**Implementation OF IOT in HealthCare**

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# Abstract

The past few decades have witnessed a significant increase in life expectancy, resulting in a growing population of elderly individuals living independently. However, this demographic often faces challenges related to mobility difficulties, symptoms of dementia, and other health issues, necessitating support and assistance. In response, this paper proposes an innovative Internet of Things (IoT)-based information system tailored to meet the indoor and outdoor needs of such individuals. Acknowledging a deficiency in methodological approaches to the design process identified through a comprehensive survey of related works, we introduce a robust Design Methodology (DM) that considers the perspectives of stakeholders, contracting authorities, and potential users. This comprehensive approach ensures that the resulting solution addresses the diverse needs and requirements of all involved parties.

Our proposed system leverages advanced technology, including a three-axial accelerometer and magnetometer, Pedestrian Dead Reckoning (PDR), thresholding mechanisms, and decision tree algorithms. Through this sophisticated architecture, the system can accurately localize monitored individuals within four distinct room-zones and discern critical activities such as falls, lying, standing, sitting, and walking. Moreover, by classifying these activities into categories of normal, suspicious, or dangerous, the system can promptly alert healthcare staff to potential issues, enabling timely intervention and assistance. Real-life scenarios validate the robustness and effectiveness of our solution, garnering satisfaction from both stakeholders and prospective users and paving the way for continued collaboration and refinement of the project. In summary, our IoT-based autonomous supporting system offers a comprehensive and reliable solution to address the needs of elderly individuals living alone, ensuring their safety, well-being, and continued independence.

# Introduction

The evolving landscape of life expectancy presents both challenges and opportunities in ensuring the well-being of aging populations, particularly those who opt to live independently despite mobility limitations or health concerns. As statistics reveal significant increases in life expectancy, especially in regions like Poland where it has lengthened by six years over the past 25 years, there arises a growing need for information systems tailored to support the safety and autonomy of elderly individuals, particularly those living alone. With gender disparities in life expectancy favouring women by as much as eight years in some cases, a considerable portion of the elderly populace finds themselves navigating their later years solo. Hence, the imperative for autonomous systems that monitor vital signs, track positioning, and discern various activities and situations becomes apparent, facilitating prompt responses to emergent dangers through appropriate alerts to caregivers or services. This underscores the necessity for sophisticated healthcare information systems rooted in IoT technologies, designed to seamlessly integrate human-centric perspectives and technical functionalities, thereby enabling elderly individuals to maintain their desired lifestyles while ensuring their safety and well-being.

This paper delineates a methodological approach towards designing an IoT-based healthcare information system, meticulously crafted to address the nuanced needs of seniors, especially those with limited abilities managing daily tasks independently. Central to this approach is the user-driven Design Methodology (DM), which incorporates the perspectives and needs of both the contracting authority and future users at every stage of development. By synergizing human constraints with technical requirements, the proposed DM aims to bridge the gap between user expectations and system functionalities, culminating in a robust system proposal capable of meeting the envisioned goals. Through rigorous case studies and real-life scenario testing, the efficacy of the designed system is validated, featuring an array of sensors such as the Inertial Measurement Unit (IMU) alongside Wi-Fi and heart rate modules, complemented by sophisticated algorithms including thresholding, Pedestrian Dead Reckoning (PDR), and decision trees. The results showcase impressive performance metrics, with precise localization accuracy within one meter, a highly effective fall detection algorithm boasting a 98% success rate, and the ability to recognize various activities with a compliance rate of 95%. Moreover, the proposed behaviour classification algorithm demonstrates remarkable accuracy, effectively distinguishing between normal behaviours and those considered suspicious or dangerous in nearly 100% of cases, thereby affirming the system's readiness to address the complex needs of elderly individuals living independently.

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# Literature Review

The Design Methodology (DM) of a product or system has been of interest to many researchers. Already in 1991, A. McKnight proposed a definition of DM as “… a sequence of activities required to get from one stage of the design process to another”.

