Republic of Iraq

Ministry of Higher Education & Scientific Research

University of Kerbala

College of Engineering

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DEVELOPMENT OF AN INDUSTRIAL ATMEGA328P MICROCONTROLLER BASED ON OPEN-SOURCE PLATFORM

A Thesis Submitted to the Council of the Faculty of the College of Engineering/University Of Kerbala in Partial Fulfilment of the Requirements for the Master Degree in Electrical and Electronic/Control Engineering

By:

Noor Saleem Atiyah

Supervisors

Assist. Prof. Dr. Ali Fawzi Najm Al-Shammari

Dr. Ahmed Selman Altuma

October 2023 Rabi Al-Awwal 1445

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بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ

"فَاسْتَجَابَ لَهُمْ رَبُّهُمْ أَنِّي لَا أُضِيعُ عَمَلَ عَامِلٍ مِّنكُم مِّن ذَكَرٍ أَوْ أُنثَىٰ"

صدق الله العلي العظيم

(آل عمران: من الآية ١٩٥)

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We certify that we have read the thesis entitled " **DEVELOPMENT OF AN INDUSTRIAL ATMEGA328P MICROCONTROLLER BASED ON OPEN-SOURCE PLATFORM** " and as an examining committee, we examined the student " **Noor Saleem Atiyah** " in its content and in what is connected with it and that, in our opinion, it is adequate as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

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Linguistic certificate

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Date: 24/ 1 / 2024

Dedication

To my first teacher, supervisor, doctor, and professor, my dear father, and to the greatest school I've ever attended, my dear mother, I dedicate this endeavor to you.

Acknowledgments

First and foremost, I would like to express my heartfelt gratitude to the almighty Allah and his beloved, the Prophet and his Ahl-Albait (AS), for their unwavering kindness. I extend my thanks to the dedicated staff at Kerbala University, particularly my supervisor, Dr. Ali Fawzi Al-shammari, and co-supervisor, Dr. Ahmed Selman, for their invaluable guidance. I am also deeply appreciative of my peers who have consistently encouraged me through every challenge. A special thank you goes out to my small yet steadfast family, my husband, and daughter, for their patience and unwavering support throughout this journey. Lastly, I want to acknowledge and appreciate every moment that may have attempted to deter me but only served to strengthen my resolve, ultimately leading me to this moment of success.

Abstract

Microcontrollers are used widely now days in different applications, such as home automation, device control, wireless sensor network, and also for industrial applications. Generally, the microcontrollers that used in industrial application must have a number of properties to fit with industrial enviroment, such as reliability and robustness.

One of the most common microcontrollers platforms is the Arduino, which is an ATMega based microcontroller. There are a number of industrial microcontroller platforms that is based on Arduino or ATMega chip due to its number of specifications like efficiency and simplicity. Among them we mention: M-DUINO5858, Iono Uno, Controllino, Arduino Industrial 101, Industruino and Ruggeduino-ET. However, there are several advantages and disadvantages in the mentioned products, which highlight the map of the problem statement and the proposal of this thesis.

This thesis analyses the current products and does a cross section of the best properties of these products. Mainly rubust connection for input/output wires, additional envelope case. Additionaly, addressing the limitations which are lack of antivibration mechanism, decreasing drop voltage in power and processing, increasing output load power. Furthermore, some problems in programming. Hence, this work can be used as a guideline to propose a new ATMega based microcontroller platform with the best combination of features.

As an output of this work, a highly adaptable open-source platform, which is referred to with name of “Kerduino”, is designed and implemented. The design process is cross number of stages from simulation then schematic and

PCB design untill 3D printing case. This product has been developed as an open-source to engage the community in the future development process and to support its sustainability.

Comparative results revealed the distinctive attributes of the Kerduino comparted to general industrial board specifications. More specifically, the device power supply is improved, as well as the mechanical properties of the device are improved too, by comparing with Arduino practically, and comparing with the enhanced industrial platforms theoretically. Finally, the cost is considered as an important factor of Kerduino design.

