Clinical Application of a Movement Analyzer

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Abstract— **Most neurological diseases bring about disorders of motility. Human visual evaluation allows of qualitative assessment. Pinpointing subtle changes in movement coordination helps early diagnosis of diseases, objective evaluation and staging of patients. Professional motion analysers are too expensive for routine medical/clinical application. A simple two-dimensional motion analyser (PAM) has been developed at the Department of Measurement and Information Systems, Budapest University of Technology and Economics. The analyser can track passive markers attached to anatomical landmark points of patients. The relative position of the camera to the marker trajectories is fixed. The finger- hand- and arm movements of patients are evaluated based on 50 samples/s, which is suitable for the task.**

General purpose motion analysers require trained operators. Simple operator interface is a must for a medical/clinical device. PAM is controlled by a notebook. After power-on the program asks for the patient identifier and the movement to be analyzed. Before testing a movement a given number of markers are attached to anatomical landmark points of patients. Finger tapping needs eight markers, pointing only one. PAM automatically detects the number of markers before starting the measurement. If more or less markers are detected than necessary, the operator is warned and measurement is not started. Otherwise recording starts after pressing a key. Evaluation of the recording is also done automatically. Speed and regularity of the movement determine the score of the patient. Scores are both displayed and stored in a file. The program runs under Linux operating system.

Movements of Parkinsonian and stroke patients were tested with PAM. Contrary to visual observation the details of movements can be accurately determined. This helps early diagnosis as well as objective and quantitative assessment of neurological patients.

Keywords— **quantitative movement assessment, movement disorders, passive markers, clinical device, PAM.**

I. Introduction

Movement coordination is affected by the actual state of a person or an animal. Changes in movement coordination can reveal and help in staging neurological diseases.

Human movements are analysed from different aspects. *Kinematics* deals with displacement, velocity, acceleration – sometimes even with jerk. Both linear and angular variables can be used to characterise the movement of body segments or joints. *Kinetics* deals with the internal and external forces that cause the movement. The internal forces mainly derive from muscle activation while external forces originate from the interaction between human or animal and the environment. [1] emphasises the role of *anthropometry* that gives data on the shape and mass of body segments and *muscle and joint biomechanics*.

Image-based motion analysis helps acquire kinematic data. Very often the movement analyser must be synchronised to devices providing further information on the actually studied movement. Force plates, accelerometers, treadmills and electromyographs are most frequently used but other signals of physiological origin may also be captured. Signals from different sensors might give valuable information; consider the force sensors embedded into different prostheses.

The aim and the process of the measurement have to be explained to the tested person. The analysis of a given movement gives meaningful and comparable results only if the measurement procedure is defined in detail. This must comprise the movement pattern as well as the arrangement of the measuring devices. To get parameters characterising the given movement accurately and reliably enough for comparative evaluation, well defined parameters and signal processing algorithms are needed. Internationally accepted standards would help. There are only a few recommendations for such standards and even these are not defined to the necessary extent.

II. The movement analyzer PAM

A Passive Marker-based Analyzer of Movements (PAM) has been developed - using mainly commercially available elements - at the Dept. Measurement and Information Systems. A digital video camera (SONY with nightshot ability, e.g. TR8100E, HC40), able to operate in the infrared range, an optical filter and a notebook with IEEE 1394 interface are the commercially available elements. An infrared LED ring

(containing 18 LEDs) with the necessary control circuitry has been developed. The infrared LEDs aid the separation of marker images from the rest of the image; they increase the ambient light suppression. The peak sensitivity of the CCD sensor of the camera was measured to be at 885 nm, the LEDs were selected in accordance with it (wavelength at peak emission: 880 - 886 nm, SFH485).

The control circuit synchronizes the flashing of the LEDs to the vertical synchron signal of the camera. A 5-ms delay assures that flashing starts when the CCD chip is sensitive. The 1-ms flashing assures a short enough sampling time and increases ambient light suppression resulting in sharp marker images. Fig. 1. shows the measurement set-up for finger-tapping test. The tripod of the camera is fixed to the tabletop. A rubber ribbon keeps the wrists of persons on the tabletop (see Fig. 1). This helps assure identical conditions during the finger-tapping test. As a result, the two dimensional view is enough to assess the finger movements. Both even and odd fields are evaluated using appropriate marker image processing. The system is inexpensive (compared to high performance motion analyzers), portable and easily applicable in the clinical environment. Fig. 2. shows two fields (odd and even) together as one frame taken by PAM in the infrared range of the finger-tapping and the pointing movements. The displacement of the markers on the ring fingers (top) and left index finger (bottom) between two fields (during 20 ms) can be observed. Each field in the digital video is processed thus the sampling rate is 50/s.