Prasad, R. and Kobayashi, H. propose a nine-step multi-methodology design process model to enhance productivity in hardware description language design. This model encompasses system specification, system partitioning, modeling or adaptation, component simulation, system binding, system simulation, logic synthesis, and logic simulation. Their methodology notably decreases the time needed for modeling and simulation activities by 31% and 16%, respectively, when compared to conventional hardware description language-based design.The design methodology proposed by S. A. Mengel et al. contains the three stages: requirements, specification, and implementation. At the requirements stage, the designers should focus on the key concept of the problem and propose a graph with the structure of the system. At this stage, they refine the proposed graph into the content flowchart, which should be easily implementable into the considered system in the last design stage. Moreover, after each DM stage, validation and verification should be conducted to ensure that the key concepts would have been met.

To enhance the productivity of complex electronics system design, H. Eskelinen suggests incorporating two questionnaires into the traditional four-stage electronics system design process, which includes system design, electronics design, mechanical design, and design for manufacturing. These questionnaires are utilized to create comprehensive requirements lists for electronic system components.

F. Wang and M. J. Hannafin state that the design-based research should be “pragmatic, grounded, interactive, iterative, flexible, integrative, and contextual.” H. Eskelinen recommends integrating two questionnaires into the conventional four-stage electronics system design process—comprising system design, electronics design, mechanical design, and design for manufacturing—to boost productivity in complex electronics system design. These questionnaires are employed to generate detailed requirements lists for the components of electronic systems.

A. Saini and P. Yammiyavar emphasize the user as the central element in designing m-health systems. They adopt the object-oriented system design methodology, common in software development, to examine the interactions and relationships between system requirements and the components of the user's needs and goals. This user-centric approach proves particularly valuable in health applications, where stakeholders and various user groups may have differing requirements and constraints.

# Contribution and Methodology

## Contribution

A variety of solutions is used in the IoT healthcare-monitoring domain for indoor and outdoor environments, a methodological approach to the design process is still missing; where design is understood as “scientific principles, technical information and imagination in the definition of a structure, machine or system to perform pre-specified functions with the maximum economy and efficiency” . More over, using a multi-environmental information system for behaviour recognition and classification requires improvement and development.

To fill the gap in the methodological approach to the design of a comprehensive information system for healthcare applications, the objective of this paper is to propose a systematic design procedure, which can enhance the development of healthcare appliances. The design process takes into account a variety of constraints beyond technical requirements, such as lifespan, energy efficiency, user comfort, and cost. The case study focuses on an IoT-based system designed for multi-environment monitoring of people and objects. Among other capabilities, it features behavior recognition and diagnostic functions. Specifically tailored to assist and locate elderly individuals, the system operates within multi-room apartments, throughout multi-story buildings, and even outdoors. Key functionalities of the system include monitoring vital signs, recognizing postures, and detecting and classifying suspicious behaviors.The development procedure approaches the design target from the perspective of the stakeholders, the authority in charge and the potential users, as the view of the system developersThe proposed design methodology was modeled, implemented, and validated through a case study focused on a system for multi-environmental monitoring of elderly individuals living alone. The system has been successfully implemented and tested in real-world scenarios. Methodology

The challenge of monitoring patients or elderly individuals exclusively indoors or outdoors is intricate, and incorporating both scenarios in the context of IoT systems adds further complexity. To address the design of such systems, we suggest systematizing the design process. Our proposed design methodology is structured into two primary stages: problem formulation and product development, with each stage consisting of three distinct steps. Additionally, to ensure no critical aspects of the system are overlooked, the perspectives of stakeholders, future users, and designers are considered at every stage of the design process.

A diagram of a product development process

Description automatically generated

### Problem Formation

The problem formulation stage is divided into three steps: defining needs, formulating requirements, and assessing feasibility. Since an essential aspect of the proposed DM is the involvement of all project contributors, i.e., stakeholders, future users, and designers, each of them may contribute to the problem formulation. However, their goals and expectations of the future system can be differed. For example, the user can focus on convenience, safety, and confidentiality; the healthcare staff may aim at the system’s reliability, ease of operation and maintenance, along with the utility of the obtained information. The stakeholders should also take into account the financial and marketing elements of the product. Meanwhile, the designers will concentrate on utilizing their tools, knowledge, and experience for the design process.

1. **Needs Definition**

This step initiates the design process, where stakeholders introduce the concept to the designers and define the general problem.In the proposed DM, this stage should be performed together with the future users to include their desires. This approach allows both stakeholders and future users to articulate their needs and expectations for the outcome of the functioning system.In this step, participants should not be focus on detailed requirements, but rather general goals of the system, so that the designers would be able to preliminarily assess whether the problem is solvable with their resources.

