Journal of Infrastructure, Policy and Development 2024, 8(3), 2899.
https://doi.org/10.24294/jipd.v8i3.2899

Article

Advancing affordable IoT solutions in smart homes to enhance independence and autonomy of the elderly

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CITATION

Akhmetzhanov B (Batyrzhan), Akhmetzhanov B (Bauyrzhan), Ozdemir S, Zhakiyev N. (2024). Advancing affordable IoT solutions in smart homes to enhance independence and autonomy of the elderly. Journal of Infrastructure, Policy and Development. 8(3): 2899. https://doi.org/10.24294/jipd.v8i3.2899

ARTICLE INFO

Received: 25 September 2023
Accepted: 26 October 2023
Available online: 18 February 2024

Abstract: There is a growing trend among elderly people to live alone and this trend is expected to increase in the future. Social isolation and limited support can have a negative impact on the physical and mental well-being of older adults. The increasing life expectancy and expanding geriatric population necessitate the development of innovative solutions to support their health, independence, and autonomy. This article addresses the key challenges and issues confronting the elderly and analyzes various IoT technologies and solutions proposed to enhance their lives. Smart home technologies improve the quality of life and enable older adults to live independently in their own homes while their adult children are at work. This article presents a smart home model for the elderly in Kazakhstan, based on their needs, concerns, and financial capabilities. The proposed prototype will be developed using an accessible, open-source intelligent system that includes health monitoring, medication adherence monitoring, alerting family members in case of falls or deteriorating health indicators, and video surveillance. Another advantage of this system is the automation of processes such as automatic lighting control, voice command functionality, home security, and climate control. Preliminary testing of the hardware model shows promising results, with plans for continuous improvement and evaluation as it is deployed. Key criteria for its implementation include affordability, accessibility, and feasibility. Based on Kazakhstan's unique socio-cultural and economic context, this paper proposes a sophisticated smart home model tailored to the specific needs and financial capabilities of elderly Kazakhs.

Keywords: smart home; social care smart system; home assistant for the elderly; intelligent control systems; IoT as a service

1. Introduction

According to UN projections, the population of Kazakhstan's population, like many other regions of the world, is expected to grow over the next few decades, reaching approximately 24 million people by 2050 (**Figure 1**). Based on data from the National Statistics Bureau over the past 22 years, the percentage of elderly citizens accounted for 11.6%, which is estimated to be 2.3 million individuals. Consequently, the country is in the initial stage of demographic aging. Taking into account this statistical information, the Ministry of Labor and Social Protection of the Population of the Republic of Kazakhstan has developed the "Active Longevity" program aimed at improving the quality of life of the elderly population (Bureau of National statistics, 2023).

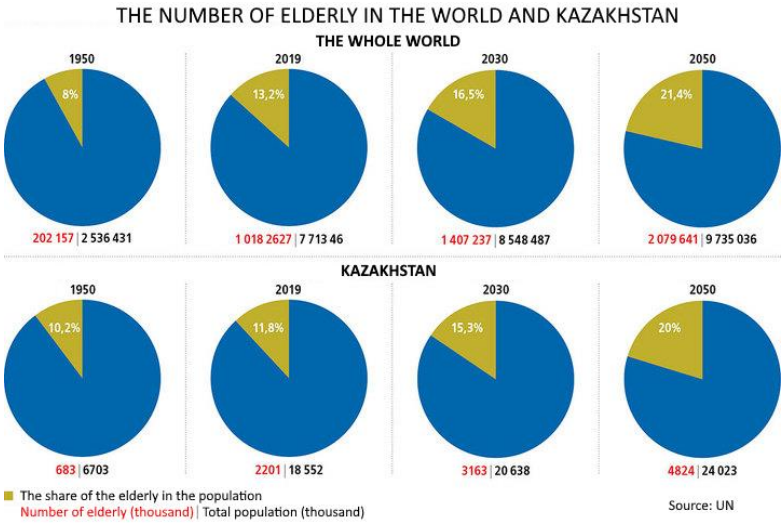

Figure 1. The number of elderly people in the world and Kazakhstan according to UN forecasts.

Some elderly people need care and assistance while their children and grandchildren are at school or work. Therefore, it is crucial to develop a smart home system that enhances the independence and autonomy of the elderly (Visutsak et al., 2017). This system should be accessible, cost effective and easy to use.

