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# ENHANCING SCALABLE USER EXPERIENCE IN SMART HOME SYSTEMS WITH UBIQUITOUS VIRTUAL REALITY INTERFACES

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**Abstract.** The popularity of smart home systems has greatly increased over the past several years, which provide convenience, automation, and control over various areas of daily life at home. However, these technologies still have issues with scalable user experience, mainly because there aren't any engaging and intuitive user interfaces. Incorporating pervasive virtual reality (VR) interfaces into smart home systems is the unique strategy proposed in this study to improve scalable user experience. The study's goal is to use VR technology to develop engaging and simple user interfaces that seamlessly integrate with the actual surroundings of a smart home. Users can engage with their smart home appliances and services through a mixed-reality experience in which virtual items and information are seamlessly incorporated into their environment by donning portable VR headsets. This application considers various difficulties related to developing Ambient Assisted Living (AAL) solutions, including unique characteristics of each end user, appliance, technology, deployment, and data-sharing problems. The Smart Home Systems take advantage of Semantic Web technologies integration abilities and their capacity facing represent significant information into legal models. A virtual reality application called Smart Home Systems allows for residential settings' setup and customization in AAL systems. Additionally, it effectively uses VR technology to streamline the creation of specialized AAL settings. The application and underlying framework were evaluated for each through two scenarios: designing a home setting specifically for specific scalable user categories.

**Key words:** virtual reality (VR) interfaces, Ambient Assisted Living (AAL), Smart Home Systems, users, customized design, smart home appliances, scalable user experience

**1. Introduction.** Incorporating ubiquitous virtual reality (VR) interfaces into smart home systems raises comfort and immersion in our daily lives. This state-of-the-art technology allows people to interact seamlessly with their homes and environs, managing numerous gadgets and getting information intuitively and immersive. Imagine entering your living room and being able to change the lighting, temperature, and audio-visual settings with a single gesture to create the ideal mood. Scalability users using VR interfaces may explore virtual versions of their homes, interact virtually with furnishings security systems, and even remotely manage energy use [1]. These systems are linked gadgets and appliances operated remotely by smartphone and voice commands. Scalable computing solutions for smart home technology enables customers to easily manage their homes, from adjusting the thermostat and shutting off the lights to monitoring security cameras and controlling entertainment systems. Smart homes adapt to our tastes and save energy while improving the quality of our lives with features like automatic routines and customized settings. Smart Home Systems have become a crucial component of contemporary living, enabling a more connected and intelligent way of life, whether boosting security, maximizing energy use, or creating a seamless entertainment experience [2]. A key factor

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that influences how people interact with their living spaces is user experience (UX), which is a key component of smart home systems. These intelligent solutions attempt to improve and simplify our residential settings by seamlessly fusing technology and daily living. The scalable user is at the center of a well-thought-out smart home system, which ensures the scalable user interface is simple to use, open to everyone, and attentive to their specific requirements [3].

Residents can easily control and personalize their settings thanks to the scalability user experience of smart home systems, which range from simple voice commands to intelligent smartphone apps. These technologies anticipate human preferences through sophisticated automation and thoughtful design, resulting in a seamless and individualized living experience. Their connection with homes has changed due to the widespread adoption of VR technologies. These systems offer intuitive and engaging experiences by utilizing VR technology, converting our homes into intelligent spaces. Users may easily access and operate various smart home features with the help of pervasive VR interfaces [4]. The options are boundless, from controlling temperature and lighting to working security and entertainment systems. These user interfaces offer more interaction, enabling users to see and change their houses in real-time. Users may easily customize their smart home settings and make educated selections using accurate simulations and virtual representations. Smart home solutions using ubiquitous VR interfaces improve comfort, convenience, and customization while altering our relationship to living surroundings [5].

Additionally, the immersive aspect of VR might pose possible health hazards, such as motion sickness or visual discomfort, particularly for people predisposed to such conditions. Additionally, those with physical limitations or those who are uneasy with technology may use interfaces that rely on VR. Further, the requirement for a steady internet connection for efficient functioning may be a drawback in places with low connectivity or during network outages [6]. Finally, when smart home systems collect and process personal data connected to pervasive VR interfaces, privacy and security problems may surface, increasing the danger of unauthorized access or data breaches [7]. As scalable smart home systems gain popularity for their convenience and automation capabilities, it faces significant challenges in scalable user experience due to lack of engaging and intuitive interfaces The study aims to create integrating pervasive VR interfaces into smart home systems, creating a mixed-reality environment that enhances user interaction with appliances and services. However, developing these Ambient Assisted Living (AAL) solutions requires addressing diverse user characteristics, appliance interactions and data, sharing complexities. The proposed VR application seeks to streamline the customization of smart home settings, yet its effectiveness and usability in real-time scenarios remain to be thoroughly evaluated. This study's novel approach to enhancing scalable user experience involves integrating pervasive VR interfaces into smart home systems.

Key contributions of this research:

1. The scalable user experience and functionality of smart home systems can be improved by including ubiquitous Virtual Reality (VR) interfaces.
2. Improved handling and interaction and pervasive VR interfaces may offer a more immersive and intuitive approach to handling scalability smart home appliances.
3. To build personalized and context-aware experiences within scalable smart homes, VR interfaces may take advantage of user preferences and contextual data.

