Telerehabilitation Prototype for Postural Disorder Monitoring in Parkinson Disease

Jorge L. Rojas-Arce[1], Luis Jimenez-Angeles[1(✉)], and Jose Antonio Marmolejo-Saucedo[2]

[1] Departamento de Ingenieria en Sistemas Biomedicos, Facultad de Ingenieria, Universidad Nacional Auonoma de Mexico, Mexico City, Mexico
{jorge.rojas.arce,luis.jimenez}@comunidad.unam.mx
[2] Facultad de Ingenieria, Universidad Panamericana, Augusto Rodin 498, 03920 Mexico City, Mexico
jmarmolejo@up.edu.mx

Abstract. The present work shows a telerehabilitation prototype for the monitoring of postural disorders in patients with Parkinson's disease. The design of this prototype originated from a proposal for the identification of business ideas in medical devices. Specifically, the steps that were followed were to detect a need, formulate hypotheses about the problem and the client who faces them in their day-to-day life, then validate them through interviews with clients, to formulate the hypothesis of the solution; and build a prototype that offers value and solves previously detected needs. This prototype allows to make measurements, and eventually corrections of the postures in patients with Parkinson's disease, using devices that can be used remotely as part of the interaction between the doctor and the patient.

Keywords: Telerehabilitation · Parkinson's disease · Business ideas

1 Introduction

The pandemic has accelerated the adoption of tele-health in many countries. In the US, according to Fair Health, the usage of tele-health has increased over 4,300% between March 2019 and March 2020.

When the pandemic will be over many of the services (like prescriptions) will be delivered from remote. Figure 1 shows with the black bar the amount of tele-consultations in 2019 (in %) versus the amount of tele-consultations expected in the post pandemic phase [1].

Tele-health is disrupting the geography of health care. In the coming years we may see the rise of points of excellence providing this service to people all over the world. This tele-service provisioning is bound to create hubs of delivery and the management of the increasing demand will be met, most likely, with automatic response systems, software applications based on artificial intelligence, plus a systematic use of natural language interaction.

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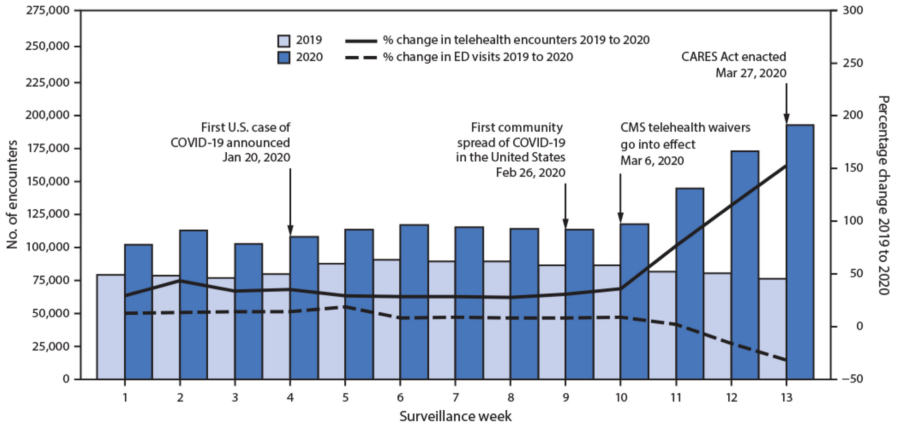

Fig. 1. Figures indicating the usage of tele-health services in the US.

Each patient will have a corresponding healthcare record, recording his vitals (possibly automatically updated in quasi-real time depending on the level of service required), prescriptions taken, plus all the result of exams, consultations and the sequence of his genome. This record will be used by machine learning algorithms to create a model of that person and a variety of software applications will be monitoring both the patient and the potential risk of the environment on that patient. In other words, this shift towards tele-health will be supported, and mediated, by the creation and use of personal digital twins.

