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Software Architecture for the Development of a Collaborative Medical Activities System in the Rehabilitation of Strokes

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Abstract. A person who has had a stroke needs rehabilitation to recover from the effects of the incident. A multidisciplinary team of experts performs rehabilitation, offering treatment from many fields, including neurology, nutrition, psychology, and physiotherapy. In the rehabilitation process, physicians interact with medical computing software and devices. The interactions represent medical activities that follow rehabilitation. Nevertheless, how specialists collaborate to do medical tasks is poorly understood using technologies since no particular means of communication enable interdisciplinary cooperation for integral rehabilitation of strokes. Therefore, we present a collaborative software architecture to assist and enable the monitoring of medical activities through multimodal human-computer interactions. The architecture has three layers: the first is to perceive interactions and monitor activities, the second is to manage information sharing and interdisciplinary access, and the third is to assess how well multidisciplinary activities were carried out. The physicians are assisted in their decision-making on the execution of the treatment plan by evaluating how the activities are carried out, which are recollected through the architecture proposed. As a result, we provide a prototype with a user-centered design that understands how the architecture supports human-computer interactions.

Keywords: Medica activities; architecture; groupware; collaborative activities; rehabilitation of stroke.

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Архитектура программного обеспечения для разработки системы совместной медицинской деятельности при реабилитации инсультов

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Аннотация. Человек, перенесший инсульт, чтобы оправиться от его последствий, нуждается в реабилитации, Многопрофильная команда экспертов проводит реабилитацию, предлагая многоплановое лечение, включая диету, неврологию, психологию и физиотерапию. В процессе реабилитации врачи взаимодействуют с медицинскими приборами и программным обеспечением. Такая работа представляет собой медицинскую врачебную деятельность, сопровождающую процесс реабилитации. Тем не менее, в силу отсутствия подходящих средств взаимодействия, позволяющих осуществлять междисциплинарное сотрудничество при комплексной реабилитации инсультов, способы взаимодействия специалистов, совместно решающих медицинские задачи, технологически понимаются плохо. Поэтому мы представляем совместную программную архитектуру, способную обеспечить мониторинг медицинской деятельности посредством мультимодального взаимодействия человека и компьютера. Архитектура имеет трехуровневое строение: первый уровень служит для восприятия взаимодействия и мониторинга деятельности, второй – для управления обменом информацией и междисциплинарным доступом, а третий – для оценки того, насколько хорошо были выполнены междисциплинарные мероприятия. Врачам помогают в принятии решений по выполнению плана лечения путем оценки того, как выполняются действия, которые рекомендуются предложенной архитектурой. В результате мы предоставляем прототип, спроектированный с ориентацией на пользователя, который понимает, как архитектура поддерживает взаимодействие человека с компьютером.

Ключевые слова: врачебная деятельность; архитектура; рабочая группа; совместная деятельность; реабилитация инсульта.

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1. Introduction

Medical activities are carried out with interactions of various devices. Also, several physicians are involved in rehabilitating patients who have suffered cerebrovascular accidents. A human-computer interaction that allows different modes of data entry is called multimodal [1]. Assume that any interaction of this kind qualifies as a recorded event. In this situation, monitoring medical actions to assess their behavior and efficiency during the event-driven rehabilitation process is feasible. This type of scenario can be represented with the design of user interfaces [2]. For this, it is important to consider that a multidisciplinary team carries out all these activities [3]. Therefore, when receiving the users' multimodal interactions; it is essential to coordinate the activities to maintain a correct record of the executed rehabilitation process. In addition, other aspects that intervene to coordinate events must be considered, such us: How are the activities related? Who or what triggers an activity? How is user collaboration perceived? How to represent the activities to evaluate the progress of the rehabilitation?

Therefore, there is no clear conception of how specialists coordinate to carry out medical activities to evaluate the rehabilitation process of people who have suffered an ictus. Particularly, there are no specific communication channels that allow multidisciplinary collaboration during the whole rehabilitation process. Hence, not having precise coordination of medical activities in a team of specialists collaborating on rehabilitation treatment could prolong care time. Also, maintaining ineffective communication between members regarding the integral treatment activities affects the patient treatment since some indications might be contradictory, so coordination to generate an integral treatment is mandatory and must be guaranteed.

This paper proposes a new collaborative software architecture focused on monitoring medical activities in collaborative teams using a groupware approach that reinforces team coordination, ordering events, and evaluating activities involved in rehabilitating patients who have suffered ictus. Also, we developed a new prototype with a user-centered design that perceives human-computer interactions supported by the new architecture.

