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Development of an Electrical circuit with Arduino implementation to automate a *Peltier* Thermoelectric cooling system

Anderson Jose Luiz Santana[1], Jonas Costa Dos Santos[2] and Ricardo Carrasco Carpio [3]

Federal Institute of Education

Science and Technology of Minas Gerais

Arcos Advanced *Campus*

Arcos, Minas Gerais

Brazil

ABSTRACT

The emergence of refrigerators marked a significant technological evolution by extending the preservation of perishable goods, a pursuit that dates back to times prior to the 20th century. Driven by technological advancements, this area of notable impact on human progress strives to create automated devices to integrate daily activities, satisfying fundamental needs. In this context, the present work aims at a comprehensive understanding of automated systems and the application of concepts such as electricity, heat transfer, and Peltier cooling technology. The core of this project lies in the development of a deep understanding of automated systems, with an emphasis on constructing an automated cooling system. This system utilizes an Arduino board as a central component, playing the pivotal role of regulating and controlling the cooling process. The ability for timely shutdown, as determined by the user, constitutes a key element, minimizing component wear and, consequently, extending the system's lifespan. The project's execution required analytical calculations to underpin prototype development. The Arduino board, in conjunction with Peltier cooling technology, resulted in an automated cooling system, providing proper preservation of temperature-sensitive products. In summary, the research illustrates the trajectory of refrigeration systems' evolution from their invention to the current era, where automation and technological integration are predominant factors. The study underscores the importance of understanding automated systems, electricity, and cooling technologies, demonstrating their practical application in constructing a functional prototype aligned with contemporary needs for preservation and energy efficiency.

Key Words: Automated Systems, Peltier Effect, Prototype, Programming. Refrigeration.

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1. INTRODUCTION

The pursuit of optimizing and swiftly accomplishing tasks through automation has gained increasing prominence in contemporary society. The ethnicization of activities aimed at saving effort in task execution has become widespread, with the automation of systems gaining notoriety in the 20th century driven by the need to increase production while saving time. This evolution gave rise to computers and programmable controllers capable of processing vast amounts of data in fractions of seconds. The modernization of the production process, in line with computerized technologies, marked this transformation.

In this context, the current work focuses on the automation of a thermoelectric cooling system, utilizing an Arduino board to control both the Peltier-based cooling system and the associated cooling system. The automation of this project aims to provide convenience and comfort to the refrigerator user, with the Arduino Uno R3 board being the central tool for such automation. This board incorporates a microcontroller designed for automated electronic projects, facilitating the prototyping and implementation of interactive systems.

Arduino enables bidirectional communication with connected electronic systems, playing a fundamental role in controlling and monitoring the refrigeration system at hand. This approach aims to meet contemporary demands for efficiency and practicality, reflecting the increasing integration of automation and technology in people's daily lives. Progress in the field of automation, through the use of microprocessors and sensors, represents a development aimed at making everyday activities, such as food refrigeration, more autonomous and convenient for users. In the current scenario, technology is increasingly integrated into people's lives, seeking ways to facilitate interaction between humans and machines.

Microcontrollers, like Arduino, and temperature sensors are fundamental components for automation, as mentioned by Stevan and Silva (2015), Arduino aims to facilitate the connection between the physical world and the digital world around it. Therefore, automating a refrigerator is necessary to meet the contemporary demand for convenience, allowing product users greater versatility. This offers a range of features that make day-to-day operation simpler [1].

The overall objective of this project is to develop an electrical system controlled by an Arduino to monitor the temperature of a portable refrigerator. Specific objectives include understanding the operation of electrical circuits, studying key concepts of Arduino operation, and creating a 3D model of the portable refrigerator. By achieving these objectives, the intention is to create a product that is efficient, practical, and meets the needs of modern users, contributing to the seamless intersection between technology and everyday life.

