GOCE DELCEV UNIVERSITY, STIP, NORTH MACEDONIA
FACULTY OF ELECTRICAL ENGINEERING

ETIMA 2025

THIRD INTERNATIONAL CONFERENCE

24-25 SEPTEMBER, 2025

TECHNICAL SCIENCES APPLIED IN ECONOMY, EDUCATION AND INDUSTRY

УНИВЕРЗИТЕТ „ГОЦЕ ДЕЛЧЕВ“, ШТИП
ЕЛЕКТРОТЕХНИЧКИ ФАКУЛТЕТ

GOCE DELCEV UNIVERSITY, STIP
FACULTY OF ELECTRICAL ENGINEERING

ТРЕТА МЕЃУНАРОДНА КОНФЕРЕНЦИЈА
THIRD INTERNATIONAL CONFERENCE

ЕТИМА / ETIMA 2025

ЗБОРНИК НА ТРУДОВИ
CONFERENCE PROCEEDINGS

24-25 септември 2025 | 24-25 September 2025

ISBN: 978-608-277-128-1
DOI: https://www.doi.org/10.46763/ETIMA2531

Главен и одговорен уредник / Editor in Chief
проф.д-р Сашо Гелев
Prof.d-r Saso Gelev

Јазично уредување / Language Editor
Весна Ристова (македонски) / Vesna Ristova (Macedonian)

Техничко уредување / Technical Editing
Дарко Богатинов / Darko Bogatinov

Издавач / Publisher
Универзитет „Гоце Делчев”, Штип / Goce Delcev University, Stip
Електротехнички факултет / Faculty of Electrical Engineering

Адреса на организационен комитет / Adress of the organizational committee
Универзитет „Гоце Делчев”, Штип / Goce Delcev University, Stip
Електротехнички факултет / Faculty of Electrical Engineering
Адреса: ул. „Крсте Мисирков“ бр. 10А / Adress: Krste Misirkov, 10A
Пош. фах 201, Штип - 2000, С. Македонија / PO BOX 201, Stip 2000, North Macedonia
E-mail: conf.etf@ugd.edu.mk

CIP - Каталогизација во публикација
Национална и универзитетска библиотека "Св. Климент Охридски", Скопје

62-049.8(062)
004-049.8(062)

МЕЃУНАРОДНА конференција ЕТИМА (3 ; 2025 ; Штип)
Зборник на трудови [Електронски извор] / Трета меѓународна конференција ЕТИМА 2025, 24-25 септември 2025 ; [главен и одговорен уредник Сашо Гелев] = Conference proceedings / Third international conference, 24-25 September 2025 ; [editor in chief Saso Gelev]. - Текст во PDF формат, содржи 357 стр., илустр. - Штип : Универзитет "Гоце Делчев", Електротехнички факултет ; Stip : "Goce Delchev" University, Faculty of Electrical engineering, 2025

Начин на пристапување (URL): https://js.ugd.edu.mk/index.php/etima/en. - Наслов преземен од екранот. - Опис на изворот на ден 30.10.2025. - Трудови на мак. и англ. јазик. - Библиографија кон трудовите

ISBN 978-608-277-128-1

а) Електротехника -- Примена -- Собири б) Машинство -- Примена -- Собири
в) Автоматика -- Примена -- Собири г) Инфоматика -- Примена -- Собири

COBISS.MK-ID 67297029

Трета меѓународна конференција ЕТИМА
24-25 Септември 2025
Third International Conference ETIMA
24-25 September 2025

ОРГАНИЗАЦИОНЕН ОДБОР
ORGANIZING COMMITTEE

Драган Миновски / Dragan Minovski
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Сашо Гелев / Saso Gelev
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Тодор Чекеровски / Todor Cekerovski
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Маја Кукушева Панева / Maja Kukuseva Paneva
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Билјана Читкушева Димитровска / Biljana Citkuseva Dimitrovska
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Дарко Богатинов / Darko Bogatinov
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

ПРОГРАМСКИ И НАУЧЕН ОДБОР
SCIENTIFIC COMMITTEE

Георги Иванов Георгиев / Georgi Ivanov Georgiev
Технички Универзитет во Габрово, Бугарија
Technical University in Gabrovo, Bulgaria

Антон Белан / Anton Beláň
Факултет за електротехника и информациони технологии
Словачки Технички Универзитет во Братислава, Словачка
Faculty of Electrical Engineering and Information Technology
Slovak Technical University in Bratislava, Slovakia

Ивелина Стефанова Балабанова / Ivelina Stefanova Balabanova
Технички Универзитет во Габрово, Бугарија
Technical University in Gabrovo, Bulgaria

Бојан Димитров Карапенев / Boyan Dimitrov Karapenev
Технички Универзитет во Габрово, Бугарија
Technical University in Gabrovo, Bulgaria

Сашо Гелев / Saso Gelev
Електротехнички факултет,
Универзитет „Гоце Делчев", Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Влатко Чингоски / Vlatko Cingoski
Електротехнички факултет,
Универзитет „Гоце Делчев", Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Божо Крстајиќ / Bozo Krstajic
Електротехнички факултет
Универзитет во Црна Гора, Црна Гора
Faculty of Electrical Engineering,
University in Montenegro, Montenegro

Милован Радуловиќ / Milovan Radulovic
Електротехнички факултет
Универзитет во Црна Гора, Црна Гора
Faculty of Electrical Engineering,
University in Montenegro, Montenegro

Гоце Стефанов / Goce Stefanov
Електротехнички факултет,
Универзитет „Гоце Делчев", Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Мирјана Периќ / Mirjana Peric
Електронски факултет
Универзитет во Ниш, Србија
Faculty of Electronic Engineerig,
University of Nis, Serbia

Ана Вучковиќ / Ana Vuckovic
Електронски факултет,
Универзитет во Ниш, Србија
Faculty of Electronic Engineerig,
University of Nis, Serbia

Тодор Чекеровски / Todor Cekerovski
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Далибор Серафимовски / Dalibor Serafimovski
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Мирослава Фаркаш Смиткова / Miroslava Farkas Smitková
Факултет за електротехника и информациони технологии
Словачки Технички Универзитет во Братислава, Словачка
Faculty of Electrical Engineering and Information Technology
Slovak Technical University in Bratislava, Slovakia

Петер Јанига / Peter Janiga
Факултет за електротехника и информациони технологии
Словачки Технички Универзитет во Братислава, Словачка
Faculty of Electrical Engineering and Information Technology
Slovak Technical University in Bratislava, Slovakia

Јана Радичова / Jana Raditschová
Факултет за електротехника и информациони технологии
Словачки Технички Универзитет во Братислава, Словачка
Faculty of Electrical Engineering and Information Technology
Slovak Technical University in Bratislava, Slovakia

Драган Миновски / Dragan Minovski
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Василија Шарац / Vasilija Sarac
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Александар Туџаров / Aleksandar Tudzarov
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Владимир Талевски / Vladimir Talevski
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Владо Гичев / Vlado Gicev
Факултет за информатика,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Computer Science,
Goce Delcev University, Stip, North Macedonia;

Марија Чекеровска / Marija Cekerovska
Машински факултет,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Mechanical Engineering,
Goce Delcev University, Stip, North Macedonia;