This paper is structured as follows. Section 2 describes the state of the art. Section 3 proposes a conceptual architecture for a collaborative system focused on stroke rehabilitation activities. Section 4 shows the user-oriented prototype with the proposed architecture as a base. Finally, section 5 presents the conclusions and future work.

2. State of the art

We explored works that consider a multidisciplinary collaboration for the complete rehabilitation of patients that have suffered a stroke, see Table 1.

The papers in the state-of-the-art review explain case studies of medical situations where collaboration is required. Mainly, they explain an analysis related to how the collaboration is carried out [6-7, 10, 14] and which patient data should be used to generate statistics [6, 9-12, 14-15]. In addition, in some works [10, 14], they establish collaboration measures to evaluate the coordination.

The works [6-7, 10, 14] explain the presence of teamwork, although only [10] and [14] contemplate collaborative activities. In contrast, [6, 9-12, 14-15] perform data treatment with statistical analysis, meta-analysis, and results graphs, but only [8-9, 13-15] have defined a workflow. Therefore, it is reflected that there is little attention to collaborative activities. On the other hand, exploring data processing is necessary since few works have considered workflows and teamwork.

Some papers [16-20] propose an entity relationship diagram to define a database. Other authors established, Workflow for data management [17, 19-20]. Three works [16-17] and [20] provide care in the subacute phase or hospital care. [19] provides care in the acute phase or primary care. [18] focuses on chronic care, which refers to follow-up in rehabilitation. Three authors [17, 19] and [20] defined a workflow, although none of these contemplated teamwork or collaborative activities. In contrast, [16] and [18], even when both included performance teamwork, only [16] approached collaborative activities.

The works [21, 23-26, 28-29] are oriented to the acute phase. [21] and [23] approached their works considering the subacute phase. Instead, [23-24, 26, 28] and [30] focused on the area of critical care. We showed that [21-25] and [27] presented data processing, and only [22, 24-25, 27] and [30] carried out collaborative activities. [21-22] and [24] use teamwork, and [24, 26-27] have a defined workflow. In the works [21-30], they proposed using desktop software, mobile applications, network services, and implementations of robotic arms, video games, and bio-robotic aids to support primary care medical decisions or assistance to develop physical or cognitive rehabilitation. These works generally have focused on primary care treatment or physical or cognitive rehabilitation; however, they do not consider the interaction between the medical team and the patient as part of the rehabilitation encompassing medical care from various specialties, an integral rehabilitation.

Table 1. Comparison of the state of the art works
1 - Acute phase care. 2 - Medical treatment. 3 - Physical and/or cognitive rehabilitation. 4 - Teamwork.
5 - Collaborative activities. 6 - Data treatment. 7 - Defined workflows. 8 - Systems and applications.

Publication	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Obana et al. [6]	✓	✓		✓		✓		
Pristipino et al. [7]		✓		✓				
Watson et al. [8]	✓	✓					✓	
Tiu et al. [9]		✓				✓	✓	
De Lecinana et al. [10]	✓	✓		✓	✓	✓		
Macisaac et al. [11]		✓				✓		
Chowdhury et al. [12]	✓	✓				✓		
Baskar et al. [13]	✓	✓					✓	
Hunter et al. [14]	✓	✓		✓	✓	✓	✓	
Daemen et al. [15]		✓				✓	✓	
Grigoriev et al. [16]		✓		✓	✓	✓		
Esensoy et al. [17]		✓				✓	✓	
Ferrante et al. [18]			✓	✓		✓		
Yang et al. [19]	✓					✓	✓	
Wantaka et al. [20]		✓				✓	✓	
Chang et al. [21]	✓	✓		✓		✓		✓
Gibson et al. [22]				✓	✓	✓		✓
Tang et al. [23]	✓	✓	✓			✓		✓
Sun et al. [24]	✓		✓	✓	✓	✓	✓	✓
Li et [25]	✓				✓	✓		✓
Ilieva et al. [26]	✓		✓				✓	✓
Park et al. [27]					✓	✓	✓	✓
Wang et al. [28]	✓		✓					✓
Ramesh et al. [29]	✓							✓
Tsoupikova et al. [30]			✓		✓			✓

We remark that monitoring and communications are central concerns in the rehabilitation process of stroke patients in the chronic phase. Only a few works have considered the chronic phase and mainly focused on the rehabilitation oriented in developing systems and applications where the patients interact or monitor a particular problem derived from the stroke, leaving behind the communication and coordination of the medical team. There is a significant appearance of works that consider data processing. However, the presence of this characteristic is essential to work with data from collaborative environments to develop applications and implement technologies. Works focused on collaborative environments have considered the development of workflow, teamwork, and collaborative activities. Nevertheless, only one work has contemplated all these characteristics. Instead, only have generated efforts to include one of two of them.

