Industry 4.0 technologies for smart households

Dmytro Dmytriv[1,†], Oleksii Duda[1,*,†], Pavlo Dudkin[1,†], Andrii Kryskov[1,†] and Olga Perenchuk [1,†]

[1] Ternopil Ivan Puluj National Technical University, Ruska str., 56, 46001, Ternopil, Ukraine

Abstract

This article studies the use of Industry 4.0 technologies to create smart households. The authors listed the advantages and challenges of Industry 4.0. It has significant potential for the digital transformation of both the production and smart households as well. Based on the analysis of the structure of Industry 4.0, a list of its key technologies was formed. The main goals of a smart household have been defined and its basic information technology components have been considered. The technologies of Industry 4.0 for smart households, its components and the connections between them, in particular, the Internet of things, artificial intelligence and machine learning, modern computing approaches, augmented and virtual reality have been studied. As a result, the operations of smart household systems based on Industry 4.0 have been classified. The systems based on Industry 4.0 for interaction with users and functionality of smart households have been highlighted separately. By deploying digital solutions based on Industry 4.0 technologies, smart households can form interconnected and efficient infrastructures of a higher order, including smart locations, smart communities and smart cities.

Keywords

applications, classification, industry 4.0, systems, smart households, technologies

1. Introduction

Over the last period of time, the term "smart" has come to be applied to technologies with some level of artificial intelligence. An important characteristic of smart technologies is the ability to collect, process and analyze information from the environment [1]. Smart technologies have become a key driver of innovative ideas such as smart household systems. Thanks to the development of cyber-physical systems, IoT devices and digital services, information exchange processes are growing. This leads to the active development of smart household technology [2].

Due to the advantages of smart technologies and the needs of the global market, the interest in the smart household in research and production circles is growing rapidly.

Research on smart households is becoming more relevant in the context of Industry 4.0. This opens up the potential for the development of new technologies and business models, saving energy and resources, improving people's quality of life in general.

The fourth industrial revolution Industry 4.0 is characterized by the in-depth integration of digital technologies into various processes [3]. At the same time, automation plays an important role in digital transformation. It leads to radical changes in the processes of design, production and operation of industrial and economic systems. In the field of automation and control, the smart household is a promising area of research and innovation.

The term "smart household" is not limited exclusively to places of residence. It encompasses a broader set of technologies for smart homes, living environments, adjacent premises, and locations [4]. Smart household technologies are integrated into smart communities, smart cities, smart manufacturing and smart society.

Smart household systems integrate a wide range of information and communication technologies to create a safe, comfortable, healthy, convenient and energy-efficient living environment. They offer automated remote control of household appliances and digital services, providing a higher quality of life [5]. One of the basic functions of smart households is remote monitoring and control based on cyber-physical systems [6]. At the same time, IoT devices and communication technologies are used for remote household management. Users of smart households can remotely control household appliances and perform various tasks for home and household care. Smart sensors can monitor temperature, humidity and air composition in residential and commercial premises [7]. Thanks to this, it is possible to maintain optimal parameters of the atmosphere according to the preferences of residents or the needs of pets. With smart object detection systems, smart household security systems provide better security.

Research on smart households based on Industry 4.0 technologies is relevant due to the active development and spread of digital technologies, increasing requirements for energy efficiency, safety and comfort. In addition, consumers are more actively interested in innovative technologies to improve the quality of life. And smart households can integrate with information and industrial systems of smart locations, smart cities and smart regions based on Industry 4.0. It enables the automation of energy, resource, goods, product and service supply processes. Therefore, this article is devoted to the study of Industry 4.0 technologies for smart households. The methods of system analysis, in particular the analysis of functional requirements and the analysis of the structure of Industry 4.0 and smart households, its components and the connections between them have been used in the study under discussion.

2. Industry 4.0: challenges, advantages and technologies

Industry 4.0 is the convergence of the physical and digital worlds in production processes. This is the fourth industrial revolution, which uses the mass integration of information and communication technologies (ICT) based on the Internet of Things (IoT) in production. At the same time, data is collected and analyzed in real time to optimize processes, improve efficiency and make decisions.