Additionally, the delivery of healthcare support, particularly monitoring, using software and personal digital twins can enable continuous consultation (one person may get in touch with her virtual doctor as many times as wished, every single day with a single subscription cost. The increased effort on the provider side is negligible, the perceived advantage on the receiving side is huge. As an additional benefit, the more a person uses the service the more data are being accrued, increasing the provider data space value [1].

The Parkinson's Disease (PD) is a neurological disorder with an overall prevalence of 0.3%, increasing up to more than 3% in the population above 80 years old, and an incidence estimated to range between 5 to 35 cases per 100'000 individuals each year [1]. Its three cardinal motor symptoms are bradykinesia, resting tremor and rigidity, which is clinically defined as the increased resistance in response to the passive motion of joints [2].

In the case of Mexico, the medical device industry is changing, because of new research topics and technological advances related to health. However, there is a situation that, in many cases, is not considered, such as the interaction of users with said devices, which in many cases is limited to obtaining only certain information about health, and/or, when they offer a treatment (therapy) that is only limited to already defined movements, which, in many cases, are not those specifically required by the user.

A medical device is an instrument, apparatus, utensil, machine, including the software for its operation, implantable product or material, diagnostic agent, material, substance or similar product, to be used, alone or in combination, directly or indirectly in beings' humans; with any of the following purposes of use [3].

- Diagnosis, prevention, surveillance, or monitoring, and/or assisting in the treatment of diseases.
- Diagnosis, surveillance or monitoring, treatment, protection, absorption, drainage, or aid in the healing of an injury.
- Substitution, modification or support of the anatomy or a physiological process.
- Life support.
- Control of conception.
- Disinfection of Medical Devices.
- Disinfectant substances.
- Provision of information through an in vitro examination of Samples extracted from the human body, for diagnostic purposes.
- Devices that incorporate tissues of animal and/or human origin, and/or
- Devices used in in vitro fertilization and assisted reproductive technologies.

Hand in hand with knowing the impact of technology, it is also necessary to identify a specific real problem related to the use of technology, from a technical point of view to a commercial aspect. Therefore, entrepreneurial processes to find something that does not yet have a solution or something that has an inappropriate solution is a starting point to talk about business [4]. In fact, in the case of Parkinson's Disease, an assessment of rigidity in an unstructured environment has been poorly investigated since it is hard to achieve with instrumentation currently available [2].

Specifically, in this work is presented a proposal to solve the problem of design, build and put in market many medical devices, whose they are no accepting and buying for patients. The origin of problem to be solved is how to identify business ideas in medical devices.

A methodology is proposed for this problem, which begins with the detection of a need on patients, a hypothesis is formulated about that need and how the patient faces them in their day to day, and then validates them through interviews whomselves. Once validated, a solution hypothesis is formulated; and a prototype is built that offers value and solves patient needs that were previously detected.

To test this proposal, a practical application of this proposal is presented, which shows the generation of a prototype that allows access to a rehabilitation teletherapy, using devices for remote monitoring of the movement of patients with the disease of Parkinson. In the development of this proposal, the online collaboration between the project team and the medical support staff stands out, as well as the online collection of patient information.

2 Methodology

The proposal presented here shows how to establish a business idea with a high probability of commercial success, since it presents an initial validation that is done with the

potential users or clients of the solution proposal that is being presented. This proposal consists of the following steps: detection of a need; formulation of a hypothesis about the problem and the client; validation of the hypothesis of the problem and the client regarding this detected need; formulation of the hypothesis of the solution; and finally, construction of a prototype that offers value to customers, solving previously detected needs. Each of these parts is presented in detail below and put into practice with the case study of patients with Parkinson's disease.

2.1 Detection of a Need

It begins with the detection of a need that motivates the development of a business idea. Specifically, this need is contextualized in the knowledge and experience that the proponent has about the environment where the detection was made. And in the same way, before the detection of this need, a business idea will arise that shows a solution for it.