In addition to demographic trends, a significant factor affecting the quality of life of the elderly individuals in Kazakhstan is the size of pensions. According to statistics (Bureau of National statistics, 2023) as of 1 February 2023, the average pension in the country amounts to 120,659 tenge (~270 USD). This low income limits access to high-tech solutions, making it important to develop affordable and cost-effective smart home systems for the elderly (Ardelean et al., 2023).

This article proposes a model for a smart home system for the elderly in Kazakhstan, based on the requirements, concerns, and financial capabilities of the target audience. To implement this model, an open-source application called Home Assistant will be utilized, allowing for the creation of customizable and flexible smart home systems. To the best of our knowledge the development of an IoT-based smart home system tailored for the elderly in Kazakhstan, taking into account the unique social and economic limitations of Kazakh people, represents a pioneering contribution to the literature in the realm of context-specific, smart living solutions.

2. Review of literature

The Role of IoT technologies in improving the lives of older people

In recent years, there has been a growing development of assistive technologies aimed at automating everyday household processes, facilitating the care of elderly individuals living in their homes, and enhancing their independence. These technologies encompass various devices designed to address limitations related to cognitive, sensory, and physical abilities, as well as changes in climate, design, and lighting, which allow for the adaptation of the home environment (Kök et al., 2017). Additionally, the installation of sensors and systems enables the tracking of daily activities of elderly individuals, assisting them in maintaining their health and safety

while living independently. These widely applicable technologies for people are commonly referred to as “smart homes”.

The concept of a “smart home” technology involves the use of basic and assistive devices to automate various functions within the home and to enable interactions between these devices. In the context of the elderly, a smart home is based on collecting information about them and disseminating it to the elderly individuals themselves, their family members, and healthcare providers (Visutsak, et al., 2017). Assistive technologies for the elderly can be categorized into two types: passive and active.

Passive devices monitor the well-being and safety of elderly individuals without directly intervening in their care. For example, these devices may include heart rate, respiratory, and sleep monitoring devices, as well as motion sensors that help recognize daily activities.

Active devices play a more proactive role in caring for elderly individuals. For instance, they may send alert signals to family members in the event of a fall or remind them to take medication. These devices actively assist in ensuring the safety and well-being of the elderly individuals (Alghamdi, et al., 2023).

By integrating passive and active technologies in a smart home environment, we can create a comprehensive system that enhances the independence and quality of life for elderly individuals while addressing their specific needs and concerns (Sooraj et al., 2020).

The objective of this article is to develop a prototype of a “Smart Home” for the elderly in Kazakhstan, based on their requirements, concerns, and financial capabilities. The prototype aims to address the specific needs of the elderly population in Kazakhstan and provide them with a technology-driven solution that enhances their independence, safety and overall quality of life.

The proposed prototype will take into account the unique challenges faced by elderly in Kazakhstan, such as social isolation, limited support, and potential financial constraints. It will be designed to be accessible, affordable, and user-friendly, ensuring that elderly individuals can easily adopt and benefit from the smart home technology.

By customizing the smart home prototype to the specific needs and circumstances of the elderly population in Kazakhstan, it will serve as a practical and effective solution to empower elderly individuals to live independently and comfortably in their own homes. The prototype will leverage available technologies and consider the local context to create a reliable and tailored smart home system that improves the well-being and quality of life of elderly individuals in Kazakhstan.

In essence, “smart homes” incorporate both semi-automated and fully automated systems for various programmed functions and tasks, such as assistance for elderly individuals, climate control, lighting management, multimedia control, and temperature regulation. This comfortable living environment is also referred to as ambient intelligence, which is sensitive and adaptive to enhance home comfort for everyone (Visutsak et al., 2017). **Figure 2** shows the proposed model of a “smart home” designed to assist elderly individuals.