1. **Requirements Formulation**

The requirements formulation is the essential step of the proposed DM. At this stage, the stakeholders and future users first formulate the desired system’s functionalities such as fall detection or localization of monitored person. Additionally, constraints related to the developed system, such as costs, sizes, and required lifespan, are presented. In the case of multi-environmental usage, the functionalities, and constraints in each of the considered environments must be defined. These functionalities and constraints constitute the requirements for the designers; moreover, this is how the stakeholders and future users can indirectly affect the structure of the developed healthcare system.

1. **Feasibility Assessment**

The designers need to evaluate the feasibility of the general needs and specific requirements outlined by the stakeholders and future users. Additionally, they must determine if current viable solutions can address the identified problems and evaluate the practicality of realizing these needs and requirements.The designers must consider also the constraints resulting from the desired working environments. If the designers encounter a problem in accomplishing the requirements, the stakeholders and future users would be asked to modify the requirements in a way that can satisfy them. Once it is confirmed that all requirements can be met, the product development stage can commence.

### Problem Development

Usually, due to the challenging trade-offs and diversity of the desired functionalities and constraints, the selection of suitable technologies and algorithms must be conducted carefully in the following 3 steps: technologies and algorithms’ selection; modelling and prototyping; and then solution validation.   
In this design phase, while stakeholders and future users are involved, it is primarily the designers' responsibility to facilitate the dialogue with all contributors. The key role of the future users and stakeholders during product development is to oversee the implementation of all their needs and requirements. After verification of the functionalities and constraints, the eventual necessary improvements can be postulated.

1. **Technologies and Algorithms Selection**

At this stage, designers suggest technologies and algorithms that align with the functionalities and constraints previously outlined by the stakeholders and future users during the problem formulation phase. When selecting technologies and algorithms, designers must also consider environmental constraints such as indoor/outdoor settings or high humidity, where the system will operate. Additionally, they must evaluate suitable technologies and algorithms within budget constraints, narrowing down to a few viable options. Consequently, cost may influence the final decision. However, if the available solutions do not meet the requirements or fail to incorporate certain functionalities or constraints, designers are tasked with creating innovative solutions or adapting existing ones to meet the needs.

1. **Modelling and Prototyping**

Modelling and prototyping the system are the main tasks of the designers. These tasks are time-consuming and often require the involvement of experts from various fields. However, in user-oriented design, both designers and future users must endorse the models and prototypes. This is an iterative process. The designers assess the performance of the solution, while future users verify whether their specified functionalities and constraints are met. Should there be any deficiencies or areas needing enhancement, the designers are responsible for resolving bugs and addressing any gaps. This process repeats until all parties involved are satisfied. Then, the outcome must be validated.

1. **Validation**

The stakeholders along with the designers must check whether all system’s needs and requirements have been accomplished. Now, it is also possible to verify the costs of the product and accept the price. In the case of any discrepancy between the desired needs and requirements and the prototyped multi-environmental healthcare information system, the designers must examine the proposed technologies and algorithms and come back to the initial stage of product development. Nevertheless, if both stakeholders and designers approve the results, the system is ready to be implemented and launched into a service.

# Flowchart of the proposed design methodology

An IoT-based information system for healthcare, designed to benefit both medical staff and patients. To create such a system, there is a specific development process.

First, healthcare professionals and patients (the stakeholders) brainstorm what features would be most helpful. This might include remote patient monitoring or medication reminders. Then, designers consider limitations (budget, technology) and functionalities (desired features). They assess if the project is feasible, and if so, choose the most suitable technology and algorithms.

The key stage involves iterative design.

Designers create prototypes, like early versions of the system, and evaluate them with the stakeholders. Are the prototypes user-friendly and do they meet the needs? If not, the designers go back to the drawing board and refine their ideas. This loop continues until a successful prototype is developed. Finally, with a validated design, the actual system is built and evaluated before reaching patients and medical staff.

# Case study

### Problem Formulation

The proposed design methodology is implemented and validated on the case study of a healthcare system form environmental monitoring region in Poland. The designed system can be used not only to support and localize the elderly people in their multi-room apartments located in multi-story buildings, but even outdoors in the buildings’ neighbourhood.

