Journal of Edge Computing, **2023**, 2(2), pp. 148-162 https://doi.org/10.55056/jec.632

Design and implementation of an IoT-based educational model for smart homes: a STEM approach

Nadiia Balyk[1], *Svitlana* Leshchuk[1] and *Dariia* Yatsenyak[1]

[1] *Ternopil Volodymyr Hnatiuk National Pedagogical University, 2, Maxyma Kryvonosa Str., Ternopil, 46027, Ukraine*

Abstract. This work presents a comprehensive study on the design and implementation of an educational model for a smart home, leveraging the principles of the Internet of Things (IoT). The model encompasses three key levels: command, communication, and management, and integrates several subsystems, including communication, signalling, lighting control, temperature regulation, garbage container filling, and sensor data monitoring. The hardware components for implementing the Mini Smart House, a practical application of the model, are detailed in the study. The Mini Smart House utilizes a range of technologies for efficient management and incorporates renewable energy sources for power. The model was independently produced by students participating in a STEM project, with research activities encompassing sketching, construction part creation, sensor assembly, Arduino board programming in the Arduino IDE environment, and system functionality testing. The Mini Smart House was validated within the STEM-center of the Physics and Mathematics Faculty of Ternopil Volodymyr Hnatiuk National Pedagogical University during the educational process and numerous trainings and seminars for pupils and teachers of computer science[1].

Keywords: Internet of Things, smart home, educational model, STEM education, resource utilization, Arduino programming, sensor technology, edge computing

1. Introduction

The recent surge in IT development has been dominated by smart technologies, which have found widespread applications across various industries, homes, and educational settings. This has equipped modern educators with many tools that make learning more engaging and innovative. The advent of the Internet of Things (IoT), a network concept that integrates numerous devices with built-in transmitters for their physical parameters, offers additional opportunities. The eminent physicist Nikola Tesla predicted the ubiquitous use of these household appliances in the early twentieth century [4].

In the early 21st century, the number of devices connected to the Internet surpassed the Earth's population, making IoT one of the significant global trends today. Almost all everyday devices are now part of the Internet, performing new functions and driving the 4th Industrial Revolution. Consequently, training IoT experts, the future creators is a crucial educational task [1, 7, 11].

[1]This article is an extended version of the paper presented at the Workshop for Young Scientists in Computer Science & Software Engineering [2].

nadbal@fizmat.tnpu.edu.ua (N. Balyk); leshchuk_so@fizmat.tnpu.edu.ua (S. Leshchuk); yatsenyak_dv@fizmat.tnpu.edu.ua (D. Yatsenyak)
0000-0002-3121-7005 (N. Balyk); 0000-0001-6600-7940 (S. Leshchuk); 0000-0002-8427-5532 (D. Yatsenyak)

The urgency of modernizing the educational process has never been greater. In this context, implementing STEM projects, using intelligent technologies, and exploring IoT possibilities can enrich the learning experience.

Smart home technology encapsulates all these concepts. A "smart home" system ensures security and resource conservation (including comfort) for all users. In its simplest form, it should be capable of recognizing and responding to specific situations occurring in the home: one system can control the behaviour of others using pre-built algorithms. Moreover, automating several subsystems provides a synergistic effect for the entire complex [10].

With the increasing computing power of gadgets, many smart home technologies and IoT have been standardized. Basic rules and recommendations for constructing the finished product at the system and individual component levels have also been defined [12]. This paper explores these concepts in edge computing, where data processing is performed closer to the data source, thereby reducing latency and bandwidth usage.

2. Research methodology

The research problem is rooted in incorporating modern, trend-aligned methods and content into the educational process. This project aims to develop a smart home model and design and create a Mini Smart House.

The research goal can be achieved by addressing the following tasks:

- Analyzing the conceptual framework in the field of Internet of Things;
- Designing the intelligent house training model and selecting the hardware components for model implementation;
- Developing the project through programming its modules in the Arduino IDE environment;
- Implementing, testing, and debugging specific project components.

The focus of the study is the technologies of the Internet of Things. The subject of the study is a smart home educational model and its realization in the form of a Mini Smart House.