To show the detection of the need, the storyboard tool [5] was used, which graphically shows how a problematic situation (need) that some customers are suffering is presented and how it is that from a proposed solution a solution is given to this need.

Figure 2 shows how the need was detected for a patient with Parkinson's disease.

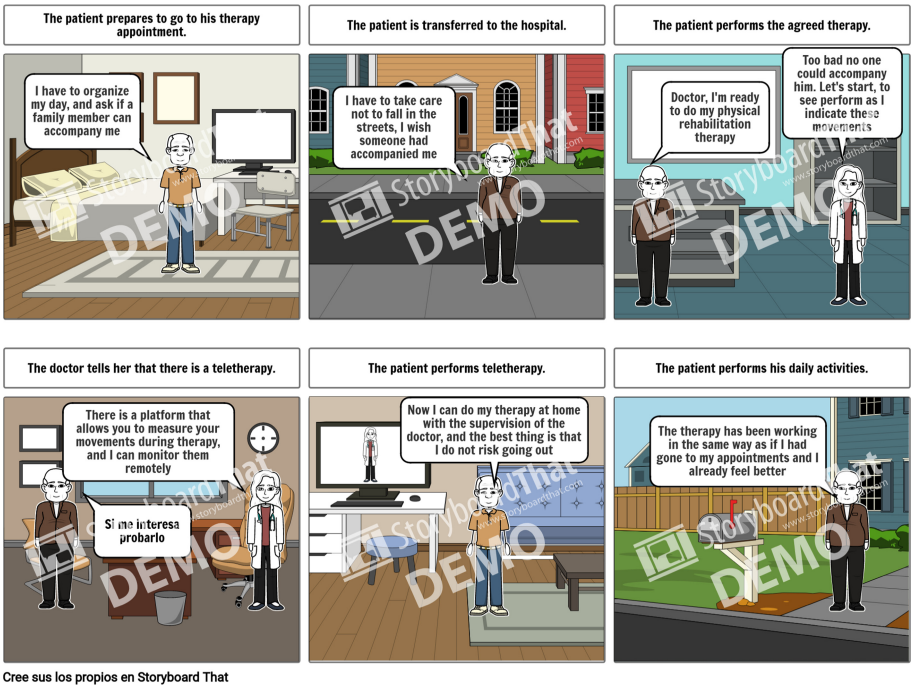

Fig. 2. Figures indicating a proposed solution for Parkinson's patients (storyboard created with the tool www.storyboardthat.com).

As can be seen in Fig. 2 (a)–(c), the daily life of a patient with Parkinson's disease is affected in the performance of their daily activities and is further aggravated by having to move to their therapies in medical institutions. Emphasis is placed on the difficulty of having to move to therapies and in performing therapies under the supervision of the doctor for their proper performance. In turn, Figs. 2 (d)–(e) also show a first approach of what a solution would look like, through a platform that allows physical rehabilitation therapy to be carried out at a distance, with the supervision of a specialist doctor.

2.2 Formulation of a Hypothesis About the Problem and the Client

The next step is to formulate the hypotheses of what is the problem that the clients face, and in turn, establish who those clients are, which will eventually use the proposed solution to be developed.

As a hypothesis of the problem, it is difficult for people with Parkinson's disease to travel to perform their physical rehabilitation therapies in health institutions.

The client's hypothesis is that they are people over 60 years of age who suffer from Parkinson's disease and are already undergoing physical rehabilitation treatment.

Both hypotheses will be validated from a survey of patients with Parkinson's disease to corroborate, or where appropriate, modify what is considered as a problem and client.

2.3 Validation of the Problem Hypothesis and the Client

To validate the hypotheses of the problem and the client previously formulated, a survey was applied, through a questionnaire, this in accordance with the restrictions presented by the COVID-19 pandemic. It should be noted that this questionnaire was carried out through an online tool and that it was applied to patients with Parkinson's disease that could be found through relatives and acquaintances who participated in the project.

