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Research on human-computer interaction and user experience of smart home system

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Abstract. This article aims to present a perceptive summary of cutting-edge home automation systems, exploring basic topics including human-computer interaction, communication technologies, networking protocols, and the fascinating science underlying the industry's most well-known application—the robotic vacuum cleaner. Put succinctly, using intelligent sweeping robots in smart homes signifies a significant advancement in machine autonomy and artificial intelligence. Furthermore, integrating renewable energy and grid management solutions with smart home systems will be fueled by the pursuit of sustainability and energy efficiency. Ultimately, exploring the intelligent home system's core has shed light on technology and its revolutionary effects on our day-to-day existence. As we stand on the edge of a better future, the convergence of connection, communication, and interaction invites us to embrace innovation and push what is possible in our personal lives.

Keywords: Smart Home, Security, IoT.

1. Introduction

A new era of residential life is ushered in by the development of intelligent home systems, which weave cutting-edge technology into the very fabric of our everyday existence. The Internet of Things (IoT) and artificial intelligence (AI) have advanced so quickly that the smart home is now real, not just futuristic. This article aims to present a perceptive summary of cutting-edge home automation systems, exploring basic topics including human-computer interaction, communication technologies, networking protocols, and the fascinating science underlying the industry's most well-known application—the robotic vacuum cleaner.

In the contemporary smart home ecosystem, numerous protocols for connectivity have surfaced, each meeting distinct requirements and limitations. Wi-Fi is the best choice for high-speed data interchange because it can handle applications that require much bandwidth, like video conferencing and streaming media. However, Bluetooth's low power consumption makes it appropriate for short-range communication, a prerequisite for many cutting-edge home applications. Because of its mesh network design and energy efficiency, the Zigbee protocol has found a niche where more extended battery life is essential. Each protocol is tailored for a certain intelligent home paradigm, and the choice is based on factors such as data rate, range, power consumption, and scalability.

The importance of human-computer connection is growing as cutting-edge home automation technologies advance. User experience has advanced significantly when users can easily engage with their intelligent home surroundings via touch interfaces, mobile apps, or voice commands. Beyond

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simple control, this engagement involves automating daily routines, adjusting to changing preferences, and building customized environments. However, several obstacles exist to achieve seamless human-computer interaction in the context of many characteristics and devices. The fascinating field of robotic vacuum cleaners, which embodies robotics and artificial intelligence in the household, will also be covered in this essay. These autonomous gadgets must have Minimal human participation to navigate rooms, detect impediments, and carry out cleaning tasks. Their sophisticated algorithms and advanced sensor arrays let them avoid collisions, navigate challenging areas, and identify items. We can learn more about the convergence of robotics, AI, and cutting-edge home technology by examining how they operate.

In summary, intelligent home systems are becoming increasingly important due to the convergence of IoT, AI, and communication technologies. The foundations of these systems are human-computer interface and connectivity protocols, which allow for smooth integration and user-centered experiences. Robotic vacuum cleaners are one instance of how robotics and artificial intelligence might be incorporated into routine home tasks. By thoroughly examining the technological marvels and essential components of intelligent home systems, this study seeks to shed light on the complex world of these systems.

2. Basic connection protocols and communication technologies for smart home systems

The connecting protocols and home systems of smart homes are essential and particularly significant components of a well-developed intelligent home system since they enable the smooth connectivity of several devices and sensors. For a smart home to function as a bridge connecting disparate components, stability, and high-speed transmission are critical characteristics. This allows information to flow between gadgets and gives users a more innovative and practical way of living.

