A Survey of Fall Prevention Systems Implemented on Smart Walkers*

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***Abstract*— A large number of people die around the world in consequence of a fall. The costs related to fatal and non-fatal falls have an enormous impact on society and have been growing over the years. There are several risk factors that increase the probability of falling, such as poor balance and lower extremity weakness. Patients with balance impairment, in order to overcome these problems, use walkers. The aim of this work is to do an analysis of the fall-related strategies already implemented in a smart walker. Therefore, an online search was performed based on the literature through Scopus and Web of Science databases. A study was also conducted on a commercial level on Google, as well as a patent review on Espacenet and United States Trademark Office. It was possible to conclude that exist a concern related to the development of an approach to prevent the fall event. However, the only implemented strategy that was found throughout this research consists in stopping the walker when a near fall is detected.**

I. INTRODUCTION

Falling is actually a huge concern nowadays. According to the World Health Organization (WHO), ”Falls are the second leading cause of accidental or unintentional injury deaths worldwide”. About 646 000 people die each year from fall around the world. Medical care is needed for 37.3 million falls that occur each year [1].

The cost associated with non-fatal falls and fatal falls represent an economic burden to society. In 2012, a fatal fall cost an average of $25.487 and direct costs were estimated at $616.5 million. In relation to non- fatal falls, in 2012, a fall cost $9463 and in total the costs were $30.3 billion. In 2015, the costs associated with fatal and non-fatal falls increase to about $637.2 million and $31.3 billion, respectively [2].

A person can suffer different injuries when falls, such as dislocations, head injuries, laceration, hematomas, and fractures [3], [4]. Nevertheless, consequences associated with the inability to stand up also happen, for instance, dehydration, hypothermia, pressure injuries and pneumonia [3]. Other effects, such as depression, fear of falling and limitation in activities are connected to fall events [3], [4].

There are several risk factors that contribute or increase the likelihood of falling. The risk factors can be divided in two types: intrinsic risk factors which are related to the patients, and extrinsic risk factors which are associated with the surrounding environment [5]. Falls in the elderly population are usually related to age, such as dizziness, acute sudden symptoms (for instance, mental confusion, arrhythmias, vertigo, and hypoglycemia) and chronic symptoms (such as lower extremity weakness, dementia, and poor balance) [5]. The environmental risks [5], [6], such as tripping or slipping, poor lighting, and inappropriate shoes wear as well contribute to falling. Falls can occur in different scenarios and in many ways. There are different types of falls, for example forward, backward and sideward falls [7].

For elderly people, assistive devices are particularly important due to the consequences of age-related diseases and neurological diseases. These devices have some benefits, such as improving the balance, reducing the load on the lower limb and assist propulsion [8]. The prescription of an assistive device should be done very carefully, and it is necessary to take in consideration clinical characteristics as vision, cognitive function, muscle force, motor capacitive, among others [9]. The walker is an example of an assistive device, and it is used to provide partial body weight support and to improve the dynamic and static stability. Over the time, assistive devices have changed, mainly because of electronic incorporation, i.e., human-machine interface, sensors, and control [9]. Besides, there is a concern in preventing falls with smart walkers. Thus, the main focus of this paper is the discrimination of strategies already developed in this regard.

The rest of the paper is organized as follows. In section II, it is handled the mechanisms existents in the literature which help to prevent the fall event. This section focus on sensors and strategies implemented. In section III, it is present the commercial smart walkers found that help to prevent the user from falling. In section IV, the patents of the smart walkers related to prevent fall are shown. Finally, section V contains the conclusion.

II. SMART WALKER IN LITERATURE

A. *Search Strategy*

In order to know which are the smart walkers that exist in the literature, an online search was performed. On October 22nd a search was realized on Scopus and on the Web of Science. The select keywords used from search were (”Walking support” AND fall), (”Smart walker” AND fall), (”Smart rollators”), and (”Walking-aid” AND fall).

The search focused on walkers that have some electronic system that allows to predict and prevent the user from fall. The points of interest during the analysis of the systems were the sensors used, their location in the walker, and the strategy developed to predict or prevent the fall event.

