

A Telemedicine System for Human Body Movements Remote and in Real-Time Monitoration

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Abstract—The pandemic situation emphasized the importance of telemedicine technologies, encouraging and making indispensable the remote communication between health experts and patients. In this scenario, human activity identification and monitoring are useful for several purposes, such as rehabilitation and physical exams. Current computational systems to support this research topic have some limitations, which inspire new proposals. The Movement Monitoring and Remote Analysis System in Telemedicine, developed by our research group, permits creating representative movement patterns from accelerometer data. In particular, the data represents displacements in the three-dimensional space of the Cartesian coordinate system. A standard curve (reference), based on data patterns for a single person or a group of people, averages a set of person/people's movement curves for each of the three axes separately. A standard curve can be used for different applications, such as diagnosis, rehabilitation follow-up, injury prevention, and movement/diseases/disfunctions research. They can also be described by valuable measures, such as area, length, among others. This work aims to present the web system and the new attributes implemented to describe these curves. The results indicate that the presented system is functional and enables the extraction of several new and relevant measures that can feed machine learning algorithms in order to construct prediction models.

Index Terms—Biomechanics, Healthcare, Mobile Applications, Pattern Recognition

1 INTRODUCTION

THE world faces a serious health pandemic caused by COVID-19. Thereby, several restrictions have been established to prevent the virus from spreading, with social distance being one of the main concerns. In this scenario, telemedicine emerged as a solution to allow remote interaction between health professionals and patients [1].

Telemedicine is an area that involves the use of communication technologies for health care and human well-being purposes, enabling expert-patients interaction and the exchange of valid information for the diagnosis, treatment, and prevention of diseases and injuries [2], [3].

Moreover, this area can facilitate the scenario in which health experts concentrate in large urban centers, while many smaller cities that are far from the large ones have a lack of medical specialties [4].

In this context, a research field growing rapidly is hu-

man activity identification and monitoring. It has motivated research, development, and innovation to solve daily life problems. These processes also have led to varied applications, such as fall detection for elderly people, sports activities monitoring, rehabilitation, and patient's physical examinations [5], [6].

Different technologies found in the literature employ Inertial Sensors (IS) to collect data related to the human body's movement [7], [8], [9]. However, these tools do not consider the peculiarities of the displacements in each plane over time. They also lack support for the analysis and identification of patterns and parameters for healthy or injured subjects.

Therefore, the method to supervise and investigate the mobility of joints and body parts, proposed by [10], aims to solve the technical problem of analyzing movements and identifying patterns. This invention considers signals collected by IS during exercises conduction by an individual. This method also provides the extraction of measures with physical-mechanical significance, such as area and length, from the curves representing the displacement data acquired over time. These curves are in the three-dimensional space of the Cartesian coordinate system.

The aim of the Movement Monitoring and Remote Analysis System in Telemedicine (SMMAR-T) is to automate the procedures and steps of that innovative method [11], [12]. Therefore, the program makes it possible to create standard curves (references) of the human body's

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movements, with or without injuries. These patterns are extracted directly from the three axes' curves separately, based on mathematical procedures [10].

Experts can use these curves for different purposes, such as research, diagnosis, and monitoring of the rehabilitation process. SMMAR-T also enables creating and making available an activity plan for an individual. She/he can carry out the planned exercises anywhere, with remote and real-time supervision by an expert. This monitoring feature was evaluated previously in [13].

Besides, the system enables the user to extract a few measures from the standard curves, such as area, length, maximum and minimum acceleration values. Last but not least, the researchers can obtain some new measures, such as the polynomial fit coefficients, used to model the curves, and the Dynamic Time Warping (DTW) similarity. All of them are obtained separately for each of the three Cartesian space dimensions. It is worth mentioning that the implemented attributes are the main contribution of this work. Therefore, they can serve as attributes to feed machine learning algorithms aiming, for example, to differentiate between healthy and unhealthy people automatically.

This work aims to present the system and the new measures implemented to describe the standard curves.