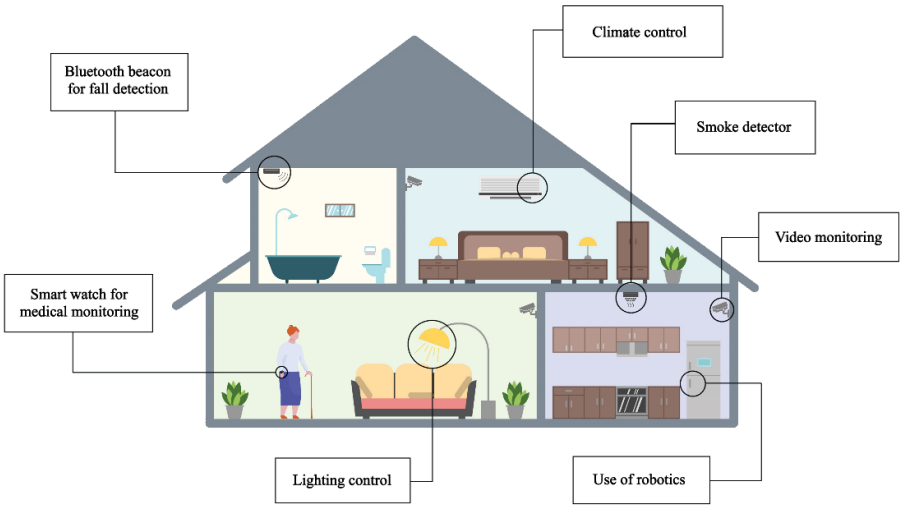

Figure 2. Proposed prototype of a smart home for the elderly.

Here is a brief description of selected smart home technologies:

- Lighting control: Lighting sensors and presence detectors detect the presence of elderly individuals in a room and automatically turn on or off the lights accordingly.
- Video monitoring: Used for monitoring the activities of elderly individuals by their family members.
- Smoke detector: Serves as a fire safety measure and detects CO_2 levels in the air.
- Climate control: Automatically adjusts temperature and humidity levels using sensors.
- Use of robotics: For example, robotic vacuum cleaners or smart kettles.
- Bluetooth beacon for fall detection: Data exchange between a wearable device and triggering alerts to family members and healthcare providers in case of a fall.
- Smart watch for medical monitoring: Wearable devices for medical monitoring and fall detection.

The utilization of smart home technologies can significantly enhance the quality of life for elderly individuals. However, for successful implementation of these technologies, it is crucial to carefully assess the needs and expectations of elderly individuals, as well as consider their psychological accessibility and perception. Moreover, the affordability and cost-effectiveness of such systems should be taken into account (Azibek, et al., 2020). Some challenges that need to be addressed include tailoring the systems to individual needs and ensuring user-friendliness for elderly individuals.

3. Methodology

The research method used in this article based on developing the multi-layer integration of diverse wireless protocols for smart home systems oriented to specific social users. Within the scope of this research, we present an approach that facilitates the amalgamation of protocols such as Zigbee, Z-Wave, Wi-Fi, Bluetooth, and LoRa into a unified multi-layer wireless/connected sensors' network (**Figure 3)**. This

approach enables the optimization of data transmission, ensuring high reliability, efficient energy management, and an elevated level of smart home system performance. A robustness of this proposed solution for the management of smart homes were tested and optimized.

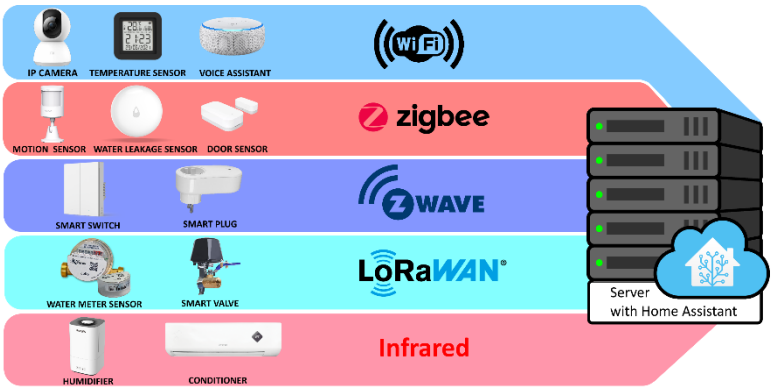

Figure 3. Architecture of multi-layer integration of wireless protocols.

4. Findings and results

4.1. Implementation of a prototype of a smart home for the elderly in Kazakhstan

4.1.1. Remote monitoring and control system

Currently, major companies, including Apple and Xiaomi, are actively developing smart home platforms based on closed-source code and proprietary devices and sensors. However, despite their wide popularity and innovativeness, these solutions may be limited and unsuitable for use by elderly individuals in Kazakhstan.

Firstly, one of the main limitations of closed platforms is their limited flexibility. The customization and integration capabilities with other devices and systems are restricted, which can hinder the adaptation of the system to the individual needs and preferences of elderly individuals. This prevents the creation of a fully personalized and flexible smart home capable of effectively meeting the unique requirements of elderly individuals in Kazakhstan.

