Development of a Simple and Cheap Device for Movement Analysis

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Abstract— **The way how someone is sitting down or standing up from a chair tells us a lot about his motion, as when sitting down or standing up his muscles, joints, knees and hip are working hard. Improper working of these kinds of abilities and organs can be detected by observing and analysing these processes of motion. For example the falling back and asymmetric load on the legs are the signs of these kinds of disorder. The process of sitting down and standing up can be analysed easily and simply by the tool which was developed by us and which includes the hardware, software and signal processing algorithms. Moreover no special prerequisites are needed during the use of this tool. The appliance was tested on a small-medium sized population (few dozens of humans).**

Keywords— **sit-to-stand (STS), motion analysis, motion disorder, home health monitoring.**

I. Introduction

In developed countries with the increasing rate and number of elderly people the examination and monitoring of the condition of movement disorder with simple instruments – perhaps at home - have become more important. Home accidents, of which a large number are due to motion disorder, are very often the reason of deteriorating living standards, or many times even the cause of death.

The subject of our study is the development and realization of a chair prepared for motion monitoring.

The idea is that the way how someone is sitting down or standing up from a chair tells us a lot about his motion [1], as when sitting down or standing up his muscles, joints, knees and hip are working hard. For instance the person can start on it again and again, may plop back on the chair or can load more heavily one of his legs etc…

In the literature there are several similar projects.

B. Najafi et. al deal with a patient - who is outside a hospital, but receives medical aid from it - monitoring in their study [2]. Their system is able to detect body postures (sitting, standing and lying) and periods of walking in elderly person using a kinematic sensor attached to the patient's chest.

T. Liu et. al Japanese engineers developed a wearable sensory system for human lower extremity motion analysis [3]. In our development, the aim was that we will be able to examine the person's sit-to-stand task without the sensors placed on the body.

A sit-to-stand assistance system equipped with a moving handrail to lead elderly and Parkinson disease people to stand up from a chair was developed by *K. Tomuro et. al* [4]. The construction provides great help for the Parkinson's disease people in their everyday life, and the system with its multi-faceted measurement opportunities can also be well used to satisfy the examination aims. The device worked perfectly, but it is very expensive, so it is not a solution for home monitoring: as most of the people cannot afford it.

The goal of the research of *M. Goffredo et. al* [5] is the visual observation based monitoring of the human body and its movements. They have done two-dimensional analysis on the recorded videos.

S. Allin and *A. Mihailidis* worked on similar research [6]. The technical equipment, which is based on three dimensional analysis of the video recordings, is able to evaluate the movement of standing up from a chair. The method based on video monitoring is not suitable for our purposes since the continuous home monitoring raises legal and ethical issues, moreover very complex problems related to image processing and shape recognition has to be solved.

Our goal was to create a cheap and simple instrument which makes it possible to monitor elderly people at home in the long run. Currently the prototype has been developed and the basic measurement methods were tested.

During our work we have equipped a chair with cheap strain gauges (used in simple and cheap commercial scales). We showed the ready made prototype to physiotherapist experts who made suggestions for some alterations and at the end of the work helped us in testing the instrument. According to their suggestion we have placed a foothold before the chair which gives even more possibilities for measurement.

During the work the hardware; which solves the filtering, amplification, sampling and the digitalization of the analogue signals provided by the strain-gauge bridges and the communication with the PC; was developed and tested. The operating software has been written too, which gives the possibility of expert controlled measurement and event-triggered automatic measurement as well. We have carried out tests on a small population (some dozens of people). Among them were healthy and slightly disabled people as well. The signal processing software is also ready; it was written and tested in MATLAB environment.

P.D. Bamidis and N. Pallikarakis (Eds.): MEDICON 2010, IFMBE Proceedings 29, pp. 61–64, 2010.
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II. System description

A. Hardware

The prototype chair is a cheap kitchen stool. The flat plate in front of the chair was made from wooden components. The positions of the footholds are variable so asymmetric layouts can be set also (Fig. 1a).

The instrument consists of a chair without a back-rest, and two footrests on a plane before the chair, onto which the patient puts his foot in the course of the measurement. The load is measured by strain gauges. 1-1 of these is placed on each leg of the chair and 4-4 of these are at each foothold (Fig. 1b).

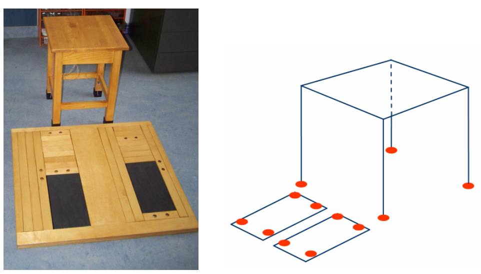

Fig. 1 The devise and the position of the sensors

Wheatstone bridge is used at each sensor in order to get a voltage signal which is proportional to the load. After the amplification and analogue filtering the signal goes to the analogue-to-digital converter of the microcontroller. A signal conditioning circuit supports the hardware minimization of the offset voltage. Data collection is performed by two AVR Atmega16 microcontrollers which work in a master-slave scheme. Data can be transferred to the PC via wired or wireless communication by the master. Measurement can be executed without PC control also. In this case the data is saved onto a Micro SD card.