Мишко Џидров / Misko Dzidrov
Машински факултет,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Mechanical Engineering,
Goce Delcev University, Stip, North Macedonia;

Александар Крстев / Aleksandar Krstev
Факултет за информатика,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Computer Science,
Goce Delcev University, Stip, North Macedonia;

Ванчо Аџиски / Vancho Adziski
Факултет за природни и технички науки,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Natural and Technical Sciences,
Goce Delcev University, Stip, North Macedonia;

Томе Димовски / Tome Dimovski
Факултет за информатички и комуникациски технологии,
Универзитет „Св. Климент Охридски “, Северна Македонија;
Faculty of Information and Communication Technologies,
University St Climent Ohridski, North Macedonia;

Зоран Котевски / Zoran Kotevski
Факултет за информатички и комуникациски технологии,
Универзитет „Св. Климент Охридски “, Северна Македонија;
Faculty of Information and Communication Technologies,
University St Climent Ohridski, North Macedonia;

Никола Рендевски / Nikola Rendevski
Факултет за информатички и комуникациски технологии,
Универзитет „Св. Климент Охридски “, Северна Македонија;
Faculty of Information and Communication Technologies,
University St Climent Ohridski, North Macedonia;

Илија Христовски / Ilija Hristovski
Економски факултет,
Универзитет „Св. Климент Охридски “, Северна Македонија;
Faculty of Economy,
University St Climent Ohridski, North Macedonia;

Христина Спасовска / Hristina Spasovska
Факултет за електротехника и информациски технологии,
Универзитет „ Св. Кирил и Методиј “, Скопје, Северна Македонија;
Faculty of Electrical Engineering and Information Technologies,
Ss. Cyril and Methodius University, North Macedonia;

Роман Голубовски / Roman Golubovski
Природно-математички факултет,
Универзитет „ Св. Кирил и Методиј “, Скопје, Северна Македонија;
Faculty of Mathematics and Natural Sciences,
Ss. Cyril and Methodius University, North Macedonia;

Маре Србиновска / Mare Srbinovska
Факултет за електротехника и информациски технологии,
Универзитет „Св. Кирил и Методиј “, Скопје, Северна Македонија;
Faculty of Electrical Engineering and Information Technologies,
Ss. Cyril and Methodius University, North Macedonia;

Билјана Златановска / Biljana Zlatanovska
Факултет за информатика,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Computer Science,
Goce Delcev University, Stip, North Macedonia;

Александра Стојанова Илиевска / Aleksandra Stojanova Ilievska
Факултет за информатика,
Универзитет „Гоце Делчев “, Штип, Северна Македонија;
Faculty of Computer Science,
Goce Delcev University, Stip, North Macedonia;

Мирјана Коцалева Витанова / Mirjana Kocaleva Vitanova
Факултет за информатика,
Универзитет „Гоце Делчев“, Штип, Северна Македонија;
Faculty of Computer Science,
Goce Delcev University, Stip, North Macedonia;

Ивана Сандева / Ivana Sandeva
Факултет за електротехника и информациски технологии,
Универзитет „ Св. Кирил и Методиј “, Скопје, Северна Македонија;
Faculty of Electrical Engineering and Information Technologies,
Ss. Cyril and Methodius University, North Macedonia;

Билјана Читкушева Димитровска / Biljana Citkuseva Dimitrovska
Електротехнички факултет,
Универзитет „Гоце Делчев”, Штип, Северна Македонија
Faculty of Electrical Engineering,
Goce Delcev University, Stip, North Macedonia

Наташа Стојковиќ / Natasa Stojkovik
Факултет за информатика,
Универзитет „Гоце Делчев“, Штип, Северна Македонија;
Faculty of Computer Science,
Goce Delcev University, Stip, North Macedonia;

PREFACE

The Third International Conference "Electrical Engineering, Technology, Informatics, Mechanical Engineering and Automation – Technical Sciences in the Service of the Economy, Education and Industry" (ETIMA'25), organized by the Faculty of Electrical Engineering at the "Goce Delchev" University – Shtip, represents a significant scientific event that enables interdisciplinary exchange of knowledge and experience among researchers, professors, and experts in the field of technical sciences. The conference was held in an online format and brought together 78 authors from five different countries.

The ETIMA conference aims to establish a forum for scientific communication, encouraging multidisciplinary collaboration and promoting technological innovations with direct impact on modern life. Through the presentation of scientific papers, participants shared the results of their research and development activities, contributing to the advancement of knowledge and practice in relevant fields.
The first ETIMA conference was organized four years ago, featuring 40 scientific papers. The second conference took place in 2023 and included over 30 papers. ETIMA'25 continued this scientific tradition, presenting more than 40 papers that reflect the latest achievements in electrical engineering, technology, informatics, mechanical engineering, and automation.

At ETIMA'25, papers were presented that addressed current topics in technical sciences, with particular emphasis on their application in industry, education, and the economy. The conference facilitated fruitful discussions among participants, encouraging new ideas and initiatives for future research and projects.

ETIMA'25 reaffirmed its role as an important platform for scientific exchange and international cooperation. The organizing committee extends sincere gratitude to all participants for their contribution to the successful realization of the conference and its scientific value.

We extend our sincerest gratitude to all colleagues who, through the presentation of their papers, ideas, and active engagement in discussions, contributed to the success and scientific significance of ETIMA'25.

The Organizing Committee of the Conference

ПРЕДГОВОР

Третата меѓународна конференција „Електротехника, Технологија, Информатика, Машинство и Автоматика – технички науки во служба на економијата, образованието и индустријата" (ЕТИМА'25), организирана од Електротехничкиот факултет при Универзитетот „Гоце Делчев" – Штип, претставува значаен научен настан кој овозможува интердисциплинарна размена на знаења и искуства меѓу истражувачи, професори и експерти од техничките науки. Конференцијата се одржа во онлајн формат и обедини 78 автори од пет различни земји.

Конференцијата ЕТИМА има за цел да создаде форум за научна комуникација, поттикнувајќи мултидисциплинарна соработка и промовирајќи технолошки иновации со директно влијание врз современото живеење. Преку презентација на научни трудови, учесниците ги споделуваат резултатите од своите истражувања и развојни активности, придонесувајќи кон унапредување на знаењето и практиката во релевантните области.

Првата конференција ЕТИМА беше организирана пред четири години, при што беа презентирани 40 научни трудови. Втората конференција се одржа во 2023 година и вклучи над 30 трудови. ЕТИМА'25 продолжи со истата научна традиција, презентирајќи повеќе од 40 трудови кои ги отсликуваат најновите достигнувања во областа на електротехниката, технологијата, информатиката, машинството и автоматиката.

На ЕТИМА'25 беа презентирани трудови кои обработуваат актуелни теми од техничките науки, со посебен акцент на нивната примена во индустријата, образованието и економијата. Конференцијата овозможи плодна дискусија меѓу учесниците, поттикнувајќи нови идеи и иницијативи за идни истражувања и проекти.