### Needs Definition

The growing number of elderly people is a global problem, and many local authorities, also of the Polish region Silesia, acknowledge its importance and are working on it. The general needs and targets introduced by the stakeholders and future users represented by elderly people and their families have considered possibilities to support elderly people, especially those of limited mobility, living alone or patients with the first symptoms of dementia. The support can be yielded by means of an autonomous system monitoring the target’s position, their vital signs are able to recognize different activities and even classify human behaviour.

### Requirement Formulation

The functionalities desired by the stakeholders and future users include the ability to locate a monitored person within their apartment with accuracy up to four room zones, as well as within a multi-story building where the apartment is located, with floor-level accuracy. Furthermore, the person’s positioning in the building’s outdoor neighbourhood with an accuracy of at least 10 m is Appl. Sci. 2017, 7, 596 8 of 26 desiredThe system should be capable of monitoring a person's location within their apartment to a precision of four room zones and within a multi-story building at floor-level accuracy. Additionally, it should monitor vital signs and detect falls. To identify necessary behavioral changes, the system must also differentiate between various postures such as sitting, standing, walking, or lying down. Furthermore, it should classify behaviors as normal, suspicious, or dangerous, notifying caregivers in the event of unusual activities. In cases of suspicious or dangerous behavior, an additional feature should provide detailed information about vital signs.

The system faces general constraints including reliability, size, comfort of the device, and a maximum price of 200 EUR. It should also be easy to install, operate, and maintain, while ensuring the user's privacy. The operational time requirement of at least one week is a specific constraint. Precise localization and reliable activity and fall recognition are necessary. Real-time, secure, and non-invasive measurements of vital signs and accurate behavior classification are also critical constraints.

These comprehensive requirements cover both the general and specific functionalities and constraints of the system. The table consists of technologies and algorithms, and these, which fulfil the stated requirements, are bolded.

### Feasibility Assessment

The designer must thoroughly examine the needs, functionalities, and constraints outlined by both the stakeholders and the future users. After the comprehensive analysis, the general needs of a system supporting elderly people living alone with limited mobility or with the first signs of dementia are assessed as technically accomplishable and feasible. Additionally, the research conducted confirmed that the functionalities and constraints related to working environments, activity recognition, vital signs monitoring, and behavior classification are technically feasible, albeit with a moderate level of technical and algorithmic complexity. However, balancing the desired low cost with the system's reliability and other constraints has been recognized as a challenging trade-off.

# Product development

### Technologies and Algorithms

A meticulous selection of technologies and algorithms was undertaken to meet predefined functionalities and constraints. Indoor localization within apartments relies on the PDR algorithm, leveraging accelerometers and magnetometers for comfort and simplicity, while multi-story building localization employs the Barfi algorithm, integrating Wi-Fi signals and atmospheric pressure measurements for accuracy and ease of operation. Outdoor localization benefits from a GPS-PDR hybrid method, ensuring accuracy and feasibility. Fall detection and activity identification utilize three-axial accelerometers and thresholding method, while behaviour classification relies on decision trees algorithm for reliability. Heart rate monitoring is facilitated noninvasively with the Polar T34 heart rate monitor, ensuring comfort and simplicity. Supporting the system's design constraints, Arduino technology ensures small size, low energy consumption, and affordability. Data collection prioritizes privacy, gathering only insensitive data, with restricted access to trusted individuals such as healthcare professionals and family members. Overall, these carefully chosen technologies and algorithms ensure functionality, simplicity, privacy, and reliability in the designed system.

### Modelling

The proposed indoor localization method utilizes a PDR (Pedestrian Dead Reckoning) approach, leveraging data from a three-axial accelerometer sampled at 90 Hz. This algorithm calculates the person's position based on previous positions, step count, length, and direction, utilizing accelerometer orientation and magnetometer readings to determine step direction accurately. Activity detection aims to recognize various postures and actions, such as sitting, lying, standing, walking, and falling, by analysing accelerometer and magnetometer data. Behaviour recognition constitutes a core function, categorizing behaviours as normal, suspicious, or dangerous by establishing a pattern of ordinary activities in specific spatial environments. Machine learning techniques, including decision trees and SVM, are employed to classify behaviours using a Behaviour Vector (BV) comprising temporal and spatial components. Suspicious behaviours exceed normal durations by up to 150%, while dangerous behaviours are unrecognizable without additional context. Heart rate monitoring supplements behaviour classification, especially for identifying suspicious and dangerous behaviours, adding an extra layer of insight into the subject's condition and well-being.