2 RELATED WORKS

Several approaches are presented in the specialized literature to monitor and evaluate the human body's movements [5], [6]. In this scenario, systems based on inertial sensors attached to the human body for data collection from an action performed by the user stand out.

Ishigaki et al. [14] developed a real-time tracking system based on IS to supervise the pelvis movement of elderly people during a walk. These individuals use a device containing an accelerometer and a gyroscope to obtain the region's displacement data under supervision. Additionally, the data is sent in real-time to a health professional's notebook, making it possible to view information about acceleration, angle, and angular velocity from the sensors graphically.

Figueira et al. [15] reported an algorithm to detect daily human activities (walk, going upstairs, and downstairs) regardless of the sensor's location. First, the algorithm calculates the magnitude of the acceleration data collected from the smartphone's accelerometer and then applies a high-pass filter. Next, it obtains three sets of attributes related to the spectral, statistical, and temporal domains from the acceleration data and the smartphone barometer data. Thereafter, the algorithm builds a decision tree to classify the activity into one of the predefined categories.

Chen et al. [16] proposed a system to recognize human activity through acceleration data. First, the approach transforms the coordinates from the smartphone's accelerometer sensor into a fixed coordinate system to avoid degradation in the recognition accuracy. Then, the proposal extracts attributes related to the time and frequency domains from the coordinate data and forward them to

the Support Vector Machine algorithm. The idea is to identify the activity performed by a person: walking, running, going upstairs and downstairs, and static (no movement).

Lee and Chang [7] presented a method and its respective system for rehabilitating the body based on mobile devices. First, someone places the mobile device in a specific location on the body part to evaluate. Second, the system sends the device's accelerometer data to a remote server, which applies the Gaussian filter to smooth the data and the Principal Component Analysis method to extract attributes. Third, it uses Dynamic Time Warping (DTW) to compare the similarity with a standard movement previously-stored and performed by the expert himself, showing the comparison result to the user. One also should note that the server stores additional information, such as medical records of patients and their respective rehabilitation plans.

Phoophuangpaioj [17] developed an application to measure the ROM of abdominal exercises. First, somebody places the mobile device, equipped with an accelerometer, on the gym machine to measure acceleration signs during the activity's performance. Then, the tool uses the collected data to calculate the values of angles and the number of user's repetitions performed during the activity session. Finally, the program interface presents the results in real-time to the individual.

Ensina et al. [13] presented an overview of the main SMMAR-T features, focusing on the remote and real-time monitoring perspective. They also evaluated the delay time that the individual's device took to send data to expert's devices. Differently, the present work aims to focus on the standard curves created by the system, as well as discuss the new measures implemented for movement analysis.

Section 4 discusses the main innovative aspects of the method implemented by us in SMMAR-T compared to the papers previously described.

3 MATERIAL AND METHODS

The SMMAR-T computational system automates the procedures and steps of the method proposed by [10]. Thus, the tool enables the expert to create and analyze standard curves of human body movements individually for each coordinate system axis. All the details about the method can be found at the respective reference.

In particular, the system is a more complete alternative to monitor and analyze the human body's movements. It uses the accelerometer inertial sensor, typically embedded in a smartphone, to collect data related to the user's displacement [11], [12].

Therefore, this program's functional and non-functional requirements were defined and refined based on meetings with specialists in the health and computing fields – please refer to Section 4 for details.

After defining the main requirements, our research group designed and implemented the computational program with the support of the incremental development model and the Model-View-Controller architecture

pattern [18], in addition to the responsive web design approach for the elaboration of web pages [19]. The authors used the following technologies to develop the system:

- **Languages:** Java, JavaScript, Cascading Style Sheets, and HyperText Markup Language;
- **Frameworks:** JavaServer Faces v2.3 and ZURB Foundation v6.5.1;
- **Libraries:** PrimeFaces v7.0 and Chart.js v0.7.0;
- **Database management system:** MySQL v5.1.30;
- **Protocols:** WebSocket and HyperText Transfer Protocol Secure (HTTPS);
- **Computational environments:** Eclipse v4.13.0 and Tomcat v9.0.2.

