Review Article

The Application of Internet of Things for the Elderly Health Safety: A Systematic Review

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Abstract

The elderly population is projected to increase from 8.5% in 2015 to 12% in 2030 and 16% in 2050. This growing demographic is chronically vulnerable to various age-related diseases and injuries like falling, leading to long-term pain, disability, or death. Thus, there is a need to use the potential of novel technologies to support the elderly regarding patient safety matters in particular. Internet of Things (IoT) has recently been introduced to improve the lifestyle of the elderly. This study aimed to evaluate the studies that have researched the use of the IoT for elderly patients' safety through performance metrics, accuracy, sensitivity, and specificity. We conducted a systematic review on the research question. To do this, we searched PubMed, EMBASE, Web of Science, Scopus, Google Scholar, and Science Direct databases by combining the related keywords. A data extraction form was used for data gathering through which English, full-text articles on the use of the IoT for the safety of elderly patients were included. The support vector machine technique has the most frequency of use compared to other techniques. Motion sensors were the most widely used type. The United States with four studies had the highest frequencies. The performance of IoT to ensure the elderly's safety was relatively good. It, however, needs to reach a stage of maturity for universal use.

Keywords: Aged, Injuries, Internet of Things, Patient safety

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Introduction

In recent years, the population of aging people has been growing faster than before, all over the world. The elderly population is projected to increase from 8.5% in 2015 to 12% in 2030 and 16% in 2050.[1] According to the World Health Organization, an elderly person is someone who is over 60 years old.[2]

Aging people are vulnerable to different diseases associated with old age.[3] They may also suffer injuries that can lead to long-term pain, disability, or death.[4] Under these circumstances, providing a safe home environment for the elderly is an essential factor. Falls, burns, and poisoning are some of those risks that can endanger the elderly. Studies have shown that falls are the leading cause of serious injuries often leading to death in the elderly over 79 years.[5] The approach of employing modern technologies to detect and prevent those risks and ensure the elderly's safety is essential. A technology that has been introduced in recent years to reduce costs, improve the elderly lifestyle, and provide patient safety is the Internet of Things (IoT) technology.[6]

IoT is defined as a network of physical devices, "things", around us, embedded with sensors, software, and other technologies to connect to the Internet and interact and exchange data through it. These devices can be controlled by applications on smartphones and tablets of the users. The IoT is simply the connection of sensors and devices to a network through which they can interact with each other and their users. It connects various devices to create an

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integrated communication architecture.[7] Wearable sensors using analytical algorithms have been introduced as part of the IoT for detecting and managing the daily activities of the elderly.[8] Recent progress in IoT technology can facilitate the design of proper health care systems for the elderly.[9] With the evolution of the IoT, reliable devices and sensors have emerged, used to meet the sophisticated needs of the elderly population.[10] Gavankar *et al*.,[11] in their research, addressed employing the IoT and smart homes for the elderly. According to him, performance expectancy, effort expectancy, expert advice, and perceived trust are the four motivational factors of IoT acceptance among the elderly.

In a systematic review, Baig *et al*.[12] addressed the applications of wearable sensors, for remote patient monitoring, for the elderly. In this study, an aging population who lives independently was considered. The results showed that there are challenges in this area, such as inaccurate sensors, batteries, and permission to be monitored by the elderly. In another systematic review, Qi *et al*.[13] discussed physical activity recognition and monitoring for healthcare using IoT. He addressed the problems of traditional monitoring methods and how they can be improved. Maksimović *et al*.[14] addressed the implementation of smart homes as a crucial aspect of IoT to meet the needs of the elderly. The researcher believes that emergency detection and safety monitoring technology are of the essence in smart homes, preventing injury and improving the elderly's safety. Tun *et al*.[15] addressed IoT applications for elderly care. Their article focused on the types of data collected, psychological data, cholesterol, vital signs, and the types of devices used for data collection, including smart homes, smart clothes, telemedicine, IoT, and robotics.

Because acute injuries and negative consequences are common in aging people, a survey on what has been done in this regard seems to be essential to adopt a proper strategy for elderly care. Many studies have suggested new architectures in the IoT. These include lower energy consumption, a better living environment, and comfort and acceptance. However, what is medically crucial is the correct detection of the emergencies that may put the patient at risk. Therefore, in this study, we evaluated the articles in which the performance of IoT to detect emergencies for aging people was examined, using specific metrics sensitivity, specificity, and accuracy. Moreover, we aim to determine which technique and which sensor are more frequent. Which setting (laboratory or home) is used in articles is the other question.

Study Method

In this study, we conducted a systematic review between the studies, until September 2021 which had evaluated the use of the IoT for elderly patients' safety through performance metrics, accuracy, sensitivity, and specificity.

