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Comparative Study of Different Types of Sensors of Smart Home for Elderly

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Abstract

This paper describes an evaluation framework for a smart home project that utilizes sensor technologies to detect activity levels and monitor older adults. An independent retirement community is designed to follow the aging model in place. Technologies used include a stove sensor, a bed sensor, a gait monitor, and a video sensor network. The evaluation framework includes focus groups with end users (older adults and health care providers) and observations. Preliminary findings indicate an overall positive attitude of older adults towards smart home sensors and a valid and reliable performance. End users must be included in all stages of smart home development (design, implementation, and testing) and actively participate in a formative evaluation of the technology. A rapidly aging population requires support systems that enable it to preserve dwellers' independence without compromising their safety. Smart homes for the elderly have the potential to offer hidden health and wellness monitoring. The aim is to provide a safe, independent living environment that can identify and predict problems by monitoring the Activities of Daily Livings (ADLs) of the inhabitants. For this, a system able to handle continuous data streams is required. Such a system can extract information using appropriate classification and learning algorithms, thus allowing the remote monitoring of health and well-being at a high level. The implementation requires appropriate sensing technologies, identification of ADLs, data preprocessing techniques, and machine learning algorithms. It is challenging due to individual differences. Such a system must be able to personalize individual needs. Our contribution was designing and implementing a platform to smartly monitor the health condition of the elderly using sensor data from a smart home through an interactive user interface that is user-friendly and multi-platform. This proof-of-concept used offline data, with the view to extend to real-time data collection in the future, which could then be used to inform support providers remotely.

Keywords: Elderly, Smart homes, Activity recognition, Smart home, Unobtrusive monitoring, Machine learning.

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1|Introduction

The Internet of Things (IoT) has gained much attention from researchers, entrepreneurs, and tech giants around the globe. The IoT is an emerging technology that connects various everyday devices and systems such as sensors, actuators, appliances, computers, and cellular phones, thus leading to a highly distributed intelligent system capable of communicating with other devices and human beings. The dramatic advancements in computing and communication technologies coupled with modern low-power, low-cost sensors, actuators, and electronic components have unlocked the door of ample opportunities for IoT applications. Smart home with integrated e-health and assisted living technology is an example of an IoT application in Geron technology that can potentially play a pivotal role in revolutionizing the healthcare system for the elderly. As the world is rapidly moving towards the new era of the IoT, a fully functional smart home is closer to reality than ever before.

In a smart home, sensors and actuators are connected through a Personal Area Network (PAN) or Wireless Sensor Network (WSN). Wearable biomedical sensors such as Electrocardiogram (ECG), Electromyogram (EMG), Electroencephalogram (EEG), body temperature and sensors can be connected to a Wireless Body Area Network (WBAN) or Body Sensor Network (BSN) to obtain automated, continuous, and real-time measurement of physiological signals. The central BSN node collects all data, performs limited data processing, and functions as the gateway to the PAN/WSN. The actuators operate based on occupants' or central computing system feedback. The central computing system collects environmental, physiological, and activity data through the PAN/WSN, analyzes them, and can send feedback to the user or activate the actuators to control appliances such as humidifiers, oxygen generators, ovens, and air conditioners. It also functions as the central home gateway, which sends measured data to healthcare personnel/service providers over the Internet or the cellular network. Standard protocols from WSNs and ad-hoc networks are used to realize communication between all wireless sensors and actuators. However, current protocols designed for WSNs are not always applicable to WBAN. Multiple sensors can be placed over clothes, directly on the body, or implanted in tissue, which can facilitate the measurement of blood pressure, heart rate, blood glucose, EEG, ECG, and respiration rate.

Smart homes often rely on the correct use of wearable devices, which are widely understood to be inconvenient for this age group. The elderly frequently object to adopting wearable devices as they add to their cognitive load, hindering performance and may even negatively affect their mood [1]. Alternative approaches to circumvent the disadvantages of wearable technologies often involve using video cameras. However, this type of surveillance is too intrusive and gives them a perception of being watched [2], [3]. Other approaches have used a voice-controlled hub [4], such as those commercially available recently. This approach, however, requires being complemented with sensors for effectiveness in smart homes. Smart home systems facilitate the protection of dignity, the safety of the individual, and independence in their own home. The idea proposes implementing a discreet system, incorporating technologies such as sensors/IoT devices with cloud integration to handle continuous data streams and smartly extract the information using appropriate classification and learning algorithms to enable continuous remote monitoring of health and wellbeing. Recent advances in sensing, networking, and ambient intelligence technologies have rapidly emerged in smart environments. The smart home concept was formalized and primarily focused on integrating different services within a home environment using a common communication system. A smart home concept is more centered on helping the residents live independently and comfortably with the help of mechanical and digital devices.

