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Transforming Nursing Home Care: An Integrated Approach Using Sensors, AI, and Monitoring Technologies

Stoyan Cheresharov[1], Georgi Dragomirov[2], Georgi Gustinov[3], Stanka Hadzhikoleva[4], Kostadin Yotov[5]

University of Plovdiv Paisii Hilendarski, 236, Bulgaria Blvd, 4027 Plovdiv, Bulgaria

[1] cheresharov@uni-plovdiv.bg, [2] georgiuk86@gmail.com, [3] jbd30@coolcsn.com, [4] stankah@uni-plovdiv.bg, [5] kostadin_yotov@uni-plovdiv.bg

Abstract – This paper introduces an innovative integrated system leveraging sensors, artificial intelligence (AI), and monitoring technologies to revolutionize care in nursing homes. Despite the availability of various digital tools, the absence of a cohesive system that synergizes these technologies represents a significant gap in current nursing home care. Our approach unifies these technologies into a single, comprehensive environment, addressing the fragmentation in existing solutions and targeting the holistic improvement of care delivery. By automating data collection and analysis, facilitating seamless information sharing, and simplifying user interaction with the system, we propose a model that significantly enhances operational efficiency, care quality, and user experience. The development and implementation of this integrated system promise a shift towards more reliable, efficient, and user-friendly care in nursing homes, setting a new standard for digital healthcare environments.

Keywords – Nursing Homes, Digitalization, Integrated Care System, AI, Sensor Technologies, Internet of Things.

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Corresponding author: Stoyan Cheresharov, University of Plovdiv Paisii Hilendarski
Email: cheresharov@uni-plovdiv.bg

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1. Introduction

Nursing homes provide care and support elderly individuals who require constant assistance and medical attention. Challenges associated with this include limited staffing, the continuous monitoring of residents' health and well-being, addressing their social isolation, maintaining a high standard of living, etc. Caring for residents often demands significant time and effort from the staff. Some residents require periodic repositioning to prevent bedsores, while others need frequent checks to ensure their bedding is dry. Continuous physical observations monitor parameters such as heart rate, respiratory rate, and signs of discomfort or pain. Ensuring residents' unique needs and preferences is vital to their sense of comfort, particularly for those requiring specialized care. Staff actions can disrupt residents' sleep and overall comfort, especially during night shifts.

Although many vital sign observations can be automated, nursing homes often use multiple fragmented systems, which complicates coordination between them and hinders adaptation to increasing demands. Traditionally, caregivers rely on pagers, monitoring systems, bells, and other signals from residents. This model requires physical visits to provide care and services. An additional responsibility for staff is medication management, which includes organizing and supervising medication intake and maintaining documentation. Documentation of visits, observations, medication administration, and other interventions must be meticulously maintained, which is time-consuming and can divert staff from direct patient care.

This study presents various aspects of developing an integrated system tailored to the unique needs of nursing homes. A unified solution is proposed,

incorporating sensors, the Internet of Things (IoT), artificial intelligence (AI), and monitoring technologies. Key features of the system include unobtrusive monitoring of residents' health, safety, security, and privacy, along with a comprehensive reduction in redundant operational tasks and staff effort to improve efficiency and resident care. Additional functions of the system include scheduling and managing staff shifts and duties, among other features. The system utilizes a range of advanced sensors and technologies to transform care delivery. Key components include facial recognition cameras, vital sign monitors, and innovative bed sensors, all working together to enhance residents' safety and comfort. The sensors monitor health metrics silently and non-invasively, thus minimizing disruptions during rest periods. Additionally, our system incorporates a novel call bell system based on radio frequency (RF) technology, which ensures prompt communication between residents and caregivers without the constraints of traditional wired systems.

A key element of our approach is the integration with a patient care system, which allows for seamless aggregation and analysis of data collected by the sensors. The incorporation of AI further distinguishes our system. The AI engine analyzes the data to provide real-time insights and alerts to predict potential health issues based on behavioral and physiological parameters. The integration of the system in a real environment enhances the quality of services provided by staff, automates part of the activities, and increases residents' sense of freedom, dignity, security, and happiness. The proposed system model has the potential to revolutionize the standard of care in nursing homes, providing the comfort of a homelike atmosphere and making them more efficient and responsive to the individual needs of residents.