ЕТИМА'25 ја потврди својата улога како значајна платформа за научна размена и интернационална соработка. Организациониот одбор упатува искрена благодарност до сите учесници за нивниот придонес кон успешната реализација на конференцијата и нејзината научна вредност. Конференцијата се одржа онлајн и обедини седумдесет и осум автори од пет различни земји.

Изразуваме голема благодарност до сите колеги кои со презентирање на своите трудови, идеи и активна вклученост во дискусиите придонесоа за успехот на ЕТИМА'25 и нејзината научна вредност.

Организационен одбор на конференцијата

СОДРЖИНА / TABLE OF CONTENTS:

Трета меѓународна конференција ЕТИМА
Third International Conference ETIMA
UDC: 004.771:[681.6:004.9-023.5]
https://www.doi.org/10.46763/ETIMA2531112j

IOT-BASED ENVIRONMENTAL CONTROL IN 3D PRINTER ENCLOSURES FOR OPTIMAL PRINTING CONDITIONS

Stefan Jakimovski [1], Goce Stefanov [1]
[1] Faculty of Electrical Engineering, Goce Delcev University, Stip, North Macedonia,
email: stefan.22578@student.ugd.edu.mk
email: goce.stefanov@ugd.edu.mk

Abstract

With 3D printing becoming a widespread manufacturing process, maintaining optimal environmental conditions is crucial for achieving high-quality 3D prints. This paper explores an IoT-based environmental control system for 3D printer enclosures, designed to regulate temperature and humidity in real time. This system incorporates sensors, microcontrollers, cloud-based databases and mobile applications in order to maintain the desired 3D printing environment.
The automation of the control of the 3D printing conditions ensures higher-quality prints, improved material consistency and durability, and reduced print failures. Additionally, remote monitoring and mobile alerts provide users with up-to-date knowledge about the current and past environmental parameters, control of settings and additional control and command features.
Experimental results will demonstrate the effectiveness of the climate control system, which in turn highlights the potential for both professional and hobbyist 3D printing applications.

Key words

IoT, ESP32, 3D Printing

Introduction

Over the last decades, additive manufacturing, such as 3D printing, has become a mainstream technology. Its ease of use and relatively low entry prices make it affordable for businesses, as well as technology enthusiasts and hobbyists [1]. Unlike the traditional subtractive manufacturing methods, 3D printing works by building different layers of the digital model, one layer at a time [2]. This provides flexibility and speed in the design and manufacturing process, as well as rapid prototyping and quick revisions. This technology is being widely adopted across various sectors, including aerospace, automotive, robotics, medicine, architecture and consumer goods [3].

3D printing is also a very economical and ecological method of manufacturing, because of its almost waste-free processes. The use of different types of materials like plastics, metals, ceramics, and biomaterials provides a wide range of possibilities. Furthermore, the use of recycled materials, for example, materials derived from recycled plastic bottles provides a secondary use for this polluting material [4]. Despite the many advantages, there are certain challenges when it comes to the use of the 3D printing processes. For 3D printing plastic materials, the quality of the printed parts depends on environmental conditions, machine tolerances, and material quality [5].

Globally, the use of 3D printing is becoming mainstream. 3D printing has revolutionized prototyping and low-volume production across industries [6]. Governments and educational institutions are promoting 3D printing for STEM education [7]. Military and defense use quickly produced 3D parts for rapid manufacturing and service [8]. With the use of 3D printing continuing to evolve, so does the demand for improved quality and speed [9].

1. Role of the environment parameters in the process of 3D printing

Environmental conditions are crucial in determining the quality, consistency, and success rate of 3D prints [10]. In the FDM (Fused Deposition Modeling) 3D printing process, different layers of extruded plastic are stacked to manufacture a desired model. This type of 3D printing is cheaper and more widespread, because of its simplicity and effectiveness [11]. In comparison to the enclosed and precisely controlled industrial 3D printing machines, many affordable consumer desktop 3D printers are exposed to ambient conditions, which can fluctuate significantly throughout the 3D printing process. These variations in the environmental parameters can affect the material and the process itself [12]. Key environmental parameters that play a crucial role in the 3D printing process are:

- Temperature
- Humidity
- Draft

Temperature is the most important environmental factor that influences the 3D printing process. The relationship between the temperature of the extruded material, and printing platform and ambient temperature needs to be carefully and continuously controlled to have high-quality 3D prints and high success rates [13] [14]. Improper temperature control can cause poor layer adhesion, warping, and cracks. Some 3D printing materials are more prone to warping due to temperature differences, such as ABS, ASA, and Nylon [15]. Humidity also plays a significant role in 3D printing, especially with the use of hygroscopic materials like PLA, PETG, and TPU. These types of 3D printing filaments absorb moisture from the air, which can lead to bubbling, oozing, and overall weak prints [16]. Drafts, convection, and uncontrolled airflow within the 3D printing area directly influence the 3D printing process by providing differential cooling of the 3D printed part [17]. This in turn can cause layer warping and delamination, especially with more temperature-sensitive materials like ABS, ASA, etc.

By carefully and actively controlling these environmental parameters, the quality of the 3D prints can be improved. This can be achieved by enclosing the 3D printer in an enclosure, within which these parameters can be measured and regulated [18] [19] [20] [21]. Combined with the IoT capabilities, such an enclosure can provide greater efficiency and ease of access [22]. By controlling the environmental parameters over an IoT network, faster workflow can be achieved, and groundwork is put in place for further automation, for example 3D printing farm comprised of many 3D printers working simultaneously, thus going a step further towards Industry 4.0 [23].

2. Design of the IoT-based 3D printing enclosure controller

To provide an enclosed environment within which the parameters will be monitored and regulated, an insulated housing is built for the 3D printer. The 3D printer that will be used in this study is the A1 model manufactured by the company Bambu Lab, whose technical characteristics are shown in Table 1. The Bambu Lab A1 with its built-in IoT capabilities, such as device login, device information synchronization, firmware/software updates, user device binding, remote printing, slicing parameter management, cloud slicing, failure detection, and other functions [24], should integrate seamlessly with an IoT-controlled enclosure for synchronized environmental management and remote monitoring.

Table 1 Bambu Lab A1 3D printer technical characteristics

Build Volume:	**256 x 256 x 256 mm³**
Chassis:	Steel + Extruded Aluminum
Hot End:	All-Metal
Nozzle:	Stainless Steel
Max Hot End Temperature:	300 ℃
Nozzle Diameter (Optional):	0.2 mm, 0.4mm, 0.6 mm, 0.8 mm
Filament Diameter:	1.75 mm
Max Build Plate Temperature:	100 ℃
Max Speed of Toolhead:	500 mm/s
Max Acceleration of Toolhead:	10000 mm/s²
Max Hot End Flow:	28 mm³/s @ABS
Part Cooling Fan:	Closed Loop Control
Hot End Fan:	Closed Loop Control
Recommended Filaments	PLA, PETG, TPU, PVA
Not Recommended Filaments	ABS, ASA, PC, PA, PET, Carbon/Glass Fiber Reinforced Polymer
Monitoring Camera:	Low-Rate Camera (up to1080P) Timelapse Supported
Dimensions:	465 x 410 x 430 mm³
Net Weight:	8.3 kg
Input Voltage:	100-240 VAC, 50/60 Hz
Max Power:	1300W@220V， 350W@110V
Display:	3.5 inches 320*240 IPS Touch Screen
Connectivity:	Wi-Fi, Bambu-Bus
Storage:	Micro SD Card
Control Interface:	Touch Screen, APP, PC Application
Motion Controller:	Dual-Core Cortex M4

Source: Bambu Lab

The 3D printer enclosure, shown in Figure 2, is constructed from 16mm MDF (Medium Density Fiberboard) sheets, which provide good structural strength and thermal insulation [25]. The access door is made from 8mm PMMA (Poly (methyl methacrylate)) sheet. The enclosure's 520x640x600 mm inside dimensions provide a suitable clearance around the moving parts of the 3D printer.