4 RESULTS AND DISCUSSION

SMMAR-T is a computational web system that automates the method for creating standard curves of joints and body parts movements [10] and manages patients', professionals', and medical appointment's data. It uses a client-server architecture, which centralizes the collected data and the access policies in a single architectural element, promoting security benefits. Thus, the server can ensure that only authorized users reach the hosted resources. Several types of computational devices with a screen, mobile or not, can access the program since it is a responsive web application.

The authors organized the proposal features according to the respective user profile:

- **Professional:**
 1. Authentication;
 2. Professional management;
 3. Patient management;
 4. Medical appointment management;
 5. Patient's activity plan creation;
 6. Remote and real-time monitoring of the user's exercise;
 7. Segmentation and analysis of specific regions of the curves obtained from the activity.
- **Patient:**
 1. Authentication;
 2. Activity plan visualization;
 3. Exercise conduction.

The system guarantees different security aspects for the transmission, storage, and access of medical information. The authentication process allows only authorized people to have access to the stored data. Moreover, each user profile is allowed to access only its features. It is also worth mentioning that the proposal uses the HTTPS protocol, which guarantees the software's authenticity, confidentiality, integrity, and reliability [20].

One of the main SMMAR-T features is the creation of the patient's activity plan by the expert. Consequently, the patient can conduct a predefined set of exercises, such as flexion and abduction, at a clinic, or his/her own home, or anywhere else. As the system is a web one, the user can also employ any mobile device equipped with an accelerometer to access his/her plan. During the exercise,

he/she can place the equipment on the body part previously specified by the expert.

Another essential aspect is that the software allows the professional to follow-up and monitor, remotely and in real-time, the execution of a patient's activities. In particular, the expert receives feedback information in the form of curves, which can be segmented for the Cartesian space's three axes, as presented in [13]. The expert can segment regions of interest from the movement curves to analyze separately. Afterward, the system calculates and displays, for each segment, a series of measures for each axis, such as the respective movement segment's duration, the area, the length, and the maximum and minimum acceleration values. The segments can, for example, characterize relevant periods in an exercise, which are comparable to the equivalent parts in other executions (sessions) of the same plan.

An important contribution of this work is the implementation of new measures from these curves. Since the system employs polynomial curve fitting, it is possible to extract and show all the coefficients generated by the function to the user. Thus, for a five-degree polynomial fit, SMMAR-T extracts six coefficients for each of the three axes and consider them as measures.

Previously, SMMAR-T used the coefficient of determination (R^2) for two purposes: (1) to verify the curve fit's quality and (2) to compare two curves, for example, with a standard curve of a new movement cycle conducted by a patient, or a reference with another one. Currently, we implemented the DTW algorithm into the system as another similarity measure. In particular, DTW is an algorithm that enables to compare time series with different sizes (number of samples). In the proposal context, the measure makes it possible to find the distance between movements with different duration times. As DTW is a distance function, we converted it to a similarity measure, as defined by (1):

$$S(w, v) = \frac{1}{1 + DTW(w, v)} \quad (1)$$

where $S(w, v)$ is the similarity between the vectors w and v (movement curves, for example), and $DTW(w, v)$ is the dissimilarity value.

In future work, we will extract new measures from these curves. One of them is the ROM for each Cartesian space axis, which our system can analyze dynamically over time. Dynamic, in this context, means that ROM can be collected and examined in real-time during the movement execution. Thus, SMMAR-T will support investigating the range of motion separately for each dimension in a three-dimensional space, while traditional techniques, such as the goniometer, consider this range for a single plane [21]. The ROM relevance emerges from the fact that many experts utilize it for different purposes, such as lesion evaluation, diagnosis, and rehabilitation process follow-up [8], [22].

Another measure that can be obtained is entropy, which is valuable in several works from other areas, such as fault classification and location in transmission lines [23]. It is important to mention that all the measures pre-

viously cited can be extracted from each of the three-axis.

SMMAR-T can provide measures that represent patterns potentially able to differentiate healthy from unhealthy people. This ability occurs because the method automated by the system creates representative standard curves in the three-dimensional space of the Cartesian system. Table 1 summarizes the measures already implemented and the ones proposed in future work.