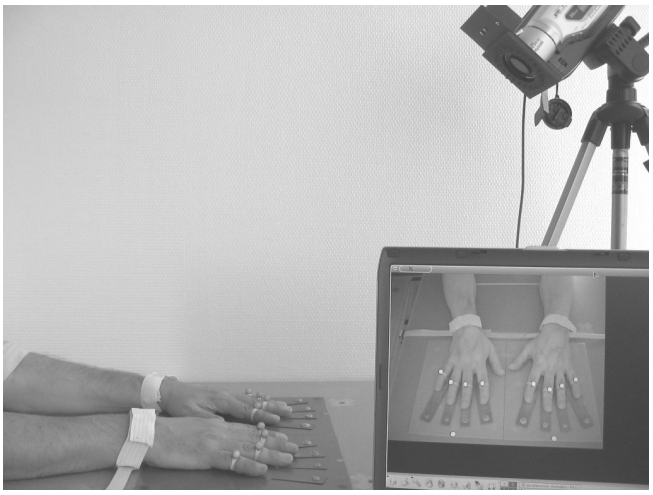

Fig. 1. The measurement set-up for finger tapping test.

The user can set the following parameters during recording with PAM: recording time (number of fields to be recorded), intensity threshold level for marker image extraction, minimum area of a marker image (bright spots smaller than this will be neglected thus eliminating ghost markers), number of markers, output file name and location.

Clinical application is promoted by autonomous operation. The device determines if the test procedure can start: the marker pattern detected by PAM must correlate with the appropriate initial position of the given movement pattern. This inspection reveals if there are excessively bright objects in the field of view (ring, wrist watch, etc.) that might be identified mistakenly as markers. If PAM detects more - or less - markers then expected, the operator is warned.

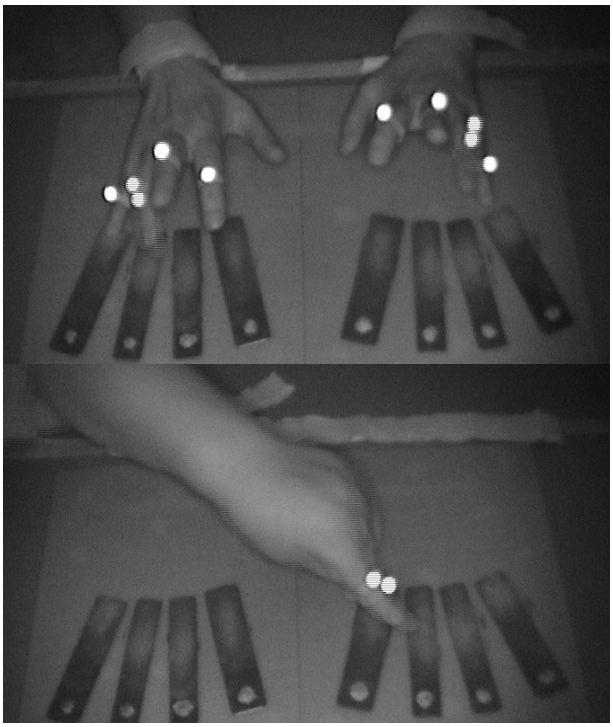

Fig. 2. The odd field and the adjacent even field displayed as one frame recorded with the PAM during finger-tapping (top) and pointing (bottom).

During the finger-tapping test eight markers must be detected in two groups. Each group must contain four markers; the positions of markers in a group must be within a rectangle of a given size. Two markers are suggested to be fixed to the tabletop. The position changes of these markers are used to cancel the trembling of the table and of the camera resulting from the

tested movement. Trembling of the tabletop was always present during the finger-tapping tests and it was always effectively compensated for.

For each tested movement default values of parameters – appropriate in most cases – are adjusted and stored. The operator can change these parameters but during the test series up to now it was not necessary. The operator has to select the movement type, the patient identifier and specify the output file name. The digital video file is quite long, about 70 Mbytes for the tests (20 s long each). The video files will be stored on the hard disk on the day of test and automatically deleted the next day. If the operator – or the neurologist – wants to preserve the digital video file, it is enough to rename the file. The marker trajectories (x and y coordinates of each marker on each field) are stored in a text file. This makes further analysis simple. Trajectories were further processed with MATLAB®.

The results quantifying the actual performance during the tested movement are displayed immediately after the recording. This gives an immediate feedback to the operator. If the result is apparently false the test can be repeated after sufficient rest. The results are also stored in a file for later use.