2.1. Basic smart home connectivity protocols and their advantages and disadvantages

Connection protocols are the cornerstone of intelligent home systems, addressing everything from data transmission to device identification. Nowadays, Wi-Fi, Zigbee, Matter, and other protocols are common transmission methods. As shown in Table 1, Wi-Fi protocol has emerged as the preferred option for connecting smart home devices due to its extensive coverage and rapid speed. Large data transmission applications, such as high-definition video monitoring, are particularly well suited for it. Conversely, Bluetooth technology is more cost-effective and works better in proximity communication, such as pairing a smartphone with an intelligent stereo. However, the sensor's overall power consumption is considerable, so its working duration could be improved. The Zigbee protocol is appropriate for sensor networks in smart homes and addresses the issues of low energy consumption and wide coverage. The Matter protocol combines the benefits of the former with low power consumption and low latency, but it still needs to gain more traction. There are better options than the present cutting-edge home protocol, which is somewhat expensive. Also, choosing the right connection protocol for a given set of communication requirements can increase the system's stability and effectiveness.

Table 1. Comparison of the performance of each connection type.

	speed	Stability	Energy consumption
Wi-Fi	High	Medium	High
Zigbee	Medium	High	Low
Matter	Medium	High	Low

2.2. Security

Data security and network topology design are aspects of communication technology, which also include data transport between devices. Innovative home systems require devices to interact steadily in various network topologies, such as mesh and star topologies, and careful planning of the various connection

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techniques is required. Furthermore, data transmission security is critical, particularly for apps like home security monitoring that handle users' private information. The user's information security is entirely protected by encryption and authentication technologies, guaranteeing that data is stored locally and not maliciously altered or stolen during transmission.

2.3. Existing problems and summary

The functionality and interactivity of intelligent home systems are additional areas of concern. It may not be easy to get different smart device brands and models to function together. Devices from many manufacturers can be managed and controlled consistently under one roof using standard communication protocols and platforms, giving consumers the practical experience of centralized control. To do this, communication technologies must be supported, and industry standards must be created and made widely known in order to encourage device interoperability. For instance, customers can handle all smart homes and the connections between them from a single terminal by utilizing Home Assistant and Home Bridge, which can dissolve the boundaries between various smart home protocols and brands. However, this necessitates some specialist expertise, which diminishes the original intent of the convenience of an intelligent house; hence, having a single terminal to operate all smart homes is essential.

In summary, the smart home system's communication technology and connection protocol are essential to achieving device interconnectivity. Developing a reliable communication network, selecting a connection protocol appropriate for the application situation, and guaranteeing secure data transfer are all essential components of developing an intelligent home system. Future technological developments will likely lead to the creation of more creative networking protocols and communication technologies, which will take the development of smart home systems to a more intelligent, effective, and cohesive level.

3. Smart home systems and human-computer interaction

Making a user's life smarter, more convenient, and more comfortable is the fundamental goal of a smart home system. However, sensible and practical human-computer interaction design is also essential to achieving this goal in addition to cutting-edge technology. In addition to the technical aspects of human-computer interaction, other aspects include everyday life, information sharing, and even the emotional bond between the user and the system. Differentiated human-computer interaction techniques in smart home systems surely give users more options and let them select the one that best fits their wants and habits [1].

3.1. Voice control and device linkage

Voice control technology is the most popular due to its innate and simple qualities. Smart audio and voice assistants enable users to manage devices, seek information, and perform other tasks using natural language commands, providing a more intelligent living experience. For instance, users can utilize the voice assistant that comes pre-installed in their HomePod to control their smart home with voice commands whenever they want, all without having to turn on their phones. If multiple HomePods are charging simultaneously, they can even use voice commands to communicate in real time with family members in different rooms. Simultaneously, the smartphone application has emerged as a crucial means of engagement for the smart home. If there is a gateway at home, users may operate the smart devices when they are away from home in another location. Users can monitor and control the equipment at home through the mobile app, allowing real-time adjustments to the home environment. This significantly increases the smart home's convenience.

As shown in Figure 1, a smart home's control can also be greatly aided by the smart control panel. In addition to being able to be integrated with an AI voice assistant to handle similar playback of music, storytelling, and other entertainment functions, the smart control panel connects all of the smart devices in the home and provides a visual user interface (UI) display on the screen, allowing the user to control the smart home more effectively and concisely. This greatly enhances the playability of the smart home

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and makes it more comfortable for the user to interact with. Take pleasure in a more cozy interactive encounter.

