v. 3, n. 8, 2023

International Journal of Health Science

AN IOT-BASED SYSTEM FOR PREVENTING FALLS IN ELDERLY PEOPLE IN HOME CARE

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Resume: Falls in the elderly at home are a highly prevalent public health problem, associated with high rates of morbidity and mortality, decreased mobility and functionality, limitations in activities of daily living, increased susceptibility to diseases, hospitalization, institutionalization and use of social and health services, entailing high costs for the public and private sectors. The technologies and strategies present in the market are effective in detecting falls, but do not contribute to their prevention. The techniques currently used, such as restricting the patient to bed, are generally not well accepted by their families and caregivers. Therefore, there was an opportunity to develop a system based on the Internet of Things (IoT) that acts in the prevention of falls in a non-invasive way. The present work aims to demonstrate the development process, the preliminary results obtained from the proof of concept of the system, the subsequent phases of development, as well as the differentials and potential benefits in relation to other technologies.

CONTEXT AND MOTIVATION

Senescence, which is the natural aging process, can bring with it physical and mental disorders and diseases characteristic of this age period. Such changes lead to greater sensitivity and functional vulnerabilities in the elderly, which leads to an increased risk of falls, making them more susceptible (1).

Falls in the elderly at home are a highly prevalent public health problem, associated with high rates of morbidity and mortality, decreased mobility and functionality, limitations in activities of daily living, increased susceptibility to diseases, hospitalization, institutionalization and use of social and health services, resulting in high costs (2).

The search for ways to avoid or minimize the risk of falls in the elderly is extremely important, as they can significantly collaborate in carrying out preventive strategies, thus avoiding such repercussions.

Within this context, one can see the importance of information technology combined with preventive strategies in the health area. The term IoT conceptualizes a computing system of interrelated mechanical and digital devices, objects, or people equipped with unique identifiers and the ability to transfer data across a network (3). The Internet of Things can significantly contribute to the health service, enabling the development of systems capable of collecting and transmitting data to intelligent terminals in the form of solutions for various everyday problems, such as the detection of risk of falls, a proposed solution that makes up the object of this research.

It was noticed, therefore, that despite the constant evolutions on the subject, there is still a need for advancement in the types of technologies that are efficient and effective for the early detection of the attempt to get out of bed by the elderly patient, so that we can prevent the occurrence of falls in this public. With this, the objective was to develop a proof of concept for a system based on an analysis of the weight distribution in the bed using load cells aimed at preventing falls in elderly people assisted in home care.

SOLUTION DESCRIPTION

The method selected to solve the problem presented here was the MIDTS: interdisciplinary method for the development of health technologies. According to FILHO, "these principles are important for projects that aim to serve the user with quality in the context of the use of health technologies"(4).

The MIDTS consists of 2 phases, each with specific activities. The first phase accommodates deepening the problem, identifying needs and designing solutions, the second phase aims at prototyping the selected solution, evaluating and recording the results. The results obtained in each activity are described below.

PROTOTYPE DEVELOPMENT

First, the interdisciplinary team met to immerse themselves in the problem and formulate a hypothesis, which served as the research's guiding question. On the occasion, a preliminary study was presented on the incidence of falls in elderly people in *home care*, carried out from the database provided by Unimed Fortaleza.

Based on the data analyzed in relation to age, it was observed that there was a prevalence of cases registered in elderly patients, where the majority were over 75 years old (79%), followed by the age group from 61 to 75 years old (14%). It was possible to verify that most occurrences of falls were from patients who walk with assistance, with 117 reports, followed by bedridden patients, with 84 records. It was observed that those elderly people who received monitoring and daily care by caregivers were the ones who most reported falls at home, with 124 reports (61%), followed by family members with 72 records (36%). There was a predominance of falls at night, with 92 cases (46%) and, with a very similar frequency, falls occurred in the morning, with 87 cases (43%). It was also noticed that in most cases the fall occurred in the Bedroom, with 124 records (61%), followed by the Bathroom with 42 reports of falls (21%).

The result of an initial search for technologies that support the detection or prevention of falls in these patients was also presented. This research revealed that some wearable devices, such as straps, smart bracelets (5), and other techniques such as patient restraint, are the most commonly applied strategies in this scenario. However, these methods and devices are quite invasive and cause a lot of discomfort to the patient, and for this reason they are not considered healthy for their quality of life by their relatives. Therefore, it was hypothesized that artificial *intelligence or Internet of Things* (IoT) has the potential to solve this problem through pattern detection.

It must be noted, from the perspective of data sensitivity and privacy, that this project was duly submitted and approved by the ethics committee, through Plataforma Brasil, CAAE nº 59625922.0.0000.5052. There is no need to collect data from users, patients or caregivers at the current stage of development.

Then, the team conducted a needs and requirements survey, through the design of personas and scenarios (6). Personas are fictional representations of one or more real groups of potential technology users. Scenarios are contextualizations of these personas in real situations of use. This exercise in empathy provides the development team with a more faithful perspective of the users' needs, as well as support in verifying any problems that may occur during the use of the solution. At the end of this activity, a list of functional (FR) and non-functional (NFR) requirements of the system was obtained, as shown in Table 1.