Search strategy

To extract the most relevant keywords, we used Mesh in PubMed, and we studied published articles in the field to extract the most pertinent keywords, IoT AND Elderly AND Patient Safety, according to the research question. We also increased the search scope using lexical equivalents of keywords and their commonly used synonyms. The following is the final search strategy. ("Internet of Things" OR IoT OR "Wearable Sensors" OR "Smart Home") AND (Aging OR aged OR "old age" OR "elder*" OR "Housing for the Elderly" OR " Life Care Centers" OR Retirement OR "Continuing Care Retirement Centers" OR hospital OR home) AND ("Patient Safety" OR "Patient harm" OR "Accident prevention" OR "Protective devices" OR "Safety devices" OR "falls prevention" OR monitor*)

Databases and selection of articles

We searched PubMed, EMBASE, Web of Science, Scopus, Google Scholar, and Science Direct databases. The search was without a time limit, and we included full-text articles on the use of the IoT for the safety of elderly patients. For a preliminary selection, two researchers worked separately based on an initial structured review of inclusion and exclusion criteria. In case of disagreement, a third researcher, who has the necessary expertise, decided whether to include the article. Finally, the number of included studies was determined based on the Prisma diagram [Figure 1] at each stage. Moreover, the non-English language articles, and the ones that are not about the elderly, were excluded from the study.

Inclusion criteria

The studies on the use of the IoT for elderly patients' safety in which these attributes, sensitivity, specificity, and accuracy, are reported were included.

Results

The studies were conducted between 2012 and 2021, of which three were in 2021 and six in 2020.

The number of Q1 articles is significant, 8 out of 28 [Table 1]. The United States with four studies had the highest frequencies in the table, followed by China with three studies. Countries