2. Related work. Literature review

The use of digital technologies in nursing homes has the potential to enhance resident care, clinical support, and administrative activities [1]. This is particularly important in the context of an aging population, where technology can help address the challenges of healthcare for older adults [2]. However, the acquisition of digital skills by staff and residents in care homes is influenced by psychosocial and environmental factors [3]. Despite the potential benefits, challenges in the use of digital technology in nursing care persist, highlighting the need for ongoing training and support [4].

2.1. Evolution of Nursing Home Care

Wan [5] provides a comprehensive overview of the current state of care in nursing homes, emphasizing the need for a service-oriented approach and the integration of technology. Karsch-Völk [6] examines the development of criteria for effective medical care in German nursing homes, highlighting the importance of collaboration between nursing home staff and physicians. Together, these studies underscore the need for a holistic approach to care in nursing homes, addressing both the physical and psychosocial well-being of residents.

The field of elderly care technology has advanced significantly in recent years, focusing on smart home solutions [7], assistive technology [8], and information technology [9]. These innovations aim to enhance the safety, security, and independence of elderly individuals while alleviating the burden on healthcare systems. Robotics in elderly care is another emerging area of interest [10], with the potential to further improve the quality of care provided to older adults.

2.2. Current Technologies in Nursing Homes

Numerous studies have explored the use of monitoring systems in nursing homes, with a focus on improving patient care and outcomes. Motwani [11] and Frech [12] highlight the potential of these systems to detect and address health issues in a timely manner, with Motwani specifically noting the use of sensors for data collection and wireless transmission to caregivers. Cislo [13] and Chang [14] further support the feasibility and benefits of these systems, with Cislo emphasizing the use of innovative sensors and a self-learning decision process, and Chang demonstrating the successful application of a wireless sensor network for vital signs monitoring. These studies collectively underscore the potential of monitoring systems, particularly those utilizing digital technologies, in enhancing the quality of care in nursing homes.

Passive health monitoring systems have been shown to significantly reduce care costs and improve the efficiency of professional caregivers in assisted living facilities [15]. These systems also enable informal caregivers to provide more support without increasing their burden or negatively impacting their quality of life [16]. Additionally, these systems are generally well-accepted by residents and may positively influence their quality of life [16]. However, their effect on life satisfaction among residents in independent senior housing remains inconclusive [16].

Various communication tools and technologies have been developed to support interactions among residents, caregivers, and families. Cranley [17] emphasizes the value of engaging residents and families in the development of a communication tool,

while Hoel [18] highlights the potential of technology-driven solutions, such as tablet computers, social robots, and computer systems, to enhance communication and interactions, particularly for people with dementia and their caregivers. Généreux [19] further supports the use of communication plans, which contain information about a resident's specific characteristics and communication disorder, to facilitate interactions with communication-impaired residents. These studies collectively underscore the importance of person-centered communication tools and technologies in long-term care.

Effective communication tools in nursing homes have been found to significantly impact resident health outcomes [20]. This is particularly important in the medication process, where an online communication platform has been shown to improve cooperation and systematize the process [21]. User and family satisfaction with nursing homes is also crucial, with determinants including quality of life, anxiety, and social and health factors [22]. Therefore, the use of effective communication tools can not only improve resident health outcomes but also contribute to user and family satisfaction in nursing homes.

Jiang [23] proposed a health monitoring system for nursing homes that utilizes lightweight security and privacy protection, including dual-band RFID and a mobile authentication protocol. This system offers real-time monitoring and high security, meeting the requirements of nursing home health monitoring. Levy [24] discussed the challenges of privacy and security in nursing home monitoring, particularly in the context of consumer-purchased monitoring devices. State regulations play a crucial role in balancing these interests. Samadbeik [25] emphasized the importance of user authentication and security controls in managing nursing data in the Electronic Health Record, with a focus on the viewpoints of IT experts and computer companies. These studies collectively highlight the need for robust security and privacy measures in nursing home monitoring systems, with a particular emphasis on user authentication and state regulations.

A range of studies have explored the benefits and limitations of security and access control systems in nursing homes. Li [26] and Jiang [23] both highlight the potential of these systems to enhance safety and efficiency, with Li's system focusing on real-time monitoring and Jiang's on lightweight security and privacy protection. Chinnasamy [27] emphasizes the importance of access control in protecting healthcare data, while Samadbeik [25] underscores the need for strong authentication and authorization methods. These studies only underline the need for reliable security measures and access control.

