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A motion capture and analysis system to aid the physician during the motor recovery of patients
Un sistem de captură şi analiză a mişcărilor pentru a ajuta medicul în recuperarea motrică a pacienţilor

Mircea Mihălcică[1], Ioan Burcă[2], Violeta Munteanu[1]
[1]*Transilvania University of Brașov, Romania*
[2]*University of Medicine and Pharmacy, Tîrgu-Mureș, Romania*

Abstract

Background. Ideally, each patient who is recovering his motor functions should benefit from a customized program. Unfortunately, in practice this does not happen, due to high costs: frequent access to a motion analysis system is mandatory. Such systems are expensive and rare, especially in less economically developed countries. A cheap and portable solution for this motion analysis system would help solve the problem.

Aims. This paper presents a solution in terms of improving the motor function recovery program of patients, by using an affordable and portable motion capture and analysis system on their gait.

Methods. By using a motion capture and analysis system, we can obtain a series of specific experimental data for a patient who is undergoing a motor function recovery period. The data is collected frequently throughout the recovery period. Experimental data based on the methodology presented in this article provides a series of parameters that may constitute elements of decision regarding the design of the recovery program of motor function of a patient, the goal being to obtain a personalized recovery program for each patient.

Results. In the article we present a case study of one patient who was surgically treated with a total knee prosthesis as a result of knee osteoarthritis. We clearly show how, by using information obtained from the analysis of movement, the physician can be assisted in making decisions on the patient's recovery program.

Conclusions. A motion capture and analysis system such as the one presented in this article, which is inexpensive, portable and designed for frequent use, is a solution for many patients who are undergoing the recovery of motor functions. The advantages of such a system are that it is inexpensive, portable, and accessible.

Key words: motion analysis, biomechanics, medical recovery.

Rezumat

Premize. În mod ideal, fiecare pacient ce își recuperează funcţiile motrice ar trebui să beneficieze de un program personalizat. Din păcate, în practică acest lucru nu se întâmplă, datorită costurilor foarte mari: este necesar accesul frecvent la un sistem de analiză a mişcării. Astfel de sisteme sunt scumpe şi rare, mai ales în ţările mai puţin dezvoltate economic. Din perspectiva acestui sistem, o soluţie ieftină şi portabilă ar ajuta în rezolvarea problemei.

Obiective. Articolul de faţă prezintă o soluţie în ceea ce priveşte îmbunătăţirea programului de recuperare a funcţiilor motrice ale bolnavilor aflaţi într-un astfel de program, cu ajutorul unui sistem de captură şi analiză a mersului, portabil şi accesibil ca preţ.

Metode. Cu ajutorul unui sistem de captură şi analiză a mersului se obţin o serie de date specifice fiecărui pacient aflat în perioada de recuperare a funcţiilor motrice. Acestea sunt colectate frecvent de-a lungul perioadei de recuperare. Datele experimentale, obţinute pe baza metodologiei prezentate, oferă o serie de informaţii ce pot constitui elemente decizionale în ceea ce priveşte proiectarea unui program personalizat de recuperare a funcţiilor motrice ale unui pacient.

Rezultate. În articol prezentăm un studiu de caz privind recuperarea unui pacient ce a suferit tratament chirurgical de înlocuire a genunchiului, în urma gonartrozei. Se demonstrează cum, folosind informaţiile obţinute în urma analizei mişcării, medicul poate fi ajutat în a lua decizii privind programul de recuperare al pacientului.

Concluzii. Un sistem de analiză a mişcărilor umane în timpul mersului, ieftin şi portabil, destinat utilizării frecvente, reprezintă o soluţie pentru foarte mulţi pacienţi în vederea recuperării funcţiilor motrice. Avantajele unui astfel de sistem, faţă de unul profesional sunt: preţul, portabilitatea şi accesibilitatea.

Cuvinte cheie: analiza mişcării, biomecanică, medicină de recuperare.