III. Evaluation of movements

Three movement patterns have been tested: finger tapping, pointing with right arm, pointing with left arm. Speed and regularity are the most expressive features to quantify movement achievement. Finger-tapping mimics playing the piano. Patients had to lift their fingers – except thumbs – in parallel and then hit the table in the following order: little-, ring-, middle- and index finger. They were asked to perform the movement as fast as they could and lift their fingers as high as they could. The pointing test consisted of 5 cycles. There were two marked points on the table 40 cm far from each other. The index finger was on the point closer to the patient. Then it was lifted, moved to the other point and back five times as fast as possible.

The ***measure of periodicity, PM*** of the quasi-periodic finger-tapping movement can be well quantified by using the singular value decomposition, SVD method [2], [3]. Contrary to the Fourier analysis, the signal is broken down to periodic functions of any kind not only sinusoidal. The periodicity of movement (PM) is characterised by the relative weight of the dominant basis function within all functions necessary to describe the complete record, i.e. all periods. This is calculated on the basis of the weights (σ_i) of all basis functions:

$$PM = \frac{\sigma_1^2}{\sum_{i=1}^{n} \sigma_i^2}$$

If σ_1 is dominant (σ_i are arranged in decreasing order) then the movement is nearly periodical. If all σ_i except σ_1 are zero then the movement is strictly periodic, it can be fully described with no more than one basis vector. As a result, the parameter value PM equals 1. In case of a nearly periodic movement σ_1 is dominant but further σ_i elements are non-zero. The PM parameter value decreases as further vectors are needed to describe the movement.

Greater amplitude or greater frequency during finger-tapping means faster finger movement, meaning better performance. It is easier to execute the movement faster with smaller amplitude, the ***amplitude * frequency*** of tapping is suggested as an appropriate parameter to characterise the speed. This feature, called amxfr, is determined for each tapping cycle and then averaged over the whole test.

$$amxfr = \frac{\sum_{i=1}^{n} \frac{A_i}{T_i}}{n}$$

where A_i : amplitude of the i^{th} tapping cycle in cm,
T_i : time period of the i^{th} tapping cycle in s,
amxfr is in cm/s,
n: number of tapping cycles during the whole test.

The regularity of finger-tapping movement is characterised by calculating PM for each tapping finger. The performance of a finger is characterised by the product of amxfr and PM. Increasing the speed usually decreases the regularity of the movement. ***The performance of a finger during the finger-tapping test is suggested to be characterized by the product of the parameters expressing speed (amxfr) and regularity (PM).*** Based on more than 300 finger-tapping tests the Finger-Tapping Test Score [4] has been devised:

$$FTTS = (PM - 0.6) * amxfr.$$

PM was greater than 0.6 for all fingers of all healthy subjects and for nearly all Parkinsonian and stroke patients. Subtraction of 0.6 adjusts the proper relative weight of PM to amxfr. PM is dimensionless, thus FTTS is given in cm/s.

Based on the scores of the fingers, scores can be calculated for the hands and for the person. One hand can be characterised by adding the results of the index-, middle- and ring fingers.

The score for ***pointing*** takes into account both the speed and the regularity of the movement. Contrary to finger-tapping, the amplitude is (should be) constant. The two end-points of the movement (table contacts) should be the same during the whole test. Significant change in the amplitude means an improper execution. Speed, accuracy and regularity are contradictory requirements; the Pointing Test Score (PTS) takes all these features into account. In addition to regularity, also the smoothness of the movement is considered:

$$PTS = fr \times PM \times (1 - h_{sm}) \times (1 - h_{ac})$$

where fr is the average frequency calculated as the reciprocal value of the average time-period during the movement (moving the finger from one point to the other and back), PM characterises the similarity of the five periods, h_{sm} expresses the smoothness of the movement and h_{ac} the accuracy of hitting the marked points [5]. Smoothness is quantified by the deviation of the average marker trajectory from the best fit of a second order curve. There is no "known good" position of the marker at the two end-points. The marker is fixed to the middle phalanx of the index finger, so it is 2 – 3 cm far from the fingertip. The distance between the marker and the marked end-point on the table also depends on the angle of the index finger to the table surface at table contact. Accuracy is characterised by the standard deviation of marker positions at the two end points. Both h_{sm} and h_{ac} are normalised, these errors can result in a maximum decline in PTS by 20 % each. The movement is nearly perpendicular to the optical axis of the camera. It follows that deviations from the marked end points will be differently projected on the sensor of the camera. Deviation that falls on the straight line from the marked end point to the camera will not be perceived. Tested persons are asked to hit the marked points accurately; substantial deviation from the marked points means the movement is not performed correctly and the score might be misleading.