2.3. Challenges in Integrating Technology in Nursing Homes

The integration of technology in nursing homes is hindered by several challenges. Cost, resistance to change, and training requirements are key barriers [28]. There is a lack of information about the cost-effectiveness and other aspects of technologies, as well as limited resources for their purchase and development [29]. Management attitudes also play a role, with some administrators lacking interest in change and a systematic approach to technology adoption [30]. Additionally, the delivery of high-tech home care by hospital-based nursing units presents clinical and technical challenges [31]. These findings highlight the need for evidence-based decision-making, participatory planning, and professional training initiatives to overcome these barriers and improve the integration of technology in nursing homes.

Integrating technology in nursing homes is a complex process, with various challenges and limitations. Weernink [32] and Lin [33] both highlight the need for careful implementation and integration of new technologies, particularly in the context of lost and misplaced items and real-time positioning and monitoring services for the elderly. However, Freedman [29] identifies several barriers to the adoption of technology in U.S. residential long-term care settings, including lack of information, limited resources, concerns about liability, and regulatory constraints. Bourbonnais [34] further emphasizes the importance of understanding the perceptions and needs of care managers, formal and family caregivers in nursing homes, in order to develop useful technologies that can improve the quality of clinical practice.

Some ethical and privacy-related challenges need to be taken into consideration when using technology in nursing homes. Berridge [35] highlights the risks to residents' privacy and dignity, as well as the potential for staff and resident monitoring. Bourbonnais [36] emphasizes the need for pilot testing and coaching activities to facilitate technology adoption, while also addressing ethical risks and prejudices. Sifford [37] discusses the benefits and challenges of electronic surveillance in LTC research, particularly in investigating resident-to-resident violence. Hall [38] underscores the importance of involving all stakeholders in decision-making and training to ensure a deeper understanding of the potential benefits and challenges of monitoring technologies.

The integration of monitoring technologies in nursing homes, while beneficial for safety, presents ethical and privacy concerns [38]. These concerns are further complicated by the need for pilot testing and

coaching activities to facilitate adoption [36]. The use of surveillance cameras in nursing home rooms raises additional ethical issues, including privacy and dignity risks for residents and the potential for staff and resident monitoring [35]. Despite these challenges, electronic surveillance has been proposed as a method to address resident-to-resident violence, particularly in the context of dementia [37]. These studies highlight the need for a balanced approach to the integration of technology in nursing homes, one that prioritizes safety while addressing ethical and privacy concerns.

A qualitative study exploring nursing home care environments where nurse practitioners work was conducted by Gregory in [39]. The research supports the growing nurse practitioner workforce to assure higher quality care for older adults in nursing homes. The author claims that nursing homes with optimal care environments that support nurse practitioner roles, increased visibility, independence, and relationships are better positioned to support care of older adults. The study reports findings of thirteen qualitative interviews with nurse practitioners to explore facets of nursing home care environments and adapt a tool to measure care environments. The authors incorporated deductive and inductive coding to identify three major emerging themes impacting care environments: 1) nurse practitioner practice in nursing homes, 2) overall goals of practice, 3) workplace challenges. Some of the most highly important survey items measured nurse practitioner and physician relationships. Since our integrated system is aiming of improving the performance of the caregivers the mentioned study is important to us.

In the interesting study of Marjanovich et. al. the claim is made that between 2% and 5% of the population in industrialized countries lives in nursing homes [40]. The author noticed that the residents often lack medical referrers, especially at night and on weekends, and emergency departments (EDs) are often the last answer to medical questions. In the research have been included 3103 calls in the final analysis (355 from equipped nursing homes and 2748 from unequipped nursing homes). The proportion of patients dispatched to an ED after the first call was lower among telemedicine-equipped than among telemedicine-unequipped nursing homes (41% vs 50%; odds ratio, 0.71; 95% CI, 0.56–0.90). Telemedicine and using modern technologies is obviously improving the quality of service in the nursing homes.