Secondly, financial constraints pose a significant barrier to access closed solutions for elderly individuals. The cost of platforms, sensors, and devices from major companies can be substantial, making them inaccessible to a wide audience of elderly individuals in Kazakhstan. Financial affordability is a crucial aspect of developing a smart home model as it should be accessible and cost-effective for elderly individuals with different income levels.

Therefore, despite the advantages and innovations offered by major companies in the field of smart homes, alternative solutions need to be developed that take into account the specific needs and limitations of elderly individuals in Kazakhstan. In this work, we will focus on the free open-source software Home Assistant, which provides a flexible and accessible platform for creating a smart home model that can be specifically tailored for elderly individuals in Kazakhstan. Home Assistant is one

of the most popular systems for organizing, automating, and managing smart home and IoT devices from a wide range of brands. One of the major advantages of Home Assistant software is its accessibility (Akhmetzhanov, et al., 2022). It is cross-platform, allowing installation on Windows, macOS, Linux, or even single-board computers like Raspberry Pi (Bora, et al., 2021). Home Assistant software enables integration with a wide range of devices, including lighting, thermostats, security sensors, smart plugs, and much more, into a unified home management system, as shown in **Figure 4**.

To achieve economic efficiency and accessibility in the smart home model for elderly individuals in Kazakhstan, the Raspberry Pi single-board computer has been chosen as the server, which costs 56,044 tenge (~117 USD), which is much cheaper than buying a separate computer or server. Raspberry Pi is an affordable single-board computer characterized by small size and low power consumption (Abd-Elrahim et al., 2021).

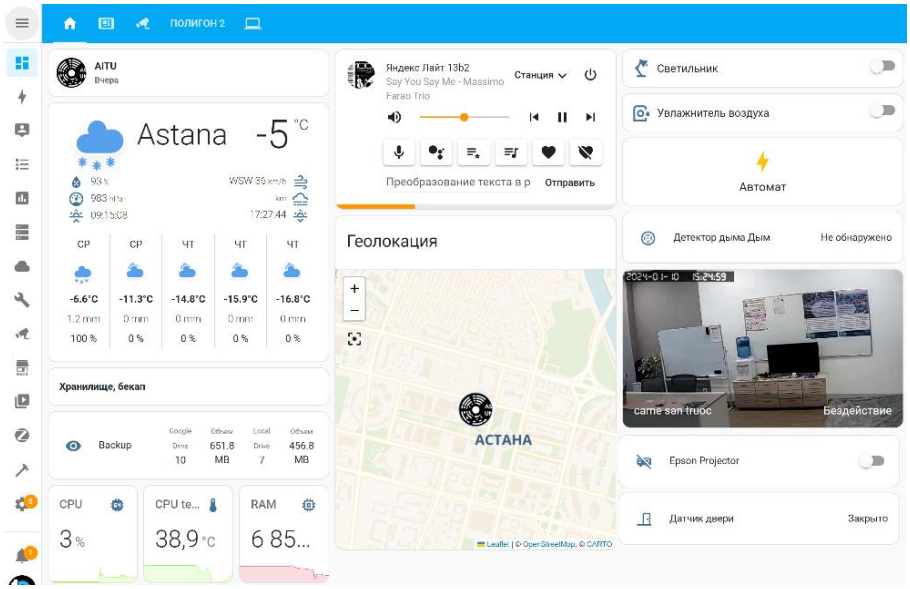

Figure 4. Home Assistant platform control panel.

4.1.2. Health monitoring sensors

In the modern world, smartwatch manufacturers are actively integrating various features and capabilities into these wearable devices. Thanks to ongoing technological advancements, smartwatches have become not only stylish accessories but also powerful tools capable of providing numerous useful functions in everyday life. In particular, manufacturers are increasingly focusing on integrating health monitoring features into smartwatches.

To implement this component of the smart home prototype, it is necessary to select smartwatches that support relevant health monitoring functions and have the ability to interact with Home Assistant. For example, smartwatches based on Google's Wear OS or Apple's watchOS provide a wide range of health monitoring features and can be integrated with various smart home platforms. Such smart watches based on Google Pear OS start from 70,000 tenge (~146 USD), including all the necessary health monitoring functions.