Furthermore, this research sets the stage for future explorations and developments in the field of industrial automation and control systems.

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List of Abbreviations

Abbreviations	Full Form
A	Amperes
ATMEL	Advanced Technology for Memory and Logic
AVR	Automatic Voltage Regulator
EtherCAT	Ethernet for Control Automation Technology.
CDC	Communication Device Class
COM	Communication port
CPLDs	Complex Programmable Logic Devices
CPU	Central Processing Unit
DC	Direct Current
DIP	Dual In-line Package
EMI	Electromagnetic interference
HID	Human Interface Device
I/O	Input/Output
I2C	Inter-Integrated Circuit
ICSP	In-Circuit Serial Programming
Iop	Output Current
IoT	Internet of Things
IP	Internet Protocol
ISP	In-System Programming
LCD	Liquid Crystal Display
LEDs	Light Emitting Diodes
LUFA	Lightweight USB Framework for AVRs
MCU	Microcontroller
MIPS	Million instructions per second
NTH	Norwegian Institute of Technology
PCB	Printed Circuit Board
PC	Personal Computers
PEF	Pulse Electric Field

pf	Power Factor
PID	Proportional-Integral-Derivative
PLCs	Programmable Logic Controllers
POC	Proof of Concept
PSRR	Power Supply Ripple Rejection
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
RS485	Recommended Standard #485
RTOS	Real-time operating systems
SMD	Surface Mounted Device
SMTP	Simple Mail Transfer Protocol
SPI	Serial Peripheral Interface
TRFR	Transforming, Rectifying, Filtering, and Regulating Voltage
TTL	Transistor-Transistor Logic
TWI	Two Wire Interface
Uno	One in Italian
UPS	Uninterruptible Power Supply
USB	Universal Serial Bus
Vdrop	Drop Voltage
Vip	Input Voltage
Vop	Output Voltage
WINAVR(GCC)	A compiler that takes C language, can be uploaded into an AVR microcontroller
RMS	Root Mean Square
p-p	Peak to Peak

List of Symbols

Symbol	Meaning
m	Milli- one-thousandth of a unit of measure (10^{-3})
μ	Micro- one-millionth of a unit of measure (10^{-6})
n	Nano- one-billionth of a unit of measure (10^{-9})
p	Pico- one trillionth of a unit of measure (10^{-12})
θ	The angle between the voltage and current waveforms

Chapter One

General Introduction

Chapter One: General Introduction

1.1 Introduction

Undoubtedly, the Fourth Industrial Revolution is a continuation of the series of industrial revolutions that began with the First Industrial Revolution in the eighteenth century, bringing significant changes to human life and aiming to improve ease, comfort, and well-being [1].

The term “Fourth Industrial Revolution” coined by the World Economic Forum in Davos, Switzerland, in 2016. While the Third Industrial Revolution represented simple digitization, the fourth represents creative digitization through a blend of interactive technological breakthroughs facilitated by innovative algorithms. The recent revolution despite the fact that is built on the infrastructure of the Third Revolution, it proposes entirely new technical ways by integrating physical, digital, and biological technologies. Investors, consumers, and citizens who adopt and use these technologies in their daily lives become partners in its creation and development [2].

Hence, the need arose for a new type of control panels in industrial control due to the increasing use of programmable logic controllers in more places and by more people, as well as the growing demand for self-control. Many attempts have started to develop a simulation platform similar to the famous Arduino platform but with more complementary capabilities and greater practicality to be used in industry more extensively and efficiently.

However, the use of the term "industrial board" combines the features of a panel, consisting of printed circuits and electronic chips, with the features of an industrial controller, often used outdoors and for high-torque motors.

This thesis focusses on the essential role played by microcontroller platforms in industrial control. It traces their evolution from their origins to their use in advanced applications. It also recognizes the challenges and opportunities they present, particularly in the age of the Internet of Things (IoT) and Industry 4.0. In this era of interconnected devices and smart sensors, microcontrollers, have the potential to fundamentally transform industrial automation when applied effectively across a range of industrial applications. Leading to the development of an industrial board model that serves the mentioned purposes, and going through its comparison and testing in relation to similar existing platforms [3].