The prevailing systems are predominantly reliant on manual checks and suffers from an absence of real-time data analysis capabilities. The literature review underscores a discernible void in the current methodologies—specifically, the absence of a comprehensive, AI-enhanced system that integrates diverse data streams effectively. This deficiency highlights the critical need for developing advanced technological frameworks that not only consolidate data from multiple sources but also utilize artificial intelligence to facilitate immediate and actionable insights.

3. Methodology, System Design and Architecture

We present a conceptual model for the development of a digital system tailored specifically for nursing homes. This model delineates the primary modules and abstract concepts integral to the system's architecture. Utilizing a cloud-native, service-oriented architectural framework, the model facilitates scalable and efficient data management and service delivery. The main conceptual framework and the corresponding modules are depicted in Figure 1, illustrating the interconnectivity and functional flow among the system components.

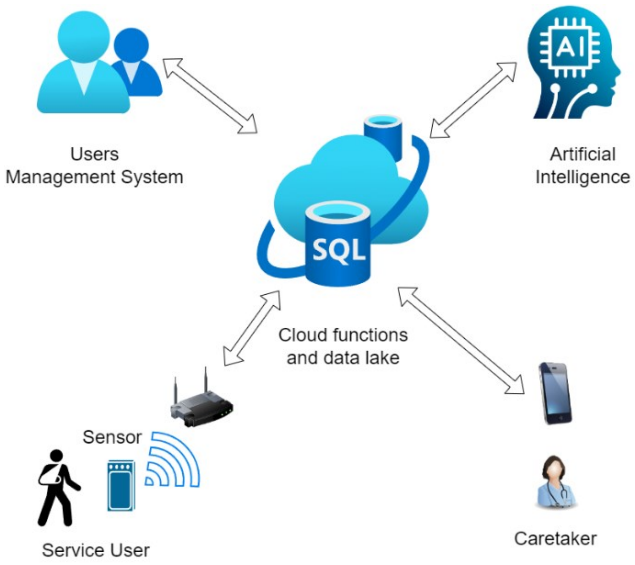


Figure 1. The formal conceptual model

The overall system architecture is illustrated in Figure 1. Within this infrastructure, sensors deployed across various rooms may originate from diverse manufacturers, contributing to variability in system integration. The simplest among these are the call bell buttons, which differ in connectivity; some are tethered through wired connections while others communicate wirelessly with a central hub. Notably, even identical hardware configurations may employ disparate communication protocols. Figure 2 provides a streamlined diagram of the sensor data flow within the system. While not exhaustive, this representation captures the fundamental pathways through which data is transmitted and integrated into the cloud

architecture, emphasizing the complexity and diversity of sensor integration in the proposed model.

One notable dataflow configuration illustrated in Figure 2. involves the direct connection of sensors, designated as "Wi-Fi sensors," to a router. These sensors, characteristic of Internet of Things (IoT) devices, possess the capability to autonomously establish a Wi-Fi connection and transmit data directly to a designated endpoint. Although this configuration is favored for its straightforward installation and operational simplicity, it incurs a substantial power demand, typically around 120 mA. Consequently, such arrangements generally necessitate a continuous power supply from the main electricity grid. Reliance on battery power alone would lead to rapid depletion, typically within two to three days, rendering it impractical for sustained use without frequent battery replacements or recharging.

The configuration denoted as "Wired sensor" in Figure 2 presents its own set of advantages and disadvantages. This setup ensures a stable and reliable connection due to the physical wiring to each sensor. However, the installation of these cables introduces logistical challenges. Although employing Power over Ethernet (PoE) can obviate the need for separate power supplies or batteries, in its absence, each sensor must either be connected to the main power grid or equipped with batteries. This necessity may complicate installation and increase maintenance requirements, especially in environments where access to power sources is constrained.