To accomplish this goal, we employed a combination of research methods: theoretical methods such as analysis of scientific and technical sources, generalization, and modelling of information processes occurring in the "smart home"; empirical methods such as observations and analysis of the experience of using IoT technologies; and practical methods for software development and testing.

The study was validated within the STEM-Center of the Physics and Mathematics Faculty of the Volodymyr Hnatyuk TNPU framework, particularly during the educational process and numerous trainings and seminars for students and teachers of informatics. This research contributes to edge computing by demonstrating how localized data processing and analysis can enhance the functionality and efficiency of IoT-based systems like smart homes.

3. Results

3.1. Exploring the fundamental concepts of the study

A smart home is designed to enhance security, conserve resources, and provide comfort for its inhabitants [9]. At its most basic, it should be capable of identifying specific scenarios within the home and responding to them using pre-established algorithms.

The term “smart home” lacks a precise definition. Hence, it is often used to refer to any system that automates device control, thereby simplifying human life and enhancing comfort levels. The inception of the “smart home” concept can be traced back to 1961 when Joel Solomon and Ruth Rodale Spira invented and patented a device for the smooth regulation of light – the dimmer.

The term “smart home” was coined and popularized by the American Developers Association in 1984, when the declining prices of electrical appliances facilitated the construction of highly functional offices [5].

Over time, scientists and engineers transitioned from theory to practice, incorporating this technology into an increasing number of objects. A distinguishing feature of a “smart home”, which sets it apart from other living space organization methods, is its progressive concept of human interaction with living space. Here, an individual can establish the desired environment with a single command, and the automation system, considering external and internal conditions, sets and monitors the operating modes of all engineering systems and electrical appliances.

The functional features of such a building can be categorized into three main areas [000]:

- Domestic functions;
- Entertainment;
- Protection and technological security.

This system does not necessitate a multitude of computers and connections. Experience demonstrates that one can transform their home into a “smart” environment with minimal drastic alterations. Essentially, it is a conventional house or apartment (or even an industrial facility, shopping mall, etc.) equipped with a “smart” system that caters to any whim or desire of its owner and resolves most household tasks. Living in such a house is enjoyable but comfortable, safe, and economical.

In the current era of digitalization, the components of the “smart home”, along with cloud computing technologies and IoT, possess significant pedagogical potential, serving both as an object and a tool for learning [3, 6, 8].

3.2. Constructing a model for a smart home

Functionality, style, comfort, and safety merely scratch the surface of what a smart home can offer. The “smart home” training model concept incorporates IoT technologies, aiming to facilitate the convenient management of essential household appliances and the utilization of renewable energy sources. The proposed components of our “smart home” model include:

- A control centre (in the form of a tablet or console) that records and interprets data from sensors;

- Sensors for motion, smoke, flooding, window or door openings, light, humidity, and temperature;
- Automatic water taps;
- Temperature regulators for batteries;
- Readers for meter indicators;
- Video intercom;
- Voice assistants (optional).

Each component is designed to independently receive sensor data and operate according to the developed algorithms. Consequently, their entire operation process can be controlled and managed from mobile devices via the Internet. As depicted in figure 1, our model comprises three levels: commands, management, and communications.

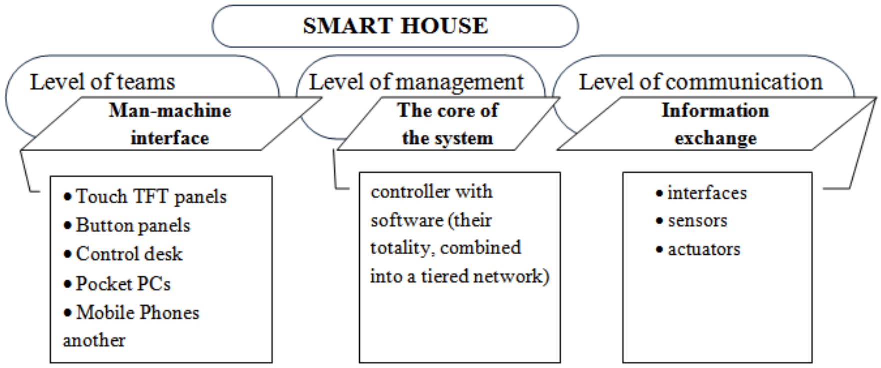

Figure 1: Educational model of smart home.