1.2 Background of Industrial Control

Industrial automation control systems involve the integration of devices, machines, and equipment within the manufacturing plant. As the automation control system manages repetitive tasks, resource utilization in production lines can be optimized. These systems also necessitate hardware, software, and communication solutions to convert sensor-collected data into information that triggers automatic actions. Automation control systems result in reduced production errors, leading to time and cost savings, as well as enhanced customer satisfaction [4]. In contemporary industrial settings, the programmable logic controller (PLC) serves as the central processing unit of the control system. It can be likened to a compact, industrial-grade computer designed to function dependably within the manufacturing facility's conditions. The PLC possesses the capability to communicate and exchange data with operators like human machine interfaces (HMI) and supervisory control and data acquisition (SCADA) systems located on the factory floor [5].

However, since microcontrollers are standalone systems [6] capable of performing the most necessary functions without the need for extra hardware, it is ,sometimes, preferred over PLCs. The microcontroller will be discussed briefly in the next section.

1.3 Microcontroller

A microcontroller, is a compact computing unit integrated onto a single chip, or a device that integrates a microprocessor, memory, and peripheral interfaces into a single package [7]. Diverse types of microcontrollers exist, encompassing the Intel 8051, PIC, MSP, ARM, and AVR microcontroller families.

These microcontrollers incorporate an array of peripherals, similar to those found in computers, including input and output components, memory, timers, serial data connections, and programmable interfaces. Microcontrollers find application in embedded software and the autonomous operation of machinery, spanning office equipment, power tools, medical devices, control systems, remote controls, and electronic gadgets [8]. For the scope of this thesis, the focus lies on the application of the AVR ATMega Microcontroller. Subsequently, we will delve into specific aspects of the ATMega's specifications in the next chapter, but first of all, a historical view about how microcontrollers, specially ATMega type, utilized in industrial automation will displayed in this context.

1.4 Arduino Platform As An Open-Source Platform

An Arduino is a programmable circuit board that operates on an open-source platform. It finds utility across a wide spectrum of makerspace projects, ranging from simple to complex activities [9]. The Arduino ecosystem involves both user-friendly software and hardware components. The Arduino IDE program supports programming in C and C++, adhering to specific guidelines [10]. While there are various alternative microcontrollers and development boards available, Arduino gains favor due to its accessible nature, clear software environment, and inclusive hardware architecture. Despite the emergence of competing options, there are additional factors contributing to Arduino's continued popularity among its widespread user base [11]. The management of diverse open-source hardware alternatives can be challenging. This research specifically centers on Arduino, which stands as one of the most renowned open-source computer hardware platforms.

1.4.1 History of Arduino

The initiative Arduino board came into existence in 2005 within the halls of the Interactive Design Institute in Ivrea, Italy, as part of a master's thesis project [12, 13]. Under the guidance of Massimo Banzi, the development of this unique prototype board aim to achieve significant improvements, aiming for reduced weight, lower costs, and enhanced accessibility for the open-source community [14]. Figure 1.1 shows the first prototype of Arduino.