**2. Related work.** The study [8] provided a unique Augmented Reality (AR) decision support system (STARE) that enhances the user's focused objects with collections of semantically relevant Internet of Things (IoT) data and matching suggestions. Research [9] determined End users may use the smartphone camera to frame the required sensor or item through the produced prototype, then receive the current automation, amend their definition, build new ones, and watch the automation involving the full present environment. The study [10] intended to give references on effective setup of interaction systems for various purposes, throw light on future development directions in this field, and aid researchers in better understanding the function of cross-device Interaction in digitalizing a complex smart home system. The study [11] investigated the possibility of automation replacing normal interactions in Ambient Assisted Living (AAL) or Smart Home settings, generally dependent on the users' location. They particularly recommend the cutting-edge strategy of using the indoor location capabilities of Augmented Reality (AR) head-mounted displays (HMD) to detect, monitor, and identify occupants to automatically manage different Internet of Things (IoT) devices in Smart Homes [12]. The study

[13] created a vision-based detection pipeline and integrated AR device to track 3D edges and identify touch interactions between fingers and edges. The human-centered approach, although technical research into smart homes, has grown quickly, focusing on home automation, gadgets, software, and protocols. Providing organic, practical, cozy, welcoming, and secure user experiences in the smart home requires a human-centered [14]. The foundation for establishing smart manufacturing shop floor systems based on ubiquitous augmented reality technology (SSUAR) was described [15]. The study [16] used a smart home environment to include eye-tracking with a brain-computer interface. The paper [17] uses the interactive functionality of a smart home environment with the passive haptics of SR, offering a unique strategy we term Smart Substitutional Reality (SSR). The study [18] investigated pervasive augmented reality in the smart home setting, allowing users to pick a control by pointing at a specific appliance, streamlining the interaction process.

The paper [19] introduced IoT, a well-defined technique that combines self-sustaining predictions and simulations of trigger-condition-action rules to determine when these rules will activate and what state changes linked smart home entities will experience. The study [20] provided an AR framework for Internet of Things applications involving telemetry and home automation. The paper [21] suggested a gesture-based safe interaction system for IoT health devices in smart homes to serve elderly or special needs individuals. The study [22] planned for a career and a virtual adviser to co-construct the procedure. The virtual adviser's knowledge about smart homes, daily routines, and help is organized in an ontology. The study [23] described the usage of a mobile application as a user interface that makes it easy for users to manage a home appliance remotely using two different tasks: voice command and graphical user interface. The study [24] used smart home technology for regular environment-integrated blending. For instance, head-mounted displays (HMD) are an augmented reality (AR) that gives users a non-intrusive method to interact with gadgets and access privacy-related data. Research [25] evaluated the buttonless device, which produces both an infrared (IR) and a visible (VIS) laser beam, is made be utilized consistently and universally for a wide range of appliances and equipment in private homes.

Article addressed the limitations of traditional intrusion prevention systems in autonomous systems by proposing the Gannet optimized-mutated k-nearest Neighbour (GO-MKNN) approach [26]. The method leverages MKNN for improved detection accuracy and adaptability, ensuring the reliability and safety of autonomous vehicles. Study explored various methods for fall identification, emphasizing the importance of mobile phone sensors in fall detection [27]. It evaluations, discussed key challenges, innovation methods and advancements in this critical area of health monitoring technology. Scalable smart door access systems utilize traditional biometric methods like fingerprint and iris recognition, but face speed and accuracy challenges [28]. Advancements in computer vision, particularly AI, improved face detection and gesture recognition, enhancing security and scalable user experience.

**Limitations** While ubiquitous VR interfaces significantly enhance scalable user experience in smart home systems by providing immersive and intuitive interactions, there are notable drawbacks. High costs associated with VR technology limit accessibility for some users. The need for advanced hardware can create compatibility issues. Scalable users also experience discomfort or motion sickness during prolonged use. Furthermore, the massive data collecting needed for tailored experiences raises privacy issues. Finally, the learning curve associated with new interfaces could hinder user adoption, particularly among less tech-savvy individuals. To overcome scalable user experience challenges in smart home systems, this study suggests integrating pervasive VR interfaces. By creating intuitive, mixed-reality interactions tailored to individual preferences, leveraging Semantic Web technologies for enhanced data sharing, and conducting user feedback evaluations, the approach aims to deliver engaging and accessible scalable computing of smart home environments.

## 3. Smart Home Systems.

**3.1. Domestic Environments and Universal Design.** Traditional product and solution design is frequently focused on standard individuals and are fictionalized representations of actual people. This scalable method must consider the numerous factors about existing end scalable users, including their skills, knowledge, social connections, and needs. The Universal Design paradigm, also called create for All, is a strategy to surpass this restriction. It focuses on providing solutions that can adjust to each scalability user's demands while considering the different characteristics that identify actual human users. The fundamental concepts of this model are also included in AAL, which deals with problems about improving people's Quality of Life (QoL) at all phases of life and giving them assistive devices for an independent existence appropriate to their capacities. To assist elderly or disabled persons in maintaining an independent and autonomous lifestyle, AAL systems search for effective solutions. Although numerous attempts have been made to build AAL solutions, most generated methods and apparatuses must consider the requirements and ignore their users' practical issues and personal contact. The initiative strives to incorporate Universal Design principles into inclusive and domotic settings.

Regarding various daily activities (ADL), the surroundings, called scalable smart homes, should be able to anticipate and adapt to the demands. Throughout its entire existence, designing a scalable smart home for families, seniors, people with disabilities, and individuals with impairments requires a variety of tools. Additionally, it necessitates paying close attention to the unique people that utilize the provided services and technologies and how they employ these functions. The huge quantity of heterogeneous data that these interactions might produce must thus be managed logically and effectively to make it accessible to both end users and distant users. With a focus on physical activity, the following subsections explore the requirements and potential for making it compatible with one with the household's equipment and tools.

**3.2. Requirements and Needs of Users.** As indicated above, an expected definition of a smart home is a residential building equipped with a collection of gadgets commonly referred to as scalable smart objects. The scalable Smart Home's equipment ensures occupants have comfortable and customized living arrangements. The numerous pieces of equipment used in traditional homes can carry out their functions independently and separately. In a scalable smart home, however, the appliances must cooperate dependably and predictably and gather, manage, exchange, and transmit information about the residents to achieve their comfort and well-being. Devices must work with other appliances, maybe specialized and multivendor, to increase dwellers' assistance for bettering, hygienizing, and securing their daily lives. However, these days, only home environments where appliances are installed using the same protocol stack and communication style can ensure this synergy among distributed equipment. Along with data and information models, services offered, and discovery procedures, targeted appliance interoperability should go beyond only communication interoperability. Reaching this degree of interoperability is a difficult endeavor that takes effort.