The Mini Smart House represents a fusion of technical, engineering, design techniques, and computer and software engineering (including computer networks and C programming), showcasing tangible results. Incorporating such projects into the educational curriculum allows learners to acquire skills in modelling relevant processes and implementing similar technologies in real-life scenarios. Students will learn to create a system that ensures safety, comfort, economy, and efficient management of their own homes. This system is scalable and customizable, ensuring effective management of smart home technology. Integrating academic subjects and implementing cross-curricular links contribute to the preparation of a modern specialist.

In our "Smart House" model, we can identify the following subsystems:

- Communication;
- Alarm system;
- Lighting control;
- Climate control;
- Sensor data monitoring;
- Cleanliness control (trash can filling).

Table 1
Calculation of the cost of hardware components of the prototype.

Name	Model	Quantity	Price UAH
Temperature and humidity sensor	DHT11	1	29
Sound sensor	KY-037	1	29
Hercon sensor for door opening	MC-38	1	49
Arduino pin extension module	I2CxPCF8574T	1	27
LCD 1602 module for Arduino	1602	1	65
Real time clock	DS1302-MOD	1	17
Buzzer	KY-012	1	18
The engine		1	50
Bluetooth module	HC-06	1	100
Ultrasonic distance sensor	HC-SR04	1	37
Conductors		30	1
LED		3	1
Arduino	Uno	2	209-894
Payless Layout Board	MB-102	2	49
Solar battery	RF136X110-3	1	120
Plastic		1	40
Plywood			120
Accessories for doors and windows			10
Laser cutting			100
Other supplies			20

Suitable software modules for all components were developed to ensure their practical functionality. Optimal development tools were selected (refer to subsection 3.3 for a description) based on the chosen hardware elements for our model (refer to table 1).

Our Mini Smart House model should consider the economic aspects of resource utilization. By analyzing pertinent data, potential savings on utility bills in a smart home can be realized.

As indicated by the study, a smart home is characterized by:

- Resource savings:
  - Electricity:
    - Up to 60% in the lighting system;
    - Up to 40% in the climate control system;
  - Up to 40% in gas and water usage;
- Reduced operational costs:
  - Service savings of up to 20
  - Cost savings on staff;
  - A significant increase in equipment lifespan;
- Prevention of emergencies;
- Increased profitability and investment attractiveness:
  - More favourable insurance conditions;

– When renting, it provides a basis for increasing the rent.

We have chosen components from the open Arduino hardware and software project for the hardware components that implement the model. Table 1 lists these components and provides a cost estimate for creating a Mini Smart House.

3.3. Implementation of the model in practice

The practical execution of the model entails the development of a smart home layout. This model serves as a preliminary project of the house, providing insights into the artistic and stylistic choices of the building, as well as its layout characteristics.

Initially, a sketch of the house was hand-drawn on paper. This sketch was digitally rendered using CorelDraw to create a more detailed layout drawing.

The next step involved selecting the appropriate material for constructing the model. Various materials such as foam, wood, or solid cardboard can be used for creating a home model. However, we found wood to be the most suitable for our Mini Smart House prototype due to its ease of machining, reliability, and durability. Consequently, plywood was chosen as the material of choice. The finalized drawings were then prepared for the laser cutting machine, enabling the cutting out of the necessary details.

Based on the finalized drawings, all structural elements were manufactured. The precision and quality of the work facilitated the easy assembly of all the details. Once all the details were prepared, the housing prototype was assembled and secured with PVA glue and hot glueing. Moving parts were attached to the curtains that were screwed onto the screws. The prototype, in its entirety, is presented in figure 2.

A vital function of any SMART system is its ability to respond to environmental parameters measured using sensors, signals, communications, and other integrated elements. The data collected is processed through the execution of program code. For programming in the Arduino IDE, the C++ programming language is utilized.