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Address for correspondence: Transilvania University of Braşov, Mechanical Engineering Department, B-dul Eroilor nr.29, 500036 Braşov, Romania
E-mail: mihmi_1@yahoo.com
Corresponding author: Mircea Mihălcică

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Introduction

There is an essential difference between theory and practice, between what exists and what is actually used in rehabilitation medicine. Despite the theoretical existence of sophisticated devices and tools developed by scientists and renowned manufacturers in the field, when it comes to everyday life, to ordinary medical centers, even well-equipped ones, this sophisticated equipment cannot be practically found. Usually, the reasons for this are purely economic: either there is not a sufficient number of patients for investment in such equipment to make profit, either the number of patients is sufficient, but their financial possibilities are not enough to recoup the investment in time. The research idea in this article started after being in touch with the harsh reality, in which it was observed that in less developed countries, not only the equipment designed for rehabilitation medicine is missing, but also the methods of treatment (modern medical interventions) are not there yet or they have just recently appeared, but usually in private clinics at high costs.

When it comes to the area of recovery of motor functions of a patient, if we eliminate the situations (very few in number) where modern equipment is frequently used, we end up with the majority of other situations where the whole procedure is recommended by medical doctors and derives mainly from the physician's skills and experience. Basically, there are a number of standard methods and exercises that the patient must follow, and these are recommended in a certain proportion and order, following a plan based almost exclusively on the physician's experience and instinct. The only information that might help the physician during the recovery period while the above procedure is followed (usually months) is extracted from the patient's regular appointments. In our opinion, there is a profound need to improve the way things are at the moment in this field, for two main different reasons: we consider that the recovery plan should be established based on some form of gait data collected from the patient, because each patient is different from the other, and we know that the efficiency of the recovery procedures varies from patient to patient. We believe that each situation should be managed individually, based on more regularly collected data than just the physician's experience and ”feeling” (Berme et al., 1990).

Hypothesis

In this article, we present a solution to the problems associated to the way rehabilitation medicine is practiced in regular clinics and rehabilitation centers, mainly focusing on the area of recovery of motor functions of patients after accidents, surgery, etc. We will propose a motion capture and analysis system which is cheap, portable and easy to install at the patient's location. The system will be used (ideally) daily by the patient to collect gait data, which will be analyzed and presented in such a way that the physician will be able to draw conclusions and eventually modify the recovery plan based not only on his experience and skills, but also on this data. We will present the way the system works, the way data is gathered, analyzed and presented, the system's advantages and limitations and, in the end, we will show a practical example with real experimental data collected from a patient, using this system.

Material and methods

The human motion analysis system proposed in this research is based on experimental data collected using video materials. Essentially, the patient is filmed during his recovery period, as frequently as possible, while walking. Markers are attached to the patient for at least the three main joints of the leg (ankle, knee and hip) and their trajectory is recorded over time (Fig. 2). Using software applications, the path of the marker is transformed into a set of coordinates in time, which can then be mathematically processed to obtain a mathematical model that can be further processed to extract the desired information (Mihalcica et al., 2014b; Meredith & Maddock, 2005).

The idea behind this system's components and installation conditions was to be able to easily install such a system at home. At minimum, a video camera able to record using at least 125 frames per second is recommended. The video recording will take place in the exact same spot, ideally in front of a monochrome wall. The starting and ending positions for the patient's motion will be clearly marked. The video camera will be installed at the knee level (the middle of the image captures the knee), perpendicular to the walking path (so that it captures the walking of the patient) at the same distance in every session. We recommend this distance to be 2 m or 2.5 m, but other distances work as long as they are specified; installing the system at home means that we should be able to adapt it to the room's shape and dimensions (Mihalcica et al., 2014a).

There will be markers installed on the patient's ankle, knee and hip and on different other areas of interest, if that is the case - ideally, the markers should have a high contrast color when compared to the patient's clothes (see Fig. 1 - we suggest to use the same markers and the same clothes in all the sessions, if possible). Also, a portable computer is needed to connect the video camera and to save the video materials during the walking sessions.

From a software point of view, we need an application able to capture motion data from a video material. Ideally, we want this application to be a well known one, decent in price and developed by a renown company in the field. Considering these conditions, we chose Adobe After Effects as the application to use for data gathering from the video materials (Mihalcica et al., 2010; Ren et al., 2007).