2. LITERATURE REVIEW

The movement of electrons in electrical circuits results from the voltage difference between two points, where electric current indicates the intensity of the electron flow. To deeply understand the functioning of electrical circuits, it's essential to master the underlying principles, as highlighted by Miller and Miller [2]. Voltage is the electrical "pressure" that directs electrons through a resistance, represented as potential difference or electromotive force (EMF), measured in Volts (V). Electric current, measured in Amperes (A), reflects the flow of electrons in a conductor, with electric charge measured in Coulombs, equivalent to $6{,}28 \times 10^{18}$ electrons.

Resistance, expressed in Ohms (Ω), is a material conductor's ability to oppose current flow. When subjected to an electrical potential difference, a conductor experiences electric current, a result of the agitated movement of free electrons. These electrons collide with atoms of the conductor, resulting in electrical resistance. The difficulty in the movement of charges is electrical resistance, which increases with more collisions. Resistors, typically made of high-resistance dielectric materials, limit the flow of charges, converting electrical energy into heat through the Joule effect.

Ohm's Laws, developed by physicist George Simon Ohm, play a crucial role in understanding electrical circuits. The First Law establishes that the potential difference across a resistor is directly proportional to the electric current flowing through it. This relationship between voltage, current, and resistance is expressed mathematically. Ohm's Second Law describes that a conductor material's electrical resistance is influenced by its length, area, and resistivity. This means that resistance is determined by specific material characteristics [3].

Electrical circuits can be arranged in series, adding voltages, or in parallel, adding currents. The determination of voltage, current, and resistance can be applied using Ohm's Laws. Current passing through a conductor with resistance generates heating (Joule effect), converting electrical energy into thermal energy. This is represented as dissipated power, measured in watts.

According to Markus et al. (2018), electronic sources, which convert alternating current to direct current, are often used in electrical circuits, replacing batteries and cells. However, as stated by Alexander et al. (2013), incorrect connections can lead to short circuits, resulting in excessive current and potential damage. Hence, protection circuits are implemented to prevent such failures [4].

Automation, as per Groover (2014), encompasses a range of technologies that minimize human intervention in processes through predetermined criteria, optimizing efficiency. This approach is applied across various sectors, offering labor and cost savings, and improving product quality. Sensors are employed to detect stimuli, converting information into understandable signals for other devices [5].

Devices like relays also play a crucial role, allowing the opening and closing of electrical circuits, controlling current flow. Relay activity is triggered by a lower current than the main circuit, providing safety to the system. Additionally, according to McRoberts (2018), the Arduino platform, developed in 2005, aims to create low-cost devices and simplifies electronic component control through C++ programming [6].

Protoboard platforms are used to fix and interconnect components. These boards have holes and lines for component connections, being an essential tool in electronic circuit construction.

In summary, the study of electrical circuits and automation covers fundamental principles, operational laws, key components like resistors and relays, as well as the application of technologies like the Arduino platform. This knowledge is crucial for the development and control of complex and automated electrical systems.

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3. METHODOLOGY

In this stage, the focus will be on the development of an electrical circuit with Arduino integration to automate a Peltier-based cooling system. The proposal aims to optimize the cooling process by controlling the *Peltier* modules, coordinated by the Arduino. The methodology encompassed research, programming, design, testing, and evaluation. The automated approach demonstrated promising results in temperature control, indicating the feasibility of this solution for practical applications. Technical characteristics were also defined for the power supply of the circuit to ensure proper operation of the entire system.

3.1 Operating Principle of the Electrical Circuit

In Figure 1.1, the complete electrical diagram of the automated system is presented. To achieve the purpose of this work, the focus lies in defining the operational principle of the electrical circuit. The coordination of all circuit elements is entrusted to the Arduino through C++ programming. In this context, a temperature sensor is placed inside a portable refrigerator. The Arduino interprets the data from this sensor, checking if the internal temperature is below the pre-set target temperature. When this condition is met, the system deactivates the *Peltier* module and reduces the fan speed, which dissipates the heat generated by the hot side of the *Peltier* module. The target temperature is manually regulated by the user through a potentiometer and is displayed along with the internal temperature on the display. Conversely, if the sensor reading indicates a temperature higher than the user-defined setting, the circuit activates the *Peltier* module, deactivating it only when the internal refrigerator temperature is 278 K below the user-set configuration. To provide clarity to the user about the state of the *Peltier* module, two LEDs are incorporated into the system: the blue LED indicates deactivation, and the red LED indicates activation of the *Peltier* module. Therefore, the project aims to achieve optimized operation through Arduino control and interaction between devices.