TABLE 1
MEASURES FOR MOVEMENT ANALYSIS IN THREE DIMENSIONS

Measures	
Originally implemented	Durantion time of the movement realization, area, length, maximum and minimum acceleration values, R^2 similarity
Newly implemented	Polynomial fit coefficients, DTW similarity
Future work	ROM, entropy

It is noteworthy that the abilities of (1) supporting remote and real-time monitoring, (2) standard curve extraction for each patient or groups of patients, and (3) simultaneous analysis of the data for the three coordinate system axes are the main contributions of the system presented in this project.

To the best of our knowledge, SMMAR-T introduced in the state-of-the-art the feature that allows the expert to segment and analyzes specific regions of the movement curves. It also innovated by enabling the health professional to monitor the activities carried out by the patient remotely. Besides, the activity sessions conducted are stored in the server, such that a professional can access the corresponding records at any time. Thus, it is possible to verify, for example, how many times a day a patient conducted each session, as well as the start and end times of each session.

Additionally, the method that SMMAR-T automates requires a single sensor (accelerometer) in a mobile device, not demanding special equipment for data collection.

From the patient activity records stored in the server, the expert can create standard curves for movements of joints and body parts for the three axes of the Cartesian space [11], [12]. These reference curves can represent, for a single individual or a group of individuals, a healthy movement or a displacement associated with morpho-functional changes. They are also candidates to serve as a reference for comparisons with new movement cycles or other standard curves.

In particular, a reference averages a set of movement curves for each axis separately, together with its respective Standard Deviation (SD) – Fig. 1. To do so, firstly, a patient carries out some predefined amount of movement repetitions. Secondly, the expert segments the regions of interest that properly represent the performed activity. Thus, a single patient's reference contains only his/her movement curves, while a reference that represents a

group of patients averages their curves. Note that we can also obtain all measures previously mentioned from standard curves for each axis.

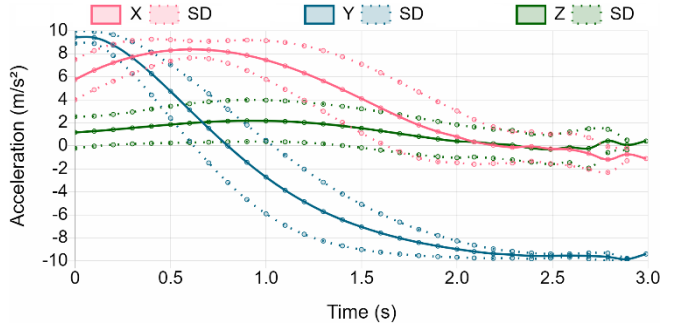


Fig. 1. Pattern curve for shoulder abduction movement carried out by a fictional patient.

Although [7] supports the comparison between an activity and a baseline movement, this baseline is generated from the expert's movement, which cannot represent the real displacement behavior. Also, their method does not allow to recognize errors in the activities. On the other hand, our system allows creating representative standard curves, as previously mentioned. An additional SMMAR-T ability is to support the identification of patients' errors in displacements through the analysis of the corresponding data in the three-dimensional space. Health and informatics experts approved all features presented by us in this work.

Therefore, SMMAR-T can serve as a complete, precise and accurate tool for monitoring and analyzing the patient's movements. Health experts can use it for different applications, such as diagnosis, monitoring the rehabilitation process, preventing and studying injuries.

5 CONCLUSION

SMMAR-T is a computational web system that experts can use to evaluate joints and body parts movements using representative standard curves for each Cartesian system axis. Another important SMMAR-T ability is the support for remote and real-time monitoring of the patient's conduction of activities. The results show that the system is functional and complies with our objective. Future works include (1) the extraction of the new measures, such as ROM and entropy, and (2) the creation of a dataset with movement patterns to ease the tool interaction with machine learning algorithms.

ACKNOWLEDGMENT

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001, Fundação Araucária (Research and Technological Productivity Scholarship 028/2019) and CNPq (process 118196/2020-0). Corresponding author: Huei Diana Lee (huei.lee@unioeste.br).

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