For activities to be detected, sensors must be deployed inside the home. Some of these sensors may be used on furniture, appliances, walls, and doors. In contrast, others may be "worn" by the inhabitants, attached to their bodies either directly or indirectly (e.g., a smartphone that is carried in a pocket). In general, different sensors are needed simultaneously to identify the various activities correctly, and each of them may provide its measurements (i.e., the raw data) in a different format. Raw data is, therefore, of little (or no) use for the activity detection algorithms. This data must be preprocessed to obtain valuable and significant information for the application. Whereas it is possible to find a good number of research reviews related to aspects such as sensor design, monitoring techniques, or machine learning algorithms and reasoning approaches, to the best of our knowledge, the underlying and fundamental issues of activity context information representation, proper sensor selection and sensor raw data processing have not received enough attention yet in the concrete context of elderly people needs. In addition, reviews tend to focus on describing solutions from a technical viewpoint but not so much from the perspective of service developers and providers. To contextualize the principal open issues, we devote the whole section (recent surveys on smart homes) to summarize some of the most significant and recent research review papers in this area. The main objective of this review paper is twofold: first, we propose a classification of the main activities considered in smart home scenarios targeted to the elderly's independent living, as well as their characterization and formalized context representation; second, we advance towards a general set of guidelines that would help researchers and developers select the sensors and processing techniques best suited to the target activities to detect, focusing on older adults and indoor smart home activities.

Implementing such a system requires the identification of ADL, appropriate sensors and technologies, preprocessing data techniques, and learning algorithms to efficiently and accurately detect anomalies in patterns to avoid mishaps, do profiling, connect and alert concerned people, and ensure their safety. Since each human is different, their records vary, and their patterns may be different. Thus, a system that adapts to a person's activities is required. Visualization of the processed data in a user-friendly and summarized manner is required, as well as a clear understanding of graphs/charts representing irregularities and patterns and providing an overall overview of each calendar day. The application should be interactive with good UX using the latest technologies available in various operating systems and devices. *Fig. 1* shows a picture of a smart home for the elderly.

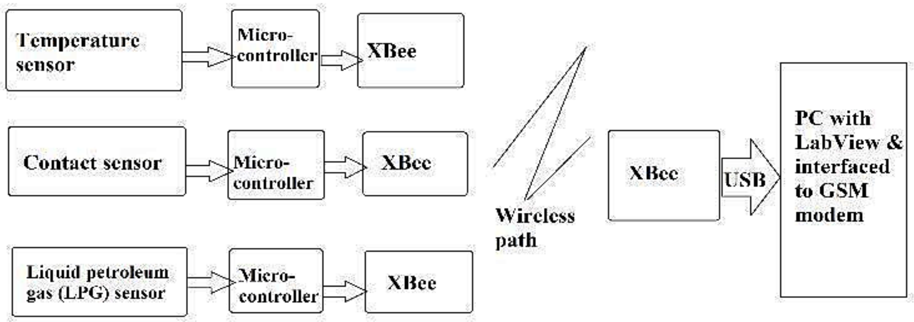

Fig. 1. shows a picture of a smart home for the elderly.

Table 1. Sensors in smart home.