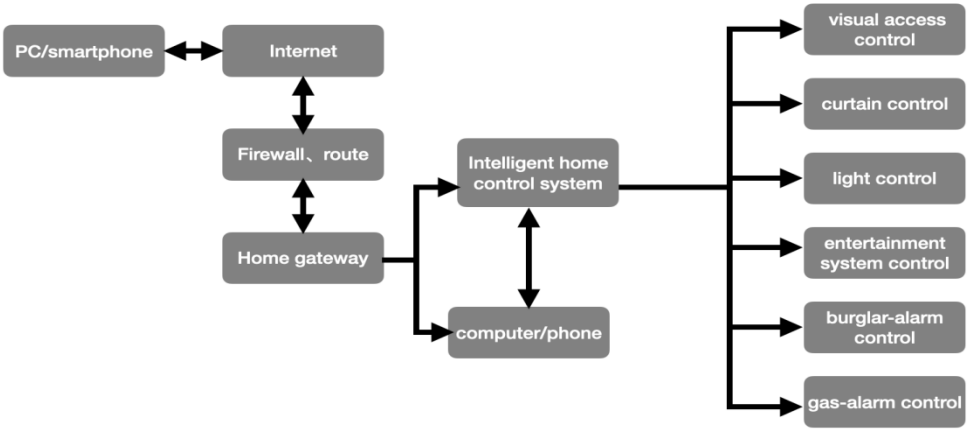

Figure 1. Smart home linkage diagram.

3.2. Existing problems

Nonetheless, there are still specific difficulties with human-computer interaction in smart home setups. Initially, users may experience inconveniences as they must adjust to disparate operation logics due to the requirement for uniform interaction interfaces and operation logics across various devices. This problem can only be solved by creating a uniform interaction design specification to ensure that users can operate across devices with consistency. Second, user privacy and data security must be considered while designing human-computer interaction. User's personal information and behavioral data must be gathered by intelligent home systems, so ensuring the security of this data has become crucial. Ensuring that user data is neither misused nor disclosed requires adopting techniques like data encryption, permission control, or storing data locally without uploading. These are important factors to take into account when designing HCI systems.

3.3. New technologies to be applied and conclusion

Additionally, a necessary condition for a seamless connection is the longevity of smart home appliances. A device with a short lifespan will cost more to operate as an intelligent home and put the user through needless hassles. Human-computer interaction will keep evolving in the direction of becoming more intelligent, seamless, and practical in the future. As artificial intelligence advances, voice recognition, gesture recognition, and habit recognition will be progressively added to intelligent home systems, enabling consumers to receive more individualized services. Human-computer interaction will also be made possible via virtual reality technology, which allows people to engage with intelligent homes through virtual settings for a more realistic experience.

To sum up, human-computer interaction influences both the level of intelligence and the user experience, making it an essential component of an intelligent home system. We can provide users with a more comprehensive range of clever, convenient, and intelligent human-computer interaction ways, as well as facilitate the continued development of intelligent home systems, thanks to ongoing innovation and technology advancements.

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4. Technical underpinnings of whole-house comprehensive technology and intelligent sweeping robots

The intelligent sweeping robot is a common application in the field of smart homes, and it exemplifies the deep integration of contemporary technology into family life. Its operational concept and all-encompassing capability demonstrate the advancement of artificial intelligence while significantly improving the convenience of everyday family life.