Industry 4.0 has significant potential for digital transformation of the production process. It can make it more efficient, flexible and sustainable. This leads to the creation of new products, digital services and business models. On the basis of [8], we will form the list of advantages and challenges of Industry 4.0 presented in Figure 1.
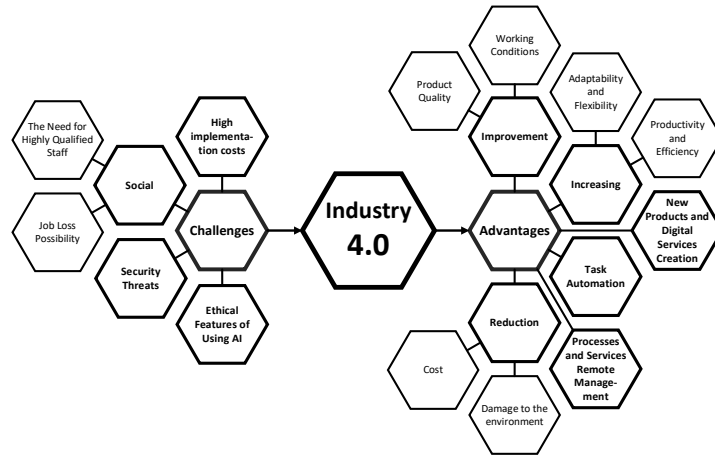
Figure 1: Industry 4.0 challenges and benefits.

Mass integration of ICT and IoT makes it possible to connect a wide range of devices, sensors, mechanisms, machines and other elements of production to the Internet. Large data sets and collections are produced in real time. ICT is used to collect, process, analyze and visualize data. This provides better control of processes and decision-making [9].

Cyber-physical systems (CFS) are used to combine physical components with computer systems. This makes it possible to create smart machines, locations and factories, to formation smart digital services. They can independently adapt and quickly respond to rapid changes in the environment [10]. The artificial intelligence (AI) and machine learning (ML) are used to predict, automate and optimize processes. The core technologies of Industry 4.0 are presented in Figure 2.
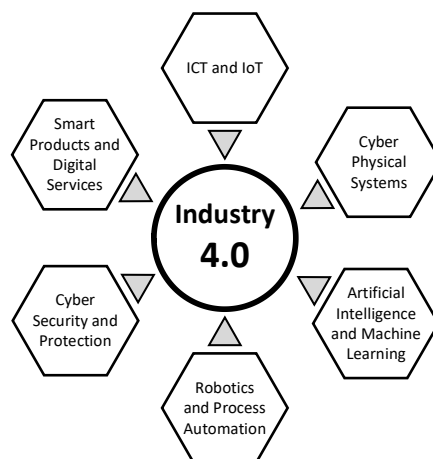
Figure 2: Industry 4.0 core technologies.

This leads to increased productivity and quality of production and smart digital services [11]. Robotics and process automation are used to perform repetitive, time-consuming or dangerous tasks. This makes it possible to free people for creative and intellectual work [12]. The proliferation of IoT and the use of AI/ML is producing new cybersecurity and data protection threats. It is critical to take effective measures to protect against cyber-attacks, secure data against unauthorized access or theft [13]. And the development of smart products and digital services that use the Internet to exchange data with other devices and systems leads to innovation [14].

At the moment, the concept of Industry 4.0 is actively developing. Innovative approaches and new technologies are emerging that are actively transforming and changing production processes. In Ukraine, Industry 4.0 can become a key factor in increasing competitiveness and economic growth.

3. Concept and benefits of a smart household

A smart household is based on the information technology concept of a smart home. A smart home is a residence equipped with technologies that enable the automation and control of various household devices, systems, and processes [4]. Key aims of a smart household are depicted in Figure 3.