Requisite	Description	Priority
FR 1. Risk detection	The system must automatically detect, through variations between weights, the patient's intention to get up	Essential
FR 2. Audible alarm	The system must emit an audible alarm when detecting the intention to get up so that the caregiver or family member can help the elderly person	Essential
NFR 1. Good usability	The system must have a good arrangement of information and elements in order to promote navigation in an easy and intuitive way	Important

Table 1 - Examples of requirements

From the requirements definition, the team matured the initial hypothesis, formulating the first solution concept for the problem. In this sense, a technology based on the internet of things, or IoT, was proposed, which would be able to detect the risk of falling in the elderly through load sensors installed at the foot of the beds of these patients. Other alternatives were considered, such as installing cameras in homes (7-9), but with computer vision algorithms capable of detecting risk. However, this second would demand a higher cost for development, as well as involve other more complex success factors, such as lighting quality or the device's image. It could also impact legal aspects such as image privacy.

Figure 1 presents the initial outline of the solution's architecture.

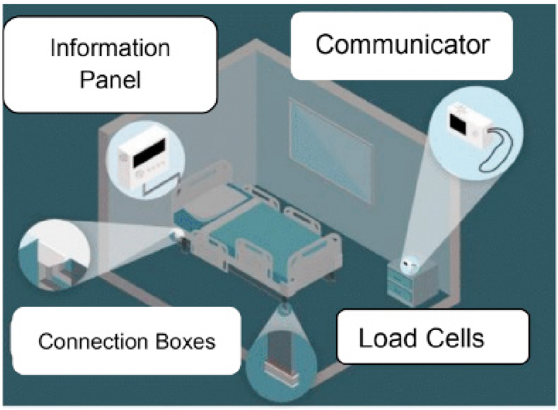

Figure 1. Solution architecture sketch

Before developing the project on a real hospital bed, it was decided to develop a proof of concept on a smaller scale to validate the use of these sensors in differentiating positions. For the development of the prototype, two ESP32's microcontrollers were used, dividing the bed into upper and lower parts. Each controller is associated with two HX711 amplifier modules, which in turn amplify the signals coming from the load cell sensors, connected to the foot of the bed, responsible for capturing the weights. An illustration of the circuit assembly can be seen in figure 2.

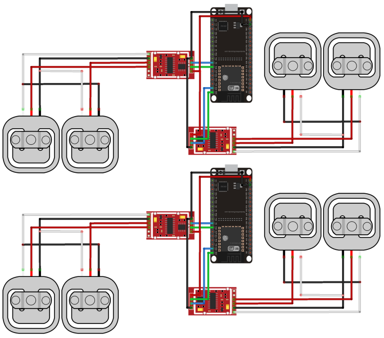

Figure 2. Prototype circuit

For assembly, a support was printed on the 3D printer to adapt the cells to flat surfaces, facilitating their attachment and improving the reading of the weights. A total of 8 load cells were fixed, 2 at each end of the prototype. As each cell supports up to 50 kilos, the proposed system can weigh loads of up to 400 kilos. It is possible to see the final assembly of the proposed system in figure 3.

Figure 3. Lower part of the prototype with the 8 fixed load cells

TESTS AND PARTIAL RESULTS

As part of collecting the sampled data, a fixed sequence was performed based on a possible patient movement scenario, in order to test the detection of the main positions. The sequence and their respective positions are:

1. Bed without patient: Initially, the system starts with no patient in the bed to calibrate the weight of the bed without anyone;
2. Patient sitting on the right edge: Simulating that the patient is getting into bed on the right edge;
3. Patient lying in the middle: Simulating that the patient is lying in bed;
4. Patient facing right: Simulating that the patient rotated to the right, indicating a possible risk of falling;
5. Patient lying in the middle: Indicating that the patient has returned to the normal position;
6. Patient facing left: Simulating that the patient rotated to the left, indicating a possible risk of falling;
7. Patient lying in the middle: Indicating that the patient has returned to the normal position;
8. Patient raised the torso: Simulating that the patient is sitting on the bed, but is not on any of the edges.
9. Patient on the left edge: Simulating that the patient is sitting on the left edge of the bed, indicating a possible risk of falling.
10. Bed without patient: Indicating that the patient is no longer being detected in the bed.

The scenario was performed using the developed proof of concept, and a 10 kg dumbbell to simulate the patient. Markings were placed on the surface of the prototype to identify the positions and facilitate positioning during the tests, figure 4 illustrates some of the tests and the prototype with its markings.

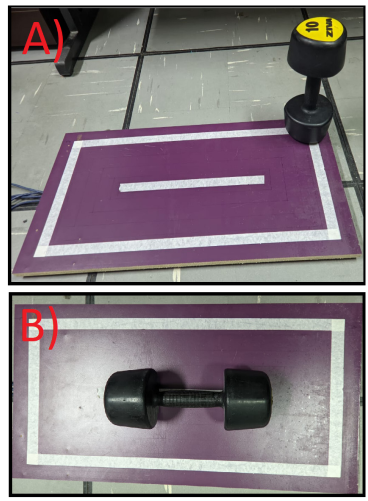

Figure 4. Tests with the prototype. A) Simulation of the patient on the left edge, stage 9 of the scenario; B) Simulation of the patient lying in the middle of the bed, steps 3, 5 and 7 of the scenario.