4.1. Main navigation system

Autonomous navigation and intelligent obstacle avoidance constitute the fundamental technologies of intelligent sweeping robots. To sense their surroundings, these robots are outfitted with various sensors, including cameras, infrared, laser, and more. Sweeping robots are able to map and identify the entire course, preventing collisions and repetitious sweeping, by gathering environmental data in real time. Smart obstacle avoidance is made possible by the robot's ability to sense objects' location and distance with extreme precision thanks to advanced sensing technologies like LiDAR [2]. Now, three popular ranging techniques use lasers to create indoor maps: LaserSmart Mapping and Navigation, NorthStar® Navigation System, and Image-based Mapping Navigation System. LaserSmart Mapping and Navigation uses laser distance measurement to create an indoor map that is used to arrange the sweeping course logically rather than erratically. The top of it is equipped with a rotating laser transmitter and receiver that creates a digital map by measuring the distances between each point on the boundary and updating it in real-time based on where the furniture is placed in the house. Additionally, it can intelligently remember and store the positional relationships so that, for instance, it may automatically begin sweeping from the node it last returned to when it has to recharge itself due to a power outage. The indoor GPS locating technique is comparable to the NorthStar® Navigation System. The NorthStar® Navigation System works on the basis of setting up an indoor signal-transmitting module. The robot then measures the offset angle between the signal and itself to calculate its position. It can only touch items in the area to create a map of the space and the locations of the things because it is unable to "see" them. In order to navigate and determine the current moving route based on the positional changes of the landmarks in the before and after images, the image-based algorithm navigation system uses three cameras on top to scan the surrounding environment. It then updates and modifies the environment model it builds by combining infrared sensors with mathematical operations and geometric and trigonometric mapping of the room.

Figure 2 shows that it is possible to determine the coordinates of the point of reflection and the location and orientation of the Lidar itself in an absolute reference. A 2D Lidar is just a Lidar that has been mounted on a rotating device. This allows it to repeatedly complete the emission/reception and computing steps, creating a 2D map (usually along a horizontal plane) out of all the points that the Lidar captured. The refresh frequency of the detection can range from 1 Hz (for one rotation per second) to 100 Hz (for 100 rotations per second), depending on the rotation speed. Similar to this, the 2D Lidar's angular resolution shows how accurate it can be when spinning. No matter the needed level of accuracy, things further away are always represented by fewer points than those closest to them. Additionally, since the ray misses items that are behind another object from the Lidar, the Lidar does not see those objects.

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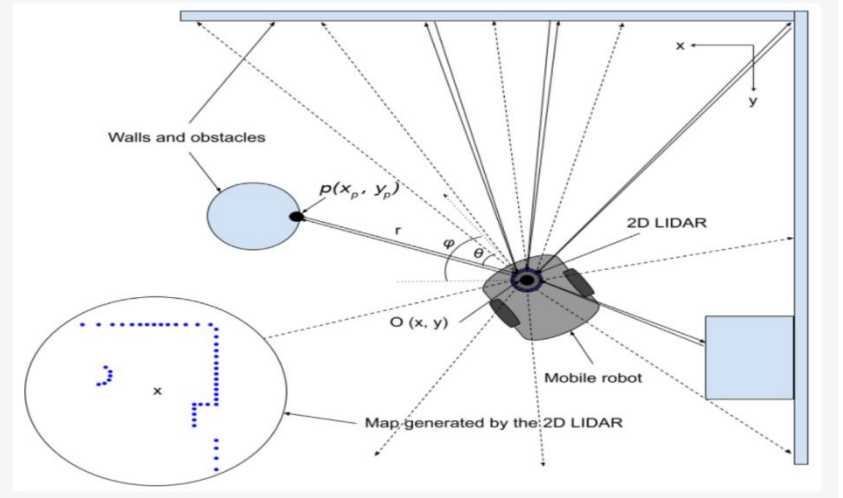

Figure 2. Calculation of household size [3].

The other option is to utilize the raster approach to describe the space, which is straightforward to realize and maintain. However, whether it accurately represents the real environment depends on how the raster size is defined. Learning along the edges results in the delineation of the subregion and the creation of a local map. The maximum distance along the edges is then expanded to the middle, after which meandering traversal is used to clear the environment. Finally, after traversing the subregion to its endpoint, learning along the edges is again used for the second edge. As we continue around the edges, we learn the next edge. To complete the sweeping of the entire environment, we divide the subregions into local maps, expand the sweeping along the edges, and learn along those borders. However, because two isolated obstacles in the environment were left out, certain areas had to be left out [4-6].