**3.3. Cooperation and Interoperability among Scalable Smart Home Appliances.** As indicated above, an expected definition of a smart home is a residential building equipped with a collection of gadgets commonly referred to as scalable smart objects. The scalable Smart Home's equipment ensures occupants have comfortable and customized living arrangements. The numerous pieces of equipment used in traditional homes can carry out their functions independently and separately. In a scalable smart home, however, the appliances must cooperate dependably and predictably and gather, manage, exchange, and transmit information about the residents to achieve their comfort and well-being. Devices must work with other appliances, maybe specialized and multivendor, to increase dwellers' assistance for bettering, hygienizing, and securing their daily lives. However, these days, only home environments where appliances are installed using the same protocol stack and communication style can ensure this synergy among distributed equipment. Along with data and information models, services offered, and discovery procedures, targeted appliance interoperability should go beyond only communication interoperability. Reaching this degree of interoperability is a difficult endeavor that takes effort.

**3.4. Project's Methodology and System for Smart Homes.** The framework's objective is to offer services and products that can accommodate weak and impaired users, enabling them to carry out tasks that would otherwise be difficult or impossible. The system provides services to all house residents and is not restricted to any particular scalable user demographic. The construction of the dwellers' home allows for the analysis of the interoperable appliances' behavior and the satisfaction of the individual user's physiological needs before their hard deployment in the actual house. Standard nomenclature for health-related features was used in the reintroduction of international classification functioning (ICF) framework, which was created to correctly measure users' health.

To facilitate communication between health stakeholders and provide a consistent, comparable depiction of people's operational experiences across the globe, ICF views an individual's functioning as a dynamic interplay between their personal, environmental, and health conditions. Due to its simple terminology that even non-clinical experts readily comprehend, many health sectors can utilize the categorization, reintegrating injured

Table 3.1: An illustration of the ICF's construction

| | |
|---|---|
| b <<Body function>> | Component |
| b2<<Sensory functions and pain>> | Chapter-first level item |
| b210 << Seeing function >> | Second Level item |
| b2102 <<Quality of vision >> | Third level item |
| b21020 << Light sensitivity >> | Fourth level item |

persons into the workforce. The categorization is split into functioning and disability is the first of two major parts describing the elements. Activities and Participation, Body Functions, and Body Structures; the second, Contextual Factors, provides a way to identify the influence of both environmental and personal factors. The relationship among a person's health and the environment in which they behave then describes how that person functions. A letter denotes each element, and numbers may add further information (Table 1). The appropriate category and its accompanying code can be chosen, together with a qualifier, to assess a person's functionality and disability.

In addition to the users' ICF categorization, the users' cardiorespiratory fitness (CRF) was considered to further our understanding of their physical state. When characterizing the user and creating Smart Home, which is made to also care for a scalable a user's health and well-being, it is important to consider the user's general physical health because it is essential in preventing the emergence of many illnesses. CRF describes a person's physical fitness by describing their capacity to engage in dynamic, moderate-to-intense exercise for an extended amount of time. Additionally, studies have indicated a negative correlation between it and the chance of dying and cardiovascular, pulmonary, and coronary diseases. As a result, CRF serves as a reliable measure of a subject's overall health condition and may be used to track the improvement or deterioration of the occupants of Smart Homes over time. Formal and shared explanations of ideas and relationships were created using semantic web technologies, including modelling domain knowledge into ontologies, residences, and appliances. Semantic web technologies may describe that devices work and services they offer, improving the semantic interoperability between them. Additionally, it is possible to set off certain inferences using "Semantic Web Rule Language (SWRL)" rules, such as deploying particular services and appliances to meet the demands of users. The Smart Home System (SHS) that created to simplify a-priori review and evaluate designing integrated appliance systems that provide AAL services to customers and their services. This program uses a virtual depiction of a home and its furnishings to enable domestic environment designers to simulate and create a home. Before actually hard-deploying the customized AAL solution, SHS makes it possible to create an accurate and thorough picture of the situation of aided users, including their daily surroundings. This is accomplished by letting the designer alter each device's features using the Semantic Web technologies' descriptions. The result is a house simulation that is as close to reality as possible, allowing the designer to arrange the appliances in response to changes in the occupants and their surroundings. The SHS creates an integrated and compiled picture of pertinent knowledge about the household environment through Virtual Reality and Semantic Web. This linkage makes it possible for real-time interaction and coexistence of virtual and physical objects, improving setup capabilities of appliances in practical settings. The digital equivalent of the actual domestic environment may also be defined and expressed formally using Semantic Web technologies. Fig.3.1 shows the scalable smart home system's function

**3.5. The System Architecture.** A program called SHS utilizes the stated integrated service-oriented platform. The major goals of this platform are to control information about the user's and home domains while enabling data flow across various equipment. The Virtual Home Framework is a framework that is built on four foundations:

1. The initial information foundation Home layer semantic, an ontology collection that explains important information in the above mentioned domains.
2. The second pillar is the virtualization scalable of a home environment, which enables the virtualization of devices like sensors and appliances.
3. Integration Services ensure data synchronization among the system's physical and virtual components.

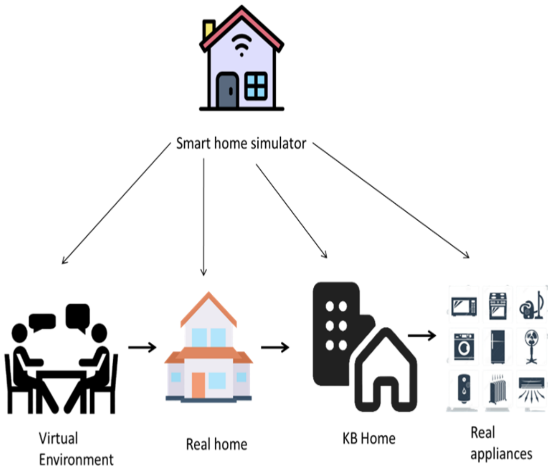


Fig. 3.1: The Scalable Smart Home System's function

This strategy is explored, and in this setting, apps may easily communicate with one another while information is integrated, distributed, and gathered using methods that are invisible to the clients.To facilitate and improve semantic synchronization generated by various home appliances and sensors:
(a) They make information gathering from any device possible.
(b) They make it possible to organize, analyze, and control the data received.
(c) When a device requests them or the required information becomes available, they communicate and dispatch it.
4. The collaboration between the three pillars of architecture results in Real Home, which displays proposed solutions using its equipment.