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B. Search Results

The nine smart walkers found during the search are described below. More specifically, the strategies implemented to detect or prevent a fall.

RT Walker is a passive device used in three studies [10]–[12]. This assistive device has rear wheels with powder brakes which enable changing the torque according to the current applied. All the systems developed in these works when near fall is detected, the walker stops to prevent the fall. In article [10], two laser range finder (LRF) are used. One is located at the same level as the user's hip to calculate the distance along the vertical direction between the walker and the user. The other sensor is placed at the base of the walker and measures the distance between the user's leg and the walker. Based on the information of the LRF is generated the 7-link human model. Next, a stability region is determined based on support polygon formed by the walker and the feet of the user. The system detects that the user may fall when the center of gravity is out of the region of stability and based on user's walking characteristics.

In article [11], the device has two stereo cameras (SC) in order to track the head, hand, shoulder, and hips. Thus, a 3D upper body model is obtained. The 3D coordinates of the parts of the body were used to classify the state normal walking, sitting, standing and falling. In article [12], the walker has a depth camera (DC) that enables the extraction of the upper body centroid position. In order to detect human action (standing, walking, sit, fall right, fall left, fall back, fall down, and fall forward) two approaches were used, namely, multivariate normal distribution function and Hidden Markov Models (HMMs). The first approach mentioned the detection of 96.25% of the falls, and the second one approach detected 98.75% of the falls. However, the HMM-based method shows a false positive detection fall rate of 8.75% while normal distribution shows 2.5%. All the aforementioned articles stop the walker when a near fall occurs.

Xu et al. [13] developed an approach to prevent the user of the walking-aid robot from falling. Two human motion intention (HMI) were studied, the upper and lower limbs of the user. The force sensors (FSs) were positioned on the handle to monitor the user's upper limbs, and the LRF was placed on the lower half walker to monitor user's leg movement. A state of normal and abnormal gait were distinguished in this work, and in the first state different falls can occur, falling forward, to the left and to the right. The support vector machine (SVM) was the approach used to classify the state of walking and, consequently, detect when a near fall occurs. In this case, the robot stops moving.

Irgenfried et al. [14] developed a device that uses a 6D-force/torque sensor (FTS) for connecting the walker with the handlebar. A mathematical model of the body was used to help identify possible fall situations in FTS signal. Stumbling were simulated to test the system, and the results showed a peak in the sensor values that can be used to detect a possible fall. In order to prevent a fall, the walker will stop.

Huang et al. [15] used wearable and non-wearable sensors to detect possible falls. A tri-axial accelerometer (Acc), a tri-axial magnetometer (Mag), and a tri-axial gyroscope (Gyro) were positioned on the waist, two thighs, and two shanks to calculate the acceleration and the angular velocity. The FSs used on handlebar enable to obtain the forward and lateral force, and rotation torque of the walker. A center of pressure (COP) is extracted, and next, the authors calculated a relative position between the midpoint of feet and COP. Which enable known whether the falls is along the horizontal direction. In order to detect the vertical falls was calculate the height of human waist. The fuzzy threshold was the approach implemented to detect the fall. Falls performed were along the vertical direction due to weakness in the legs and two types of falls along the horizontal direction, namely, falling forward and falling to the left side. When a fall is detected the walker brakes.

Mou et al. [16] and Azqueta-Gavaldon et al. [17] developed a walker assistive device targeted to Parkinson's disease patients and the elderly. The first authors, in order to analyze the gait, namely, step length, velocity, and acceleration of each leg in each step, used a LRF. The FSs were placed on the handle in order to know when the user is turning, push, pull, and going backward. It is important to emphasize that the standard deviation of velocity and step length were recorded. The tests were performed with Parkinson's disease patients. Based on the gait analysis, through an adaptative HMM was possible to classify the three kinds of gaits (festinating gait, freezing of gait and normal gait). In order to prevent the user from falling when the sudden push is detected the walker stops.