Figure 3: Key aims of a smart household.
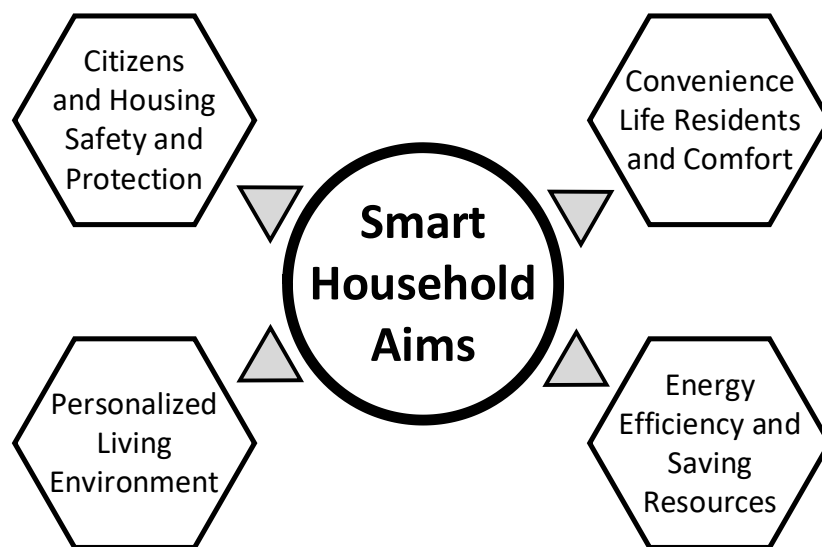
A list of main information technology components in a smart household:

- Transmitters and sensors that collect data about the environment, in particular, humidity, air composition, the presence of solid particles, illumination, movement, resource consumption, etc [15].
- Actuators control household and household appliances and devices, lighting and security systems, processes, etc. [16].

- Data storage facilities make it possible to store large and fast-moving sets and collections of data accumulated as a result of the operation of transducers, sensors and actuators. Peripheral (EDGE), fog and cloud storages are used for operational storage of information in smart household systems [17].
- Controllers process data from sensors, make decisions and send commands to activators [18].
- Analytical tools are used to process, systematize, and analyze the collected data sets of a smart household [19].
- User interfaces enable residents to control household systems using smartphones, tablets or personal computers [20].

Smart households have a number of advantages. In particular, they involve:

- the convenience of managing household devices, appliances, and systems using voice commands, smartphones, or tablets;
- increased energy efficiency of automatic regulation systems for air conditioning, heating, lighting, supply, and consumption of resources, etc.;
- improved safety characteristics of protection, monitoring, and regulation systems for the environment, informing, and warning about potential risks and dangers;
- personalization of the processes of adjustment and creation of an individual living environment according to the preferences and needs of residents;
- saving time by automating typical and routine tasks, such as cleaning and garbage disposal.

Thanks to this, smart households are becoming more accessible and popular among a wide range of consumers. With the development of technology and the decrease in the cost of equipment, they will become an integral part of our lives in the near future. A smart household is a complex system that must be carefully designed, planned, implemented, and integrated into smart community or smart city systems.

4. Industry 4.0 technologies for smart households

Industry 4.0 technologies (see Figure 4) make smart households more comfortable, safer, more economical and more environmentally friendly.

Industry 4.0 has a significant impact on the development of smart households in a number of key aspects:

- Increasing the connectivity of data collection and storage processes. CPS and IoT make it possible to connect a wide range of household sensors, appliances and devices to the Internet. At the same time, large sets and collections of data on the behavior of residents, energy consumption, the state of the environment, etc. are being produced.