The SHS performs its role to enable designers to set up and test AAL solutions tailored to particular users.

**4. Knowledge Base at Home.** An ontology set called KBHome models, physical status information, scalable and information about the living spaces that make up the home and the installed and deployable appliances. The Web Ontology Language (OWL) and Resource Description Framework (RDF), along with Semantic Web Rule Language (SWRL), were chosen as the implementation languages for the knowledge base. Pellet was used as the reasoner to carry out reasoning operations on the ontologies. The four primary ontologies that makeup KBHome each target a different domain.

**4.1. User's Cardiorespiratory Fitness and Health Ontology.** Starting with his registry entries, this domain ontology describes ideas related to the scalable user's domain. The ICF codes and qualifiers used to describe the user's health state are the most important aspect of this ontology. This goal necessitated some re-engineering of the ICF ontology, which is accessible to the public via the Bio Portal: The particular ICF codes, which were first depicted as persons, were changed into datatype characteristics to enable the modeling of several health conditions using a single ICF code. As shown in the following calculation, the user's $UP_2$ maxvalue may be utilized to evaluate the customized workload of an activity.

$$WL(Cycle - ergometere) = (((UP_2 max.0.65) - r))/n \tag{4.1}$$

The user must enter the data into an interpolation program to determine the angular coefficient m and user-dependent intercept q. According to ACMS, 65% of the recommended training intensity is the lowest, which might still increase users' CRF. To compute loads of exercise that are applied to a cycle ergometer, Equ.4.1 may easily be transformed into SWRL: As shown in Fig.4.1, it is feasible to express pertinent information about the user and some aspects of their physiological condition in this manner.

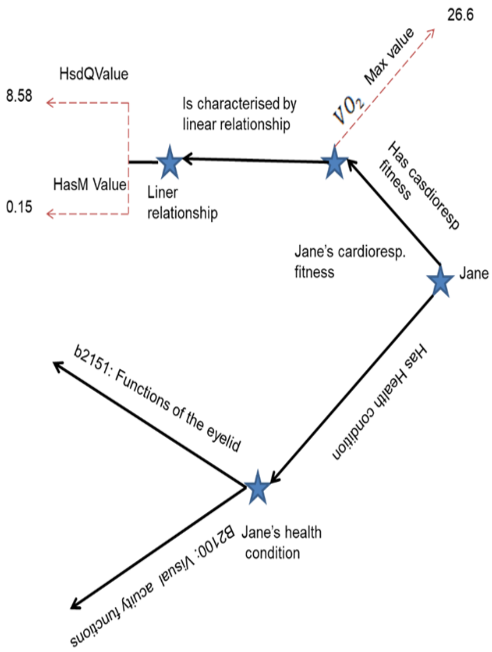


Fig. 4.1: An illustration of user characterization in the KBHome

**4.2. Domestic Environment Ontology and Appliances.** By describing the appliances and connecting them to the environment where they are used, this ontology intends to provide information about the equipment. The first module gives a straightforward depiction of atypical residential setting, complete with classes and people. This description is accomplished by utilizing the HicMO language, a collection of XML attributes that may describe the features of any device. HicMo details were transformed into datatype and object properties following the NeOn methodology's principles to develop XML descriptor semantics. This makesit feasible to offer that ID cardany equipment now installed and deployable in a home. Each program is listed individually and connected to one or more appliances in a submodule integrated with a scalable smart object's description. The third module enables describing these measures because each appliance can give one. Measurements that describe a user's physiological condition utilize a largely re-engineered that describes household items, and devices used, providing a unit ontology trustworthy explanation. Fig.4.2 shows a sensor that measures a user's body temperature.

**4.3. Service coordination in the house.** This ontology explains the actions brought about by a single or a combination of environmental or user-related conditions. It is possible to specify the circumstances under which a certain action is activated by using SWRL rules. This ontology included scenarios similar to the one above, outlining the events under which appliances can provide the necessary services. A complicated issue entails adopting tailored services for certain user categories with disabilities.

**4.4. Arrangement of Living Environments.** Appliances may provide useful services to their users, helping them to manage their limitations when doing regular activities, depending on their characteristics and the programs they contain. This ontology enables the classification of appliances into different varieties. Therefore, using the groups "Cognitive Impairment Appliance, Hearing Impairment Appliance, Motor Impairment Appliance, and Visual Impairment Appliance," household equipment is also categorized according to their appropriateness for specific users with disabilities. A structure project may be modelled by utilizing these aspects. With a distinct ID number and customized style, each task may be customized with the appliances and development. It is also possible to specify that project is meant for Fig.4.3. According to the programs offered for

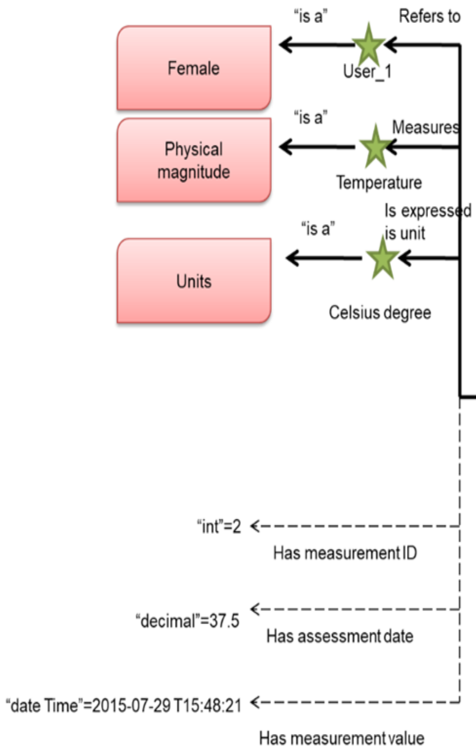


Fig. 4.2: A model of a KBHome application, as an example

the application, ontology also enables automatic inference of whether a device is acceptable for a certain type of disabled user.