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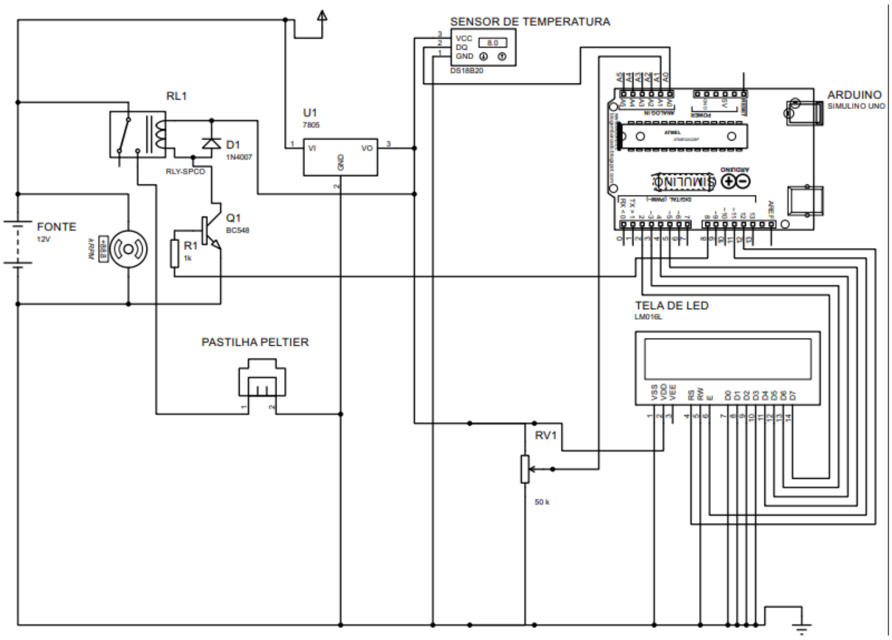

Figure 1.1: Electric circuit

Figure 1.2 illustrates the equations for the calculation of the entire electrical circuit, which was carried out using Ohm's Law. Based on this circuit, the electrical calculation was performed for the entire system, where the power supply for the Arduino, according to technical specifications, should have a voltage of 5V. Therefore, a relay was implemented to establish the connection of the refrigeration system independently from the Arduino. The relay is utilized to power and de-power the refrigeration system, thereby allowing the incorporation of a power supply ranging from 12V to 220V into the electrical system.

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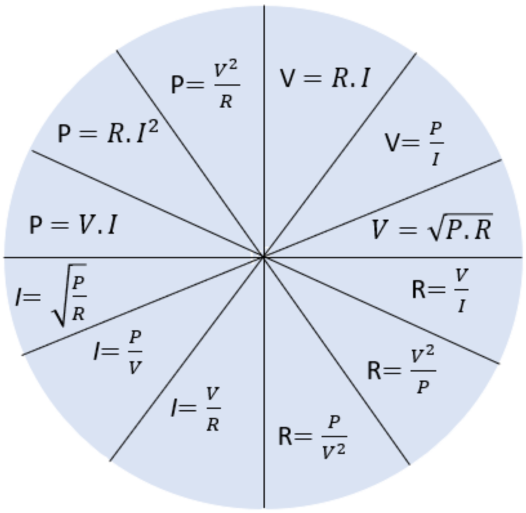

Figure 1.2: Equation the circuit electric

4.2. The Arduino programming

As shown in Figure 1.3, the Tinker cad platform was utilized. Tinker cad is a free online platform that helps translate Arduino programming language into machine code and also facilitates electronic system simulation. Compilation is typically done through a development environment or IDE, which is a computer software with an embedded compiler that was used to send the created code to the Arduino. Arduino programming is done using the C++ programming language.