- Automation of management processes. AI and ML are used for analytical data processing, decision-making, and task automation in various smart household systems.
- Personalization and adaptation. Smart household systems based on Industry 4.0 can dynamically adapt to the individual preferences and needs of residents. At the same time, the comfort of living conditions increases.
- Energy efficiency and sustainability are ensured through smart systems and digital services. Such systems can optimize resource consumption processes [21]. At the same time, harmful emissions and damage to the environment are reduced.
- Industry 4.0 opens up opportunities for the development of innovative information technology products and digital services of a smart household. At the same time, virtual assistants based on the Decision Support System (DSS) can be implemented.
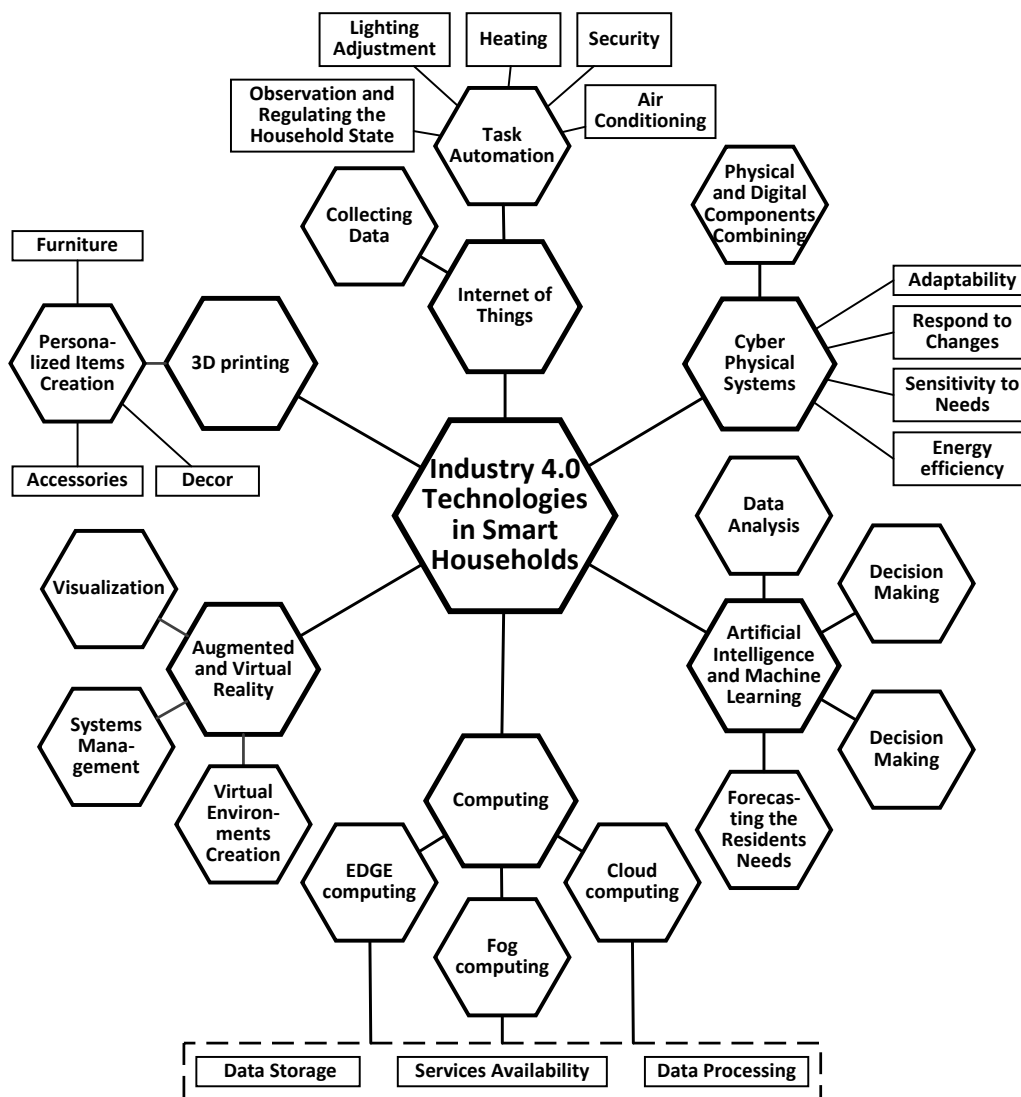

Figure 4: Industry 4.0 technologies in smart households.

Industry 4.0 is constantly developing. At the same time, new technologies are emerging that can be used to improve smart households.

Modern technologies of Industry 4.0 in smart households require the use of biosensors [22], [23] in particular, to monitor the health status of the elderly or residents with special health needs. An important characteristic of various types of biosensors is stability [24], [25]. The authors of [26] and [27] study the processes of modelling sensor responses. In addition, in [28] it was used in the planning of measures to increase the ecological and economic efficiency of the agricultural land use system. Numerical modelling in cyber-physical biosensor systems [29], [30] is important at the stage of their design.

Smart homes are expected to become more common and affordable shortly. Table 1 presents the classification of operations for smart household systems based on Industry 4.0.