In this method, a designer may pick from a list of devices that are assumed to be capable of coping with a user's handicap, and the results of this ontology's reasoning process can be used as a framework for supporting decisions throughout the living environment's design phase.

**5. Scalability Smart Home Services Personalization.** The offered solution must be customized if a scalable smart home is to be created to provide its residents with the tools and services to improve their autonomy and well-being in ADL. This process involves gathering the subjects' demands, assessing their health, and designing a unique solution that can assist users in controlling their disabilities and enhancing their class of life.

**5.1. Identification of User.** The physicians' involvement is necessary to complete the ICF-based module to assess the health state of the home occupant(s). The healthcare staff must evaluate all employing validated assessments and clinical scales created with a focus on a certain area, the scalable user's impairments, and general health state of older adults. Alternative methods call for estimating the CRF indirectly after measuring the subject's "Heart Rate (HR)." Additionally, they believe every one of a certain age has the same maximum heart frequency. Using a multistage workout strategy, the CRF of the Smart Home inhabitant may be found after specifying the tools and equipment required to assure subject's safety throughout test.

The selected protocol calls for a low-intensity warm-up phase that lasts for three minutes, following which the workload will rise by 20 W. Each element causing the increase in effort is described in full in Fig.5.1 and Table.5.1.

Since the ultimate goal of a test is subject's greatest attempt to push themselves over their physiological limits, trained clinical staff must continually check the subject's health during the test. As a result, the exercise

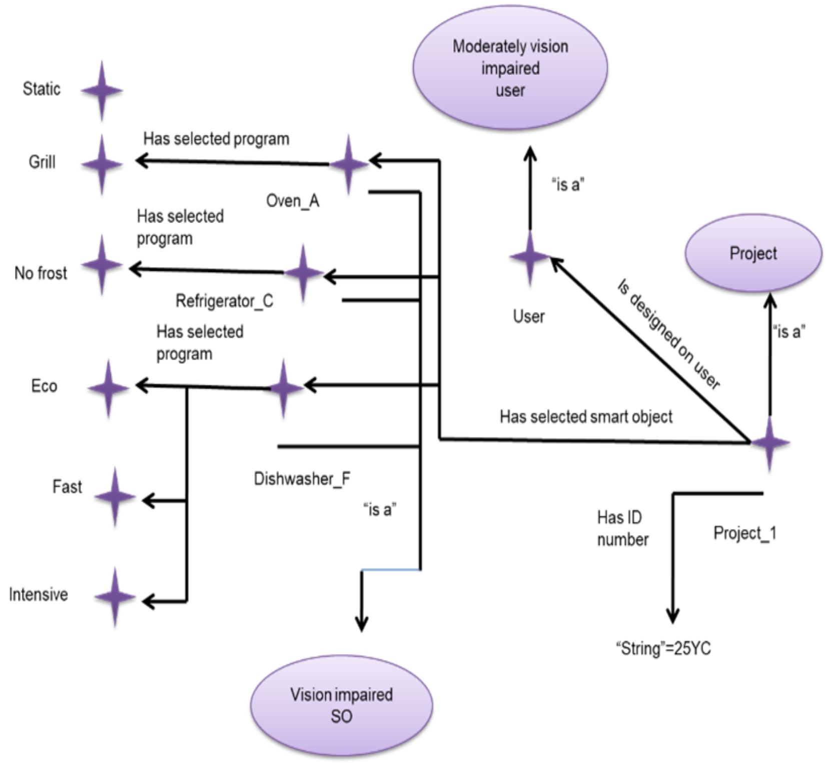


Fig. 4.3: Project designed for a user with visual impairment using the KBHome

Table 5.1: Test variables for the maximum amount of cycling activity

| HR warm-up(bpm) | Ma $*$ WL(W) | $\Delta$ WL(W) | Starting WL |
|---|---|---|---|
| $\leq$ 90 | 161 | 21 | 101 |
| 81$\leq$ HR $\leq$ 91 | 142 | 21 | 81 |
| 91 $\leq$ HR $\leq$ 100 | 101 | 21 | 65 |
| $\geq$ 100 | 88 | 21 | 45 |

must end promptly if any of the circumstances indicated in Table.5.2 materialize. Additionally, if practice is interrupted, a person needs medical assistance until equilibrium and normal levels are achieved.

After completing these two evaluation rounds, each subject receives a detailed report on their health state, according to the international ICF standard, accurate information about their CRF, and as a result, their physical capacities. The latter would allow for personalizing each person's daily workout regimen. Because it is safer than the treadmill, the only other piece of exercise equipment that can directly manage the workload, a smart home arrangement, a cycle ergometer is kept as a training tool. Using a bike ergometer is acceptable for people with significant motor impairments or postural control problems. These critical issues are identified at first clinical evaluation, which is formalized by the completion of the ICF, and they need to be treated using specific methods, such as an arm ergometer.

**5.2. The scalable smart home's user's configuration and test.** The scalable Smart Home designer may create a mixed reality setting that can provide the finest answers in response to the user's needs by starting with the informational bits obtained during the user assessment phase. In this situation, employing mixed reality and virtual reality has several benefits. As was already indicated, the first is the capability of