Fig. 1 – A sample of a video recording session. There is high contrast between the markers and the subject's clothes, also between the clothes and the wall.

We also need some software to use in order to process the raw data obtained with Adobe After Effects.

We used Microsoft Excel tables to store the data gathered with Adobe After Effects, and we used MATLAB programs (which we wrote) (Chapman, 2008) to process this data mathematically and to obtain the models needed for each patient (again, two popular applications) (Smith, 2010), (Chapra & Canale, 2006).

The patient will be asked to stand at the starting point (clearly marked on the floor, starting from left to right, depending on the foot of interest - foot undergoing surgery, or an accident, etc.) with both feet on the ground. He will then start walking, in a normal, unforced and relaxed manner, from the starting point to the end point. This walk will be video recorded using the camera and one video will be individually saved. Then the procedure is repeated, the more walks, the better the results - we recommend to have at least 10 walks per session, but we also recommend for the patient to stop when walking becomes unpleasant (there is a high chance that the patient will change his walking habits when he/she feels pain, and this would alter the results in an unwanted way). These walks will be gathered and the video materials will be saved - we will consider this and will refer to it as a ”walking session” from now on (Lee & Cohen, 2006; Zhou et al., 2013).

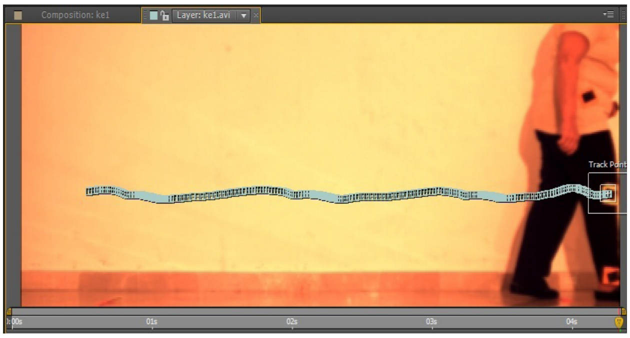

Fig. 2 – Using the system to follow the knee marker during one walk - screenshot from Adobe After Effects, where the element that captures the trajectory can be seen.

These walking sessions will take place with a high frequency (a strong point of our system is the fact that it can be installed at the patient’s home or at the recovery location) - we recommend to have one walking session at least once per week, ideally every 3 days. The data will be gathered and compared in time, using mathematical models (Safonova et al., 2004). There are many factors which can be taken into consideration, starting from the basic shape of the motion (seeing, for example, how high the patient can lift his/her knee or ankle) to more specific things such as velocity during gait (full-length velocity or segmented velocity, such as the velocity of the ankle when lifting the leg), step and stride length, etc. This data will change in time and can give an idea about how the recovery is going. Based on this data, his expertise and skills, the physician can then modify the recovery plan for the patient (Jordan et al., 2007).

Some special situations might arise. There is the common case when the patient uses support during his recovery program. This support can be (most common examples here) a walker, crutches or a walking stick. Also, a very common situation, the patient changes support during recovery: he starts by using the walker, after a few weeks he changes to crutches, and then to the cane or even to no support at all. These periods should be approached separately. The walking sessions with the walker should be analyzed separately, then the crutches, etc. In fact, we hope that our system would actually be able to give „clues” for when the change should happen (and if it should happen) (Nixon et al., 2006). From what we experienced with our practical cases, after the patient’s walk stabilizes and there is no improvement for a few walking sessions with some form of support (the main parameters remain the same - have an acceptable variance), it is recommended that the patient will try some new, less restrictive form of support (Hardt & Von Stryk, 2002).

We followed the recovery of motor functions in a female subject, 59 years old, her physical parameters being 150 cm and 72 kg. She suffered from knee osteoarthritis, which was surgically treated with total knee prosthesis. Also, procedures took place aiming to correct the morphology disorders of the knee, by removing degenerate tissue, in order to allow articular regeneration. An informed consent of the subject participating in the research was obtained.