As considerations of the questionnaire, it is specified that the responses are collected for scientific purposes only and they will be handled with the highest degree of privacy. At the time of the people responding, they were told not to provide personal data to comply with the aforementioned.

The computer tool for the application of the questionnaires was Google Questionnaires (https://docs.google.com/forms/d/e/1FAIpQLSdRsHYCwPDL3SkMIjV-BkNQtrjeXwo8FpJ7epjREzNhUm89xw/viewform), since it is easy to implement for the creation of a friendly interface with people when answering questions.

The questions that make up the questionnaire are shown in the following table (Table 1):

Table 1. Questionnaire to validate problem and customer hypotheses.

No	Questions
1	Gender:
2	Age:
3	How long have you been with treatment?
4	What is your treatment based on? a) Drugs b) Rehabilitation - Therapy c) Others (specify the patient)
5	Do you consider that your treatment has impacted on your economy?
6	What daily activities do you consider to be difficult to carry out? a) Basic Activities • Bath • Get dressed • Use the toilet • Eat • Get out of bed • Other (specify) b) Activities implemented: • Cook • Carry out household chores • Buy groceries • Taking medications • Traveling only by public transport • Laundry • Make phone calls • Other (specific)
7	During the development of the activities mentioned above, which of the following symptoms are the most recurrent? (You can select more than one) a) Tremors (upper limbs) b) Tremors (lower limbs) c) Muscle stiffness (upper limbs) d) Rigidity (lower limbs) e) Slow movement (bradykinesia) f) Balance problem g) Difficulty writing h) Other (specify)

(*continued*)

Table 1. (*continued*)

No	Questions
8	Of the following symptoms, which one would be the first to fix in the short term? a) Tremors (upper limbs) b) Tremors (lower limbs) c) Muscle stiffness (upper limbs) d) Rigidity (lower limbs) e) Slow movement (bradykinesia) f) Balance problem g) Difficulty writing h) Other (specify)
9	Do you do any physical therapy activities related to your illness? (If the answer is "Yes", go to question 9.1) So b) No 9.1. If the answer to question 9 was "Yes", describe what physical therapy you do
10	Do you currently use any medical equipment to help you with your rehabilitation therapy? Example: wheelchair, special spoons, walking sticks, among others. (If the answer is "Yes", go to question 10.1) 10.1. If the answer to question 10 was "Yes", write what medical equipment you use
11	What is the main difficulty/annoyance you face in your therapy?
12	At home, do exercises help you with your treatment? (If the answer is "Yes", go to question 12.1) 12.1. If the answer to question 12 was "Yes", write what exercises you do
13	Do you think that making use of medical equipment for your therapy at home makes your exercises easier?
14	What savings would you value most? on time b) Money c) Effort
15	What do you think would make therapy more accessible to you?

Some of the results obtained were:

In relation to Fig. 3, it is observed that 44% of those surveyed undergo rehabilitation therapy as treatment, which validates those patients carry out physical rehabilitation therapy activities for their Parkinson's disease.

In relation to Fig. 4, it is observed that the most recurrent symptoms are among tremors (upper limbs), balance problems, and slow movement (bradykinesia), which hinders their daily life, and of course that their transfer to medical appointments to carry out their physical rehabilitation therapies.