The microcontroller chosen for the control of environmental parameters is the ESP32. With its 240 MHz processor speed, 34 GPIO pins, as well as built-in Wi-Fi and Bluetooth capabilities, it's a good choice for the IoT-based 3D printing enclosure controller [26].

Fig. 1 The Bambu Lab A1 3D printer
Source: Bambu Lab

Fig. 2 Enclosure for the 3D printer
Source: Author

For the measurement of the environmental parameters, the DHT22 temperature and humidity sensor is chosen. The DHT22 sensor module has a measurable temperature range of -40 to +80°C with ±0.5 °C accuracy and a humidity range of 0 to 100%RH, with an accuracy of 2%RH, which provides a reasonably accurate representation of the desired parameters [27]. For displaying the real-time data measured by the sensor, the IPS 240x240 TFT LCD display module is used. With its 240 by 240-pixel size, it allows the measured data to be displayed, as well as other status and debugging information. The picture shown on the screen of the IPS 240x240 TFT LCD display module is shown in Figure 5. For the heating of the environment, a 360W 220V AC resistive plate heater with a 10A relay module is used. For cooling and ventilation, a 120x120x25mm 12V/0.28A DC fan is used. Separately, for the cooling and ventilation of the 3D printer's processor and control boards, a pair of 40x40x10mm 12V/0.11A DC fans are used. The power for the electronic components is provided by a 12V/5A DC SMPS power supply, as well as a 12V to 5V DC to DC Buck converter. For better visibility inside the enclosure, a string of 12V LED lights is also used. The electronic components are connected as per the circuit diagram shown in Figure 3.

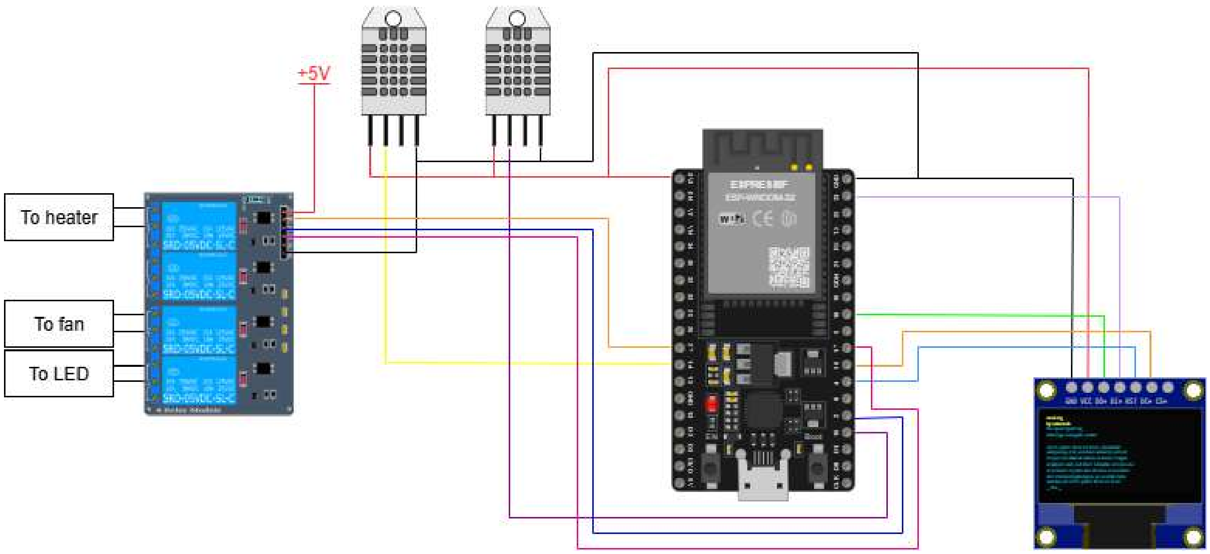

Fig. 3 Circuit diagram of the IoT-based 3D printing enclosure controller
Source: Author

As we can see from the circuit diagram, the DHT22 sensors are connected to the ESP32 microcontroller to pins 14 and 15. The LCD display is connected to pins 18, 23, 4, and 16, which provide SPI (Serial Peripheral Interface) communication, as well as reset signal and backlight power. Pin 16 is used for controlling the heating relay, and pin 17 is used for controlling the cooling and ventilation fan. Pin 2 controls the LED lighting in the enclosure.

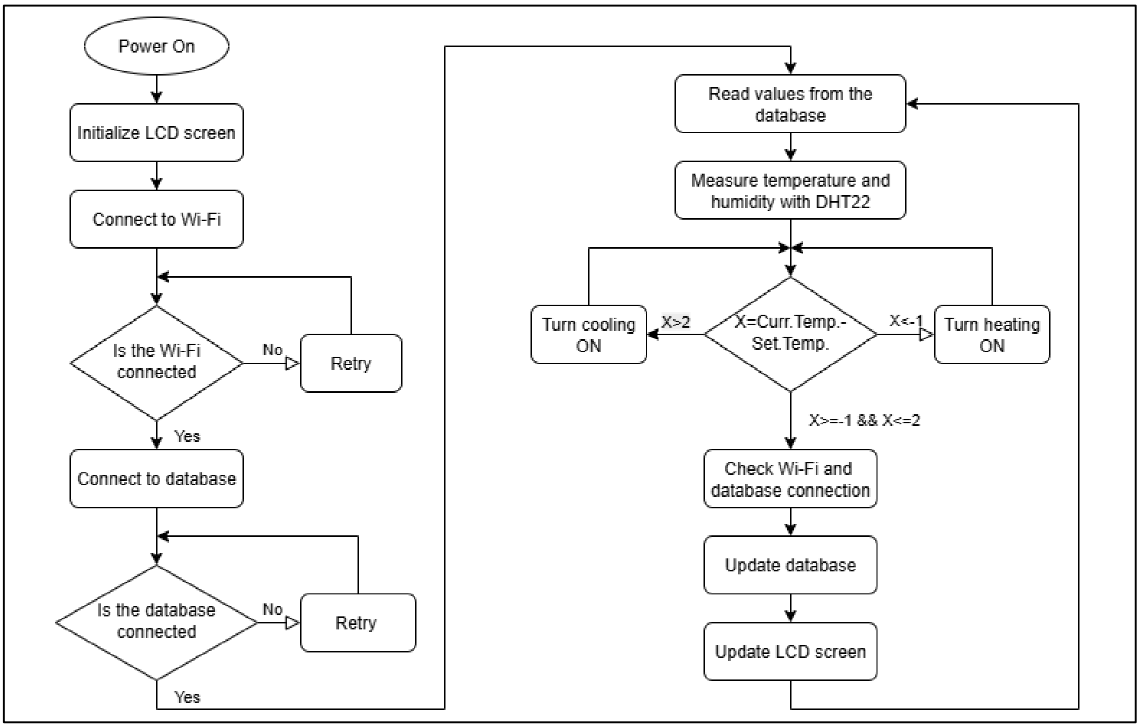

Fig. 4 Control algorithm for the IoT-based 3D printing enclosure controller
Source: Author