The MC2 Biotechnic prosthesis with mobile plate and posterior stabilization was used for the total knee prosthesis procedure (it is considered the ”standard” prosthesis, the main prosthesis used for this procedure in Romania).

Our video recordings and measurements were made at 63 frames per second, using the high-speed AOS X-PRI camera. The camera was installed in lateral direction, visually perpendicular to the direction of the subject’s walk (the camera records the sagittal plane of the subjects during gait).

The high-speed camera was placed at a distance of 280 centimeters from the walking path, and the distance that the subjects cover during their walk is 230 centimeters.

Results

Multiple measurements were made during the full period of recovery for this subject, but considering the aims of this paper, we will focus on the ones corresponding to the moment when the patient was instructed (by the physician) to change the recovery exercises. We will present the data and the parameters obtained in order to better understand how our system can help the physician with this decision.

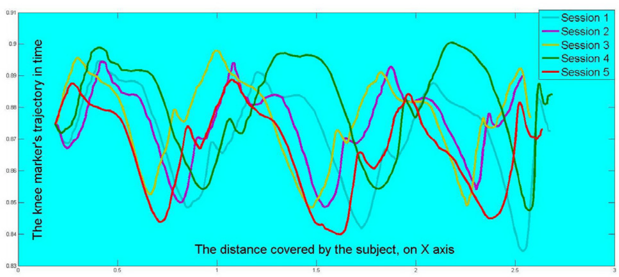

Fig. 3 – The first five sessions of gait, without big differences between them.

In Fig. 3, we can observe the knee marker trajectory during the first 5 recorded sessions. By simply studying the trajectories, we can easily see that there were no major ”changes” in the gait at that time of recovery. The next figure (Fig. 4) captures and presents the moment when the first changes were visible.

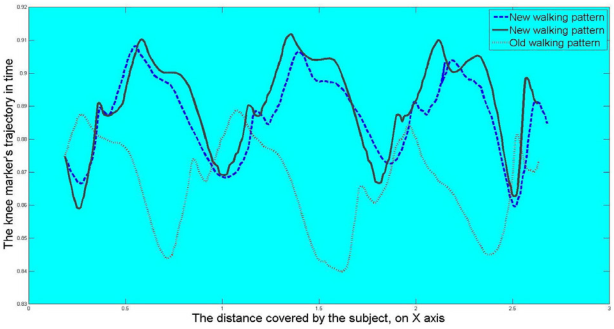

Fig. 4 – The moment when the first changes in gait appeared - obvious changes.

The patient strictly followed the original recovery program and the recovery exercises. The gait pattern changed rapidly with time, and after two more sessions, it stabilized to another trajectory, as it can be seen in Fig. 5.

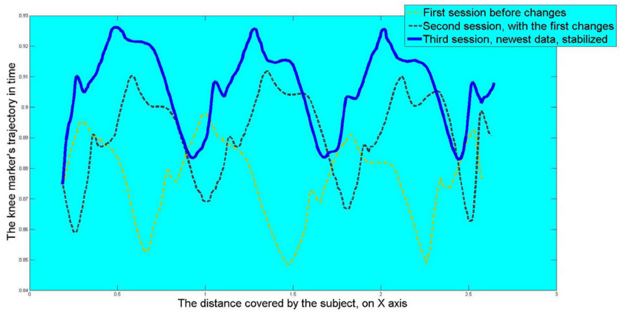

Fig. 5 – The gait stabilized close to the upper trajectory.

These representations were used as the first parameter that influenced the decision to change the recovery program (the number of some physical exercises was increased, new physical exercises were introduced while others were removed). It can be easily seen that, with time, the patient could lift her leg higher and higher, up to a point where there was no more improvement. It was the first clue that the patient needed a change in the recovery program for a faster recovery process - but it was not the only parameter that could influence the decision. We also took into consideration the velocities of the knee, both on the X and Y axis (Tofan et al., 2009). We will present those below.