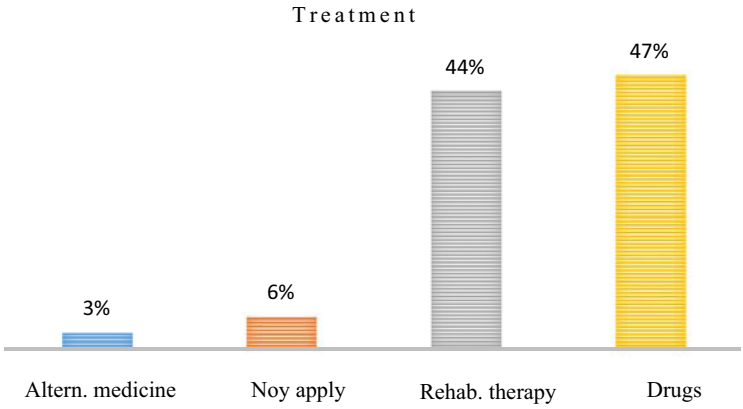

Fig. 3. Treatment carried out by the surveyed patients

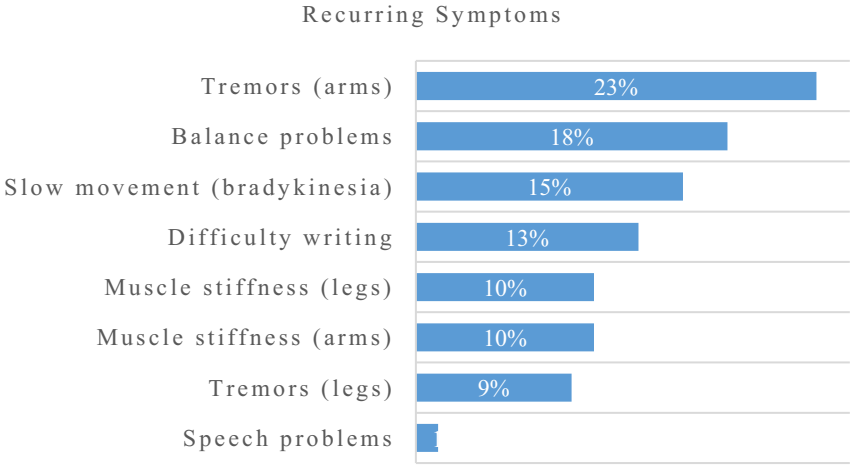

Fig. 4. Treatment carried out by the surveyed patients

Regarding the client's hypothesis, as can be seen in Fig. 5, it is observed that, in fact, patients over 60 years of age are mostly those who attend physical rehabilitation therapies, and that there is no distinction regarding gender.

2.4 Formulation of the Solution Hypothesis

Based on the detected needs of patients with Parkinson's disease, Fig. 3, it is established to think about devising a therapy proposal that they can carry out remotely and avoid going to their doctor's appointments. Beyond the fact of having to be transported, there is the fact of recurrent symptoms, where it takes a greater relevance to perform your rehabilitation physical therapy in the best way.

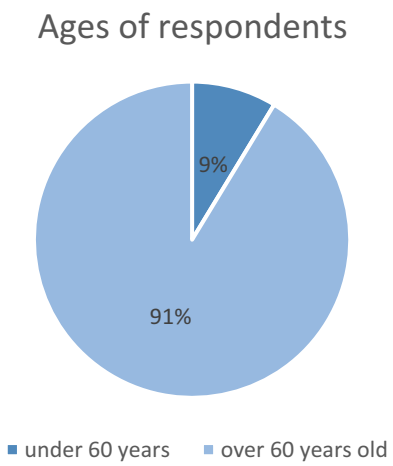

Fig. 5. Ages of the respondents patients

That is why the following solution hypothesis is established: having a technological platform that has electronic devices that allows to monitor the movements of patients remotely to perform a rehabilitation teletherapy.

To validate this solution hypothesis, the lean startup methodology [6] proposes to build a functional prototype that complies with the characteristics that allow to eliminate the detected need. The next step is to build a conceptual prototype so that customers can interact with it at a later stage.

There are symptoms related to Parkinson's disease, such as gait. Table 2 [7] shows the gait measures to take into account for a rehabilitation process; these same measures could be remotely monitored in order to provide adequate assistance when patients are executing it [8].

Table 2. Gait measures to monitor.