Sensors	Measurement	Data Format	Advantages	Disadvantages
Video cameras	Human actions, environmental state	video	Precise information	Computational expenses
Microphones	Voice detection, other sounds	Audio	Certain and rich information about sound	High computation cost
Simple binary sensors	Movements and location identification	Categorial	Low cost, minimal computation requirement	Limited information
RFID	Object identification	Categorial	Small size and low-cost	Reader collision, range limited
Temperature sensors	Environmental parameters	Time series	Intuitive monitoring of environment and object	Limited information for activity monitoring
Wearable inertial sensors	Acceleration	Time series	Low cost	Can not provide sufficient information

2 | Literature Review

This section starts with the definition of smart homes and related work. It also talks about the Activities of Daily Livings (ADLs) and their conceptualization. Smart Homes Smart homes for elderly people are associated with a system that monitors and logs daily living activities, identifies patterns, detects anomalies, understands individual human activity, visualizes data, and notifies the concerned. The main idea is to make certain that elderly person conducts daily living activities as per their routine and ensure safety by identifying and notifying situations, helping them care for their health, and making living alone independent and safe [4], [5]. Related work there are a number of relevant projects on smart homes which we have reviewed. Firstly, tiger place, created by The University of Missouri, observed an elderly person's activity and overall health through smart sensors specifically focusing on movements in bed and around the dwelling [6]. Another smart home project by the University of Toronto collected data from binary sensors installed on house appliances, such as switches and tables, for assimilating and processing the data. Summarization algorithms were used to identify the changes in the system based on the data collected from sensors. Centre for Advanced Studies in Adaptive Systems (CASAS) is a project run by the University of Washington State that collects data of people from sensors placed in an apartment that stores the data in files, uses algorithms and techniques to extract patterns and predictions of trends in a smart home [7], [8]. This dataset has been widely used in the literature of the human activity recognition field [9]. It presents a literature review on technologies for monitoring and its outcomes for independently living elderly people. They talk about the effects of research conducted for monitoring ADL along with fall detection using various sensors such as PIR motion sensors, body-worn sensors, pressure sensors, video monitoring, and sound recognition in detail, along with their monitoring aims. Present methods for mining data for ADL using smart home sensors. They talk about controlling sensors and actuators in data-driven smart home systems using web technologies and commercial sensors to monitor the ADL of elderly people in their homes.

Researchers review different smart home scenarios catering to the elderly living alone. Various data-capturing techniques from sensors, along with the processing of data-detecting activities using multiple algorithms, have been discussed in this paper. This paper has emphasized the selection of sensors and data processing techniques to avoid the failure of smart home applications. All the components that lay out the challenge are composed, and the idea is designed primarily based totally on it. Next is the connection between the Arduino uno and the bluetooth through the bluetooth module, which is the most crucial part of the task. After every connection, the Arduino board has to be programmed, and the Arduino program has to be installed. Ultimately, the android root to cellular phones governs the Arduino uno through bluetooth [10]. Sensors and actuators play an essential function in smart automation houses by reducing the distance between the real world and the virtual domain. Smart homes use several sensors to gather statistics about the house environment using passive infrared consisting of inertial measuring devices, RFID tags, or sensors. Physiological parameters will be calculated using wearable sensors, including BP, HR, SpO2, Galvanic Skin Response (GSR). Actuators can reply to the remarks from the occupants or the critical choice-making platform via small-scale maneuvers to govern surroundings or supply tablets, including insulin, to the occupant's body. These sensors and actuators can communicate with the relevant computing and choice-making platform over the wi-fi connection medium. The sensors, specifically the wearable clinical sensors, want to be power-efficient and unobtrusive to facilitate long-term monitoring [11].

Cloud computing and its uses in smart home: cloud computing will be crucial to IOT-based smart homes. We can control or access the devices from any place, any time, and any device with the help of the Internet. Rapid technological advances are causing problems with storing, processing, and accessing large amounts of data. Significant innovations are related to the sharing of IOT and cloud technologies. Both combined will allow us to process data(collected by sensors) and inputs. Devices have helped develop cloud-based smart home automation.

This technology has attracted the attention of researchers and developers, and various forms of advanced technology are being researched and introduced to improve the performance of smart home automation.

Knowledge of ongoing development in this area provides useful information for researchers and developers. Therefore, push them to investigate or rationalize smart home automation. The rest of this section describes the author's views on recent advances in smart home automation. Consumers have long been waiting for smart electronic devices. With affordable remote control capabilities via smart devices, this technology is considered smart and attractive and provides users convenience and comfort. However, smart home automation technology is still new and unstable. Various devices are also connected to your home network [10], [11]. The main strength of cloud computing is its ability to dynamically adapt to different situations, including number of requests, location of users worldwide, etc. Suppose many resources are accessible and allocated to the meeting to complete the task. In that case, this allows you to work with your customers and turns resources that can be used by other applications requiring more resources. It is beneficial for the user and the service provider, too.