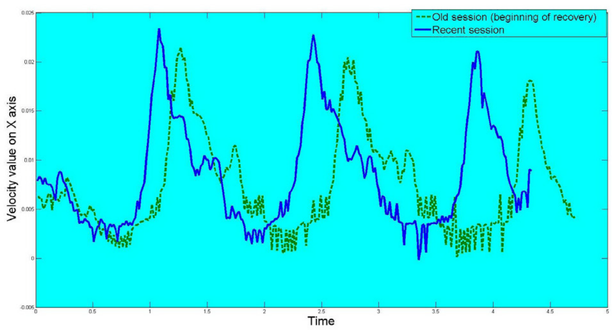

Fig. 6 – The velocity of the knee marker, on the X axis.

The information in Fig. 6 is very important. It tells us that during the recent session, the patient can walk the distance faster (the time is shorter, the overall velocity is higher) and the top velocity is higher than the one corresponding to the old session. This means that the patient performs overall in a better way than before. We kept measuring the velocities until the improvements were no longer relevant. This was the second parameter that could be considered when making the decision to change the recovery program.

It is important to note that all this analysis was (and must be) done under the strict supervision of the physician (in the example above, we only notified the physician of the changes occurring in the patient’s gait and we let him perform the recovery procedure as he considered appropriate). There are lots of factors to consider here - for example, if the patient is walking with support and our analysis hints that he/she can change or drop the support (walker, cane, etc.), there might be the case that, despite the fact that the patient’s gait parameters stabilize, he/she still feels pain when walking without support, and (most likely) the physician should not force him/her.

In our situation, the measured parameters led to the idea that our patient recovered faster than expected. In other situations the opposite might happen, recovery might go slower than expected and the physician should delay some changes - this varies from patient to patient. Again, our system does not aim to influence an extreme decision, but to help the physician correlate his experience with some scientific data in order to make the best decision, which varies depending on the situation.

Discussion

Our procedure is designed in such a way that the collection of data can be performed easily even by individuals who are not comfortable using computers, as long as the instructions are followed. However, some computer interaction is needed (usually, only clicking a few buttons). Unfortunately, the patient cannot perform the operation alone, some other individual has to help.

We strongly recommend that each patient be approached individually and that the results obtained from other patients already recovered using the aid of this system, have mostly an informative meaning. The data gathered from previous patients is still valuable and can be used as a calibration for the new patient’s analysis, but only at the start of the analysis program and only if the physical characteristics (height, weight, age, gender) and the medical situation somehow match. Our practical experience with the system tells us that some patients recover faster, others slower, even if the other physical parameters of the patients are close in numbers.

There is no ”unique model” which can be generally applied and each walking session must be analyzed individually. The collection of data using Adobe After Effects and then the processing of data using MATLAB applications is demanding work. Depending on the data obtained and the aim of the analysis, the MATLAB code might need to be changed (this rarely happens, and mostly when there is the need to analyze some specific, out of ordinary parameter). Even if the system is affordable and easy to use, there is a cost in terms of time associated with its use.

Conclusions

1. Using the system presented in this paper, we managed to offer a good prediction about some steps in the recovery of a patient who underwent a knee replacement procedure as treatment for knee osteoarthritis.

2. More patients are in the process of recovery (however, the data gathered so far already allow for some good conclusions). This system successfully aids the physician by offering him experimental data in order to better analyze the patient's recovery. The data obtained using the motion capture and analysis system should be seen as a support for the physician, and, in correlation with his experience and skills, should help him during a patient's recovery process. One of the main benefits of using a system as the one presented in this paper is that such a system allows for each patient to be approached individually so that his/her treatment is specifically adapted to him/her, which, in our view, is the correct way medicine should be practiced. The system is affordable, portable, can (and should) be used frequently and there is no need for the physician to be involved in the collection of the experimental data, as long as the conditions of use are strictly followed.

3. In the future, we aim to improve both the system's functionality and the way the analysis is done. After gathering enough experimental data from a lot of patients, we aim to find more correlations between gait patterns and the way the recovery process develops in time, and in the end to determine more scientific parameters which can be used during the recovery process.

Conflicts of interests

There were no conflicts of interests.

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