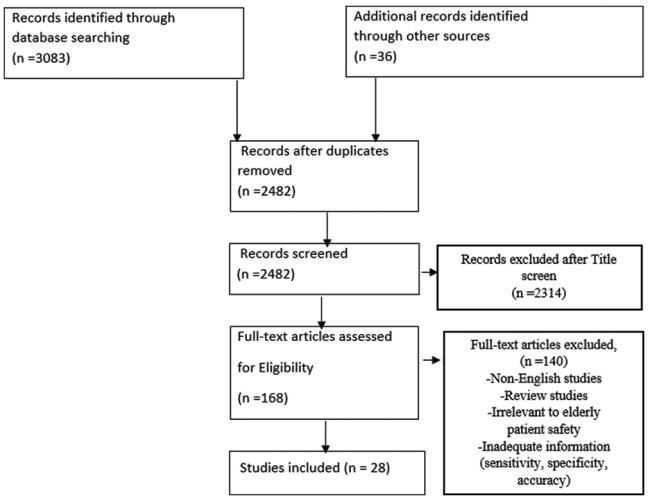

Figure 1: Prisma flowchart

Table 1: Basic information of papers

Citation	Authors (*n*)	Year	Country	Q	Setting	Participants (*n*)	Sensitivity (%)	Specificity (%)	Accuracy (%)	AUC
Fall detection based on posture classification for a smart home environment	2	2019	India	Q1	Home	12	100%	97.14%	95%	-
The smart insole dataset: gait analysis using wearable sensors with a focus on elderly and Parkinson's patients	8	2021	Greece	Q2	Laboratory	29	-	-	91%	-
An IoT-based device-type invariant fall detection system	3	2019	Bangladesh	-	Homes, Hospitals, Retirement Homes	126	-	-	99.7%	-
Detection of gait abnormalities for fall risk assessment using wrist worn inertial sensors and deep learning	3	2020	Slovenia	Q2	Laboratory	18	-	--	88.9%	-
Wearable sensor-based preimpact fall detection system with a Hierarchical classifier	8	2020	Portugal	Q1	Home	15	95.5%	97.3%	95.8%	-
A patient-specific single sensor IoT-based wearable fall prediction and detection system	3	2018	Pakistan	Q1	Home	600	98.6%	99.3%	-	-
A real-time patient monitoring framework for fall detection	3	2019	Canada	Q2	Home	8	-	-	99.62%	-
Heterogeneous sensor data fusion for human falling detection	3	2021	China	Q1	Home	-	100%	90%	95%	-
Health monitoring system for elderly patients using an intelligent task mapping mechanism in a closed-loop healthcare environment	4	2021	Korea	Q2	Healthcare center	100	92%	-	95%	-
Hierarchical coherent anomaly fall detection low bandwidth system with a combination of wearable sensors for identifying behavioral abnormalities	2	2020	China	Q1	Home	15	92%	-	-	-
Toward using wearables to remotely monitor cognitive frailty in community living older adults: an observational study	8	2020	America	Q2	Home	159	93%	54%	85%	73%
Assessing the feasibility of augmenting fall detection systems by relying on UWB-based position tracking and a home robot	8	2020	America	Q2	Home	10	99%	97.8%	98.5%	99.79%
A vision-based system for monitoring elderly people at home	3	2020	Italy	Q2	Home	790	-	-	-	-
Recognizing falls, daily activities, and health monitoring by smart devices	5	2019	Thailand	Q3	Home	48	-	-	99.51%	-
A smart home environment to support risk monitoring for the elderly living independently	3	2019	South Africa	Q3	Home	6	97.08%	89%	92.34%	-
Novel hierarchical fall detection algorithm using a multiphase fall model	5	2017	Switzerland	Q2	Developmental	-	99.79%	98.74%	99.33%	-
Deep learning to predict falls in older adults based on daily life trunk accelerometry	5	2018	Switzerland	Q2	Home	296	-	-	-	75%
Validation of the accuracy of an SVM-based fall detection system using real-world fall and nonfall datasets	8	2017	Canada	Q1	Home	24	78%	-	99.99%	-
Home camera-based fall detection system for the elderly	4	2017	Spain	Q2	Laboratory	-	96%	96.9%	97.6%	-
RiSH: a robot integrated smart home for elderly care	5	2019	America	Q1	Home	12	88%	91.9%	86%	79.9%
Fall down detection under a smart home system	2	2015	Taiwan	Q2	Laboratory	8	-	-	100%	-
Smart sensing systems for the detection of human motion disorders	11	2015	Italy	-	Laboratory	-	94.5%	96.7%	95.6%	-
Development of a user adaptable human fall detection based on fall risk levels using a depth sensor	4	2018	Malaysia	Q2	Developmental	-	96.6%	82.5%	88.5%	80.5%
An analysis of sensor locations of the human body for wearable fall detection devices: principles and practice	1	2016	Turkey	Q2	Laboratory	-	97%	-	-	-
Optimal accelerometer placement for fall detection of rehabilitation patients	3	2018	Malaysia	Q4	Home	14	-	88.7%	-	-
Human fall detection in surveillance video based on PCANet	5	2016	China	Q2	Home	10	89.2%	90.3%	-	-

Contd...

Table 1: Contd...

Citation	Authors (*n*)	Year	Country	Q	Setting	Participants (*n*)	Sensitivity (%)	Specificity (%)	Accuracy (%)	AUC
A posture recognition based fall detection system for monitoring an elderly person in a smart home environment	5	2012	England	-	Laboratory	-	80%	-	97.08%	-
Hidden Markov model-based fall detection with motion sensor orientation calibration: a case for real-life home monitoring	3	2017	America	Q1	Home	15	98.1%	99.2%	-	-

such as Switzerland, Canada, Malaysia, Italy, and Thailand each have two studies [Table 1].

The five types of sensors used in the studies are shown in Figure 2. As seen, motion sensors were the most widely used type, almost 50%. Accelerometer sensors are in second place and were used in 25% of studies. The ambient sensors were used in only 4% of studies.

The support vector machine technique has the most frequency of use compared to other techniques. Next is the k-nearest neighbor (KNN) technique with eight frequencies of use. The third place goes to the neural network technique that has been used in six studies. Techniques such as the least-squares method, Hidden Markov models, Linear Regression, Kalman Filter Algorithm, and Hierarchical classifier have been used only once. In terms of performance metrics, the accuracy was used the most (six times) by the nearest neighbor. Considering the other metrics, sensitivity and specificity were used the most (seven, six, and two times, respectively) by the vector machine support [Table 2]. *n* is the number of these metrics used in the articles.

Discussion

We did a systematic review of the studies in which the performance of IoT to detect emergencies for aging people was examined, using specific metrics, sensitivity, specificity, and accuracy. Our study showed a summary of reviewed articles and indicated that motion sensors are used widely for data gathering in the studies. Moreover, the support vector machine technique used the most by researchers compared to the other techniques. We also showed the frequency of performance metrics reported by each technique.

The growing population of aging people overloads social security and the health care systems with exorbitant costs all over the world.[16] The IoT technology affects the health care system by reducing costs and providing better services.[14] Although patient safety has different aspects,[17] many IoT studies have identified the aging person falling.[18,19] First, all efforts are made to prevent the person from falling, and in the