The algorithm that controls the ESP32 is shown in Figure 4. It consists of the initialization of global variables and functions, after which the LCD screen with its corresponding function library is initialized. The LCD screen is used going forward to ease the process of connecting to the Wi-Fi and Firebase real-time database system. If proper connections are established, then the main function of the controller is initiated. The controller reads the temperature and humidity from the DHT22 sensors and compares them to the pre-set value for the enclosure's ambient temperature. If the enclosure temperature is lower than the set value by more than 2°C, then the heater is turned on until the set temperature is met. For safety reasons, if the control of the heater overshoots the set temperature by 2°C, then the cooling and ventilation fan is activated in order to lower the temperature to the set point. After the proper control of the heater/fan is completed, the connection to the Wi-Fi network and database is checked, and if it passes the check, then the database is updated with the current temperature and humidity of the enclosure. After the database update, the LCD screen is updated to show the current values. The screen update period is 1s, whereas the database update period is 5s, so as for not to overload the database with unnecessary minute changes in the values.

The key aspect of the IoT-based 3D printing enclosure controller is the ability to monitor and control the environmental parameters remotely, by using a mobile application. This application is able to show the current temperature and humidity inside the enclosure, the minimum and maximum temperature and humidity values for a selected period and the temperature of the 3D printer's CPU. Furthermore, this application provides an indication of whether the heating or cooling is on, and the user can input the set temperature of the enclosure. These values are updated from and to the database, which allows remote control of the temperature in the enclosure. Remote control of the LED lighting is also possible. The GUI (Graphical User Interface) for the 3D printing enclosure controller mobile application is shown in Figure 6.

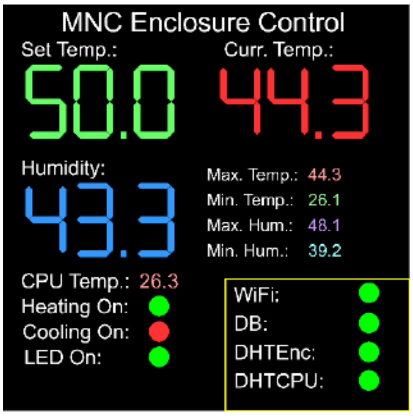

Fig. 5 Data shown on the IPS 240x240 TFT LCD display module
Source: Author

Fig. 6 GUI of the mobile application
Source: Author

3. Results and discussion

Once everything is assembled, the IoT-based 3D printing enclosure controller can be tested in operation, to verify that it can effectively monitor and regulate the environmental parameters of the enclosure. The test consists of three separate testing phases:

1. Baseline test
2. Temperature regulation test
3. Full operation test

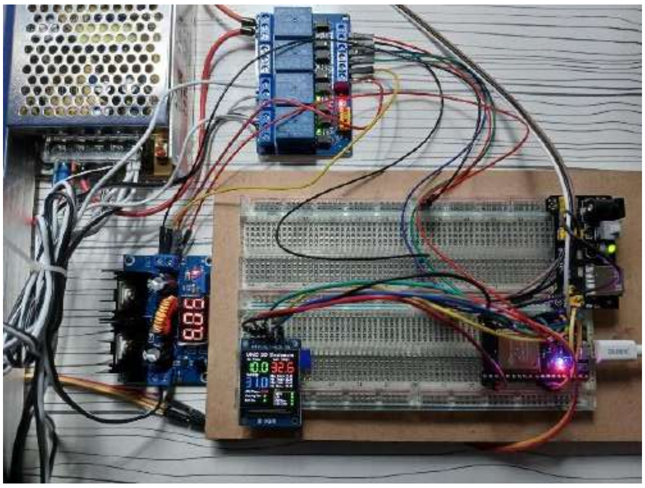

Fig. 7 Testing setup for the IoT-based 3D printing enclosure controller
Source: Author

The first test is a baseline test, conducted to ensure proper operation of the sensors and the microcontroller. This test is conducted with a relatively stable room temperature, and all the measured values are monitored and compared to a control thermometer and hygrometer. The collected results of the baseline test are given in Table 2.

Table 2 Baseline test results

	Time	Measurements with DHT22 sensors				Control measurements				
	HH:MM	Temp. Enc.	Hum. Enc.	Temp. CPU	Hum. CPU	Temp. Enc.	Hum. Enc.	Temp. CPU	Hum. CPU	Room Temp.
1	00:00	27.1	40.8	27.2	41.3	27.4	41.1	27.4	41.1	27.1
2	00:10	27.1	40.9	27.0	41.0	27.3	41.2	27.3	41.1	27.1
3	00:20	27.2	40.9	27.1	41.2	27.3	41.1	27.3	41.2	27.1
4	00:30	27.1	40.8	27.1	41.1	27.3	41.1	27.3	41.2	27.1
5	00:40	27.2	40.7	27.2	41.2	27.3	41.1	27.3	41.2	27.1
6	00:50	27.0	40.6	27.1	41.2	27.3	41.1	27.3	41.2	27.1
7	01:00	27.1	40.8	27.0	41.1	27.3	41.1	27.3	41.2	27.1
8	01:10	27.2	40.9	27.1	41.0	27.3	41.1	27.3	41.2	27.1
9	01:20	27.1	40.9	27.1	41.1	27.3	41.1	27.3	41.2	27.2
10	01:30	27.0	40.8	27.2	41.2	27.3	41.2	27.3	41.2	27.2

Source: Author

The second test is the temperature regulation test, where a desired temperature of 40°C is set using the mobile application, and the work of the controller is monitored. During this test, the 3D printer was not in operation, but the CPU cooling fans were turned on. The results of the temperature regulation test are given in Appendix A. The graphical representation of the results from the second test is shown in Figure 8. As can be observed, the enclosure temperature is regulated by the controller, and it follows the set temperature of 40°C, within the predefined regulation range of 2°C.