3.4. Practical deployment of the model

The code created in the Arduino IDE environment is uploaded to the Arduino Uno board, enabling us to program the microcontrollers. The Arduino Uno, a widely utilized open-source microcontroller board based on the ATmega328P microcontroller, is equipped with all the necessary features for convenient microcontroller operation. These include 14 digital inputs/outputs (6 of which can be used as PWM outputs), 6 analogue inputs, a 16 MHz quartz resonator, a USB connector, a power connector, an In-Circuit Serial Programming (ICSP) connector, and a reset button.

The Arduino Uno board can employ three communication protocols: ZigBee, Wi-Fi, and Bluetooth. Considering the instructional purpose of the Mini Smart House model, we opted for the Bluetooth protocol. This allows system connectivity via a smartphone or tablet. While Bluetooth does have limitations, such as a short signal propagation distance, it is suitable for our model, where a stable connection within 10 meters is sufficient. This choice also allows for low power consumption, compact size, and relatively low component cost. A low-power transmitter, for instance, consumes only 0.3 mA in standby mode and averages 30 mA during data exchange.

Figure 2: View of the "Mini Smart House" prototype.

Bluetooth offers data encryption using an 8- to 128-bit practical key and provides one-way or two-way authentication.

Figure 3 illustrates the connection of a Bluetooth module to an Arduino UNO board.

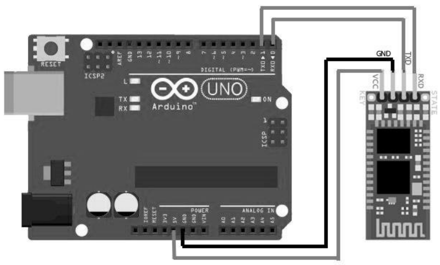

Figure 3: Bluetooth HC-06 connection scheme.

The software to connect the Bluetooth module to the smartphone using the following code:

```
#include "alarm.h"
#include "claplight.h"
#include <SoftwareSerial.h>
int ledpin=12;
int BluetoothData;
void bluetooth_setup()
```

```
{
    Serial.begin(9600);
    Serial.println("Bluetooth On please press 2-5");
    pinMode(ledpin,OUTPUT);
}
void bluetooth_loop()
{
    if (Serial.available())
    {
        BluetoothData=Serial.read();
        if (BluetoothData == 50)
        {
            clap_bl = true;
            last_bl = false;
            Serial.println("Clap Light  On! ");
        }
        if (BluetoothData == 51)
        {
            clap_bl = false;
            Serial.println("Clap Light  Off! ");
        }
        if (BluetoothData == 52)
        {
            alarm_bl = true;
            Serial.println("Alarm On! ");
        }
        if (BluetoothData == 53)
        {
            alarm_bl = false;
            Serial.println("Alarm Off! ");
        }
     }
 }
```

Bluetooth connectivity allows the Mini Smart House model to control various household appliances such as lighting, ventilation, and alarms. It also enables the retrieval of sensor data, including temperature, humidity, and landfill levels.

A practical example of the model's security control implementation is the development of alarm systems. This involves using a Hercon sensor for door opening detection and a piezo speaker for alarm sound generation. When the door is opened, the sensor sends an electrical signal to the Arduino, triggering a loud alarm. This alarm can be turned on or off using Bluetooth connectivity. The connection diagram for these components is depicted in figure 4.

When the alarm system is on, the sensor sends an electrical signal when the door is opened on the Arduino board, from which the sound is output to the speaker. The event processing

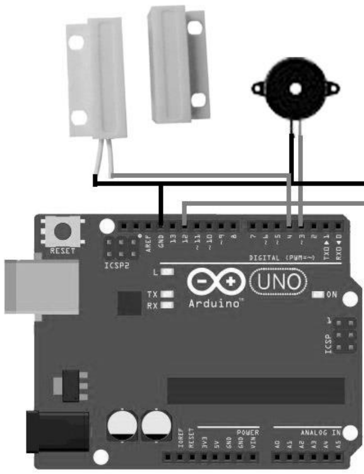

Figure 4: Scheme of the alarm system.