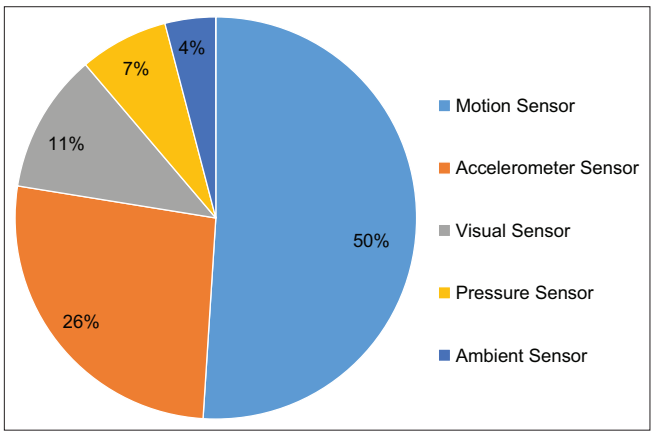

Figure 2: The information of sensors

Table 2: The techniques' frequency of use

Techniques	Frequency	Percentage of frequency of use	Accuracy (*n*)	Sensitivity (*n*)	Specificity (*n*)	AUC (*n*)
Support vector machine	10	34%	5	7	6	2
K-nearest neighbor (KNN)	8	27%	6	3	1	1
Random forest	3	10%	3	1		
Decision tree	4	13%	4	2	1	1
Artificial neural networks	6	20%	4	3	1	1
Bayesian classifier	2	6%	2	-	-	-
Long short-term memory (LSTM)	4	13%	3	-	-	1
Least-squares method	1	3%	-	1	-	-
Hidden Markov models	1	3%	1	-	1	-
Image processing	2	6%	1	1	2	-
Linear regression	1	3%	1	-	-	-
Kalman filter algorithm	1	3%	1	1	1	-
Hierarchical classifier	1	3%	1	1	1	-

second stage, to detect elderly falling. There are smarter systems that track the patient's gait, detect the patient's unbalanced movements, and warn before the person falls.[20,21] Finally, the alarm provides the necessary information to the medical center or family members after accurate verification. This technology can be implemented in many smart homes.[22-24] Many senior citizens still live alone. Therefore, the use of affordable devices that can monitor the elderly in their own home is considered the main value of these studies.[25]

According to surveys, 57% of studies about the use of the IoT in health used simulation.[26] China, with three studies, has the maximum number of studies of this kind among Asian countries. It is projected that the number of patients who have dementia and need IoT technology will reach 68 million in Asia by 2050, indicating the importance of the technology on this expanded continent.[27] Galambos emphasized the desire of the elderly to use smart sensors and their recognition of the efficiency of their application.[5] Motion sensor 11 is the most used among sensors, considering that the main activity for patient safety has concentrated on diagnosing and preventing patients from falling.[6] Therefore, it is justifiable that motion sensors are the most used. Accelerometer sensors are the second most widely used after motion sensors. These sensors usually have good performance. Javed stated that there is a strong relationship between efficiency and the use of these accelerometers.[4]

The support vector machine technique is the most widely used technique. This technique is mathematically complex and has heavy calculations.[8] Given that this technique performs well for binary classes[9] and patient safety and IoT are mainly associated with the binary class of fall detection, this technique can be a good candidate for the purpose. The second most used technique is KNN, applied by researchers because of its good performance. The third technique is the neural network. It is one of the most powerful data mining techniques, and the layered architecture is one of the strengths of this technique.[10] The Decision Tree technique and Random Forests were used in seven studies in total. The ability to identify different patterns is the main reason for using these techniques.[11] Most studies have been performed in the laboratory environment because the development of these systems requires laboratory phases to reach the optimal diagnostic mode.

In a few studies, the number of participants was more than 100. Most of these studies utilized wearable devices to test more people. The maximum number of participants was in studies that used wearable devices. Because these devices are easier to use, they can be worn on different body parts, while the person can perform their daily activities. Thus, it is recommended that, in interventional studies with a specific number of participants, the convenient use of the sensor as well as its technical features is considered so that the efficiency of the sensor can be evaluated based on evidence.

It is suggested that in the future, interventional studies will be carried out to directly evaluate the impact of the use of IoT in the elderly's own place of residence. For example, in a smart nursing home, check the reduction of falls and injuries after installing the equipment; although this work is expensive, it can clearly remove doubts about the economic use of this technology.

Conclusion

Regarding the importance of formulating an appropriate strategy for taking care of aging people, who are more exposed to the risks of age-related events and injuries, many studies have researched the potential of the IoT technology to prevent fall injuries in particular. The evaluation of these studies' results indicates that the performance of IoT to ensure that the elderly's safety was relatively good. However, it needs to reach a stage of maturity for universal use.

Summary points

The potential of the IoT to improve elderly patients' safety has been researched in many studies.

- The IoT can be implemented not only in the nursing home but also in the living environment of the elderly.

- Motion and accelerometer sensors were used widely in the studies for remote patient monitoring.
- IoT performance in elderly patients' safety, fall detection, in particular, has the most successful implementation.
- Support vector machine is the most used technique for fall detection in the studies.
- The studies, in which wearable devices were used to monitor, had the maximum number of participants.

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Conflicts of interest

There are no conflicts of interest.

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