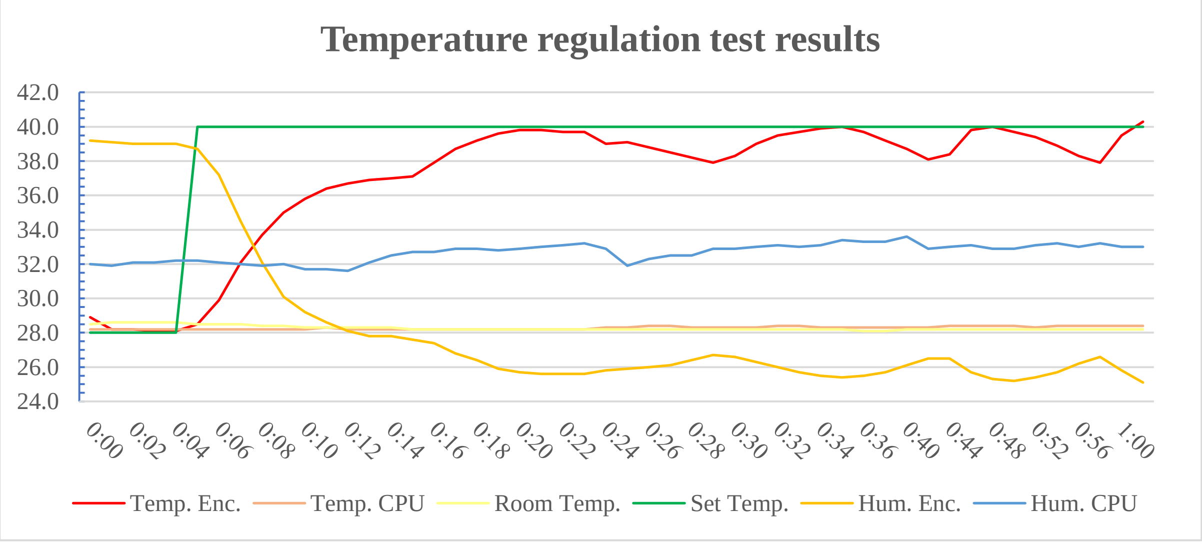

Fig. 8 Graphical representation of temperature regulation test results
Source: Author

The last test is the full operation test. In this test, the 3D printer is turned on and a control test piece is being printed, whilst the enclosure controller regulates the temperature set from the mobile application. The results of the full operation test are given in Appendix B. The graphical representation of the results from the last test is shown in Figure 9. As can be observed, the enclosure temperature is regulated by the controller, and it follows the set temperature of 40°C, within the predefined regulation range of 2°C.

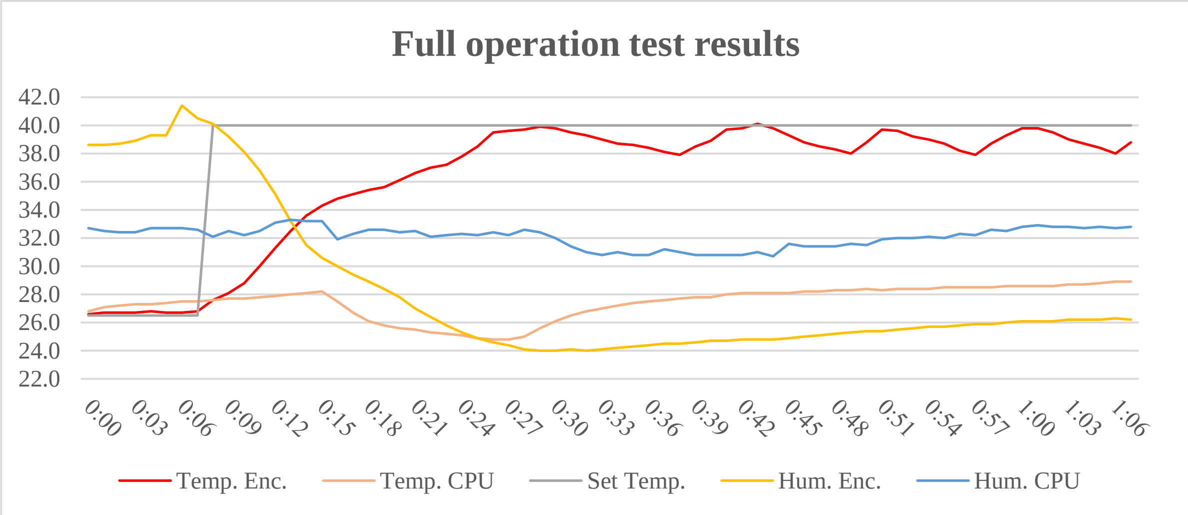

Fig. 9 Graphical representation of the full operation test results
Source: Author

4. Conclusion and Future Work

As we can see from the results of the first test, the IoT-based 3D printing enclosure controller does measure temperature and humidity with relatively good accuracy and differentiates from the control thermometer and hygrometer measurements within the accuracy range of the sensor itself.

In the temperature regulation test, we can observe that the IoT-based 3D printing enclosure controller manages to increase the ambient temperature and provide further regulation of the temperature. However, oscillations in the temperature can be observed. This could be the result of the use of natural convection and the bang-bang type of regulation of the temperature. As the results show, a drop in humidity is indicated as the temperature rises, which is helpful in the 3D printing process, especially in printing hygroscopic materials. The results show stability of the CPU's temperature and humidity, which is also a positive result, because these open types of 3D printers are not designed to handle higher ambient temperatures.

The third test, i.e. the full operation test confirms the results of the second test. The IoT-based 3D printing enclosure controller can regulate the ambient temperature with the added heating of the 3D printer in the enclosure.

In the future, a PID temperature regulation is recommended, which will help lower the oscillations of the ambient temperature, as well as a PTC heater with forced convection heating. A more powerful heater could be helpful in achieving the set temperature faster, and allow higher thermal capacity in the whole system. Furthermore, the implementation of a touch screen is necessary to provide the ability to change the set temperature locally without using the mobile application, as well as changing the Wi-Fi network credentials, which for this research were written in the source code. In addition, better insulation of the enclosure is also recommended, which will help mitigate thermal loss due to the thermal conductivity of the build materials and will provide additional sound and vibration insulation. In the human interaction with the IoT system aspect, push notifications from the mobile application would be practical, as it would allow the user to be notified of wanted and unwanted behavior of the system, such as an overheating event, or a malfunction of a component.

References

[1] S. Doloi *et al.*, “Democratizing self-driving labs: advances in low-cost 3D printing for laboratory automation,” *Digit. Discov.*, vol. 4, no. 7, pp. 1685–1721, 2025, doi: 10.1039/D4DD00411F.

[2] S. Saefudin *et al.*, “A Review of Factors Affecting the Mechanical Performance of PLA in FDM 3D Printing,” *Adv. Sustain. Sci. Eng. Technol.*, vol. 7, p. 0250208, Apr. 2025, doi: 10.26877/chs1gc62.

[3] W. Yu, M. Li, W. Lei, and Y. Chen, “FDM 3D Printing and Properties of PBAT/PLA Blends,” *Polymers*, vol. 16, no. 8, 2024, doi: 10.3390/polym16081140.

[4] C. Maraveas, I. V. Kyrtopoulos, and K. G. Arvanitis, “Evaluation of the Viability of 3D Printing in Recycling Polymers,” *Polymers*, vol. 16, no. 8, 2024, doi: 10.3390/polym16081104.

[5] K. Gunaydin and H. Türkmen, *Common FDM 3D Printing Defects*. 2018.

[6] I. Gibson, D. Rosen, and B. Stucker, *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*. New York, NY: Springer, 2015. doi: 10.1007/978-1-4939-2113-3.

[7] I. Usembayeva, B. Kurbanbekov, S. Ramankulov, A. Batyrbekova, K. Kelesbayev, and A. Akhanova, “3D Modeling and Printing in Physics Education: The Importance of STEM Technology for Interpreting Physics Concepts,” *Qubahan Acad. J.*, vol. 4, no. 3, pp. 45–58, Aug. 2024, doi: 10.48161/qaj.v4n3a727.