IV. Clinical applications

In the Brain Injury Unit of the National Institute for Medical Rehabilitation (OORI) 15 patients (8 females, 7 males) participated in the finger and arm movement assessment. All patients were right handed, 9 had hemiparesis on the left, 6 on the right side. The average span between the onset of the disease and the selection for the test was 18 weeks (minimum 2, maximum 55, more than 26 weeks for three patients). [6] gives further details about the patients. The patients had hemiparesis resulting from upper motoneuron laesion. Twelve patients performed the tests twice on the same day, with at least 30 minutes break among the tests. The actual performance of four patients was assessed twice a week during a four-week period.

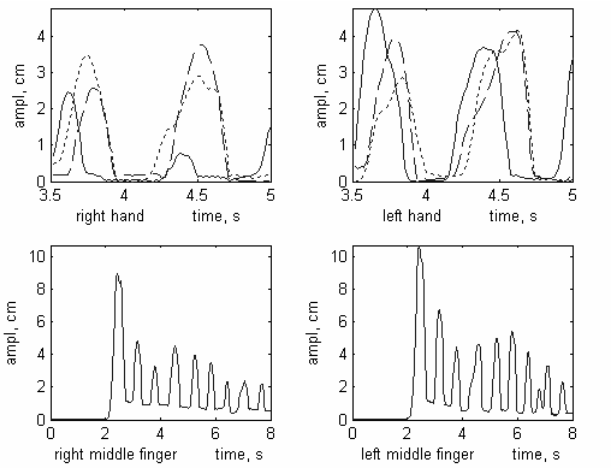

Fig. 3. Trajectories of markers attached to index, middle and ring fingers (top) and index fingers (bottom).

Hemiparetic inpatients were selected if they were able to understand and perform the movement task. A written consent signed by the patient was a must for inclusion. The permission for the research was obtained from the Ethical Committee of OORI. Dementia or loss of ability to move fingers were reasons to exclude a patient.

Patients performed three movements. These were: finger-tapping test, pointing with right hand, pointing with left hand. Using conventional tests (Hand Movement Scale (HM), Modified Ashworth Scale, Functional Independence Measure (FIM) and Rivermead Scale), neurologists assessed the motor function of arm and hand in parallel with the instrumental movement analysis.

Figure 3. shows the trajectories of a 24 year old hemiparetic patient five months after the onset of stroke. Movement disorders can be studied in detail based on the marker trajectories. Figure 4. shows the correlation between conventional rating scales and parameters calculated by PAM.

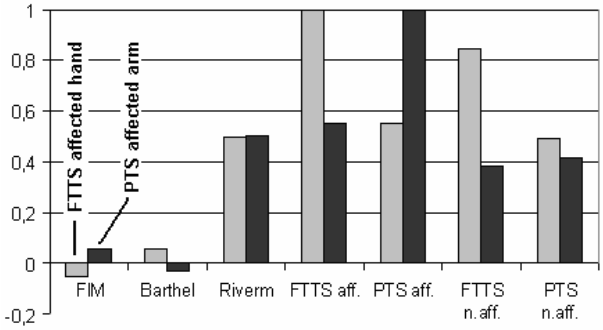

Fig. 4. Correlation between conventional rating scales and parameters calculated by PAM. (n. aff.: not affected)

These parameters quantify the movement itself, they can be used to complement the rating of patients by conventional tests.

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References

1. Winter DA (1990) Biomechanics and Motor Control of Human Movement. John Wiley & Sons, Inc. New York/Chichester/Brisbane/Toronto/Singapore, 1990.
2. Kanjilal PP, Palit S, Saha G: Fetal ECG Extraction from Single-Channel Maternal ECG Using Singular Value Decomposition. IEEE Tr on BME, vol. 44. 1997 No. 1. pp. 51-59.
3. Stokes V, Lanshammer H, Thorstensson A: Dominant Pattern Extraction from 3D Kinematic Data. IEEE Tr. on BME, 1999 January, pp. 100-106.
4. Jobbágy Á, Harcos P, Karoly R, Fazekas G: Analysis of the Finger-Tapping Test. Journal of Neuroscience Methods, January 30, 2005. Vol 141/1, pp. 29-39.
5. Nepusz T: Mozgásamalízis alkalmazása agyi érkatasztrófán átesett betegek kvantitatív állapotfelmérésére. (Applying movement analysis for the quantitative assessment of stroke patients. Thesis work, in Hungarian. Diplomaterv, BME Villamosmérnöki és Informatikai Kar, 2005.
6. Herczeg E, Baumgartner I, Fazekas G, Kovács Zs, Nepusz T: Mozgásanalizáló rendszer alkalmazása féloldali bénult betegek kézfunkciójának felmérésére (Application of a motion analyser system for the assessment of hand function of patients with hemiparesis. Rehabilitáció, 14. évf. 4. sz., 2004 december. 31-34. old. in Hungarian.

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