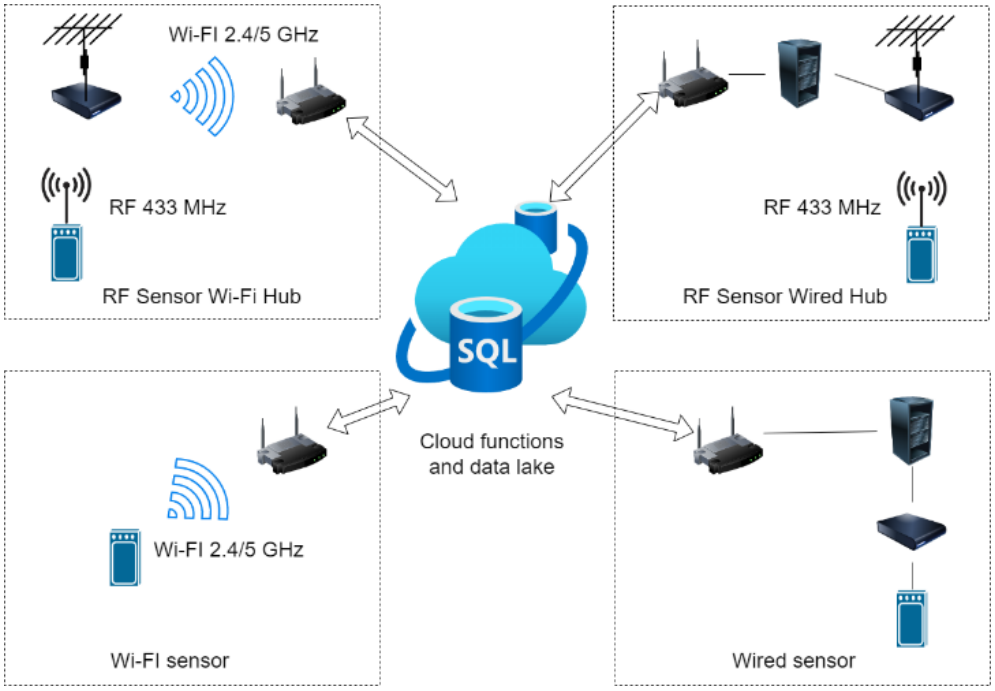


Figure 2. Sensors data flows

The dataflow configuration labeled as "RF Sensor Wired Hub" in Figure 2. employs a central hub that receives signals from all connected sensors and transmits these via a wired connection to a server. This setup facilitates system maintenance by centralizing signal reception and enabling remote server access, thereby streamlining administrative tasks. However, the scalability of this configuration poses potential challenges; the central hub might become overwhelmed with data processing demands if the number of sensors is large. Additionally, the risk of signal interference increases when many sensors transmit simultaneously on the same frequency, potentially leading to signal jamming and data loss.

The configuration termed "RF sensor Wi-Fi Hub" depicted in Figure 2, implements a decentralized approach where each room is equipped with a receiving hub. This hub collects signals from all sensors within the room and subsequently transmits the data to the cloud via a Wi-Fi connection to the router. This arrangement enhances the system's resilience and scalability by distributing the data collection points, thereby reducing the load on any single device and facilitating robust signal transmission even in complex environments.

In each of these configurations, the deployment of repeaters for either lower frequency or Wi-Fi signals can enhance system performance. These devices are instrumental in extending the range of signal transmission, ensuring consistent and reliable communication across larger or structurally complex environments.

Additionally, cameras have been installed in each room as part of a strategic upgrade, paving the way for the next generation of the system. This future enhancement will incorporate facial and expression recognition technologies, enabling the system to generate events based on nuanced visual data. By analyzing facial expressions, the system will offer a more sophisticated level of monitoring, capable of detecting subtle cues that may indicate changes in a resident's emotional or physical state. This advancement is expected to significantly enrich the system's responsiveness and accuracy, providing caregivers with timely and pertinent alerts based on real-time visual analytics.

Reliability is paramount in the design and operation of this system. To ensure ongoing functionality, a heartbeat monitoring system is integral. This system periodically sends signals through all components to verify their operational status. Alongside these heartbeat checks, payload data carrying useful information may be concurrently transmitted, enriching the system's utility. However, the primary value of the heartbeat signal lies in its role as a diagnostic tool; receipt of this signal confirms the proper functioning of all system elements. Conversely, if a heartbeat signal is not received within a domain-specific predefined period, it is presumed that there is a malfunction. Consequently, an alert is triggered to notify maintenance personnel of the issue, prompting immediate attention to prevent system failure.