Azqueta-Gavaldon et al. [17] developed a system that monitors the walking movement of the user. The rollator has a depth camera (DC) placed at the same height as the rollator seat. This sensor will measure the distance between the user's leg and the rollator. In order to test the system, three different possible falling situations were tested, freezing of limbs, stumble, and loss of balance (all forward falls). It is important to highlight that the tests were performed by healthy people. However, the system was designed for people with lower reflex, so it is important to test the system with these patients instead with healthy people. When the distance between the user and the rollator is higher than a threshold, the rollator stops to prevent the fall (the delay in brake activations is 80-90s). The overall accuracy was 95% and the precision was 93% of the braking system.

Martins et al. [18] developed a system that uses an infrared (IF) sensor placed at the height of the chest in the smart walker, in order to measure the distance from the user to the walker. Based on this distance an algorithm was developed to detect a forward fall because in these events the distance will decrease abruptly. In this case, the walker stops. Regarding backward falls, two FSs were placed on each handlebar, and if the user does not have his hand on the handlebar the walker stops. The same happens when the user does not have the forearm in forearm support. In this case, it detects by using FSs. Note that the walker does not move backward, thus if the user pulls the walker, the walker stops.

It is possible to note that different sensors are used in order to detect a possible fall event. The FSs are used in handlebar to monitor the upper limbs as well as the LRF placed on the upper part of the walker. On the other hand, the LRF placed in lower part of the walker allows monitoring the lower limbs of the user. The cameras are used to track the head, shoulder, and hips, to calculate body centroid and to track the lower limbs. The wearable sensors are used only in one study. They are placed on the waist, thighs, and shanks. Fig. 1 resumes all sensors' locations discriminated in the above-mentioned studies.

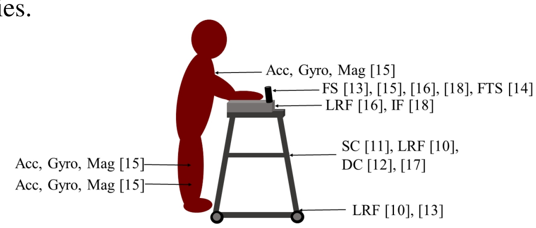


Fig. 1: Scheme of the sensors' location of the smart walkers found in the literature.

III. COMMERCIAL SMART WALKER

A. Search Strategy

A search was performed on Google in order to know which smart walkers are commercially available. In this search, only the walkers with the characteristics mentioned in the previous section were included.

B. Search Results

Two smart walkers were found, namely, RT.1 [19] and RT.2 [20]. These smart walkers provide a few particularities that became the using of walker more attractive. When the user is on uphill the torque is automatically controlled, and on downhills the brake torque is also automatically controlled which facilitates its use. In the case of lateral inclination is possible to walk straight despite the gravity. If the user releases the walker on the slope unintentionally (detect by the sensor in the grip), the walker stops. This would not happen in standard walkers. When there is an abrupt increase in speed for some reason, for instance, a fall, the speed will decrease due to automatic braking [19], [20]. The RT.1 provides other services related to internet of things [19].

IV. SMART WALKER PATENTS

A. Search Strategy

Between October 31st to November 4th an advanced patent search was performed on United States Patent and Trademark Office (http://patft.uspto.gov). On November 10th was performed another search patent on Espacenet (https://worldwide.espacenet.com). The selected keywords were [(”walker”) AND (”near-fall” OR ”falling” OR ”fall prediction” OR ”fall detection” OR ”fall prevention”)]. The selection of patents was performed in three steps, first based on the title, second based on abstracts and schemes, and ultimately based on the full text. It is noteworthy that this search only included electronic systems implemented in walkers that can prevent or detect falls.

B. Search Results

At the end of the process, a total of 10 patents were selected related to walkers. On United States Patent Trademark Office was found 17550 patents and 126 patents on Espacenet. After eliminating the duplicate patents and based on title, 201 patents were selected. Based on abstracts and drawing, 185 patents were excluded. Finally, based on full text, 10 patents were selected, where 8 were from States Patent Trademark Office and 2 from Espacenet. Only three patents of the eleven that are most closely related to the concepts developed in the previous section will be presented. Fig. 2 shows a flow diagram of the whole process for selecting patents.