The state-of-the-art review shows a lack of consideration for the communication, collaboration, and monitoring of the activities needed to rehabilitate cerebrovascular accidents in order to evaluate how the treatments and the medical collaboration are helping the patients. As far as we know, no equivalent software or project has been proposed to follow the medical rehabilitation process considering a groupware architecture for collaborative medical activities. Therefore, in this work, we propose monitoring and evaluating the rehabilitation of cerebrovascular accidents, including technological developments and the application of emerging technologies with collaborative activities.

3. Software architecture proposal

This paper presents an architecture for software development to monitor collaborative medical activities for patients suffering from stroke consequences (see Fig. 1). We developed the architecture considering three main layers 1) User presentation layer, 2) Control layer of the multidisciplinary team, and 3) Control layer of medical activities. Besides, a component focused on data administration services is contemplated.

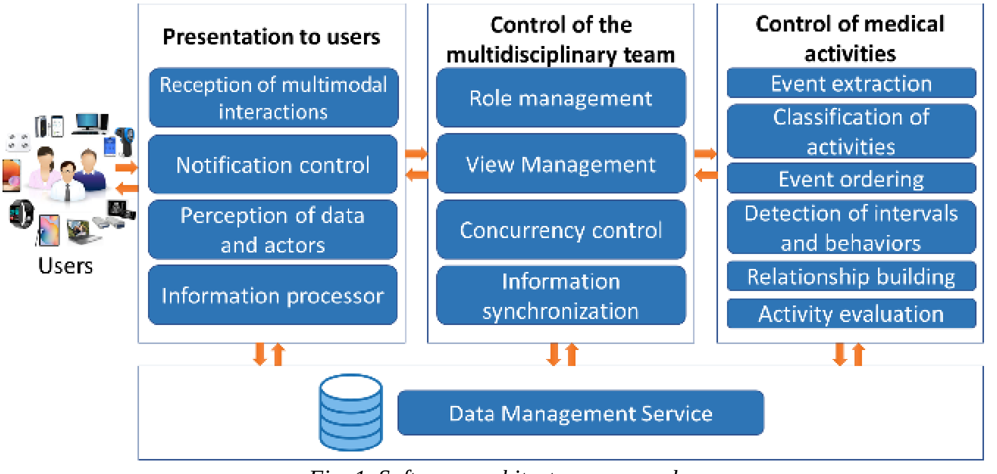

Fig. 1. Software architecture proposal

3.1 User presentation layer

The user presentation layer consists of four components. The first component, “Reception of multimodal interactions,” is designed to receive data interactions from various devices. Therefore, it is considered a multimodal system, which allows data entry from different types of devices, for instance, laptops, tablets, smartphones, and smartwatches. Each human-computer interaction will be recognized as an event logged on to the devices. The data is collected through Wi-Fi or Bluetooth connections between the devices and the application to record the events in an orderly manner according to their appearance over time. Each device will enable the reading of data, such as the manual recording of information, in addition to automatic readings, such as blood pressure, heart rate, and physical activity, among other medical data that smart devices can detect.

The second component is “Notification control”. Controls the sending, receiving, and status checking of notifications, that is, checking if the notification has been sent, received, and read. Notifications can be sorted by importance and use different notification channels such as email, SMS, and smartphone notifications. The notifications will be delivered to users to warn or remember situations, for example: reminding the patient of the date of a medical appointment, informing a specialist of the treatment ordered by another doctor for his patient, request for consultation from one treating doctor to another specialist, to name a few. In addition, since it is a system for medical collaboration, all the specialists who care for a patient must be kept informed of the progress of their treatment and rehabilitation. Therefore, when an activity is carried out that changes or affects this treatment, the participants must be kept informed; so it is important to control the sending and receiving of notifications to users.

The component “Perception of data and actors” involved in treating the patient refers to keeping the participants aware of all the activities carried out as part of the treatment. This component focuses on implementing awareness to perceive the changes made by the actors and controlling the identification of activities. Therefore, the system must identify the significant changes to generate notifications about the changes or actions performed.

The "Information processor" sends and receives user data through communication channels to ensure delivery. This component considers using the AES algorithm for data encryption to maintain the data's security and the information exchange between the system users.