Here are the components to perform all of the operations needed to run the embedded devices and circuits, as well as a sensor for collecting data on internal and external home surroundings and measuring the home's condition. These sensors are connected to the device and the house itself. These sensors are not any IOT sensors. Data from the sensor is collected and continuously sent over the local network to the smart home server, a processor that performs local and built-in actions. You can also connect the application to the cloud using the internet, which requires advanced resource collection of software components wrapped as API, allowing external applications to run it. Such an API can handle sensor data or manage the necessary actions. We need an actuator to provide and execute commands on a server or another control device. It converts the required activity into command syntax. The device can run. At the same time, processing the received sensor data, the task checks to see if the rule was met. The system can send commands to the correct device processor in such cases. Here is the cloud data, and we can store it in our local repository to analyze it and check its behavior according to the environment. To take that and store data, we take inputs from sensors to read it [12].

3 | Proposed Study

A set of sensors and detectors are used to gather data and control actions/events. The data collected by the sensors are sent to the monitoring software running on the Arduino board. The values in the gathered data are sent to the system's users and compared with the previously set values to decide whether to trigger an alert. A prototype smart home was developed in this study to carry out a set of experiments. Before the installation, the system was designed and tested using Fritzing. When someone opens the door in the prototype home, the lighting system is automatically switched on. The lighting system is automatically switched off when the user passes to another room from the entrance. Since the inputs and outputs of the proposed smart home systems cannot be handled by standard Arduino boards, which have a limited number of inputs and outputs, an Arduino Mega board was used. An Arduino Ethernet shield was used to communicate between the sensors. The Arduino Mega board was used to process and send the gathered data to the system's users, making the system remotely manageable and providing communication ability to various sensors. The monitoring software has a web-based interface accessible by mobile devices such as smartphones. Users can manage specific activities, see triggered alerts, and read current or logged sensor values in the web-based interface. Whenever a user accesses the monitoring software, the user's identity, login and logout dates and times, and activities on the monitoring software are recorded. The application presented in this paper is a simple example of a smart home application still under development.

We reviewed articles published where a smart home device was used and evaluated in studies with older adult participants. The applications and settings of the existing studies, data types, and outcomes, as well as the limitations of the existing studies, were discussed. One significant research gap identified in this review is evaluating the effect of smart home devices on older adults' quality of life, health, and well-being. Most of the articles tested and evaluated the performance of the smart home devices or studied users' acceptance and opinions. However, while improving quality of life and assisting older adults were common research goals in most of the studies, only a few investigated how smart home devices affected the quality of life of older adults.

It suggests that despite the great potential of smart homes in improving older adults' lives, the research in this area might still be in its infancy. Many more studies on the influence of smart home devices on older adults' lives are needed to understand better the effects and benefits of these devices for supporting older adults and to understand factors that can contribute to their effectiveness. This gap was raised in a 2008 review by Demiris et al. [4]. their review included 20 articles, abstracts, and web pages, with most studies focusing on feasibility and technical solutions and with a few tests in laboratory settings and with a limited number of participants. Since then, we have seen a larger number of user studies with older adult participants and in different settings being published, with many conducted at participants' homes. However, despite the increase in user studies and advancements in smart home devices, evaluating the effects of smart home devices on older adults' lives remains a challenging gap that needs to be addressed in future work.

Aside from the limitations raised by the reviewed studies (e.g., limited participants, participants with specific demographics, or limited data sample sizes), one of the common limitations we found in the studies was that they did not report the type of devices and only reported on the data that the devices collected. The device type is essential information that should be reported, as it can affect the interpretation of the results (e.g., understanding the accuracy of data collection, participants' preferences of specific products, etc.) and allow replicability of the studies. Another limitation was that the methodology and results were not described thoroughly in some cases, as pointed out in a review.

One of the common technical challenges, which was also identified in a review, was to account for multiple residents, especially where users' activities were being monitored. It can limit the performance of the existing systems to homes with a single resident. Future studies on improving the performance of smart homes with multiple residents can be beneficial in expanding their potential for supporting older adults. It could also influence the study setting. Most reviewed studies evaluated smart homes in a home setting, followed by a research lab, while other types of technologies, such as social robots, have been more commonly tested at care centers. It could be partly due to challenges related to having multiple residents and privacy and security issues that can affect the adoption of these technologies in care centers.