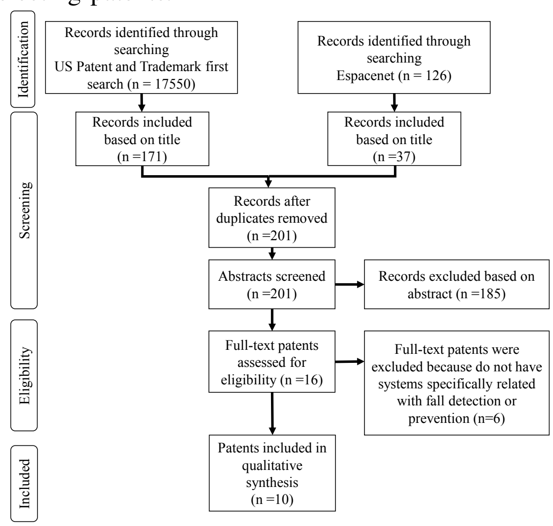


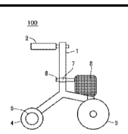
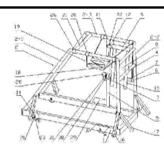
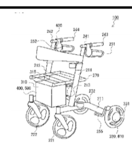
Fig. 2: Flow Diagram based on PRISMA flowchart.

The ”Walking assistive device” (Table I) approach is based on distance to prevent the user from falling. This walker has a distance detection sensor, which enables the measurement of the distance between the walker and the user, and a control unit to control the driving unit that moves the walker. If the distance measured between the walker and the user is out of the safety distance range, the control unit will actuate in the motor, and determine its rotation in order to prevent the user from falling. In this patent, other embodiments are addressed based on distance as well. One of these embodiments uses also an inclination sensor that calculates the angle of inclination and sends it to the safety distance range setting unit. Other embodiments are used, such as a sensor of pressure, speed sensor, among other always to improve the method to prevent falls [21].

The ”Anti falling-walker” (Table I) has mechanisms to avoid falls. This device has a hip strap that, in case of fall, it can hold the user and prevent injuries associated with the possible fall. The walker is equipped with an alarm device, a displacement sensor, and a motor. All of this components are connected to the battery. When the user is falling and reaches a set position, the displacement sensor will send a signal to the alarm device. The motor turns on and a seat cushion will rotate downward to prevent a fall [22].

The third patent in Table I has motors and a speed limiting unit which allow limiting the rotation of the wheel when the speed is greater than a predetermined value. This device has also a leg motion detection unit that permits measuring the distance between the user and the walker. When the distance increases the motor can stop or reverse the rotation applied to it. An attitude detection sensor is used to detect the attitude of the device and control the rotation of the wheel. With a grounding sensor, it is possible to know if the device is in contact with the ground. If it is not, it is probable that exist a step. In one situation that the walker changes the inclined state through these sensors, it is possible to detect the inclination. In dangerous situations, the motors can be controlled to provide a stable conduction. The sensors in the walker allow a safe conduction that prevents the user from falling [23].

TABLE I: The name, number and scheme of the three patents selected based on established criteria

Name	Walking assistive Device [21]	Anti-falling walker [22]	Electric walking assistance device [23]
Scheme			

V. CONCLUSION

The search performed on walker devices showed that studies were done in order to detect and prevent falls, thus improving the people quality of life. Concerning smart walkers, in all found devices the only prevention strategy implemented was to stop the walker when a possible fall is detected [10]–[18]. These prevention measures provide an increase user safety mainly in forward falls, due to the support act of the walker. Regarding sideward and backward falls, this mechanism cannot be so efficient. Thus, more studies should be performed, and other strategies should be implemented in order to improve the user's stability and balance. Regarding commercial smart walkers, only two were found and the fall prevention strategy is similar to the literature. In relation to the patents selected the approaches presented to prevent fall event are identical to those found in both literature and commercial devices. Thereby, it is possible to conclude that is important to invest in the robustness of the strategies to prevent the fall event.

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