module is as follows:

```
const int buzzer = 3;
const int sensor = 4;
int state; // 0 close - 1 open switch
int alarm_delay = 500;
int alarm_timer = 0;
bool alarm_bl = true;
void alarm_setup()
{
    pinMode(sensor, INPUT_PULLUP);
}
void alarm_loop()
{
    if(!alarm_bl)
    {
         noTone(buzzer);
         return;
    }
    if(alarm_timer < alarm_delay)
    {
         alarm_timer+= 1;
         return;
    }
    else alarm_timer = 0;
    state = digitalRead(sensor);
    if(state==HIGH)
```

```
        {
            tone(buzzer, 1000);
            alarm_timer=0;
        }
        else
        {
            alarm_timer += 1;
            noTone(buzzer);
        }
    }
```

The lighting control subsystem in the Mini Smart House model offers a convenient method for switching lights on and off without the need for physical interaction with a switch. This is achieved by simply clapping one's hands. The key hardware components of this subsystem include a sound sensor and an LED. Alternatively, lighting can also be controlled via a smartphone. The hardware connection diagram for these components is illustrated in figure 5.

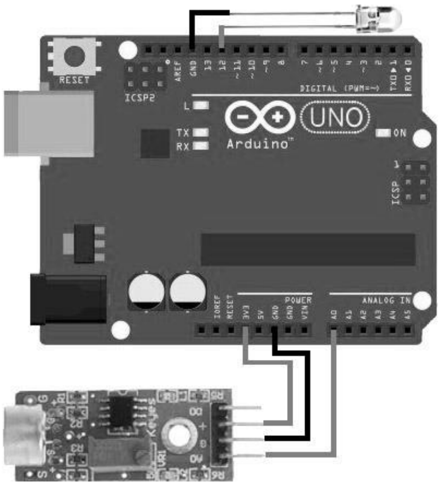

Figure 5: Scheme of the lighting control subsystem.

The processing of subsystem events is carried out by program code.

```
int ledPin = 12;
int threshoid= 20;
int volume;
int v = 0;
int knowckSensor = A0;
int sensorreading = 0;
int ledState = LOW;
bool clap_bl = true;
bool last_bl = false;
```

```
int claplight_delay = 50;
int claplight_timer = 0;
void claplight_setup()
{
    Serial.begin(9600);
    pinMode(ledPin, OUTPUT);
}
void claplight_loop()
{
    if(clap_bl == false)
    {
        last_bl = clap_bl;
        digitalWrite(ledPin, LOW);
        return;
    }
    else if(last_bl == false && clap_bl == true)
    digitalWrite(ledPin, HIGH);
    last_bl = clap_bl;
    v = analogRead(knowckSensor);
    if(v >= threshoid)
    {
         if ((sensorreading == 0))
         {
            digitalWrite(ledPin, HIGH);
            Serial.println("Knock!");
            sensorreading = 1;
         }
         else
         {
            digitalWrite(ledPin, LOW);
            Serial.println("No!");
            sensorreading = 0;
         }
         //v = 0;
         delay(50);
     }
}
```

The climate control subsystem in the Mini Smart House model employs a temperature sensor and a fan. The Arduino controller activates the fan when the temperature exceeds a certain threshold. Conversely, the fan is deactivated when the temperature falls below this threshold. The schematic representation of this climate control subsystem is depicted in figure 6.

The model also incorporates a feature that displays sensor data and the date and time on a screen. This subsystem comprises a screen, a clock module, and sensors. The connection scheme for these components is illustrated in figure 7. Additionally, sensor data is also transmitted to a smartphone.

The waste management aspect of the Mini Smart House is controlled using an Arduino board and a proximity sensor. The sensor, which uses acoustic ultrasonic radiation, determines the distance to an object. This contactless proximity sensor offers high measurement accuracy and stability, and its results are largely unaffected by solar radiation and electromagnetic interference. The sensor monitors the fill level of the waste container and sends a signal to the Arduino. If the fill level reaches or exceeds 80%, a "Trash filled" message is sent to the phone.