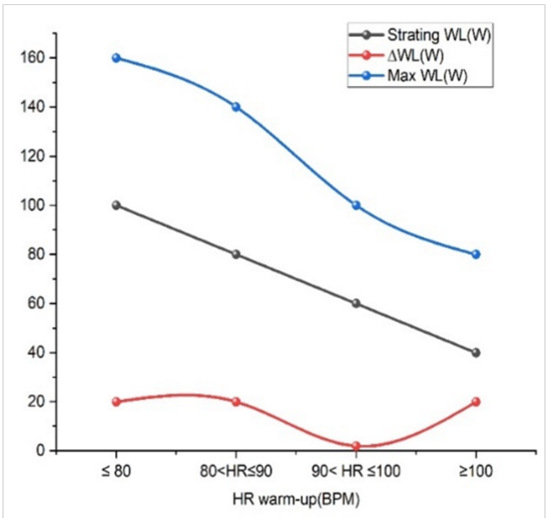


Fig. 5.1: Testing parameters for the highest level of cycling exercise

Table 5.2: Conditions for stopping the bicycle exercise test at maximum intensity

| Conditions for test interruption |
|---|
| Loss of limb coordination |
| Sudden pallor |
| decreased blood pressure |
| Dizziness, faintness, or confusion |
| Severe desaturation (SpO2 $<$ 80%) |
| Hypertension (HT) |
| ECG alterations indicating ischemia or ectopy |
| Chest pain suggests ischemia |
| Dyspnoea |
| Heart rate is higher than 85% of the highest estimate of HR |

testing the different equipment's communication in real-time. The second option is offering an end-user chance to encounter the VEs first-hand with dual goals of familiarising themselves with their newly configured scalable Smart Homes and providing feedback to the designer that may enhance a final home design. Finally, a designer of a smart home and final user may assess that sensor and appliance performance without actually owning it thanks to the usage of virtual reality and semantic models, saving time and money; resulting numbers represent the impact on PMV value a scalable home environment's variable elements alter and make sense. As shown in Fig.5.2 and Table.5.3, the impact of temperature and relative humidity on the PMV value is calculated.

**5.3. Customized scalable Smart Home Inauguration.** The designer can model the ultimate users' existing home using an authoring tool in this step after receiving the blueprint and reconstructing a digital model of the interior spaces. The creator can enhance the digital representation of the area with additional devices and appliances house using this program by selecting them from the ones portrayed in the semantic catalog specified. The user's preferences and peculiarities were put in a semantic repository and queried via SPARQL to update the catalog in real-time inside the VE. Following the scalable architecture mentioned above, which enables data flow between the physical and virtual worlds, a designer might include actual hardware and digital illustration of a scalable smart home with sensors. The designer may save and preserve the project for future adjustments after creating customized surroundings and validating communication between the gadgets,

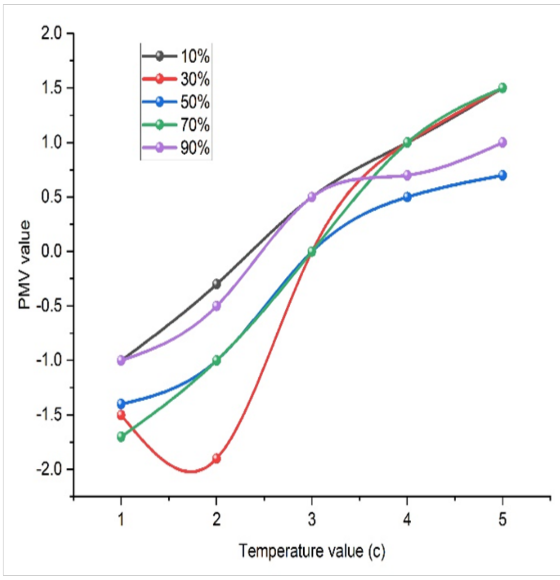


Fig. 5.2: The impact of temperature and relative humidity on the PMV value

Table 5.3: Temperature and humidity affect PMV

| Temperature value (c) | PMV value | | | | |
|---|---|---|---|---|---|
| | 10% | 30% | 50% | 70% | 90% |
| 1 | -1 | -1.5 | -1.4 | -1.7 | -1 |
| 2 | -0.3 | -1.9 | -1 | -1 | -0.5 |
| 3 | 0.5 | 0 | 0 | 0 | 0.5 |
| 4 | 1 | 1 | 0.5 | 1 | 0.7 |
| 5 | 1.5 | 1.5 | 0.7 | 1.5 | 1 |

sensors, and human users.

**5.3.1. The designed solution is being tested.** The scalable smart home system allows the end user to evaluate a solution that was particularly built following their characteristics and demands after the design phase. The explanation could implement various stages contingent intended user's features and kind of setting. Because of the greater sensation of presence they evoke and the more natural engagement they frequently offer, immersive and semi-immersive experiences undoubtedly represent the most promising way to test various scenarios and understand that Smart Home services operate. The target user must be carefully considered when selecting VR technology, nevertheless, since there is no denying that utilizing head-mounted displays poses a danger of unpleasant events and illness for fetus elderlies or severely cognitively handicapped individuals, as shown in Fig.5.3 and Table.5.4 scalable Smart home security has grown in value recently. Revenue is predicted to reach $5 billion in 2020 and 8.2$ billion in 2023.

Therefore, other solutions ought to be chosen even in return for a diminished sensation of presence. When using real appliances or equipment that are part of the final solution, it is best to utilize non-immersive surroundings. If the interaction is accurately recreated in the virtual world, it might become easier and more manageable. Once the best solution has been found, it may be tested again in the configurator before being installed by the end user at their real location.

**6. Real-World Use Case Validation.** Two actual use cases served as a basis for SHS of proposed framework; in contrast to the first, second concerns the design of a kitchen for a user that is visually challenged

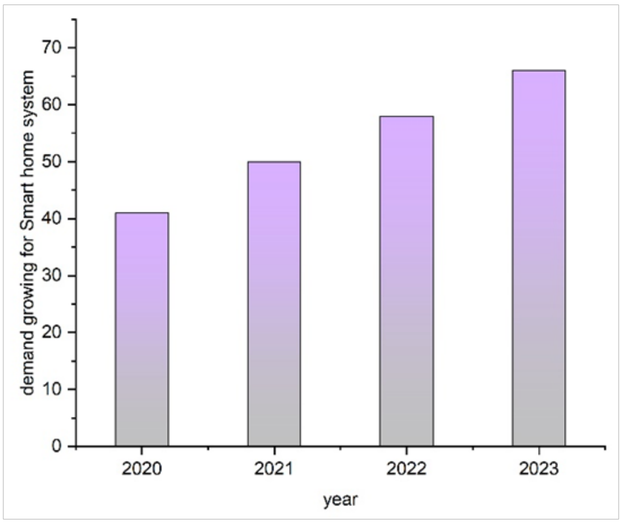


Fig. 5.3: Demand for smart home systems is increasing

Table 5.4: Scalable Smart home demand rising

| year | demand growing for Smart home system |
|---|---|
| 2020 | 41 |
| 2021 | 50 |
| 2022 | 58 |
| 2023 | 66 |

and addresses the topic of active aging by imagining an older user participating in physical activity performed at home.