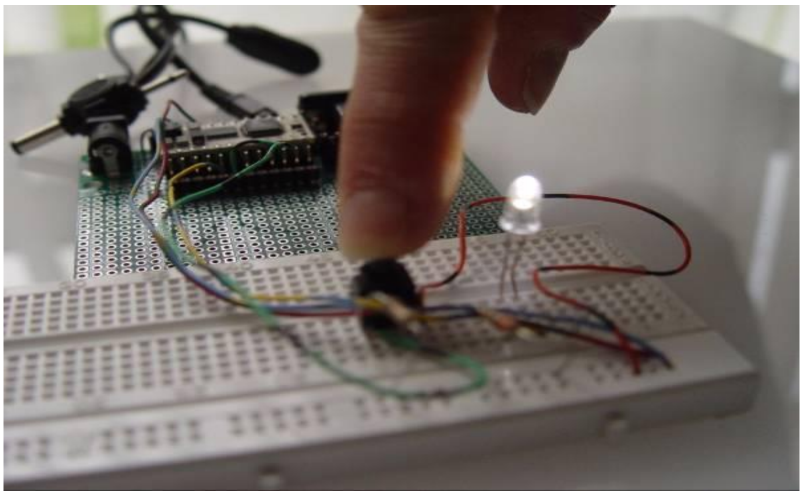


Figure 1. 1: The first prototype of Arduino.

1.4.2 Types of Arduino Boards

Arduino has developed a diverse range of over 100 hardware items, encompassing a variety of offerings such as boards, shields, carriers, kits, and supplementary accessories [15]. This extensive collection of products underscores Arduino's obligation to accommodating to a wide spectrum of user needs and project requirements. Over the years, their catalog has expanded to include an array of options that empower amateurs, makers, and professionals to effectively bring their ideas to life using versatile and adaptable hardware solutions. Different types of Arduino boards are presenting in Figure 1.2.

Figure 1. 2: Different Types of Arduino Boards

Arduino encompasses three distinct hardware families: Nano, MKR, and Classic. Each family offers a unique set of boards designed to serve various project requirements.

The Nano Family is characterized by its compact size, and it includes a range of boards such as the Nano Every, an entry-level option, as well as more advanced models like the Nano 33 BLE Sense and Nano RP2040, which boast additional features for diverse applications [16].

The MKR Family introduces a collection of boards, shields, and carriers that can be combined to create innovative projects. This family empowers users to leverage the hardware synergies between different components, allowing for the development of impressive creations.

Within the Classic Family, an iconic boards will be find like the well-known Arduino Uno, along with first classical models like the Leonardo and Micro.

When selecting a microcontroller board, specific characteristics play a pivotal role in determining its suitability for a particular application. Factors like the microprocessor's capabilities, memory capacity, input and output options, and physical dimensions guide the choice of the appropriate design.

For instance, the Lilypad board is custom-made for e-textiles, featuring sensor boards that are perfect for wearable designs, even being washable for added convenience. When projects require a significant number of input and output lines, boards like Arduino Due or Arduino Mega, with up to 54 digital I/O pins, become valuable considerations [17].

Larger programs or complex projects necessitating substantial memory can benefit from boards such as the ARM Cortex-M0+-based Arduino M0, which boasts 256KB of ROM and 32KB of RAM.

Specialized applications are also catered to within the Arduino ecosystem. For audio-focused projects, the MKR Zero offers dedicated features. The Arduino YN pairs with the Linux distribution Linino OS, integrating Wi-Fi capabilities. The Arduino Ethernet REV 3, based on the Uno board, incorporates Ethernet connectivity and a micro SD card reader, making it suitable for network-related tasks [18].

For applications that involve breadboards, the Arduino Nano offers a compact alternative [19]. While it lacks a DC power connector and features a smaller USB port compared to the Arduino Uno, the Arduino Nano is particularly well-suited for projects involving breadboard circuits. This makes it an ideal choice for individuals already familiar with electronics and those who frequently employ breadboards in their work.

Even unique functionalities are present, as demonstrated by the Micro board, which can serve as a mouse or keyboard due to its built-in USB port. This expansive range of boards empowers creators to align their project requirements with the optimal hardware solution, making Arduino a versatile platform for innovation.

1.5 Arduino Usage

Arduino's unparalleled adaptability has positioned it as a versatile tool that transcends industry boundaries, bringing innovative concepts and practical solutions to diverse applications. In the following sections, it delve into several key fields where Arduino's capabilities have made a significant impact: defense applications [20], diverse sectors [21, 22], medical applications [23, 24] , prosthetics and orthotics applications [25] and education [26, 27] .