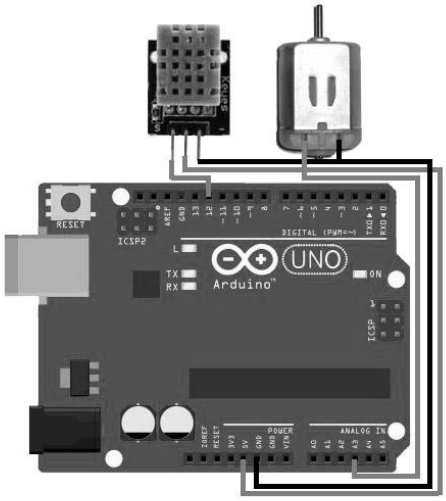

Figure 6: The scheme of the climate control subsystem.

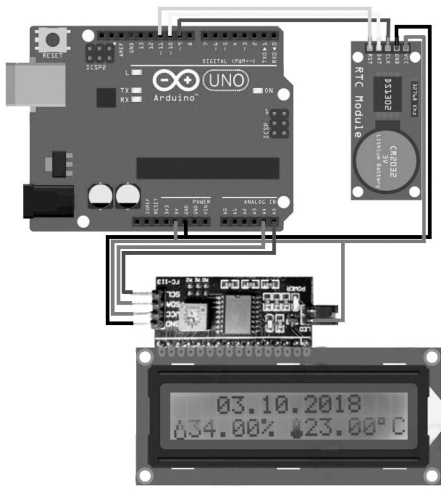

Figure 7: Schematic diagram of the monitoring subsystem.

Software implementation of the module of the fill level of the waste container subsystem is:

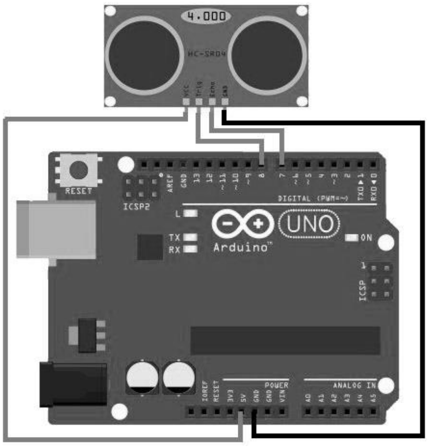

Figure 8: Scheme of the purity control subsystem.

```
#define trigPin 8
#define echoPin 7
#define led 6
int dumpDelay = 0;
void dump_setup()
{
    pinMode(trigPin, OUTPUT);
    pinMode(echoPin, INPUT);
    pinMode(led, OUTPUT);
}
void dump_loop()
{
    dumpDelay += 100;
    if(dumpDelay < 2000) return;
    dumpDelay = 0;
    long duration, distance;
    digitalWrite(trigPin, LOW);
    delayMicroseconds(2);
    digitalWrite(trigPin, HIGH);
    delayMicroseconds(3000);
    digitalWrite(trigPin, LOW);
    duration = pulseIn(echoPin, HIGH);
    distance = (duration/2) / 29.1;
    Serial.println(distance);
    if (duration < 300 || (duration >= 500 || duration <= 0))
    digitalWrite(led, HIGH); else digitalWrite(led, LOW);
}
```

Nowadays, energy-saving technologies are becoming widespread. In the "Mini Smart House" prototype, we use a RF136X110-3 on a 5V solar battery connected to a Power Bank battery that nourishes our system.

4. Conclusions

Exploring contemporary educational technologies (STEM, Smart, Internet of Things) has provided a theoretical and methodological foundation for constructing an educational model of a smart home, leading to the development of the Mini Smart House.

This completed project integrates various disciplines, including technical, engineering, design methods, and computer and software engineering (computer networks, C++ programming), showcasing tangible outcomes. The methodologies allow us to simulate pertinent processes and apply analogous technologies in real-world scenarios. Consequently, students can construct a system ensuring security, comfort, economy, and efficiency in managing their homes. This system is scalable and customizable, guaranteeing effective management of smart home technologies.