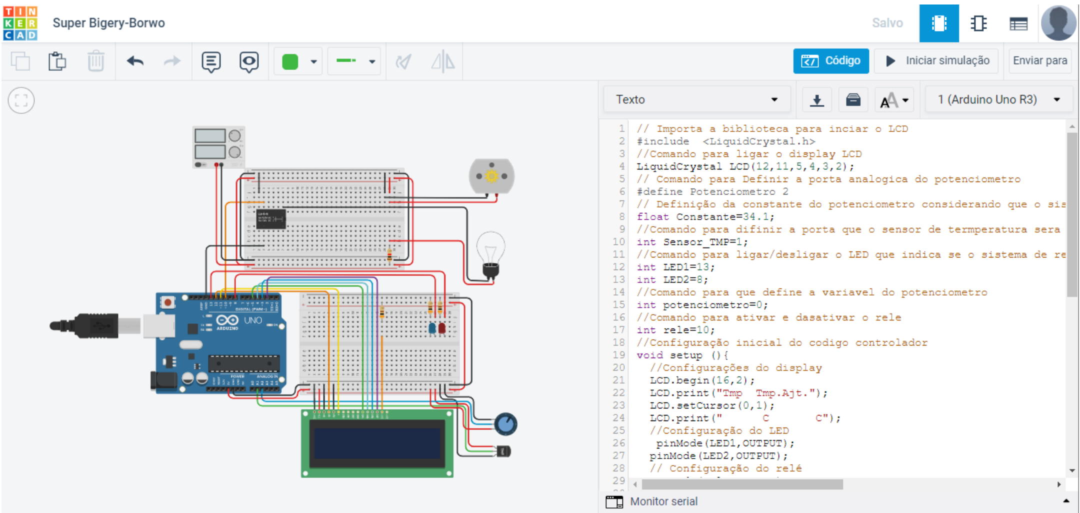

Figure 1.3: Tinker cad simulation environment

Based on the components used in the Tinker cad environment, the costs for each necessary component for the assembly of the electrical circuit are presented in Table 1.1.

Table1.1. Budget table for the electrical circuit.

Component	Quantity	Unit cost (R$)	Partial total value (R$)
Arduino	1	132,90	132,90
LED	2	0,28	0,56
Relé 12V	1	11,90	11,90
Display LCD	1	28,40	28,40
Resistor 300	3	1,90	5,70
DS18B20	1	16,37	16,37
Power source 12V	1	49,90	49,90
Wires 4mm	1 m	12,00	12,00
Wires 2mm	1 m	3,49	3,49
Total value	-	-	**R$ 249,01**

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4.3. Technical specifications of the Peltier insert

In Figure 1.4, we have the Peltier module to be used in the project. Figure 1.5 displays the technical characteristics of the Peltier modules, as they bear a coding on one of their surfaces, specifying some of their properties. *Peltier* modules are typically composed of joined blocks of bismuth telluride (Bi2Te3), classified as type-N and type-P, with these blocks placed between ceramic plates.