Disorders	Gait measures to monitor
Post-stroke	Gait velocity, time-distance measures, joint angles
Anterior cruciate ligament injury	Knee flexion, hip abduction-adduction
Knee replacement	Joint angle at different gait events, ground force reaction
Lower limb osteoarthritis	Gait speed, knee joint angle, hip angle, peak moments of knee extension, hip flexion and ankle plantar-flexion
Spinal cord injury	Gait speed, cadence, stride length
Prosthetics	Range of motion, energy storing, energy cost
Orthoses	Ankle joint angle, stride length

So a prototype platform that measures the march will be built, in order to offer remote guidance and assistance.

2.5 Construction of the Solution Prototype

A practical application of this proposal is presented, where a prototype of a technological platform that allows the quantitative measurement and evaluation of a remote rehabilitation program in individuals with Parkinson's disease is shown. It should be noted that this platform will have devices that allow the collection and analysis of precise and detailed information on the movements of physical therapies in patients with Parkinson's disease.

The proposed prototype consists of continuously monitoring the angles formed by the elbows, shoulders, arms, hips and knees; as well as the number of steps and the postural inclination of an individual with a diagnosis of Parkinson's disease who is under a certain physical rehabilitation therapy.

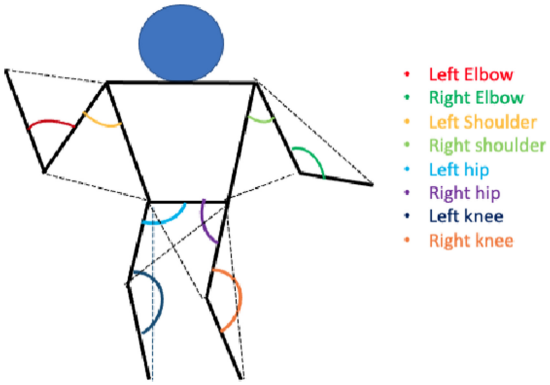

Fig. 6. Identification of angles for continuous monitoring during physical rehabilitation therapy

Figure 6 illustrates the identification and nomenclature of the angles used in continuous monitoring. For the identification and monitoring in real time of these angles, a 5 megapixel resolution video camera was used connected to a Google coral TPU development board [9], allows the use of BlazePose that is a convolutional neural network for high-fidelity body pose tracking, capable to infer 33 3D landmarks on the whole body from RGB video [10], including the shoulders, wrists, elbows, hips, knees and ankles.

3 Results

Figure 7 shows a volunteer subject making repeated movements from left to right, starting from a central position, in order to evaluate the magnitude of the movement of her head and shoulders. In Fig. 7.B are depicted the specific landmarks considered to extract the angles of movement that are graphed in Fig. 7.C.

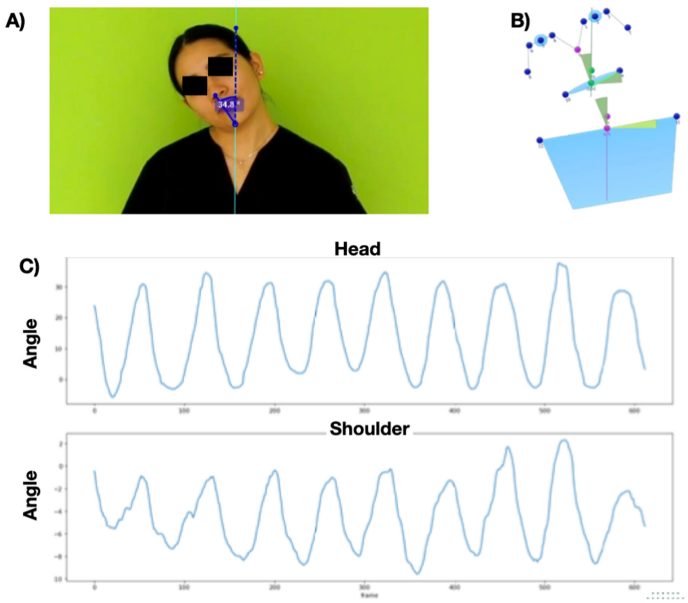

Fig. 7. Head and shoulder movements computed by the proposed system.