Table 1
Classification of operations for smart household systems based on Industry 4.0

Category	System types	System designation
Security and monitoring	Anti-theft systems	Video surveillance and recording
		Integration with smart systems
	Object detection systems	Monitoring the movement of objects
		Automatic inclusion
		Assistance to people with disabilities
	Security systems	Sensors at penetration points
		Alarm signals on a smartphone
		Remote security control
	Elderly care systems	Identification of falls
		Activity monitoring
Resources and energy efficiency	Energy management systems	Energy consumption monitoring
		Automatic adjustment
		Use of solar panels and alternative energy sources
	Resource management systems	Observation of resource supply processes
		Optimization of consumption processes
	Waste management control systems	Monitoring waste collection and sorting
		Optimization of waste removal processes
Availability and support	Assistive technologies for people with disabilities	Touch screens
		Reminders
	AR/VR systems	Virtual reality therapy
		Distance education and training

A significant part of smart household systems can combine the functions of several categories. For example, image recognition systems can be used both to identify residents and monitor the activity of the elderly. This makes smart households personalized, adaptable and flexible. Table 2 presents systems based on Industry 4.0 for user interaction and functionality in smart households.

Table 2

Systems based on Industry 4.0 for user interaction and functionality in smart households

Category	System types	System designation
Management and automation	Image processing systems	Face recognition
		Image analysis
		Detection of suspicious activities
		Child tracking
		Pet tracking
		Gesture recognition
		Creation of automation scenarios
	Gesture control systems	Contactless control
		Application in AR/VR
		Accessibility for people with disabilities
	Device control mechanisms	Voice control
		Control using smartphones
	Ambient luxury systems	Smart lighting
		Smart audio
		Climate control systems
		Aromatization of the air
Convenience and entertainment	AR/VR systems	Games
		Virtual tours
	Elderly care systems	Drop sensors
		Activity monitoring
		Safety and assistance when needed
		Assistant robots
		Telemedicine systems
		Medication reminders and important tasks
		Cognitive function monitoring systems
Outhouse systems and farm buildings	Management systems for smart commercial premises	Control and regulation of temperature, humidity, ventilation and lighting
		Equipment condition monitoring
		Receiving accident notifications
	Homestead management systems	Control and regulation of lighting, watering, fertilization and other resources
		Monitoring of soil and plant conditions
		Weather and microclimate tracking
	Pet care systems	Automated food and water dispensing based on schedule or sensor signal
		Electronic door for pets
		Animal GPS trackers

Understanding information technology approaches based on Industry 4.0 is very important for researchers, developers and manufacturers in the field of smart households. This will make it possible to increase the functionality, efficiency and security of smart household systems adapted to the different needs of users.

Industry 4.0 is still at an early stage of development. It is expected to continue to develop in the coming years, offering new opportunities and innovations for the smart home. Smart households based on Industry 4.0 have the potential to significantly improve our lives, making them more comfortable, safe, economical and environmentally friendly [31], [32].

5. Conclusions

Industry 4.0 technologies play an important role in the design and implementation of smart households. They integrate IoT devices and cyber-physical systems, artificial intelligence and machine learning, modern computing approaches, virtual reality and 3D printing. Smart households implement innovative digital services, increase the efficiency of process management, optimize the use of resources and improve the quality of life. Thanks to Industry 4.0 technologies, smart decision support systems are being developed that effectively manage user identification, access rights distribution, and privileges. This increases the security of data collection and processing, leads to an improvement in the efficiency of the use of systems, and reduces operating costs in general. The implementation of information technology projects for smart households demonstrates how the use of advanced technologies in Industry 4.0 contributes to the improvement of efficiency, sustainability, and quality of life for citizens. By deploying digital solutions based on Industry 4.0 technologies, smart households can form interconnected and efficient infrastructures of smart locations, smart communities and smart cities. They offer a wide range of smart services in real time. One of the promising areas of further research is the specifics of the integration of smart households in higher-order systems. Industry 4.0 technologies and smart households are actively evolving. Therefore, it is advisable to further investigate the features of forming information and technology platforms for smart households and the details of interaction between their components.

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