3.2 Control layer of the multidisciplinary team

The control layer of the multidisciplinary team contains four components that aim to address the problems of coordination, collaboration, and communication. The first component is "Role management", assigning permissions and access according to the user's role. For example, a patient will have different permissions than a medic, or a specialist physician will have different permissions than a treating physician. A treating physician is in charge of carrying out the comprehensive follow-up of the patient, while a specialist only focuses on caring for the patient according to his specialty. The treating physician will decide on the appropriate information to share with each specialist.

The "View management" is a component closely linked to the previous one since it on the roles and permissions of the users, the views, or interfaces that each one can have.

We include a "Concurrency control" component focused on controlling the multiple inputs of users simultaneously since we must ensure that each user has updated data according to the activities carried out by each participant. The "Concurrency control" component controls the multiple inputs that can be given simultaneously from different devices to access the system. It provides the consistency of the information according to the events obtained from multimodal human-computer interactions.

The "Information synchronization" component is essential to maintain control of the information. All information entered or registered by users must be synchronized so that, when the data are consulted by any other member from any other device, the latest data processed should be displayed, thus maintaining the integrity of the information.

3.3 Control layer of medical activities

The control layer of medical activities includes six components necessary to process collaborative medical behavior. The first component is "Event extraction", responsible for identifying each event carried out from any device. An event occurs when an action is spontaneously generated by a user/process at any instant within the system to monitor the patient's rehabilitation.

Component, "Classification of activities", groups events into activities since an activity is a set of ordered events. This component is in charge of controlling the activities according to the established treatment. Besides, the "Event ordering" component is focused on registering and maintaining the events' order using a causal algorithm to visualize the events as they have occurred in the system, we can use works such as [31, 32]. The activities are ordered according to the events generated by the users. For example, an activity can be the request of a treating physician for a consultation with a specialist, and this activity is composed of the following events:

- Doctor: Sends the request for consultation by a specialist
- Specialist: Receives the consultation request information
- Patient: Receives the data of the request for a specialist consultation
- Patient: Sends the data of the scheduled time for a consultation with a specialist
- Specialist: Receives information on the consultation schedule
- Doctor: Receives information on the consultation schedule

The fourth component is "Detection of intervals and behaviors" to determine the beginning and end of the activities. In this component, we must identify from the set of events those that represent an interval. An interval is an activity with internal events composed of a subset of total events. On the other hand, detect behaviors refers to the set of events that define a specific activity. In this way, specific activities are detected to evaluate the collaboration in the last component.

The component "Relationships building" establishes the relationships between the sending and receiving data generated in the system. In this sense, it defines the relations between the activities. A weighted graph is used to establish the relationships between the activities.

Finally, the component "Activity evaluation" the evaluation of activities will be the component that processes the activities, events, intervals, behaviors, and relationships. Considering all these factors, it will be in charge of determining the fulfillment of the treatment activities for rehabilitation at a certain point in time. To generate the evaluation, a fuzzy cognitive map will be used to obtain the performance of the group's behavior, according to the activities carried out at a specific time. Thus, according to the evaluation, doctors will be able to analyze whether the activities carried out are effective and adequate according to the treatment recommended in the rehabilitation process.

3.4 Data administration services

This last component is responsible for storing the data and sending and receiving data. Besides, it is responsible for executing the queries and stored procedures for information management. This service must process the information in real-time to be available and accessible from any device that the multidisciplinary team uses as an access point.

4. Prototype of the medical activities

This section shows a prototype representing the events' interactions described in Table 2. The proposed architecture presented in Section 3 has been used as a developed base. Hence, the prototype reflects the action component. However, explaining the medical activities is essential to reflect the architecture in a prototype.

Table 2. Medical activities of multimodal human-computer interactions

NP	Activities
1.	Record of medical indications
2.	Access to study reports
3.	Checking attendance
4.	Measurement of vital signs: Body temperature, Pulse, Respiratory rate, respiration,
5.	Blood pressure
6.	Administrate medication
7.	Physical activity
8.	sleep monitoring
9.	SpO2 sensing
10.	Detect stress levels
11.	Attention to falls
12.	Therapies with augmented reality walks
13.	Exercises with an electrical stimulation machine of interactive therapy
14.	Record of therapies with rehabilitation equipment (balls, dumbbells, mirror boxes, putty)

The list of activities in Table 2 is designed to obtain multimodal data. For example, it is possible to detect a person's physical activity with a smartwatch. More data can be obtained from other devices used during rehabilitation (e.g., Smartphones, PCs, scales, thermometers, ultrasound machines). The medical activities in Table 2 have been considered to develop the prototype. Following, we present the prototype screens, where data on medical activities are obtained from multimodal human-computer interactions.