Once successfully configured, the smartwatches will start collecting data on heart rate, activity levels, and other health indicators of elderly individuals. This data can be displayed in the user interface of Home Assistant, allowing real-time monitoring of the health status of elderly individuals. Additionally, based on this data, automatic notifications or system responses can be set up in case of deviations or events that require attention or medical intervention.

As a tool for fall detection, the main emphasis is placed on the use of smartwatches. Most modern smartwatches are equipped with built-in motion sensors, including an accelerometer and a gyroscope. These sensors are capable of measuring movements and changes in the device's orientation in space (Kulurkar et al., 2023).

In the context of the research, the accelerometer of the smartwatch is utilized to record the speed of movement along three axes: Ax, Ay, Az. The gyroscope determines angular velocity around these axes, capturing the device's orientation. Representing the measured acceleration and angular velocity as A and ω respectively, the following expressions can be used:

$$\sqrt{A_x^2 + A_y^2 + A_z^2} = A \tag{1}$$

where *A* represents the resultant acceleration.

Additionally, to determine the orientation of the smartwatch, angular velocity along the three axes is recorded as ω_x, ω_y, and ω_z. This corresponds to the equation:

$$\sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} = \omega, \tag{2}$$

where ω denotes angular velocity.

Taking into consideration the provided data, the resultant acceleration and angular velocity of the smartwatch can be determined using the corresponding expressions Equations (1) and (2). The fall detection algorithm is based on conducting experiments to establish threshold values of acceleration that characterize this event (Azibek et al., 2020). Since different daily activities such as sitting, walking, and lying down are associated with specific angular velocity and acceleration patterns, by comparing these measured values, fall events can be identified.

4.1.3. Video surveillance and security

Video surveillance and security provision are essential aspects of the smart home model for elderly individuals. The use of IP cameras allows accessing video footage from various points within the homes of elderly individuals, enabling monitoring of the surroundings and activities (Ismail et al., 2018). With the ability for remote access, family members and caregivers can keep an eye on the elderly individuals from any remote location, which is particularly useful in case of absence or the need for additional supervision.

An important aspect of implementing video surveillance and security is integration with alert and alarm systems (Akhmetzhanov et al., 2022). The Home Assistant system allows linking video surveillance with other smart home components, such as motion sensors or smoke detectors. In the event of an alarming situation, such as a home intrusion or fire outbreak, the system can automatically trigger alerts, send notifications to mobile devices, or activate a sound siren to attract attention.

Adhering to an economically efficient system, it is worth noting that practically any IP cameras from different manufacturers can be integrated with the Home Assistant system. Therefore, for the prototype implementation, a budget-friendly YooSee camera priced at 8500 tenge (~17 USD) with support for Full HD streaming was chosen (**Figure 5**).

Figure 5. Live Streaming Video screenshot.

4.1.4. Reminding system

The reminder system is an important component of the smart home model for elderly individuals. Implementing this system through a Telegram bot provides a convenient and reliable way to deliver reminders about various tasks and events (Azibek et al., 2020).

In this smart home prototype, the Telegram bot serves as a communication interface between the Home Assistant system and elderly individuals. The bot allows sending reminders and notifications to users' smartwatches and mobile devices in the form of text messages.

This system helps elderly individuals stay organized and not miss important tasks and events. They can receive reminders about medication intake, important appointments, household chores, and other activities, contributing to their safety and well-being in their home environment (**Figure 6**).

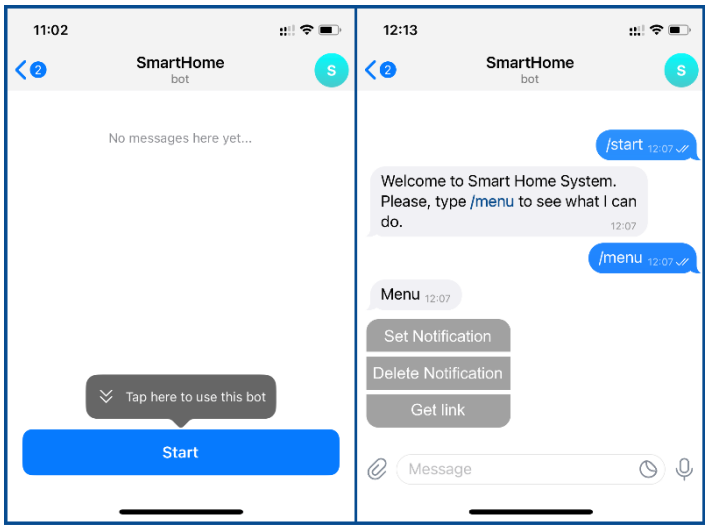

Figure 6. Telegram App for reminding system.