It is crucial, however, to acknowledge that even in these outlined scenarios, the Arduino might exhibit limitations. Its functionality might be constrained, lacking the industrial-grade certifications and ruggedness often required in demanding industrial environments. Consequently, while the Arduino can find niches within the industrial sphere, it's essential to weigh its capabilities against the specific requirements of each application and consider alternative solutions where necessary.

1.6 Arduino Uno

Among the extensive array of Arduino boards, the Arduino Uno stands out as one of the most widely adopted choices, often recognized as the quintessential Arduino board [28]. Its popularity can be attributed to a combination of factors that cater to both beginners and experienced enthusiasts.

The Arduino Uno comes equipped with an array of user-friendly features, making it a versatile tool for various projects [29]. the schematic shows that it boasts 2.54mm sockets that facilitate easy attachment of external devices, offering seamless expansion possibilities. An onboard LED adds a visual indicator element to projects, enhancing interactivity. Built-in power management features, such as an external DC power connection, contribute to the board's adaptability to diverse power sources [30].

Furthermore, the Arduino Uno features a USB-B connector, allowing direct connectivity to a computer for programming and data exchange. This streamlined interaction simplifies the development process and enables quick testing and iterations.

Understanding its schematic configuration, programming, and architecture is essential for working effectively with this board. Arduino Uno Schematic could be found in [31]. Programming the Arduino Uno involves writing code in the Arduino Integrated Development Environment (IDE), which uses a simplified version of the C/C++ programming language.

1.6.1 Architecture

The architecture of the Arduino Uno is based on the ATMega328P microcontroller. It's an 8-bit RISC (Reduced Instruction Set Computer) architecture with the following key features [31]:

Processor Clock: The ATMega328P operates at a clock frequency of 16 MHz.

Flash Memory: It has 32KB of Flash memory for program storage.

SRAM: It includes 2KB of SRAM for data storage.

EEPROM: There's 1KB of EEPROM for non-volatile data storage.

I/O Pins: The microcontroller provides 14 digital I/O pins and 6 analog input pins.

Peripherals: It supports features like PWM, interrupts, timers, and communication interfaces (UART, SPI, I2C).

Power Management: The microcontroller has various sleep modes to conserve power when not in active use.

Arduino IDE: The Arduino IDE provides a simplified software development environment with libraries and tools to program and upload code to the ATMega328P.

1.6.2 Industrial Applications using Arduino Uno

Arduino platform often embraced for educational and hobbyist projects, the Arduino Uno embodies a foundation of creativity and innovation. However, its design and specifications indicate that it might not be the most suitable choice for deployment in demanding conditions characterized by vibrations, extreme temperatures, humidity fluctuations, or unstable power supplies.

While caution is typically advised against employing the Arduino Uno in such challenging environments, it's intriguing to consider the potential applications of this board in industrial contexts. Notwithstanding its limitations, a few instances come to light where the Arduino Uno could find its place in the industrial landscape, addressing specific challenges within various categories [32]:

1. **Small-Scale Automation Projects;** in scenarios requiring uncomplicated automation, the Arduino Uno can serve as a capable runner. Applications like basic robotic arms or conveyor systems benefit from its versatility and ease of integration. These small-scale automation projects leverage the Arduino Uno's ability to control simple mechanical movements, opening avenues for enhanced productivity and efficiency[33].

2. **Low-Power Monitoring and Control;** within environments demanding low-power solutions, the Arduino Uno play a pivotal role. Monitoring applications, such as tracking temperature or humidity levels in greenhouses or laboratories, support with its capabilities. Its minimal power consumption and simplicity make it suitable for scenarios where energy efficiency is a priority [34].

3. **Straightforward Data Logging;** when the need arises to gather and record data in a straightforward manner, the Arduino Uno can prove valuable. Utilizing the board for tasks like measuring and logging temperature or humidity data in controlled settings, such as greenhouses or laboratories, showcases its adaptability for basic data acquisition needs [34].