Before starting the collection, the behavior of the weight distribution at the 4 ends of the prototype was studied, in each of the 10 stages of the scenario. At the end of the study, weight distributions were obtained according to Table 2. Points A, B, C and D represent the lower left, lower right, upper left and upper right ends, respectively.

Steps 1 and 10 were not accounted for in the tests because they dealt with the absence of load, that is, when the patient is not on the bed.

Thus, these cases are detected by the absence of charge and not by their distribution.

Phases	Point A	Point B	Point C	Point D
2	10,53%	**67,76%**	5,26%	16,45%
3	**19,40%**	**29,10%**	**23,88%**	**27,61%**
4	5,26%	**41,35%**	3,76%	**49,62%**
5	**20,00%**	**28,15%**	**23,70%**	**28,15%**
6	**33,33%**	16,30%	**40,74%**	9,63%
7	**19,40%**	**28,36%**	**23,88%**	**28,36%**
8	**39,86%**	**48,55%**	1,45%	10,14%
9	**73,05%**	18,44%	5,67%	2,84%

Table 2 - Distribution of weights in each stage of the scenario

Table 2 was completed, in each of the stages, the points that stood out the most, that is, the points where they were most loaded. With this, it can be seen that it is possible to differentiate the position of the patient by analyzing the distribution of loads on the four extremities.

All weight measurements are sent to a dashboard developed in Node-Red that illustrates, through graphics, the weights at each end and an overview of the load distribution between the 4 points. Each graph shows a weight-by-time distribution for each end of the bed, minus the center graph which shows an overview of the 4 ends at the current time. The dashboard is responsible for indicating the current state of the patient, which can be: absent patient, patient facing right, patient facing left, patient sitting, patient on the right edge, patient on the left edge or patient lying in the middle. If the patient remains in a risk position, an alarm signal is sent. This interface can be seen in Figure 5.

Figure 5 - *Dashboard* for data visualization

The results of data collection are shown in Table 3. For each step, the following parameters were collected: The time for detection of the change in position, if the system correctly detected the patient's position, if it could not detect the position or if it detected partially (when it took more than 5 seconds to update), or when it fluctuated between two or more different positions.

Average time to update	3.13 ± 0.92 seconds
Update < 5s	257
Update > from 5s	13
Total samples	270
Best case	1.08 seconds
Worst case	6.5 seconds

Table 3 - Results of load tests

At the end of the tests, 270 samples were collected, the times of the first detections were not counted, as the scenario started with the patient out of bed, so the system started in the right state and did not need to update. Through Table 3, it can be seen that the mean time to detect and update the patient's position is approximately 3.13 seconds with a standard deviation of 0.92. The low standard deviation indicates that the system does not vary much in response time, remaining between 2 and 4 seconds. It is also possible to note that in 95.18% of the cases the system responded with a shorter time than the stipulated, maximum detection time of 5 seconds. There were no cases in the tests where the system detected the wrong position or that it oscillated between more than one position.

RELEVANT POINTS OF INNOVATION

By simulating the weight of the patient's body in his bed and possible movements which he himself could perform, it was observed that the use of the proposed device will be able to prevent a possible accident due to a fall by triggering safety alarms. From this, it can be verified that the results of the tests performed during the development of the proof of concept are within a grade of the accepted value. Therefore, it is enough to make a safe assumption that the device will help to reduce accidents due to falls and the impacts that these can have on the health of the elderly, their family, community and health system.

It was observed that in the devices found in the literature, the use of technologies with high degrees of sensitivity and specificity was valued, with the need for video, sound and vibrating resources that detect the occurrence of a fall with a high degree of sophistication, and cost per times also high.

The importance of the sensor that is under development is due to several aspects. Among them, it can be mentioned that it will be able to detect the movement that precedes the fall, making it possible to prevent the incident. In addition, it is a technology that is not attached to the patient's body, allowing comfort and preservation of mobility and performance of activities of daily living such as patient hygiene.

Furthermore, this prototype is not influenced by the external environment as it is located at the foot of the patient's bed and the determining factor will be the weight variation that will occur when moving on the bed.

FINAL CONSIDERATIONS

In light of the progress of the project to its present stage, it was possible to conclude that it is feasible and possible to determine and consequently detect patterns of load distribution, through the proposed sensor architecture. This will enable the team to advance in full-scale prototyping and the design of other system artifacts.

In subsequent phases, the team will have to determine the fixed standards for detecting the patient's positioning, as well as the acceptable variations for the system's configuration, using beds and real people. After configuring the audible alarm, clinical tests will be carried out with a sample of people to verify this functionality.

ACKNOWLEDGMENTS

We thank ''Universidade de Fortaleza", more specifically the VORTEX Laboratory team and the Technology Directorate of ''Universidade de Fortaleza" for supporting this research. As well as Unimed Fortaleza, for allowing access to their stats related to the subject. And health professionals for providing insightful information regarding patients' needs.

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