**6.1. Establishment Inside a Real Environment: The Kitchen.** A kitchen designer in this case study must utilize the SHS to design a kitchen while choosing the best equipment; a person with a slight vision impairment and hyposmia is the intended user. The designer builds a virtual representation of the kitchen using the user's kitchen plans. In this approach, user chooses the appliances and sensors to a list provided by the KBHome that is suitable for their impairment(s). The KBHome gathers information for this user.

1. Two induction cooktops: one with textured button surfaces that may provide high contrast, other having a black cover, controls with a high degree of difference and a lit digital display.
2. Two convection ovens have a set of control lights, a digital display, and a backlit display.
3. A total of four dishwashing models featuring backlit, high-contrast displays.
4. Two refrigerator types featuring digital, backlit interfaces that show the current interior temperature and light.

**6.2. Assessment of the Application.** Following the formative assessment process, the configuration part validation is carried out. This kind of validation entails watching and evaluating empirically how layout of the kitchen is the job that causes representative users to engage with the VEs. This review uses qualitative and quantitative data to pinpoint usability issues and gauge user learning curves and task performance. Five designers will participate in the study to do this; during the initial training phase, which will last around 15 minutes, they will be given a situation and a scalable Smart Home System program. A computerized model of an empty kitchen will also be made available to them as a starting point for their work to make it easier and quicker. Timing issues, mistakes, possible software flaws, and user feedback will all be recorded throughout the configuration step. For the System Usability Score (SUS),each participant will get a questionnaire after the

Table 6.1: Conditions for stopping the user's cycling exercise test during the domestic activity

| Conditions for test interruption |
|---|
| "Severe" pain |
| Decreased blood pressure |
| "Very strong" perceived e=ort |
| Hypertension (Ht) |
| Heart rate is higher than 85% of the highest estimate of HR |

experiment. Additionally, open feedback will be gathered and considered to modify the program to suit the intended audience's requirements better.

**6.3. Environment Setup for Physical Activities in the Home.** In the first use case, a fragile 72-year-old woman must exercise daily on a bicycle-ergometer set up in her bedroom, a common scenario for older individuals. It was discovered that her CRF was 18.3. The actress is provided a suitable physical exercise to complete while keeping track of her outcomes and conditions. Using a tablet, the user is provided with performance-related information. She is asked to go into the bedroom to complete her daily physical exercise, and a presence sensor there recognizes her. It next expected to set up the bedroom for the workout by venting it and waiting until it reaches the right temperature. The user may put on the sensors and start the activity once the temperature and air quality are appropriate. The exercise's workload will be determined based on the user's health situation. The physiological condition is watched as she engages in the activity. The information on the physical activity and the physiological measures identified is kept and made available to the carers after the exercise session. The scalable user receives all the instructions and may utilize a virtual tablet to evaluate her work in real-time and even get other notifications depending on sensor data.

The designer creates a virtual depiction domestic setting with an actuator to allow automated window opening and closing, incorporating actual sensors into the environment utilizing SHS characteristics. A presence sensor, an ambient temperature, and a sensor for air quality, which can gauge room's CO2 content, are all included in the virtual environment. These sensors may all be used to determine whether the user is in the space. The KBHome contains information on user's CRF and state of health. The user may navigate the virtual environment and touch the tablet to receive instructions to prepare the space for her activity and click the exercise icon. The bike ergometer is in the bedroom, and she is first told to enter. She may be detected by the presence sensor, which also activates the room's air quality sensor. It determines the amount of CO2 present in the space and stores the information in the KBHome, where it is analyzed.

**6.4. Validation on Elderly Subjects for the Physical Activity Configured Environment.** The same procedure is used to validate older adults. A modest sample of target customers is engaged in a first-pilot study to examine possible software concerns in a designed scenario.The enlisted subjects must include the following requirements: age 65 and older, with a mild-to-moderate impairment of total physical stamina, and be deemed by a physician to benefit from light daily physical activity. Severe cognitive or eyesight impairments and incapacity to give informed consent are exclusion criteria. Each participant should receive a clinical CRF assessment after enrollment. CRF results will determine the target workload after the test.

Attempts are made to closely resemble the specified circumstance in the setting to verify an elderly-focused scenario. Therefore, a whole room simulates the situation, including a cycle ergometer, blood pressure monitor, pulse oximeter, tablet, presence sensor, automated window, air quality sensor, and virtual temperature. A wall projector will show the intended user all of the virtual items. Each topic will get instruction from knowledgeable staff who will provide an overview of each component and the system's goal and functionality. The participants can engage with the system when comfortable with the setup. Still, they will remain under continual clinical and technical staff monitoring. They will follow the instructions provided on the tablet. After opening and closing each subject's (virtual) window and setting the workload following CRF, each issue will cycle for 20 minutes. The measured parameters go beyond the limits in Table.6.1 to assure the safety of the training at all times. Collecting impartial quantitative data will validate this scenario and the subject interviews using a specially created questionnaire. Semi-structured interviews were deemed the best method for gathering

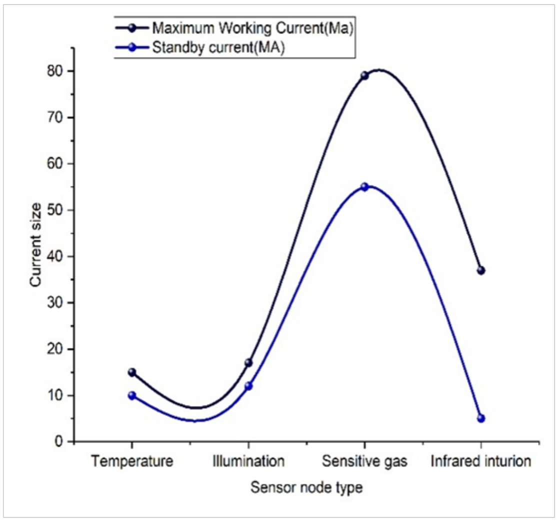


Fig. 7.1: Sensor node type

Table 7.1: The typical sensor node operating current

| Sensor node type | Current size | |
|---|---|---|
| | Maximum Working Current(Ma) | Standby current(MA) |
| Temperature | 15 | 10 |
| Illumination | 17 | 12 |
| Sensitive gas | 79 | 55 |
| Infrared intrusion | 37 | 5 |

qualitative information needed to evaluate the acceptability and utility of the proposed system according to the population's characteristics.