4.1.5. Automation devices

Automation devices allow for the automation of various processes and operations in the home, enabling control over devices and creating scenarios that optimize the daily lives of elderly individuals. These devices include:

- Smart lighting: Smart lighting systems allow for controlling the lighting in the home through smartphones, voice commands, or automated scenarios (Khattar et al., 2019). Elderly individuals find it convenient to use smart lighting to adjust brightness, color, and lighting schedules, enhancing comfort and safety. For example, the system can automatically turn on the hallway lights when the elderly person needs to navigate during dark hours (**Figure 7**).

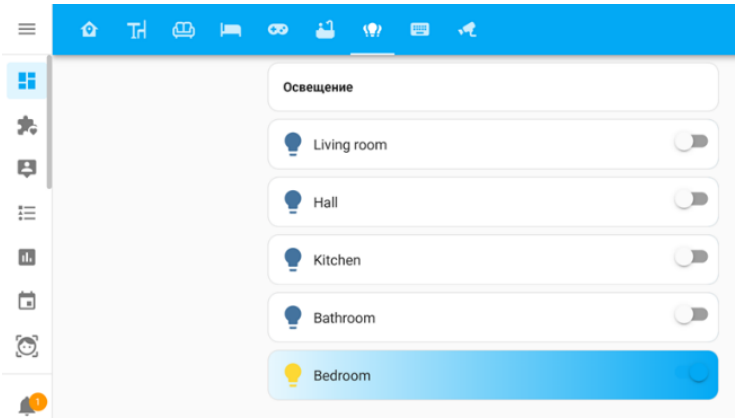

Figure 7. Lighting control panel in the Home Assistant system.

- Smart plugs and switches: These devices enable elderly individuals to control and automate the operation of electrical appliances and devices in the home. Smart plugs can be used for remote control of devices such as coffee makers, electric kettles, and televisions (Zhakiyev et al., 2023). This can be helpful if the elderly individuals need to turn on or off appliances without physical involvement.
- Smart thermostats: Devices that allow for monitoring and regulating the temperature within a room. Smart thermostats can be integrated with the Home Assistant system, enabling automatic temperature adjustments according to the preferences and schedule of the elderly individuals (Rezende, 2023). For example, the system can maintain a comfortable temperature upon waking up or before the arrival of household members.
- Process automation: The Home Assistant system allows for creating scenarios and automated processes that optimize the functioning of the smart home (Wynn et al., 2023). For instance, one can set up a “Leaving Home” scenario that automatically turns off the lights, closes windows, and activates the security system upon leaving the house. Such automated processes help elderly individuals reduce routine tasks and enhance convenience and energy efficiency in their homes (**Figure 8**).

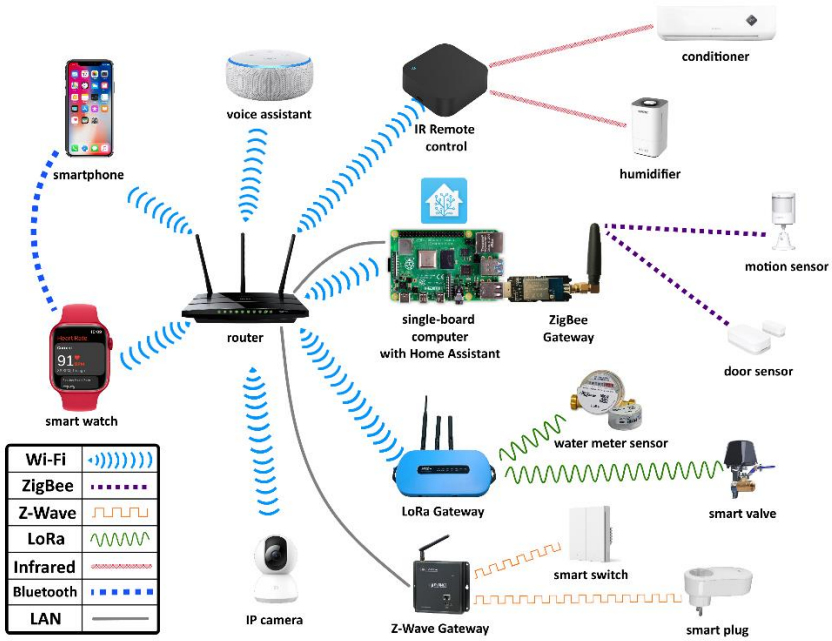

Figure 8. Device connection topology.