Therefore, aside from the need to have more studies on the impact of smart home devices on older adults, it would be beneficial to study how each of the devices can benefit individuals in different settings (e.g., individuals' homes, a room in a care center, or a common/shared area), and how they need to be adjusted for different settings. Similarly, privacy considerations may differ according to the setting and context. For example, they discussed a situation where constant monitoring could reveal information that the user does not wish to share with caregivers (i.e., planning a surprise for the caregiver in this case). While in most of the existing studies, researchers specified the type and frequency of data collection, future studies can consider empowering users themselves to control and make decisions on the type and frequency of data collected by the system (even if this means limiting the system's functionalities), which could lead to better acceptance and adoption.

The reliability of smart home devices in user studies is another important factor, as also emphasized in [5]. Many studies have reported different types of technical issues that can affect the performance and acceptance of devices. Unlike the review, which found the common readiness levels at TRL 6, we found high technology readiness levels for the devices used in the reviewed studies, with the majority being at TRL 9. It can be because the current review focused on user studies with smart home devices, many of which were conducted over a more extended period, such as weeks or months, which requires a higher technology readiness level for the devices used. We conducted three focus group sessions with older adults. Each session lasted approximately one hour. Overall, participants had a positive attitude towards smart home technologies. Their perceptions of the potential of the technology focused on a reactive role (detecting emergencies) rather than a proactive one (monitoring a situation to detect trends or predict issues or concerns) [13].

This paper experiments with setting up a domestic automation device using the IoT concept. The layout can manage domestic home equipment like lights, fans, and air conditioning remotely controlled by a cellular phone. The operating version is an example of any individual in our homes or offices turning on/off the light, and other individuals get data in the form of messages to the phone. All sensors are interfaced and checked out with every different. The device receives an output for recognizing the consequences of numerous home equipment linked to the house automation device. The temperature sensor will detect the room temperature automatically and change it according to the data the user provides. Every smart home system uses different technologies; Android phones play a significant role in all systems. GSM networks allow people to control things anywhere globally, whereas Bluetooth networks can manage things within a particular range.

4 | Limitations and Future Scope

Regarding the limitations of this research, it is crucial to remember that while extensive literature references and summary screening of social phenomena were conducted in determining the evaluation indicators, the quantification assessment is still highly subjective. Therefore, future research will aim to improve the subjectivity of the evaluation and further explore it using more objective methods and experimental data. In addition, this research has a relatively small sample size; only older adults living in the Yangtze river delta who have experience using smart homes and can complete human-computer interactions independently or with the help of others are taken as the primary target. In the choice of sampling method, convenience sampling was used, which means that interviewers may tend to select respondents who are closer to them or easily accessible, thus having an impact on the precision of sampling. Meanwhile, this is only a typical case and only explores the factors influencing this target group's willingness to use smart homes for senior citizens within a specific range, limiting the statistical power and generalization of the results. Phenomena such as different economic and cultural development, social inclusion, and different concepts of old age result in diverse strengths and breadths in the implementation of smart products for the elderly, resulting in different differences among the elderly, thus affecting the reasonableness of the experimental data. In future research, the study can be improved through offline and online open-ended questionnaires synchronized collection by comparing the social environment in the region where the elderly are located, such as the sense of belonging to a social class, social trust, social activities, the government system support and other aspects of the degree of influence of factors to consider.

Our review had several limitations. While we attempted to be comprehensive with our search queries and modified them, it is always possible that some articles might not have been found. For example, they were not identified if they did not contain any search keywords. Although our review only included studies with the devices used by actual participants, we did not add any keywords for user studies to increase comprehensiveness. We manually screened the papers to include those that had user studies. This resulted in a significantly more significant number of documents for the screening stage, prolonging the review time.

Further, as the included reviewed articles were all written in english, studies published in a language other than english were not considered. Different databases may apply a 10-year condition differently. For example, some allowed us to clearly define the dates for the past ten years (e.g., ACM DL), while others did this automatically. Further, we did not verify the validity of the methodology and results presented in the reviewed articles and relied on the authors' reports. As there was missing information in some cases, our results on the data type may only reflect the kind of data collected and not a proper data analysis on that data. To explore and validate the aspects influencing older consumers' use of smart homes and to determine their level of importance, this study employs the Technology Acceptance Model (TAM) with additional variables. In addition, user interviews were conducted to understand this population's barriers and specific needs when using smart home services regarding user characteristics, experience of use, and willingness to use. Two hundred relevant samples were examined to summarize the study's findings using Structural Equation Modeling (SEM) and factor analysis.