### Prototyping

The prototype of the system integrates various components to function effectively. At its core lies the Arduino-compatible WiDo Wi-Fi WG1300 module, featuring an ATmega32u4 microcontroller and supporting communication via the 2.4-GHz IEEE 802.11 b/g standard. Additionally, the system incorporates the AltIMU-10 v4 Inertial Measurement Unit (IMU), which includes a three-axis gyroscope, accelerometer, magnetometer, and altimeter. These components are mounted on the Polar T34 Heart Rate Transmitter chest strap and powered by a Li-Pol Redox 1800 Mah 20C 2S 7.4-V battery. The behaviour identification and classification processes are carried out on a Lenovo ThinkPad T440s with an i5-4200u 1.6-GHz CPU, 8 GB of RAM, running the Windows 7 64-bit operating system, and utilizing MATLAB Version 2015a for modelling purposes. This integrated system enables the monitoring and classification of behaviours efficiently, utilizing both hardware and software components to ensure accurate and reliable performance.

# System Validation

### Path Tracking Algorithm

The validation process of the proposed solution begins with analysing the accuracy of step detection and direction estimation. Through empirical testing, it was found that applying a simple Butterworth low-pass filter to the raw readings of the accelerometer allowed for discerning single steps with 98% validity. However, there were challenges with direction estimation, with a mean uncertainty of 1.33° and a maximal error of 3°, leading to localization errors. To address this, direction changes smaller than 6° were neglected, reducing localization errors significantly. The proposed Path Dead Reckoning (PDR) algorithm with a 6° threshold demonstrated effective localization, with a mean uncertainty of 33 cm and a maximal error of 66 cm, meeting the system's requirements for four room-zone level accuracy.

Further validation involved testing the system's performance on a predefined path, revealing insights into localization characteristics. The localization uncertainty varied across different path sections and directions, with mean uncertainties ranging from 4 cm to 40 cm. Clear differences were observed between walking back and forth, potentially influenced by test psychological bias. Despite this variability, the overall mean localization uncertainty was 33 cm, meeting the system's accuracy requirements. However, it was noted that prolonged use of the algorithm could lead to localization drift, necessitating recalibration. Load sensors similar to those used in car seats were proposed as re-calibration points, ensuring sustained accuracy over time.

Overall, the validation process demonstrated the effectiveness of the proposed solution in meeting the specified needs and requirements. Despite challenges with direction estimation and localization drift, the system exhibited satisfactory accuracy for indoor localization at a four room-zone level. Implementation of recalibration measures would further enhance the system's long-term performance and reliability in real-world scenarios.

### Form of Activity Recognition

To meet the requirement of detecting falls in a distinguishable manner from other activities such as standing, sitting, lying down, and walking, the system employs a form of activity recognition. This involves analysing the Signal Magnitude Vector (SMV) and accelerations in the x-, y-, and z-axes to set appropriate identification thresholds for each activity. Through tests involving falls of volunteers, thresholds were justified and set to recognize falls based on characteristic peaks in acceleration readings. The final fall test, consisting of various fall scenarios, achieved a satisfactory detection validity of 98%.

However, the system faces challenges in directly distinguishing between standing and sitting postures due to similarities in acceleration patterns. Further analysis revealed that the observed differences were insufficient to differentiate between these activities based on static measurements alone. To address this, the system focuses on identifying dynamic activities such as sitting down, standing up, lying down, and getting up. By analysing acceleration patterns during these dynamic activities, distinct thresholds for recognition can be established.

Validation of the proposed solution involved volunteers performing various activities, including falls, lying down, standing, sitting down, and walking. The recognition accuracy for each activity was summarized, demonstrating the system's effectiveness in distinguishing between different activities. This comprehensive approach to activity recognition ensures accurate and reliable detection of falls while also addressing challenges in differentiating between static postures.