Figure 8 shows a volunteer subject with hands on waist, making repeated lateral flexions of trunk. Principal landmarks of mouth, shoulders, back tilt, pelvic tilt, flexion of the left and right elbows were considered to graph their respective angles.

Figure 9 shows a volunteer subject making repeated movements of her right hand touching her left shoulder, starting with the hands at the sides. Principal landmarks for elbows and shoulders were considered to graph their respective angles.

4 Discussions

A proposal was presented for the identification of business ideas in medical devices, highlighting in the first instance the formulation of hypotheses for the problem and the customer to be analyzed. These formulations were validated with surveys of patients with Parkinson's disease. Then a solution hypothesis was formulated that led to the construction of a conceptual functional prototype, which will soon also be validated with the patients.

Regarding the functional prototype, the technological components that make it up are very relevant, that is, those that make up the platform for the realization of physical rehabilitation teletherapy, which will allow monitoring the movements of patients with Parkinson's, in order to influence in the performance of their movements.

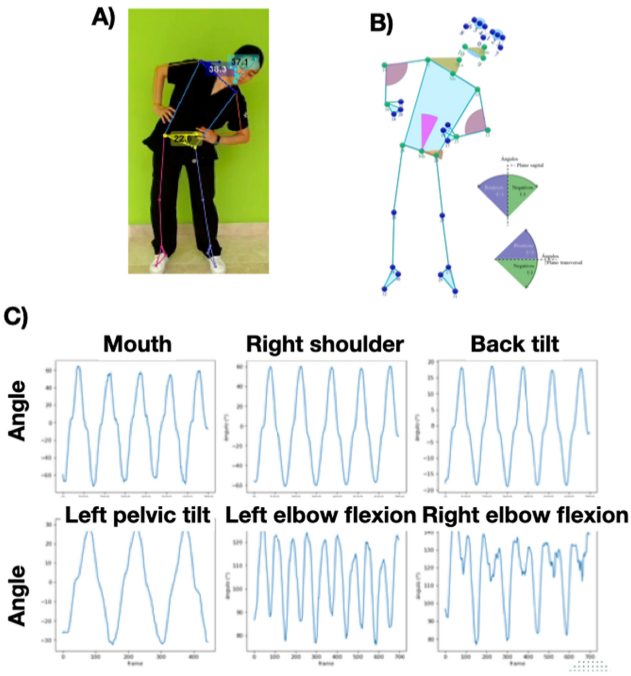

Fig. 8. Movements computed by the proposed system when the subject make repeated lateral flexions of trunk

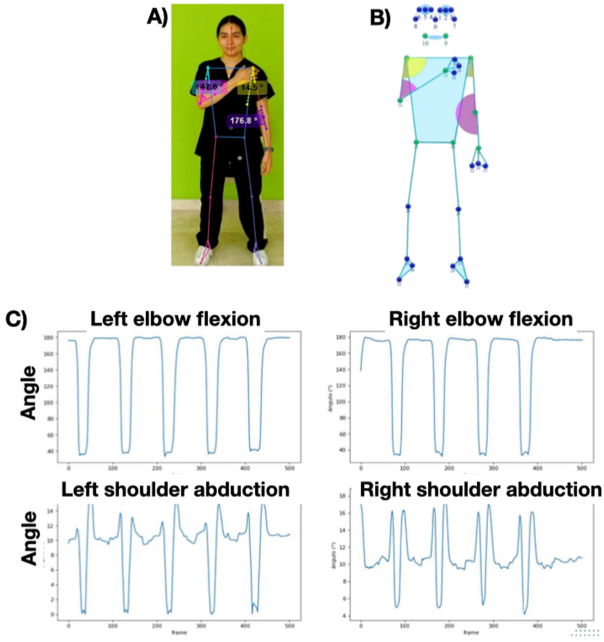

Fig. 9. Movements computed by the proposed system when the subject make repeated contralateral movements of her arms

5 Conclusions

A telerehabilitation prototype for the monitoring of postural disorders in patients with Parkinson's disease proposal was presented. This prototype was based on a methodology por the identification of business ideas in medical devices, highlighting in the first instance the formulation of hypotheses for the problem and the customer to be analyzed. These formulations were validated with surveys of patients with Parkinson's disease. Then a solution hypothesis was formulated that led to the construction of a conceptual functional prototype, which will soon also be validated with the patients.