We remark that activity one is carried out to confirm and attend a medical appointment. Therefore, there are multimodal interactions to execute the complete activity. This activity is composed of four events. In event one, the patient confirms the appointment from his smartphone. Besides, in event 2, the medical doctor receives the confirmation notification, as shown in Fig. 2. In event 3, the medical doctor sends the information from the medical consultation record, an interaction from a laptop. In event 4, the patient receives the information from his medical consultation, providing an exchange from a Tablet, as shown in Fig. 3.

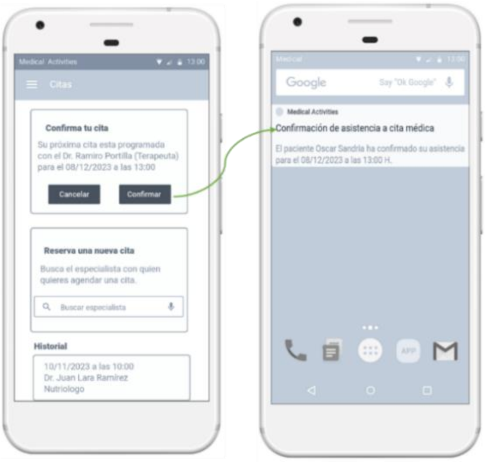

Fig. 2. Screens of the events 1 and 2

Fig. 3. Screens of events 3 and 4

Fig. 3 shows screen A, where a PC displays the medical system. In the system, the medical specialist keeps track of his patients; the doctors also record patient data and treatments. Screen B shows the treatments and medical indications the patient can consult; in this case, the device is a Tablet.

Fig. 4 shows the data collected from devices. In this case, the information from a scale is collected to obtain weight, fat percentage, and muscle, among other data. On the other hand, the data of SYS, DIA, and beats per minute from a blood pressure monitor are obtained. The information can be consulted in the medical system from another device, in this case, from a laptop. The data are collected from the devices via Wi-Fi or Bluetooth, according to the requirements of each device. These prototype screens provide multimodal human-computer interactions of medical activities considered. On the other hand, the internal behavior of the prototype considers the layers mentioned in section 3.

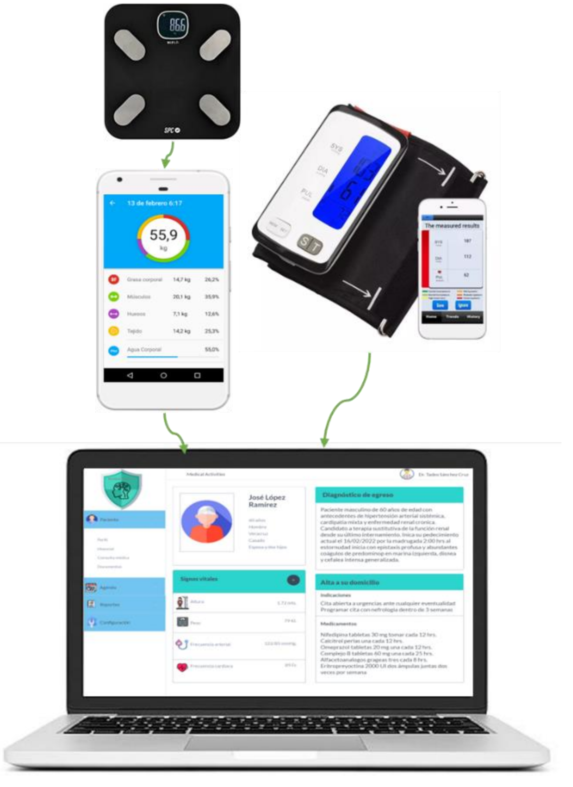

Fig. 4. Representation the data collected from devices

5. Conclusions and future work

In this paper, we proposed an architecture centered on tracking the interactions and teamwork of a medical team that treats patients with the chronic phase of stroke.

The architecture for a collaborative environment enables the collection, comprehension, and control of data produced by multimodal interactions and the coordination of a multidisciplinary team while collaborating with rehabilitating individuals who have had an ictus. We can determine how the medical activities were created to assess the state of the rehabilitation at a certain period from the events collected from the multimodal interactions. This helps the multidisciplinary team see how well the activities assessing rehabilitation progress from implementing the treatment plan created for each patient are working. With this knowledge, medical professionals might suggest modifying the rehabilitation plan or continuing to carry out the previously determined activities.

Future work will involve setting the assessment mechanism into practice with the architecture described to assist doctors who attend stroke rehabilitation in determining if patients comply with treatment regimens.

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