In conclusion, the Arduino board stands out as a prominent contender, harnessing the capabilities of the ATMega328 single chip microcontroller [35]. Nonetheless, it's important to note that the standard Arduino board, such as the Arduino Uno, is purpose-built for non-industrial settings.

Consequently, its viability diminishes considerably when exposed to demanding conditions characterized by vibrations, extreme temperatures, humidity fluctuations, and unstable voltage supplies

When considering an industrial ATMega microcontroller board or platform, detailed consideration must be directed towards factors such as the specific microcontroller model, accessible features and interfaces, as well as the overall dependability and quality of the board [36]

1.7 The Development of an Industrial ATMega328P Based open-Source Platform

The industrial ATMega328P-based open-source platform has a rich history rooted in innovation and collaboration, evolving into a versatile technology with widespread applications. At its core is the ATMega328P microcontroller [14], pivotal in open-source boards tailored for demanding industrial environments. The platform's inception involved recognizing the need for a flexible and cost-effective solution, leading to a collaborative project centered around the ATMega328P [37]. Open-source principles transformed industrial control, fostering a global community that created an accessible platform enriched with documentation and software libraries [38]. This community-driven evolution, marked by hackathons and events, shaped the platform's adaptability and found applications across diverse industrial sectors [39]. The platform's modularity, with added sensor modules and communication interfaces, further enhanced its adaptability for seamless integration into existing infrastructures, meeting modern industrial requirements [40]. This cooperative environment continues to drive continuous advancement in industrial control.

1.8 Problem Statement

The development of a new open-source industrial microcontroller platform utilizing ATMega328P is incited by a series of limitations in existing solutions. These limitations encompass scenarios where the current platform's efficiency falls trip, especially when confronted with source power exceeding 20 volts. Moreover, the absence of a robust anti-vibration mechanism in the current setup reduces the platform's reliability, making it susceptible to vibrations in industrial settings. Additionally, the nonexistence of an optimized wiring system mechanism put aside challenges in the tough connectivity demands of current industrial environments. Addressing these challenges is essential, presuppose the creation of a new platform that not only exceeds voltage constraints but also introduces effective anti-vibration mechanisms and innovative wiring systems. Moreover, make the proposed solution as an open-source platform in order to involve the technical community in this project, which is one of the advantages of open-source technologies. Such a platform would redefine industrial control capabilities, offering enhanced performance, robustness, and adaptability for a variety of industrial applications.

1.9 Objectives

The main objective of this work is to design an industrial microcontroller board based on ATMega328P that improves the following features:

1. **Connection Terminal Optimization;** identify and implement connection terminals that enhance robust communication between inputs and outputs, ensuring reliable data transfer.

2. **Voltage Regulation Enhancement;** explore and implement an optimal voltage regulator that can tolerate varying input voltages while maintaining consistent output voltage levels.

3. **Anti-Vibration Mechanism Integration;** integrate a reliable anti-vibration mechanism into the platform's design to enhance its stability and performance in vibration-prone industrial environments.

4. **Industrial Environment Conditions Resistance;** improve the weather and environmental conditions resistance to increase device reliability in industrial and outdoor environment.

5. **Community Involvement;** making the solution as an open-source would achieve the objective of involving the community in this project. This would support project sustainability.

1.10 Thesis layout

This thesis is divided in five chapter as following:

- **Chapter One: General Introduction**: This chapter serves as an introduction to the entire thesis. It outlines the research problem, objectives, and scope.

- **Chapter Two: Literature Review - ATMega Microcontroller Boards**: This chapter reviews existing literature, focusing on ATMega microcontroller boards, highlighting their features and applications.

- **Chapter Three: Methodology**: This chapter explains the research design and approach, detailing methods, tools, materials, and principled considerations.

- **Chapter Four: Results and Discussion**: The research outcomes are presented and critically analyzed in this chapter. Furthermore, any encountered limitations are acknowledged.
- **Chapter Five: Conclusions and Recommendations**: The final chapter summarizes findings, draws conclusions, and offers recommendations for future research.