As is known, gait analysis is usually carried out using subjective and qualitative approaches, such as human observation by the doctor and the opinion of the patient. Therefore, the main quantitative measures that can be derived are cadence, gait speed and distance traveled.

This rehabilitation prototype will provide a platform that will perform and interpret the measurements of the movements of the patients in a quantitative way, thus avoiding the misinterpretations derived from the observation of the doctors, and the opinion of the patients when they are consulted.

Regarding the functional prototype, the technological components that make it up are very relevant, that is, those that make up the platform for the realization of physical rehabilitation teletherapy, which will allow monitoring the movements of patients with Parkinson's, to influence in the performance of their movements.

The information shown in the results makes it possible to identify that it is possible to perform remote measurements in patients with Parkinson's in order to control and improve their movements.

Finally, discussions on the adoption of portable sensors for clinical measurements are being expanded through the review of case studies. The greater the use of these measurement instruments based on technological platforms by doctors and by patients themselves, the appropriate implementation within clinical practice may be required, in this case for patients with Parkinson's disease.

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References

1. Saracco, R.: Post-pandemic Scenarios – XIV – Telehealth. https://cmte.ieee.org/futuredirections/2021/04/16/post-pandemic-scenarios-xiv/. Accessed 10 July 2021
2. Raiano, L., Di Pino, G., Di Biase, L, Tombini, M., Tagliamonte, N.L., Formica, D.: PDMeter: a wrist wereable device for an at-home assessment of the Parkinson's disease rigidity. IEEE Trans. Neural Syst. Rehabil. Eng. **28**(6), 1325–1333 (2020). https://doi.org/10.1109/TNSRE.2020.2987020
3. S., F. La industria de dispositivos médicos en México. https://www.expomed.com.mx/es/conferencias/blog/contenido-dispositivos-medicos/la-industria-de-dispositivos-medicos-en-mexico.html. Accessed 10 July 2021

4. Valencia-Juliao, H.: Panorama del emprendimiento de base tecnológica en la salud. http://www.cienciamx.com/index.php/sociedad/politica-cientifica/16251-panorama-emprendimiento-base-tecnologica-salud. Accessed 10 July 2021
5. Hart, J.: The Art of the Storyboard: A Filmmaker's Introduction. https://books.google.nl/books?id=3WfmPt0gbagC&hl=es. Accessed 10 July 2021
6. Llamas-Fernández, F.J., Fernández-Rodríguez, J.C.: La metodología Lean Startup: desarrollo y aplicación para el emprendimiento. https://doi.org/10.21158/01208160.n84.2018.1918. Accessed 10 July 2021
7. Chen, S., Lach, J., Lo, B., Yang, G.Z.: Towards pervasive gait analysis with wearable sensors: a systematic review. J. Biomed. Health Inform. **14**(8), 1521–1537 (2016). https://doi.org/10.1109/JBHI.2016.2608720
8. Chen, Y., Shen, C., Wei, X.S., Liu, L., Yang, J.: Adversarial posenet: a structure-aware convolutional network for human pose estimation. In: Proceedings of the IEEE International Conference on Computer Vision, pp. 1212–1221 (2017)
9. Cass, S.: Taking AI to the edge: Google's TPU now comes in a maker-friendly package. IEEE Spectr. **56**(5), 16–17 (2019)
10. Bazarevsky, V., et al.: BlazePose: on-device real-time body pose tracking. arXiv preprint arXiv:2006.10204 (2020)