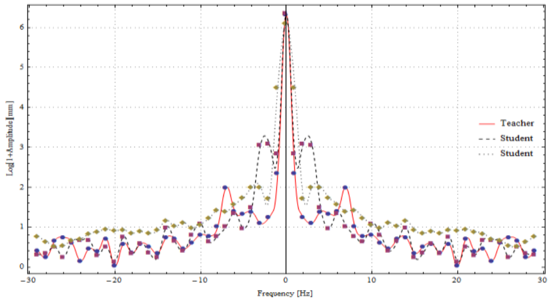

Fig 10: Spectrum corresponding to student-7, student-8 and teacher

Table 1: Frequency and amplitude values of markers (Y axes)

Y axis	Markers				
	S1	S2	S3	S4	S5
Frequency [Hz]	3.0	6.0	5.0	4.0	4.0
Amplitude [mm]	6.0	3.0	5.0	4.0	8.0

Y axis	Markers			
	S6	S7	S8	T
Frequency [Hz]	3.5	3.0	1.0	7.0
Amplitude [mm]	10.0	20.0	50.0	5.0

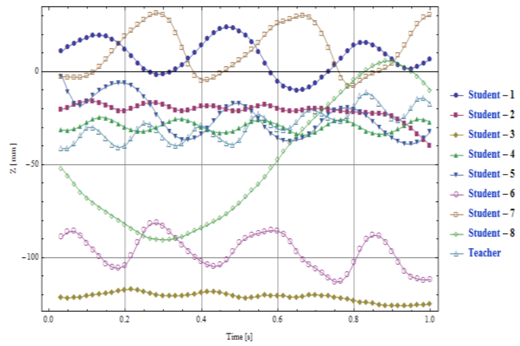

Fig 11: Trajectory of the marker along Z axes

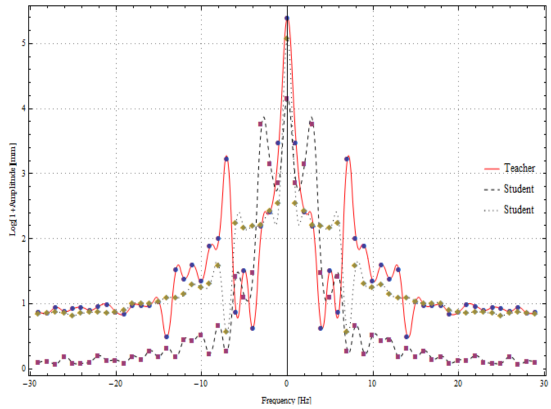

Fig 12: Spectrum corresponding to student-1, student-2 and teacher

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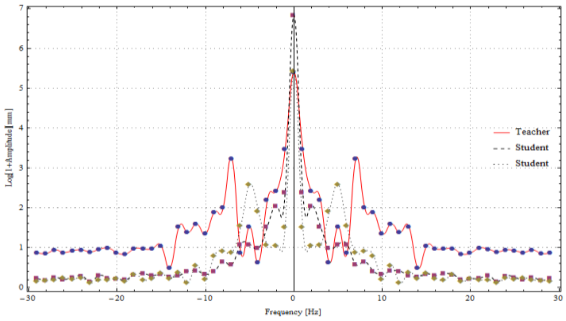

Fig 13: Spectrum corresponding to student-3, student-4 and teacher

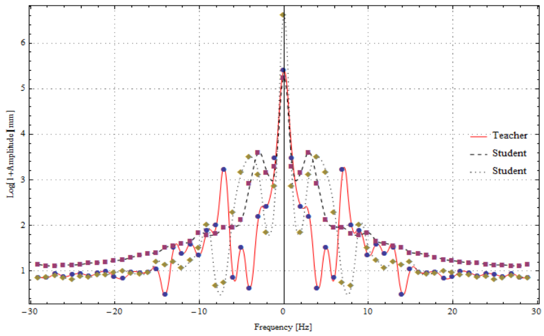

Fig 14: Spectrum corresponding to student-5, student-6 and teacher

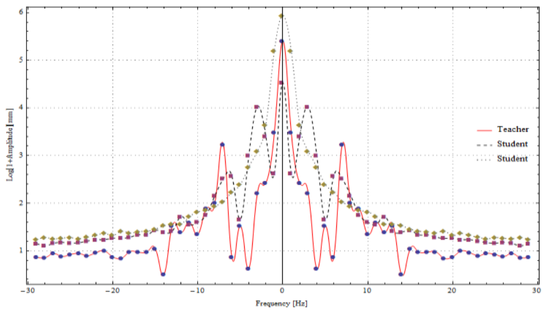

Fig 15: Spectrum corresponding to student-7, student-8 and teacher

Table 2: Frequency and amplitude values of markers (Z axes)

Z axis	Markers				
	S1	S2	S3	S4	S5
Frequency [Hz]	3.0	6.0	5.0	5.0	4.0
Amplitude [mm]	24.0	5.5	8.0	8.0	20.0

Z axis	Markers			
	S6	S7	S8	T
Frequency [Hz]	3.5	3.0	1.0	7.0
Amplitude [mm]	24.0	38.0	100.0	12.0

IV. CONCLUSION

In this paper a stereo camera based measurement framework has been proposed for evaluating the skills of therapeutic masseurs and thus supporting their skill improvement. Thus it can be considered as a machine vision based massage training system. It was shown how the measured frequencies and amplitudes as well as the trajectories may differ depending on the skills of the masseur. The proposed arrangement of markers ensures the measurement of the hand posture as well as the body shape in real time. In addition line markers have been placed across the body in order to estimate the pushing force based on their deformation, however this latter is a subject of further research.

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AUTHOR'S PROFILE

Hiroko Komai was born in Japan on November 2nd, 1962 and has received all of her training in her home country. After receiving the R.N. license in 1983, she practiced in general hospitals, particularly in the emergency department and rehabilitation ward. She obtained her M.Sc. in Nursing

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