As outlined earlier, the four data flow models presented serve as a general framework for understanding potential configurations within the system. Detailed exploration of each configuration is beyond the scope of this publication, as each model warrants an in-depth study due to its unique technical nuances. Various communication protocols, such as EV1527, and modulation techniques, including Amplitude Shift Keying (ASK) and On-Off Keying (OOK), could be employed depending on specific requirements. Additionally, for applications requiring transmission over greater distances, Long Range (LoRa) communication technology offers a viable solution, enhancing the flexibility and reach of the system.

Data originating from various sensors, each utilizing a distinct data flow model as depicted in Figure 2. , is typically transmitted in binary or simple text formats. These data streams are captured by specialized hardware devices that interface with server computers via RS232 or USB connections. On these servers, dedicated services are continuously operational, tasked with the critical functions of reading and interpreting the incoming data. Following this initial processing, the data is converted into JSON format, which standardizes the information for enhanced interoperability and ease of handling. Subsequently, this formatted data is transmitted to designated endpoints within the cloud infrastructure, ensuring timely and accurate data availability for further analysis and application.

The endpoints within the system consist of functional applications, each equipped with HTTP-triggered functions that facilitate responsive data processing upon receipt of incoming data. Additionally, certain functions within these applications are configured to activate on a time-triggered basis, systematically processing data that has been previously collected and stored. This architecture allows for the deployment of multiple functional applications, each tailored with specific functions designed to meet diverse operational needs. This modular approach not only enhances the system’s flexibility but also optimizes the efficiency of data processing tasks across different segments of the network.

The consolidation of business logic and services within the cloud framework underpins our system architecture, enabling remote management and development capabilities. This cloud-centric approach confers numerous advantages. Primarily, it offloads the responsibility for infrastructure maintenance to cloud service providers, thereby alleviating the need for extensive local IT resources. Such decentralization allows for meticulous control over individual functions and optimizes the utilization of cloud-specific features. Applications developed in a cloud-native environment inherently exhibit enhanced robustness, stability, and scalability. Furthermore, these applications are simpler to maintain and evolve due to their integration with the dynamic, resource-elastic infrastructure provided by cloud platforms.

The cloud functions serve a pivotal role in aggregating data from diverse sensors and sources, recording this information into a cloud-based data lake. This repository houses all sensitive information pertaining to service users, ensuring comprehensive data capture in a secure and scalable environment. The utilization of a data lake not only facilitates robust data storage capabilities but also supports advanced analytics by providing a centralized point of access to a wide array of data types and structures. This architecture enhances the ability to extract actionable insights while rigorously maintaining data privacy and security standards essential for handling sensitive information.

Time-triggered functions within the system are designed to transmit essential data to third-party APIs for analysis and processing, facilitating a seamless

integration of external computational resources. Additionally, some sensor providers enable access to sensor data via web sockets or RESTful APIs. This arrangement allows for two modes of data retrieval: active polling by our system at regular intervals, or passive reception where data is pushed directly to our endpoints by the providers. Both methods ensure that the system remains consistently updated with the latest sensor data, enhancing the timeliness and accuracy of the information available for processing and decision-making.

Certain sensor providers, such as those manufacturing wristwatch devices, utilize available mobile networks to transmit data directly to their respective servers. Subsequently, this data is pushed to designated endpoints within our system. This method facilitates a continuous stream of data flow, ensuring that our system receives timely updates. Such integration allows for real-time monitoring and responsive interaction with the data received, enhancing the overall efficacy of the service provided by these sensors.

Dedicated virtual machines within the cloud infrastructure are configured to manage data transactions with the RESTful APIs of sensor providers. These virtual machines actively pull data from and push data to these APIs, facilitating a dynamic exchange of information. This setup ensures that the data integration is not only seamless but also robust, allowing for continuous synchronization and real-time updates. The use of virtual machines specifically for this task leverages their scalability and reliability, which are critical for maintaining consistent performance and availability in cloud-based systems.

The data lake serves as the principal reservoir of data for Artificial Intelligence (AI) providers. Raw data is routinely pushed from the data lake to these providers at regular intervals, facilitating continuous data analysis. Upon analyzing this data, AI providers generate insights that are encapsulated in events. These events are then transmitted back to our system and directed to specific endpoints designed to handle this information. Simultaneously, these events are also archived within the data lake for future reference and analysis. This cyclical flow of data ensures that the insights derived from AI analysis are both actionable and integrative, enhancing the overall decision-making processes within the system.