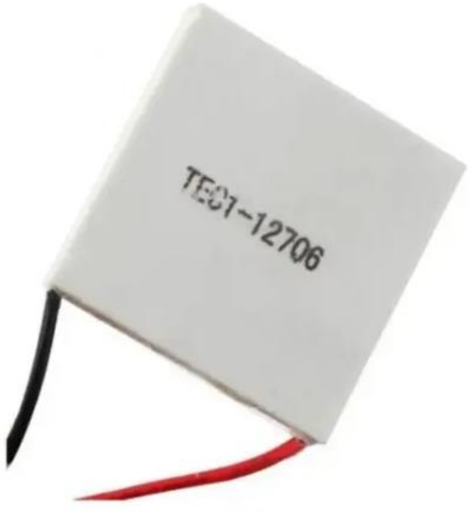

Figure 1.4: Used Peltier module

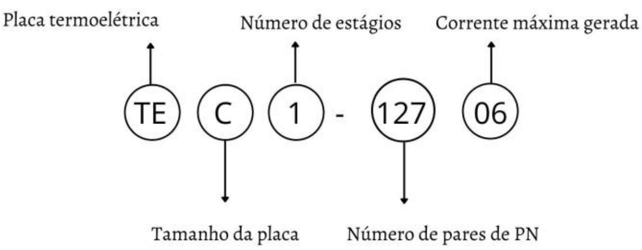

Figure 1.5: Peltier module codes

4.3. Arduino technical specs

In Figure 1.6, the technical specifications of the Arduino Uno R3 are displayed. This model is used in the current project to interface the electrical components with the Arduino. Therefore, understanding its technical specifications is necessary for proper connection of the components.

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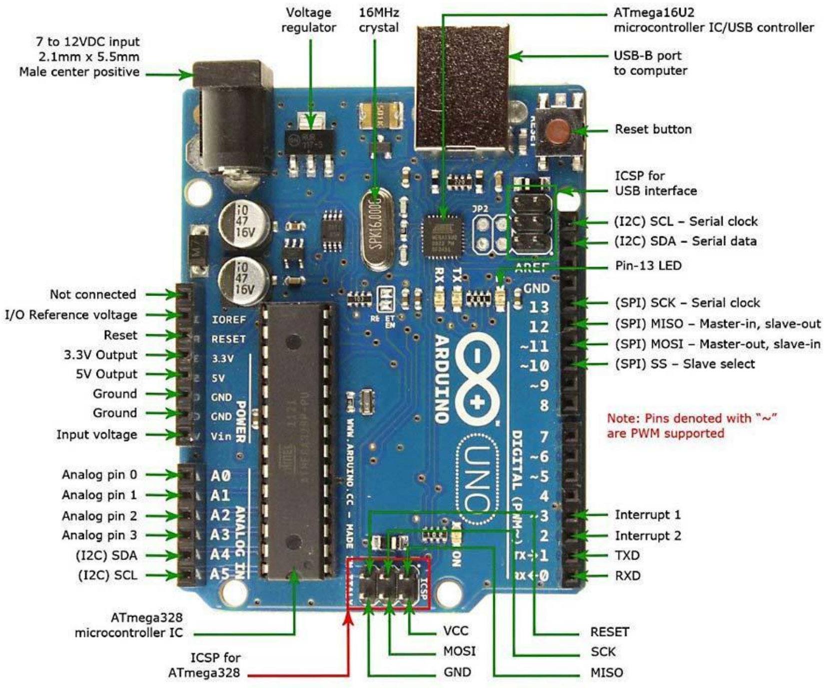

Figure 1.6: Arduino specifications

5. RESULTS

Through the development of code within the integrated development environment (IDE) of Arduino, coding was facilitated to create the electrical circuit with its components. The comprehensive representation of the electrical circuit is shown in Figure 1.7, where the *Peltier* module is indicated by the lamp, and the cooler is denoted by the motor. The remaining components are illustrated accurately. Upon simulation within the simulation environment, it was determined that the circuit achieves the objectives outlined within this project. Based on this verification, a three-dimensional (3D) modeling of the implemented circuit within the portable refrigerator was undertaken to determine its optimal arrangement. The portrayal of the portable refrigerator with the incorporated electrical circuit is highlighted in Figure 1.8.