The Mini Smart House project holds practical significance for both students and educators. It can be incorporated into the curriculum of various subjects in school, including computer science and physics, thereby enhancing the learning experience.

References

[1] Afroz, A., Khamari, S.S. and Behera, R.K., 2024. Solar Powered Smart Home Automation and Smart Health Monitoring with IoT. In: S.K. Udgata, S. Sethi and X.Z. Gao, eds. *Intelligent systems*. Singapore: Springer Nature Singapore, *Lecture Notes in Networks and Systems*, vol. 728, p.169 – 182. Available from: https://doi.org/10.1007/978-981-99-3932-9_16.

[2] Balyk, N., Leshchuk, S. and Yatsenyak, D., 2019. Developing a Mini Smart House model. In: A.E. Kiv, S.O. Semerikov, V.N. Soloviev and A.M. Striuk, eds. *Proceedings of the 2nd Student Workshop on Computer Science & Software Engineering (CS&SE@SW 2019), Kryvyi Rih, Ukraine, November 29, 2019*. CEUR Workshop Proceedings, vol. 2546, pp.198–212. Available from: https://ceur-ws.org/Vol-2546/paper14.pdf.

[3] Bremer, A., 2015. Diffusion of the "Internet of Things" on the world of skilled work and resulting consequences for the man–machine interaction. *Empirical Research in Vocational Education and Training*, 7, p.8. Available from: https://doi.org/10.1186/s40461-015-0021-9.

[4] daCosta, F., 2012. *Rethinking the Internet of Things: A Scalable Approach to Connecting Everything*. Apress Berkeley, CA. Available from: https://doi.org/10.1007/978-1-4302-5741-7.

[5] Dingli, A. and Seychell, D., 2015. Smart Homes. *The New Digital Natives: Cutting the Chord*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp.85–101. Available from: https://doi.org/10.1007/978-3-662-46590-5_7.

[6] Hu, Y., Tilke, D., Adams, T., Crandall, A.S., Cook, D.J. and Schmitter-Edgecombe, M., 2016. Smart home in a box: usability study for a large scale self-installation of smart home technologies. *J. Reliab. Intell. Environ.*, 2(2), pp.93–106. Available from: https://doi.org/10.1007/S40860-016-0021-Y.

[7] Huda, N.U., Ahmed, I., Adnan, M., Ali, M. and Naeem, F., 2024. Experts and intelligent systems for smart homes' Transformation to Sustainable Smart Cities: A comprehensive review. *Expert Systems with Applications*, 238, p.122380. Available from: https://doi.org/10.1016/j.eswa.2023.122380.

[8] Koper, R., 2014. Conditions for effective smart learning environments. *Smart Learn. Environ.*, 1(1), p.5. Available from: https://doi.org/10.1186/S40561-014-0005-4.

[9] Oliveira, L., Mitchell, V. and May, A.J., 2020. Smart home technology - comparing householder expectations at the point of installation with experiences 1 year later. *Pers. Ubiquitous Comput.*, 24(5), pp.613–626. Available from: https://doi.org/10.1007/S00779-019-01302-4.

[10] Oteafy, S.M.A. and Hassanein, H.S., 2012. Resource Re-use in Wireless Sensor Networks: Realizing a Synergetic Internet of Things. *J. Commun.*, 7(7), pp.484–493. Available from: https://doi.org/10.4304/JCM.7.7.484-493.

[11] Rajeswari, Vinod Kumar, N., Suresh, K.M., Sai Kumar, N. and Girija Sravani, K., 2023. IoT-based smart home security alert system for continuous supervision. In: A. Kumar, S.L. Tripathi and K.S. Rao, eds. *Machine Learning Techniques for VLSI Chip Design*. John Wiley & Sons, Ltd, chap. 4, p.51 – 63. Available from: https://doi.org/10.1002/9781119910497.ch4.

[12] Wang, P., 2023. Digital multimedia signal processing via AIoT and its application in smart home. *Internet Technology Letters*, 6(5), p.e335. Available from: https://doi.org/10.1002/itl2.335.