However our goal was the analysis of the standing up and sitting down, a simple stabilograph like system was a side product of our research. Sense of balance and stability can be measured by using the footholds only.

B. Software

There are two basic types of measurements which can be performed with the developed tool.

Examination of the process of sitting down and standing up is the first measurement type. In this case all of the 12 sensors are used. During the routines, which have been executed yet, the patients have had to sit down and stand up for three times.

The other measurement type is the examination of the balance and the stability. During this process, the patient stands on the footholds and stays for 30 seconds. It is executed first in natural body position and in another measurement the patient is asked to load his legs equally, he can check the balance on the monitor, which provides a biological feedback.

Each of the measurement types is controlled by its own MATLAB GUI (Graphical User Interface). One of the two GUIs plots load-time figures for the examination of the sitting down standing up process. The second one, which is used during the examination of the sense of balance, calculates load distribution between the two legs and among the parts of the foot and gives the biofeedback mentioned.

The sum and the difference of the results of some sensor groups can be plotted also. For instance the sum of left and right side sensors placed on the chair and the difference of them can be calculated so the asymmetry of the left and right side can be examined easily.

The data processing can be split into two groups. The first group contains the analysis of the load-time figures during the examination. The second one is based on the projection of the centre of the mass of the patient onto a horizontal plane.

During the analysis of load-time figures (Fig. 2), rise time, fall time and overshoot were calculated after the determination of the level of 100% load. Then these parameters were examined and their standard deviations were obtained. This method was used basically in the sit down stand up process analysis.

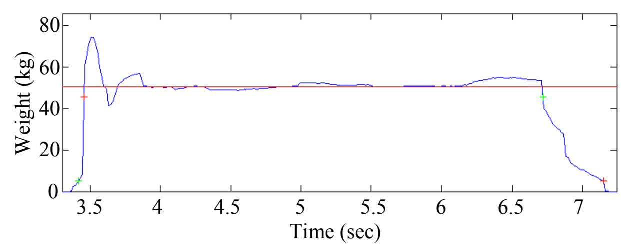

Fig. 2 Load-time figures

The accurate coordinates of the sensors were determined. The weighted mean of coordinates of the sensors, where the weights are the loads measured by the sensor, gives the coordinates of the centre of the mass (1).

$$X_{COG} = \frac{\sum_{i=1}^{12} x_i m_i}{\sum_{i=1}^{12} m_i}; \quad Y_{COG} = \frac{\sum_{i=1}^{12} y_i m_i}{\sum_{i=1}^{12} m_i} \qquad (1)$$

The calculation of the coordinates of the centre of mass can be executed for each sample so the movement of the centre of the mass can be plotted. The movement of the centre of mass was examined for both measurement processes (sitting down-standing up, stability).

For stability measurement the ratio of the parts of the graph near and far from the stable point was calculated as well. (Near and far were defined using a reference circle.) The value of this ratio is inversely proportional to the sense of the balance of the patient; therefore it gives a tool for the examination of stability. The reference area was determined this way: the smallest circle which contains all of the measured points of the centre of mass projection was calculated for every measurement. Then the average of these circles was taken and the reference circle became the quarter of this average one.

III. Results

A. The Results of the Examination of the Sit-to-Stand Task

The corresponding diagnostic software was tested on the data of 32 patients. The averages and the standard deviations of the rise times, fall times, overshoots were calculated. We looked for such parameters that the patients with motion disorder show significant difference from the parameters of healthy people.

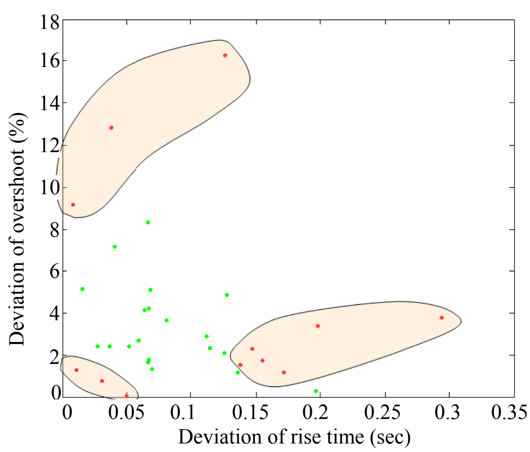

Fig. 3 Examination of the parameters

An example plot is shown in Figure 3. The two groups were distinguished by their colours (red dots are the patients with some disease and green dots correspond to the healthy people). The standard deviation of the overshoots is given as the function of the standard deviation of the rise times. It seems that the green points, which are representing the healthy people, are closely located to the centre of the figure while the red dots can be found in three different groups. These groups are in different directions from the location of the green points. Supposedly these three groups can be characterized by the disease of the patients.