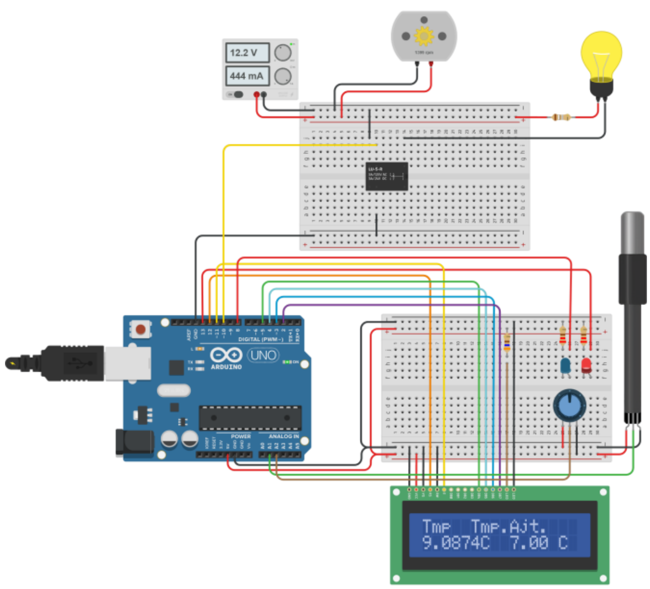

Figure 1.7: Representation of the electrical circuit

DOI: 10.31695/IJASRE.2023.9.9.3

Figure 1.8: Portable refrigerator

To ensure the proper functioning of the electrical circuit, it is imperative to evaluate which power supply will fit the operational criteria. Based on the technical specifications of the components of the refrigeration system, it was possible to derive values of voltage, current, resistance, and power that would allow for proper operation. Under these assumptions, the electrical circuit must incorporate a voltage regulator for the Arduino. In this context, considering that the circuit is configured in a parallel arrangement, it's possible to determine the required current, power, and voltage from the power supply to ensure the uninterrupted operation of the system. The derivation of these values was based on the principles of Ohm's Law outlined in Chapter 2. Table 4 presents the obtained results, with the input parameters for the calculations extracted from the technical specifications of the components (Table 1.2).

Table 1.2. Technical characteristics of the component

Component	Voltage (V)	Current (A)	Resistance (Ω)	Power
Arduino Uno R3	7	1	7	7
Cooler	12	0.2	60	2.4
***Peltier* module**	12	5.4	2.45	64.8

Table1.3. Table of instructions for the electrical circuit

Results	Value
Total resistance	1.7 **Ω**
Total Current	7 A
Total Voltage	12 V
Total Power	77 W

Based on the obtained results, it is concluded that the power supply needs to be capable of providing a current of 7 amperes, power of 77 *watts*, and voltage of 12 volts. Consequently, the power supply must have these specifications to adequately supply the electrical circuit. The calculations performed for the electrical circuit encompass the provision of energy to the *Peltier* module, used as a cooling component in the project. However, this module demonstrated a temperature variation between 12 and 18 degrees Celsius. Considering that the optimal temperature for preserving food in a way that it's not frozen and can be enjoyed pleasantly is around 5 degrees Celsius, the *Peltier* module did not meet this criterion within the container. Given that the designed circuit can handle a higher power from the power supply, it is feasible to automate a compression-based refrigeration system, which is notably more efficient than *Peltier*-based cooling.

4. CONCLUSION

Upon concluding the project, we have determined that the executed programming met the essential requirements for controlling the refrigeration system. However, in the case of the Peltier-based cooling system, we couldn't achieve the necessary demand to effectively cool the compact environment. Despite this limitation, the developed programming logic demonstrates potential when applied to compression-based refrigeration systems. In this context, it shows the capability to fulfill cooling criteria for the environment while allowing precise control to minimize unnecessary expenses. Moreover, there is the prospect of incorporating a

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remote management system, enabling control via the internet. This enhancement would add value to the system by making it more practical and accessible, potentially benefiting a broader range of users. Thus, the programming wouldn't be limited to conventional cooling applications only, but would also extend to scenarios where convenience and remote control are crucial. In summary, the work carried out demonstrated that the programming met the project's requirements, proving particularly applicable to compression-based refrigeration systems. Furthermore, the potential for online control integration represents an exciting opportunity to enhance the effectiveness and utility of the developed system.

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