[8] M. Marciniak, “The 3D Printing in Military Applications: FDM Technology, Materials, and Implications,” *Adv. Mil. Technol.*, vol. 18, no. 2, pp. 241–257, 28 2023, doi: 10.3849/aimt.01846.

[9] D. Ramadhan, F. Sodiq, H. Saputra, and M. Putra, “Dimensional Consistency Analysis in High Speed 3D Printing,” *Turbo J. Program Studi Tek. Mesin*, vol. 14, Jul. 2025, doi: 10.24127/trb.v14i1.3795.

[10] Y. Wei and H. Zhang, “Influence of Temperature and Humidity on Mechanical Properties of Calcined Oyster-Shell Powder-Modified 3D-Printed Concrete,” *ACS Omega*, vol. 9, no. 37, pp. 39180–39187, Sep. 2024, doi: 10.1021/acsomega.4c06129.

[11] A. Kafle, E. Luis, R. Silwal, H. M. Pan, P. L. Shrestha, and A. K. Bastola, “3D/4D Printing of Polymers: Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), and Stereolithography (SLA),” *Polymers*, vol. 13, no. 18, 2021, doi: 10.3390/polym13183101.

[12] F. Livolsli, T. May, D. Caputo, K. Fouladi, and B. Eslami, “Multiscale Study on Effect of Humidity on Shape Memory Polymers Used in 3D Printing,” *J. Manuf. Sci. Eng.*, vol. 143, pp. 1–25, Mar. 2021, doi: 10.1115/1.4050550.

[13] D. Krapež, M. Jusufagić, M. Obućina, M. Kuzman, and M. Kariz, “Effect of Filament Material and Printing Temperature on 3D Printing Extrusion Force,” *Appl. Sci.*, vol. 15, p. 2046, Feb. 2025, doi: 10.3390/app15042046.

[14] F. Al-Shalawi, A. Ariff, M. Ariffin, C. Kim, and D. Brabazon, “INFLUENCE OF NOZZLE TEMPERATURE, BED TEMPERATURE, AND PRINTING SPEED ON THE TENSILE STRENGTH OF 3D-PRINTED PLA SPECIMENS,” *ASEAN Eng. J.*, vol. 15, pp. 85–90, May 2025, doi: 10.11113/aej.v15.22190.

[15] Y. L. A. Alshammari, F. He, and M. A. Khan, “Modelling and Investigation of Crack Growth for 3D-Printed Acrylonitrile Butadiene Styrene (ABS) with Various Printing Parameters and Ambient Temperatures,” *Polymers*, vol. 13, no. 21, 2021, doi: 10.3390/polym13213737.

[16] İ. Özsoykal, A. Yurt, and M. A. Selver, “Investigating the Temporal Stability of 3D-Printed PLA Samples under Ambient Storage Conditions: CT Attenuation Stability in 3D Printed Materials,” *Adv. Med. Pyhsics Appl. Sci.*, vol. 1, no. 2, pp. 45–52, May 2025, doi: 10.63187/ampas.31.

[17] N. Ramos, C. Mittermeier, and J. Kiendl, “Experimental and numerical investigations on heat transfer in fused filament fabrication 3D-printed specimens,” *Int. J. Adv. Manuf. Technol.*, vol. 118, no. 5, pp. 1367–1381, Jan. 2022, doi: 10.1007/s00170-021-07760-6.

[18] A. Saleh, A. Shbeeb, and M. Sattar, “Layer adhesion investigation of three dimension printed parts by controlling the environment temperature,” *Adv. Sci. Technol. – Res. J.*, vol. 19, pp. 74–83, Jan. 2025, doi: 10.12913/22998624/197333.

[19] T. May, B. Eslami, and K. Fouladi, *Optimization of 3d-Printer Enclosure Environment*. 2021. doi: 10.21203/rs.3.rs-555977/v1.

[20] S. Thumsorn, W. Prasong, A. Ishigami, T. Kurose, Y. Kobayashi, and H. Ito, “Influence of Ambient Temperature and Crystalline Structure on Fracture Toughness and Production of Thermoplastic by Enclosure FDM 3D Printer,” *J. Manuf. Mater. Process.*, vol. 7, no. 1, 2023, doi: 10.3390/jmmp7010044.

[21]R. Wibowo, A. Fauzi, and S. a, "ANALYSIS OF FAN COOLING SPEED, PRINTING SPEED AND LAYER HEIGHT ON PRODUCT GEOMETRY ACCURACY IN 3D PRINTING," *Int. J. Adv. Res.*, vol. 11, pp. 943–951, Sep. 2023, doi: 10.21474/IJAR01/17606.
[22]R. Grande, A. Vallejo-Peña, and C. Urzí Brancati, "The impact of IoT and 3D printing on job quality and work organisation: a snapshot from Spain," Seville: European Commission, JRC125612, 2021.
[23]Y. Xie, W. Liu, Q. Yang, X. Sun, and Y. Zhang, "SharkNet Networks Applications in Smart Manufacturing Using IoT and Machine Learning," *Processes*, vol. 13, no. 1, 2025, doi: 10.3390/pr13010282.
[24]"Bambu Lab Security," Bambu Lab Wiki. Accessed: Jul. 14, 2025. [Online]. Available: https://wiki.bambulab.com/en/general/bbl-security
[25]B. Moezzipour and A. Moezzipour, "Thermal Behavior of Insulation Fiberboards Made from MDF and Paper WastesToplinska svojstva izolacijskih vlaknatica izrađenih od otpadnog MDF-a i papira," *Drv. Ind.*, vol. 72, pp. 245–254, Jul. 2021, doi: 10.5552/drvind.2021.2019.
[26]A. Zulfiqar, *Hands-on ESP32 with Arduino IDE: Unleash the power of IoT with ESP32 and build exciting projects with this practical guide*. 2024.
[27]A. Siswoyo, "Optimization of Temperature Sensor Selection for Incubators: Real-Time Accuracy Analysis of DHT22, LM35, and DS18B20 in Controlled Environment Simulations," *Internet Things Artif. Intell. J.*, vol. 5, Mar. 2025, doi: 10.31763/iota.v5i1.877.