4.2. Optimization

Algorithm optimization and thorough path planning are two of the sweeping robot's most crucial components. The path planning module and internal algorithm must cooperate for the robot to finish the sweeping duty effectively. The robot must choose the best sweeping path based on sensor data and map information to prevent missing areas and repetitious sweeping. The algorithm's optimization directly impacts the cleaning efficiency and coverage of the robot and the way path planning is coordinated [7].

4.3. Intelligent recognition and real-time adjustment

Intelligent sweeping robots typically make use of computer vision technologies to recognize items. The robot can recognize barriers, furniture, and even stains on the floor by using camera photography and image processing. The detected distance signal is then transmitted to the controller, which starts the control strategy to calculate the control quantity according to the collected distance signal. Finally, the master controller controls the motors of the intelligent sweeping robot according to the control quantity so that the robot's direction of motion is changed to avoid obstacles [8-11].

This increases the robot's sweeping efficacy and efficiency by allowing it to carry out targeted sweeping under various scenes and requirements. Intelligent sweeping robots excel at doing whole-house dead-end sweeping. The robot will use an algorithm to ensure every area is covered when creating the sweeping path, preventing omissions. Based on map planning, some advanced sweeping robots can even return to the charging cradle automatically to refuel and resume unfinished sweeping chores. As a result, even when the user is not home, the robots can complete the whole house sweep.

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4.4. Existing problems and solutions

Smart sweeping robots still have to overcome some design and technical obstacles. Precise mapping and route planning come first. Accurately drawing indoor maps is a prerequisite for whole-house sweeping, meaning that more excellent standards for sensor accuracy and algorithm optimization must be met. The cleaning effect's balance is the second. The robot must be cleaned thoroughly and cleanly in an effective manner.

Furthermore, intelligent sweeping robots require constant noise control and battery life optimization. Additionally, the sweeping robot may be programmed to work with other smart home appliances. For instance, it can be programmed to perform varying degrees of sweeping based on how clean the house is after the user leaves, detected by the door's sensors.

Put succinctly, the use of intelligent sweeping robots in smart homes signifies a significant advancement in machine autonomy and artificial intelligence. These robots offer users a unique, exhaustive experience with features including whole-house sweeping, autonomous navigation, and intelligent obstacle avoidance. Robots can use massive data and cognitive AI recognition to establish precise route planning and swiftly respond to sporadic changes in the home landscape, just like people, as technology advances. Anticipate an increased role for intelligent sweeping robots in the innovative home system, which will let consumers live in a more convenient and intelligent environment.

5. Conclusion

In the vast fabric of technical advancement, smart home systems serve as a symbol of human advancement. Human-computer interaction, communication technology, and networking protocols have come together to create an ecosystem that improves our lives in a seamless way. As we make our way through the complex web of contemporary life, the efficiency and convenience provided by the smart home become more and more essential. But the adventure doesn't stop there. Smart home systems have a bright future ahead of them, full of uncharted territory for development and improvement. More advanced connection, predictive intelligence, and adaptive automation are to be expected as the Internet of Things and artificial intelligence develop further. Furthermore, integrating renewable energy and grid management solutions with smart home systems will be fueled by the pursuit of sustainability and energy efficiency.

Data security and privacy issues become increasingly important as smart home technologies become more and more interwoven into our daily lives. User education, robust encryption, and secure authentication procedures are essential to safeguard the smart home ecosystem from potential attacks. The distinctions between technology and domestic life will become increasingly hazy in the upcoming years, changing how we engage with our environment. The tale of the smart home is far from over, with every new chapter presenting both opportunities and difficulties.

In the end, exploring the intelligent home system's core has shed light on technology and its revolutionary effects on our day-to-day existence. As we stand on the edge of a better future, the convergence of connection, communication, and interaction invites us to embrace innovation and push the envelope of what is possible in our personal lives. Remember this as you turn the last page of this quest: the intelligent home story is a reflection of our changing relationship with technology, a dynamic narrative in which we are both protagonists and creators.

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