### Behaviour Classification

The behaviour classification system is designed to categorize behaviours into three classes: normal, suspicious, and dangerous, with each class requiring various levels of attention. Normal behaviour timeframes are established based on the monitoring of elderly individuals during their daily activities, while suspicious behaviour timeframes are set to exceed normal ones by 1% to 50%, and dangerous behaviour timeframes exceed both normal and suspicious ones. Additionally, certain activities occurring at unusual times or places are considered suspicious or dangerous regardless of their timeframes. A training database consisting of over 1200 situations is created, coded based on various variables such as time of day, surroundings, and activity type.

Six different machine learning techniques are applied to establish patterns of normal, suspicious, and dangerous behaviours, with the decision tree and k-nearest neighbour classifiers showing the highest classification validity. The decision tree classifier, optimized by increasing the number of splits, achieves an overall classification validity of 99.1%. The confusion matrix demonstrates high classification validity for normal (99.1%), suspicious (98.4%), and dangerous (99.5%) behaviours, with critical mistakes occurring in only a small percentage of cases. Further verification with randomly chosen behaviours confirms the system's accuracy, achieving an overall classification accuracy of 100%.

In summary, the designed behaviour classification method effectively categorizes behaviours into distinct classes, demonstrating high classification validity and accuracy in identifying normal, suspicious, and dangerous activities. This system holds significant potential for monitoring and addressing safety concerns, especially in contexts involving elderly individuals or vulnerable populations.

# Result

This system design process showcases a meticulous approach towards meeting stakeholders' and future users' requirements, particularly focusing on critical aspects like localization accuracy, fall detection, and activity recognition. The validation results demonstrate a robust methodology, especially evident in the high accuracy achieved in indoor location monitoring despite challenges such as natural body motions affecting position estimation. The implementation of filters and threshold adjustments effectively mitigated errors, enhancing the system's reliability. Furthermore, the comprehensive validation of fall detection and activity recognition methods through extensive testing underscores the system's efficacy, with high validation rates indicating its potential for real-world deployment. The utilization of machine learning techniques for behaviour classification further enhances the system's adaptability, with decision trees proving to be particularly effective after optimization, ensuring an elevated level of accuracy in identifying normal, suspicious, and dangerous behaviours. Overall, the systematic validation process ensures that the proposed solution meets the stringent requirements of stakeholders and users, paving the way for successful implementation and commercialization.

The iterative refinement and validation of the proposed system components illustrates a commitment to ensuring functionality and reliability in real-world scenarios. The detailed analysis of test results not only identifies potential limitations but also offers effective solutions to enhance system performance, such as addressing localization uncertainties caused by specific movements like turns. Moreover, the validation of activity recognition methods through extensive testing demonstrates a thorough understanding of user behaviours and effective algorithmic approaches to differentiate between various activities with high accuracy. The high validation rates achieved across various aspects of the system, including fall detection and behaviour classification, underscore the effectiveness of the applied methodologies and techniques. This systematic approach not only instils confidence in stakeholders and future users but also lays a solid foundation for further enhancements and adaptations as the project progresses towards implementation and eventual commercialization, ensuring a robust and reliable solution that meets the needs of its intended users.

# Conclusion and future work

As society grapples with an aging demographic, ensuring the well-being and safety of elderly individuals becomes increasingly paramount. Leveraging advancements in technology, particularly in the realm of Internet of Things (IoT), presents an opportunity to develop comprehensive support systems tailored to the needs of aging populations. The proposed design methodology outlined in this paper addresses the multifaceted challenges of home care for elderly individuals, considering not only technical requirements but also broader constraints such as energy efficiency, usability, and affordability. By integrating sensors like IMUs, Wi-Fi, GPS, and heart rate monitors, the system aims to provide indoor and outdoor localization, health monitoring, fall detection, and behaviour recognition capabilities, thereby empowering elderly individuals to live independently while ensuring prompt assistance in case of emergencies.

The validation of the design methodology through real-life case studies underscores its efficacy in meeting the critical requirements of stakeholders and future users. By successfully demonstrating functionalities such as room-zone level localization, fall detection, and activity recognition with classification, the system proves its reliability and suitability for deployment in home care settings. Future endeavours are directed towards expanding the system's capabilities to multi-story buildings and outdoor environments, as well as enhancing activity recognition to include specific daily tasks like meal consumption and medication intake. Moreover, improvements in sensor technologies and energy-saving algorithms are identified as key areas for further refinement, aiming to extend device lifespan and enhance overall usability, thereby ensuring continued support for the evolving needs of aging populations.

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