Cloud-based functions play a crucial role in analyzing sensor data and information received from Artificial Intelligence (AI) systems. Upon analysis, these functions generate specific events based on predefined criteria tailored to each type of sensor data. For instance, events may include notifications such as "wet bed," activation of a call bell, or alerts indicating that a resident has left the bed. These events are crucial for operational responsiveness and are not broadcast indiscriminately. Instead, they are strategically routed to handheld devices of specifically assigned caregivers. This targeted delivery ensures that alerts are promptly addressed by the responsible personnel, enhancing the efficiency and effectiveness of the caregiving process. Each type of sensor data has distinct boundaries and criteria that define the conditions under which these events are triggered, ensuring that the system's responses are both appropriate and timely.

The mobile application serves as a sophisticated user interface for caregivers within the system. It not only presents the generated events but also categorizes and prioritizes them according to their urgency and relevance. Each type of event is visually distinct within the application to facilitate quick recognition and response. Additionally, the integration of text-to-speech technology enhances the usability of the application; it vocalizes event notifications, allowing caregivers to receive critical updates audibly. This feature is particularly beneficial as it enables caregivers to stay informed without the necessity of continuously monitoring their devices visually, thereby improving their efficiency and allowing them to maintain focus on direct patient care.

To enhance security and operational efficiency, a specialized Mobile Device Management (MDM) system is implemented to manage and secure the mobile devices used by caregivers. This MDM system is configured to grant specific privileges to the mobile application responsible for processing events, ensuring it operates with the necessary authority and access. Furthermore, the MDM restricts the functionality of these devices to only those applications that are pertinent to caregiving tasks. This controlled environment prevents the execution of non-essential apps, thereby safeguarding sensitive data and optimizing the devices' performance for professional use. This strategic application of MDM technology plays a crucial role in maintaining the integrity and confidentiality of patient-related information, while also ensuring that caregivers have seamless access to vital operational tools.

4. Implementation and Validation

As a culmination of our research, the architecture previously delineated was successfully employed to construct a digital system for nursing homes. This system serves as a proof of concept, demonstrating the practical viability and effectiveness of the integrated technologies. By implementing this architecture, we have established a foundational model that not only

addresses the specific needs of nursing home care but also showcases the potential for broader applications in similar healthcare environments. This proof of concept validates the theoretical constructs and operational strategies proposed, paving the way for further development and refinement in future iterations.

The development of the described system was guided by agile software development principles, with continuous input from caregivers and management to ensure relevance and usability. The cloud functions were developed using C#, a modern programming language that benefits from robust support and seamless integration within Microsoft's ecosystem. This integration was a pivotal factor in selecting Azure as the cloud provider, as it offers well-coordinated tools that facilitate rapid application development. Furthermore, the Microsoft environment supports Continuous Integration and Continuous Delivery (CI/CD) pipelines that are well-suited to C#, .NET, and Azure technologies. This integration enhances the development workflow, simplifying the processes of application deployment and iterative updates, thereby ensuring that the system remains adaptable and aligned with evolving user needs.

Within our system, a mix of third-party and bespoke sensors is employed to capture data tailored to specific care requirements. Third-party sensors transmit data to their respective providers' servers, which then reroute this information to our designated endpoints or web sockets, ensuring seamless integration into our architecture. Conversely, many sensors are custom-developed within our organization to align precisely with unique operational needs. These are typically constructed using Single Board Computers (SBCs), Systems on Chip (SoCs), and Microcontrollers (MCUs). Notably, certain microcontrollers and development boards are equipped with advanced connectivity features such as Wi-Fi and Bluetooth, making them ideally suited for our application. Examples of such devices include the Espressif ESP 32 and ESP 8266, which offer robust performance and versatility, crucial for the real-time data communication demands of our system.

A primary challenge in implementing sensors within our system is ensuring their reliability while adhering to several operational constraints: they must be battery-operated, possess long battery life, be easy to install and relocate, and maintain an aesthetically pleasing appearance. Given these requirements, the use of power-intensive technologies such as Wi-Fi and Bluetooth is often impractical. Consequently, our approach has shifted towards utilizing lower, license-free frequencies, which are less demanding on power resources. The transmitters employed in this spectrum are smaller, consume less power, and consequently have a longer operational life. Integrating these with Microcontrollers (MCUs) set to sleep mode, paired with low-power transmitters, forms an optimal solution. This combination ensures extended durability and efficiency, meeting the system's need for continuous, reliable performance without frequent maintenance.