## 7. Analysis of a scalable smart home system for virtual reality.

**7.1. The scalable smart home node's power consumption test.** The survey's intelligent home technology collects data in battery-powered mode; therefore, the terminal node's service life depends on how much power it uses. This part primarily evaluates the ZigBee network node's power usage, which helps predict the node's battery life. For data gathering, two dry cells power sensor nodes. More than 2.5V must be present in the battery. The node is unable to ensure regular functioning otherwise. The data collecting nodes for temperature and humidity, lighting, and power consumption test principally uses high-sensitivity gas detection and an infrared intruder detection checkpoint, as shown in Fig.7.1 and Table.7.1.

Formula 7.1 provides the computation for an average working current, assuming that current in node's operating mode isc, the active time is $J_j$, and current in sleep mode is $J_i$, and the sleep duration is $S_j$.

$$J_a vg = \frac{(c * S_j + J_i * S_i)}{(S_j + S_j)} \tag{7.1}$$

The average operating current (Iavg) of all tested sensor nodes is calculated using formula (2). The second design makes use of a 2000mAh battery. Calculating the working period of the sensor node using formula (3) is possible, given that the average battery discharge depth is around 60%.

$$S = 2000x0.6/J_a vg(day) \tag{7.2}$$

The formulas (2) and (3) may be used to determine the duration of sensor node operation using test data. Calculate the ZigBee terminal's temperature, humidity, and light intensity data collecting nodes utilizing the test results. These batteries completely fulfill the specifications for low power usage and can operate in an actual system. They can function constantly for approximately 4 months when just one battery power supply is used.

*Perspective Projection.* Perspective projection converts 3D virtual scene points to 2D screen coordinates. The perspective projection matrix can be shown as code for copy

$$o = [e/aspect_ratio000][0e00][00(z_far + z_near)1][00 - (2 * z_far * z_near)0] \tag{7.3}$$

where $z_near$ and $Z_far$ are the near and far clipping planes, respectively, and f is virtual camera's focal length. Aspect ratio is the ratio of the screen's width to height.

*Transformations.* Objects are positioned and oriented in the virtual scene via transformations. Scaling, rotation, and translation procedures are used in this. These transformations can be represented by a 4 X 4 transformation matrix called the model-view matrix (M):

$$N = [QS][0^S 1] \tag{7.4}$$

T is a 3D translation vector, 0T is a zero vector, and R is a 3x3 rotation matrix. One uses the model-view matrix to translate 3D object coordinates to the camera's coordinate system.

*Homogeneous Coordinates.* Computer graphics uses homogeneous coordinates to make transformations simpler. The following equations can be used to convert a point (x, y, z) in 3D space to a homogeneous coordinate (x', y', z', w'):

$$W' = W/XZ' = Z/XY' = Y/XX' = 1 \tag{7.5}$$

*Binocular Disparity.* By giving each eye slightly distinct images, binocular disparity creates a stereoscopic perspective. The interocular distance and the distance between the item and the viewer both affect how much difference there is. Given the object's depth (z), the formula for scalable computing the disparity (d) is as follows:

$$d = \frac{(2 * eye_distance * focal_length)}{z} \tag{7.6}$$

where $eye_distance$ is the space between the observer's eyes, and $focal_length$ is the virtual camera's focal length. Please be aware that these equations only offer a simplified picture and do not account for all the complexity inherent in virtual reality systems. An in-depth grasp of computer graphics, computer vision, and signal processing is necessary since VR technology involves various methods and methodologies.

**8. Conclusion.** This article introduced scalable Smart Home System as an AAL application that simulates the setting of a home utilizing Semantic Web and Virtual Reality technology. The health of the residents, which is periodically evaluated by medical staff, is modelled as a semantic knowledge base (KBHome), which enables automatic inference of various devices that allow the inhabitants to complete several everyday duties without assistance. By giving a formal account of the users' physiological condition, cardiorespiratory fitness, measurements for ambient comfort, gadgets, and behaviour, the ontologies open the door to providing the inhabitants with specialized services. Reasoning results permit, on the one hand, determination of range about devices assists residents with daily tasks, allowing them to live freely and cope with their disabilities; However, KB Home may provide instructions for residents to establish a daily physical exercise schedule. One of the scalable smart home system's most important aspects is the language for clinical and nonclinical practitioners in areas connected to health. The scalable smart home system personalizes support by assessing users' health through heart rate and cardiovascular fitness (CRF), a subject with CRF engages in tailored exercises, monitored using sensors for safety and efficiency during cycling sessions. The results of the discussion process are input into a VR-based application that can imitate a genuine household environment so that the appliances may be chosen and installed by smart home designers so that their behaviour and potential for accommodating people with disabilities may be studied advantage of this virtual setting procedure is that it is entirely suited to user's actual expectations and restrictions and considerably saving setup costs and time by testing the appliances in a virtual environment before setting up a scalable smart home. In addition to their many advantages, smart home systems and commonplace virtual reality (VR) interfaces have certain drawbacks. Smart home systems scalable user experience will continue to incorporate the use of virtual reality environments in the future including developing interfaces that adapt to the user over time, enhancing cross-device communication and compatibility, incorporating Artificial Intelligence (AI) for the customization of space environments, fancier haptic devices to enhance the control scalable experience and make it more natural and cleaner which in turn focuses on developing better and scalable smarter homes.

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