Appendix A

Table 3 Temperature regulation test results

	Time	**Measurements with DHT22 sensors**						**Time**	**Measurements with DHT22 sensors**				
№	HH:MM	Temp. Enc.	Hum. Enc.	Temp. CPU	Hum. CPU	Room Temp.	**№**	HH:MM	Temp. Enc.	Hum. Enc.	Temp. CPU	Hum. CPU	Room Temp.
1	00:00	28.9	39.2	28.2	32.0	28.5	**26**	00:25	39.1	25.9	28.3	31.9	28.2
2	00:01	28.2	39.1	28.2	31.9	28.6	**27**	00:26	38.8	26.0	28.4	32.3	28.2
3	00:02	28.2	39.0	28.2	32.1	28.6	**28**	00:27	38.5	26.1	28.4	32.5	28.2
4	00:03	28.1	39.0	28.2	32.1	28.6	**29**	00:28	38.2	26.4	28.3	32.5	28.2
5	00:04	28.1	39.0	28.2	32.2	28.6	**30**	00:29	37.9	26.7	28.3	32.9	28.2
6	00:05	28.5	38.7	28.2	32.2	28.5	**31**	00:30	38.3	26.6	28.3	32.9	28.2
7	00:06	29.9	37.2	28.2	32.1	28.5	**32**	00:31	39.0	26.3	28.3	33.0	28.2
8	00:07	32.1	34.5	28.2	32.0	28.5	**33**	00:32	39.5	26.0	28.4	33.1	28.2
9	00:08	33.7	32.1	28.2	31.9	28.4	**34**	00:33	39.7	25.7	28.4	33.0	28.2
10	00:09	35.0	30.1	28.2	32.0	28.4	**35**	00:34	39.9	25.5	28.3	33.1	28.2
11	00:10	35.8	29.2	28.2	31.7	28.3	**36**	00:35	40.0	25.4	28.3	33.4	28.2
12	00:11	36.4	28.6	28.3	31.7	28.3	**37**	00:36	39.7	25.5	28.3	33.3	28.1
13	00:12	36.7	28.1	28.2	31.6	28.3	**38**	00:38	39.2	25.7	28.3	33.3	28.1
14	00:13	36.9	27.8	28.2	32.1	28.3	**39**	00:40	38.7	26.1	28.3	33.6	28.2
15	00:14	37.0	27.8	28.2	32.5	28.3	**40**	00:42	38.1	26.5	28.3	32.9	28.2
16	00:15	37.1	27.6	28.2	32.7	28.2	**41**	00:44	38.4	26.5	28.4	33.0	28.2
17	00:16	37.9	27.4	28.2	32.7	28.2	**42**	00:46	39.8	25.7	28.4	33.1	28.2
18	00:17	38.7	26.8	28.2	32.9	28.2	**43**	00:48	40.0	25.3	28.4	32.9	28.2
19	00:18	39.2	26.4	28.2	32.9	28.2	**44**	00:50	39.7	25.2	28.4	32.9	28.2
20	00:19	39.6	25.9	28.2	32.8	28.2	**45**	00:52	39.4	25.4	28.3	33.1	28.2
21	00:20	39.8	25.7	28.2	32.9	28.2	**46**	00:54	38.9	25.7	28.4	33.2	28.2
22	00:21	39.8	25.6	28.2	33.0	28.2	**47**	00:56	38.3	26.2	28.4	33.0	28.2
23	00:22	39.7	25.6	28.2	33.1	28.2	**48**	00:58	37.9	26.6	28.4	33.2	28.2
24	00:23	39.7	25.6	28.2	33.2	28.2	**49**	01:00	39.5	25.8	28.4	33.0	28.2
25	00:24	39.0	25.8	28.3	32.9	28.2	**50**	01:02	40.3	25.1	28.4	33.0	28.2

Source: Author

Appendix B

Table 4 Full operation test results

	Time	Measurements with DHT22 sensors					Time	Measurements with DHT22 sensors			
№	HH:MM	Temp. Enc.	Hum. Enc.	Temp. CPU	Hum. CPU	**№**	HH:MM	Temp. Enc.	Hum. Enc.	Temp. CPU	Hum. CPU
1	00:00	26,6	38,6	26,8	32,7	**35**	00:34	38,7	24,2	27,2	31,0
2	00:01	26,7	38,6	27,1	32,5	**36**	00:35	38,6	24,3	27,4	30,8
3	00:02	26,7	38,7	27,2	32,4	**37**	00:36	38,4	24,4	27,5	30,8
4	00:03	26,7	38,9	27,3	32,4	**38**	00:37	38,1	24,5	27,6	31,2
5	00:04	26,8	39,3	27,3	32,7	**39**	00:38	37,9	24,5	27,7	31,0
6	00:05	26,7	39,3	27,4	32,7	**40**	00:39	38,5	24,6	27,8	30,8
7	00:06	26,7	41,4	27,5	32,7	**41**	00:40	38,9	24,7	27,8	30,8
8	00:07	26,8	40,5	27,5	32,6	**42**	00:41	39,7	24,7	28,0	30,8
9	00:08	27,6	40,1	27,6	32,1	**43**	00:42	39,8	24,8	28,1	30,8
10	00:09	28,1	39,2	27,7	32,5	**44**	00:43	40,1	24,8	28,1	31,0
11	00:10	28,8	38,1	27,7	32,2	**45**	00:44	39,8	24,8	28,1	30,7
12	00:11	30,0	36,8	27,8	32,5	**46**	00:45	39,3	24,9	28,1	31,6
13	00:12	31,3	35,1	27,9	33,1	**47**	00:46	38,8	25,0	28,2	31,4
14	00:13	32,5	33,2	28,0	33,3	**48**	00:47	38,5	25,1	28,2	31,4
15	00:14	33,6	31,5	28,1	33,2	**49**	00:48	38,3	25,2	28,3	31,4
16	00:15	34,3	30,6	28,2	33,2	**50**	00:49	38,0	25,3	28,3	31,6
17	00:16	34,8	30,0	27,5	31,9	**51**	00:50	38,8	25,4	28,4	31,5
18	00:17	35,1	29,4	26,7	32,3	**52**	00:51	39,7	25,4	28,3	31,9
19	00:18	35,4	28,9	26,1	32,6	**53**	00:52	39,6	25,5	28,4	32,0
20	00:19	35,6	28,4	25,8	32,6	**54**	00:53	39,2	25,6	28,4	32,0
21	00:20	36,1	27,8	25,6	32,4	**55**	00:54	39,0	25,7	28,4	32,1
22	00:21	36,6	27,0	25,5	32,5	**56**	00:55	38,7	25,7	28,5	32,0
23	00:22	37,0	26,4	25,3	32,1	**57**	00:56	38,2	25,8	28,5	32,3
24	00:23	37,2	25,8	25,2	32,2	**58**	00:57	37,9	25,9	28,5	32,2
25	00:24	37,8	25,3	25,1	32,3	**59**	00:58	38,7	25,9	28,5	32,6
26	00:25	38,5	24,9	24,9	32,2	**60**	00:59	39,3	26,0	28,6	32,5
27	00:26	39,5	24,6	24,8	32,4	**61**	01:00	39,8	26,1	28,6	32,8
28	00:27	39,6	24,4	24,8	32,2	**62**	01:01	39,8	26,1	28,6	32,9
29	00:28	39,7	24,1	25,0	32,6	**63**	01:02	39,5	26,1	28,6	32,8
30	00:29	39,9	24,0	25,6	32,4	**64**	01:03	39,0	26,2	28,7	32,8
31	00:30	39,8	24,0	26,1	32,0	**65**	01:04	38,7	26,2	28,7	32,7
32	00:31	39,5	24,1	26,5	31,4	**66**	01:05	38,4	26,2	28,8	32,8
33	00:32	39,3	24,0	26,8	31,0	**67**	01:06	38,0	26,3	28,9	32,7
34	00:33	39,0	24,1	27,0	30,8	**68**	01:07	38,8	26,2	28,9	32,8

Source: Author