Data transmission within our system can be executed through two distinct methods: encoded and modulated, or solely modulated without encoding. For instances where encoding is utilized, the EV1527 encoding scheme is employed. This specific method allocates 20 bits for the unique address of the transmitting device, ensuring precise identification, while the remaining 4 bits are dedicated to transmitting the actual data. This structure enhances the security and integrity of the data transmission process, enabling reliable and distinct communication between devices within the network.

The system underwent rigorous testing in a controlled environment over a period of one month, followed by a scaled-down implementation in the field to gather real-world data and feedback. During these tests, the system achieved a 99% accuracy rate in recognizing and transmitting events, demonstrating its robustness and reliability. Additionally, the power consumption metrics for sensors equipped with RF transmitters were quantified, showing a draw of 10 mA at a voltage range of 3.2 to 5 V. These results affirm the system's effectiveness in operational conditions and its efficiency in terms of energy usage, critical factors for long-term deployment in dynamic environments.

Aggregating collected data into a data lake facilitates various analytical operations, allowing for diverse slicing and dicing of the data to extract meaningful insights. To visualize and monitor this data effectively, Power BI was employed as the tool of choice. This business analytics service provides robust data representation capabilities, enabling the creation of interactive visualizations and comprehensive dashboards. Utilizing Power BI enhances our ability to interpret complex datasets and monitor system performance in real time, making it an ideal solution for overseeing and refining the operational processes within our system.

5. Discussion

The proposed system was implemented to enhance the organization and performance across 14 nursing homes. It has proven effective in its core functions, detecting events and promptly alerting caregivers. This capability ensures that critical information is communicated swiftly and accurately, facilitating

timely interventions and improving the overall care process. The effectiveness of the system in these settings demonstrates its utility in enhancing operational efficiency and the quality of care provided to residents, thereby affirming its value as a significant technological advancement in the healthcare sector.

The system provides an integrated approach by seamlessly combining third-party software and artificial intelligence with sensor data from various providers. It efficiently processes and sends event notifications to the handheld devices of caregivers, ensuring that they receive timely and relevant information. Furthermore, the system supports integration with multiple data providers while offering a single sign-on feature, which simplifies the authentication process and enhances user convenience. This capability allows caregivers to access a unified platform that aggregates diverse data streams, facilitating a comprehensive overview and efficient management of care activities. This holistic integration not only improves operational efficiency but also enhances the responsiveness and adaptability of caregiving practices in dynamic healthcare environments.

The implementation of the system has had a demonstrably positive impact on several key aspects of nursing home operations. Specifically, it has streamlined caregiver workflows, significantly enhancing their efficiency and reducing response times to resident needs. Additionally, the system has bolstered resident safety by enabling more precise and timely monitoring, thus facilitating early intervention in potential issues. Overall, the quality of care provided within these facilities has seen marked improvements, evidenced by increased satisfaction among residents and staff alike. These enhancements collectively demonstrate the system's effectiveness in transforming the care environment through advanced technological integration.

Future enhancements of the system could involve the integration of cameras equipped with facial recognition technology to bolster security measures. This addition would allow caregivers to remotely verify the status of residents without physical presence, enhancing efficiency and response times. Communication capabilities could be augmented through microphones and loudspeakers embedded in the cameras, facilitating direct interaction with residents. Additionally, these cameras could ensure that only authorized individuals gain access to the facility and specific rooms, further enhancing security.

The potential for expanding the role of Artificial Intelligence (AI) is considerable. Future iterations of the system could incorporate expression recognition to generate alerts based on residents' emotional or physical distress signals. AI could also play a more significant role in medical management, assisting with medication prescriptions and preliminary diagnostics. Moreover, AI-driven workflows could optimize operational tasks, assigning responsibilities based on real-time needs to maintain optimal living conditions for residents.

With the rapid advancements in AI and robotics, coupled with continuous improvements in medical technology, the possibilities for enhancing care through technology are virtually limitless. These advancements promise not only to improve the efficiency of care delivery but also to significantly elevate the quality of life for residents by providing more personalized and proactive care solutions.

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