After the comprehensive data processing and model validation analysis, we derived the six dimensions of the model of influencing factors on the use of smart home products by the elderly and the weight sizes of their corresponding 13 influencing factors. The study's findings indicate that older users' propensity to adopt smart homes is greatly affected by their perceived usefulness and ease of use. Meanwhile, there has been a significant improvement in the perceived ease of use of smart homes and the usefulness of smart homes for older users. In addition, technical support has a significant negative effect on the perceived usefulness of smart homes and a considerable positive impact on the perceived ease of use of smart homes. Furthermore, perceived value has a significant positive effect on perceived usefulness and ease of use of smart homes. Finally, there is a significant negative impact of perceived risk on perceived usefulness and perceived ease of use of smart homes by older users. The results of this study provide in-depth insights at the theoretical level for a comprehensive understanding of smart home acceptance willingness among the elderly population. This study enriches the existing theoretical framework by introducing and expanding the TAM. It provides new perspectives for research in other related fields by constructing a more comprehensive and detailed model. It contributes to a more in-depth understanding of older users' acceptance of smart homes and their influencing factors and provides a valuable reference for future research. In addition, this study adopts an empirical analysis method to verify the validity of the extended TAM model by collecting and analyzing data. It enhances the credibility and applicability of the theory and provides empirical support for subsequent theoretical studies.

5 | Conclusion

In this paper, we have presented a design and implementation of a system that could monitor the health conditions of elderly persons living alone discreetly using sensors. This system allows individuals to be in touch and remotely monitor health and environmental status. The primary purpose of smart homes for the elderly is to allow non-invasive and unobtrusive monitoring without affecting their dignity while they remain comfortable in their homes. For future work, the system caters to an individual's activities, which could differ widely if multiple elderly persons live in a smart home.

Given the deepening trend of population aging, smart homes for aging are becoming more apparent. Although smart home appliances have the potential to enhance the lives of the elderly significantly, their popularity is still in its infancy in China, especially among the elderly. Smart home products developed, produced, and designed for the elderly are extremely scarce, and the elderly still face many difficulties using smart homes. Therefore, we need a deeper comprehension of the various aspects influencing elderly users' acceptance and use of smart homes.

At the practical level, this study serves as a significant guide for the progress and promotion of the smart home industry. Our findings are crucial not only for the elderly population in the Yangtze River Delta region but also for providing valuable lessons for other regions and countries facing similar demographic issues. Given that the physical functions of the elderly are declining, including mobility, cognition, vision, and ability to cope with their surroundings, they are less capable of controlling and managing various home devices. The government should step up policy support to guide more social forces to participate in legislative support and provide shopping allowances to encourage the elderly to try out smart home devices. Service providers and designers should fully understand target users' characteristics and actual needs and emphasize the products' functionality, operability, and user experience to develop easy-to-use smart home solutions. Children should always pay attention to the elderly, actively guide the use of smart homes, and teach them patiently in the process of using them to assist them in realizing their self-worth.

This paper presented a systematic review of user studies on smart home environments and devices for supporting older adults, which used or evaluated smart home devices in studies with older adult participants. Results showed a range of devices used in the studies with older adults, along with information about the devices, different settings where the smart home devices were used in studies with older adult participants, data types, evaluations, outcomes, and limitations. Based on these results, we discussed research gaps and directions for future work, such as limited user studies on the impact of smart home devices on older adults' lives, health, and wellbeing, as well as limitations in participant groups, technical challenges, challenges with supporting multiple occupants, and constraints in reporting the methodology. Overall, it appears that smart home environments have great potential to support older adults, but significant future work is needed to understand their potential impacts better.

Author Contributions

Conceptualization, methodology, software and formal analysis by Surbhi Roy. author have read and agreed to the published version of the manuscript.

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Data Availability

All the data are available in this paper.

Conflicts of Interest

The author declare no conflict of interest.

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