The selection of specific sensors and devices depends on the requirements and preferences of elderly individuals, as well as their financial capabilities. On the market, all auxiliary devices (sensors, relays, thermostats) have a low cost, where the price starts from 3000 tenge (~7 USD), which makes them affordable. It is important to choose accessible and reliable components that will operate effectively within the smart home model for elderly individuals in Kazakhstan.

5. Discussion

The proposed prototype as a key element of Smart Urban infrastructure developed using an accessible, open-source intelligent system that includes health monitoring, medication adherence monitoring, alerting family members in case of falls or deteriorating health indicators, and video surveillance. Despite the advantages and innovations offered by major companies in the field of smart homes, alternative solutions need to be developed that take into account the specific needs and limitations of elderly individuals in Post-Soviet countries. In this work, we focused on the free open-source software, such as Home Assistant, which provides a flexible and accessible platform for creating a smart home model that can be specifically tailored for elderly individuals in Kazakhstan. Home Assistant is one of the most popular systems for organizing, automating, and managing smart home and IoT devices as a Service from a wide range of brands. One of the major advantages of Home Assistant software is its accessibility.

Finally, this system supports the automation solutions of processes such as automatic lighting control, voice command functionality, home security, and climate control. Preliminary testing of the hardware model shows promising results, with plans for continuous enhancements and evaluations as it is further deployed. Key criteria for its implementation include affordability, accessibility, and feasibility.

6. Conclusion

Loneliness and limited support are significant challenges faced by many elderly individuals. These factors can have a negative impact on their physical and mental well-being, as well as overall quality of life.

Smart home technologies present a promising solution to support the independence and autonomy of elderly individuals. Our research has shown that integrating IoT technologies into smart homes can significantly improve the lives of elderly individuals by providing them with safety, health monitoring, and automation of routine tasks.

The key criteria for implementing a smart home for elderly individuals in Kazakhstan, which are taken into consideration, include affordability, accessibility, and feasibility.

In conclusion, the prototype version of a "Smart Home" for elderly individuals is designed based on convenience, efficiency, an easily understandable interface, and intelligent interaction between the device and the intelligent software. This system presents an architecture of combined functions that can measure vital parameters, detect fires and falls, send reminders and notifications via email, and automate processes. Additionally, a hardware model has been implemented and its performance tested. Further enhancements and improvements are expected as the system is deployed and evaluated. Drawing from Kazakhstan's unique sociocultural and economic context, this paper contain proposes a sophisticated model of a smart home tailored to meet the distinct needs and financial capacities of elderly people. Thus, the amount for the implementation of a "smart home" for the elderly, depending on the needs, starts from 137,500 tenge (~287 USD), which is more affordable than ready-made solutions from large companies.

Future work in the practical implementation of IoT as a Service will use prediction methods using machine learning focused on refining predictive models with more extensive datasets from Smart metering systems. Additionally, a cost analysis will be implemented based on collected data, allowing householders in the future to incorporate basic machine learning elements into their daily routine operations.

Author contributions: Conceptualization, BA (Batyrzhan Akhmetzhanov) and BA (Bauyrzhan Akhmetzhanov); methodology, NZ; software, BA (Bauyrzhan Akhmetzhanov) and BA (Batyrzhan Akhmetzhanov); validation, BA (Batyrzhan Akhmetzhanov), SO and NZ; formal analysis, BA (Bauyrzhan Akhmetzhanov); investigation, BA (Batyrzhan Akhmetzhanov); resources, NZ and SO; data curation, BA (Bauyrzhan Akhmetzhanov); writing—original draft preparation, BA (Batyrzhan Akhmetzhanov); writing—review and editing, NZ and SO; visualization, BA (Batyrzhan Akhmetzhanov); supervision, NZ and SO; project administration, NZ; funding acquisition, NZ. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This research has been funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. BR10965311 "Development of the intelligent information and telecommunication

systems for municipal infrastructure: transport, environment, energy and data analytics in the concept of Smart City").

Conflict of interest: The authors declare no conflict of interest.

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