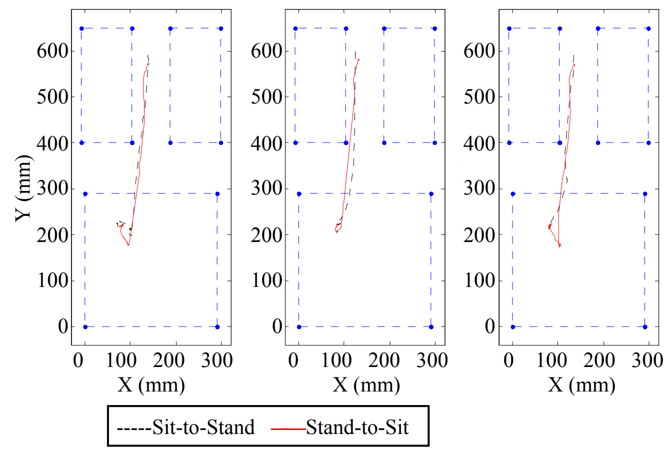

Fig. 4 Examination of the movement of the centre of mass

Further conclusions can be drawn from the graphs which show the projection of the movement of the centre of the mass during the patient is sitting down and standing up. An example is shown in Figure 4. It can be noticed in this figure that the three measured stand-to-sit and sit-to-stand curves are highly similar to each other. This indicates that everybody has its own specific sitting down and standing up movement. This depends on the movement coordination and the work of the motion system. Therefore these curves characterize the movement of the person so doctors may use them to diagnose the patient.

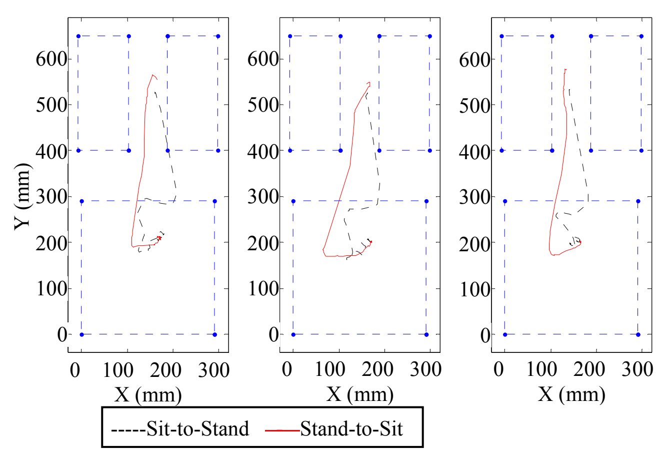

Fig. 5 A curve of the movement of the centre of mass of a patient with motion disease

The graphs, which are highly different from the typical ones, can be informative also. Figure 5 shows the curves of a patient with a lower lamb disease. It can be seen that the patient's centre of mass suddenly moves to right at the two third of the process.

B. *Results of the Examination of the Sense of Balance*

The diagnostic software was run on the preliminarily tested 32 patients. The tool calculated the percentage of the measured points which are in the reference circle. If the patient keeps its balance well, even the 100% of the samples can be in the circle (Fig. 6).

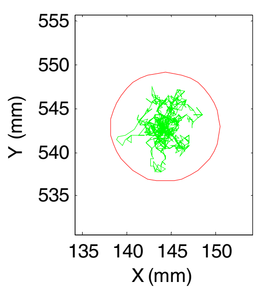

Fig. 6 100%

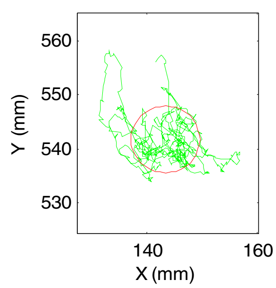

Fig. 7 85,32%

The calculations were performed in two measurements. In the first case the patient did not see the indicator on the screen, while in the second case the patient did see. So in this latter case a biofeedback about the distribution of the load was realized. Two facts were discovered by comparing these two percentage values.

At first, in most of the cases (about 80% of the cases) the biofeedback improved the parameters of the sense of balance. However in special cases (mostly with old patients), concentrating on the frequently and swiftly changing indicator made the examined persons disconcerted. The reason of this effect can be that the person overcompensates. In other words the patient sees the indicator which exceeded the limits then he or she changes its body position but the change is too much so the indicator exceeds the limits in the other direction.

Secondly the patients can be divided into three groups by our investigations. The members of the first group passed the described process with the result of 85-100% (Fig. 6-7), patients in the second group earned 35-80% while the people in the third group got a result of 5-25%.

IV. Discussion

A configurable mechanical construction and measurement system was developed. Strain gauge sensors were used in the system. The conditioning, digitalising of the analogue signals of the sensors and the data collection and signal processing were developed as well. A multi-function diagnostic software was written. This tool helps the doctor, who executes the examination, to check the condition of the patient easily.

The tool meets our preliminary goals because it is simple, cheap (a total cost of 45-55€), in the long run appropriate for home usage and it was presented that several examination methods can be performed with it.

Acknowledgment

The authors would like to express their gratitude to György Baur (Budapest University of Technology and Economics) for his precious help in the forming of the mechanics. They would also like to thank Dr. Mónika Horváth - Head of the Department of Physiotherapy of Semmelweis University - for her useful advises.

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