Chapter Two

Literature Review:
ATMega Microcontroller Boards

Chapter Two: Literature Review: ATMega Microcontroller Boards

2.1 Literature Review on Development of an Industrial ATMega Microcontroller Platform

A historical view of the development of industrial platforms based on ATMega microcontrollers provides insights into how these platforms have evolved over time to meet the increasing demands of industrial automation and control systems. The history can be divided into several key phases:

Early Adoption (2000s); the adoption of microcontroller-based systems in industrial applications was already well underway. Microcontrollers like the ATMega series gained popularity due to their cost-effectiveness, ease of use, and versatility.

During this period, industrial platforms using ATMega microcontrollers were primarily focused on basic control tasks, data acquisition, and simple automation processes.

Researchers and engineers explored the integration of ATMega microcontrollers into various industrial equipment, such as sensors, actuators, and monitoring devices [41].

Arduino Revolution (Late 2000s - Early 2010s); the emergence of Arduino in the late 2000s brought a significant shift in the development of industrial platforms based on ATMega microcontrollers.

Arduino, which often uses ATMega chips as its core, democratized embedded system development. It offered a user-friendly IDE, a vast community of makers, and an array of open-source libraries and hardware components.

Industrial applications started to benefit from this ecosystem, leading to the creation of cost-effective, accessible, and customizable solutions.

Arduino-based industrial platforms gained popularity for tasks like data logging, control systems, and process monitoring [42].

Integration of IoT (Mid-2010s); in the mid-2010s, the Internet of Things (IoT) gained prominence in industrial settings. Industrial platforms based on ATMega microcontrollers began to incorporate IoT connectivity, allowing remote monitoring and control.

Integration with Wi-Fi and Ethernet modules enabled real-time data transmission to central control systems, cloud platforms, or mobile devices.

These platforms played a vital role in the development of smart factories and Industry 4.0 initiatives, where automation, data analytics, and connectivity became paramount [43].

Scalability and Industrial-Grade Solutions (Late 2010s - Early 2020s); as industrial demands grew, ATMega-based platforms evolved to offer more robust, industrial-grade solutions.

Platform scalability became a focus, allowing industries to expand their automation systems as needed.

Enhanced hardware features, such as ruggedized designs, wide operating temperature ranges, and protection against electromagnetic interference (EMI), made ATMega-based platforms suitable for harsh industrial environments.

Recent Advances (2020s); in recent years, advancements in the capabilities of ATMega microcontrollers, along with the integration of more powerful processors and communication interfaces, have expanded the possibilities for industrial platforms.

Real-time operating systems (RTOS) and advanced communication protocols, including Ethernet/IP and EtherCAT, have been integrated into these platforms [41].

2.2 ATMega Microcontrollers Innovation

Alf-Eigel Bogen and Vegard Wollan, both students at the Norwegian Institute of Technology (NTH), originated the ATMega Microcontrollers, which belong to the AVR family [44]. In 1996, Atmel Corporation acquired the project and further advanced its development. AVR microcontrollers encompass three distinct categories: TinyAVR, MegaAVR, and XmegaAVR. The Tiny AVR microcontroller is extremely compact and serves undemanding applications. On the other hand, the Mega AVR microcontroller, larger than its Tiny AVR peer, finds widespread use due to its abundant integrated components, massive memory capacity, and easy accessibility. Meanwhile, the Xmega AVR microcontroller, characterized by amplified complexity, excels in intricate applications with its faster processing speed and expanded memory [44].

Atmel Corporation manufactures ATMega Microcontrollers as part of the MegaAVR microcontroller family. The AVR microcontrollers span a range of configurations catering to tasks of varied complexities, about 8-bit, 16-bit, and 32-bit operations [45]. An ATMega Microcontroller, based on an 8-bit RISC architecture established on Harvard Architecture, stands out through its integration of diverse components, robust memory, and broad applicability [46].

The selection centers on the ATMEGA328P, the most prevalent AVR controller acknowledged for its use in the most famous microcontroller platform, ARDUINO platform. This Microchip-designed controller boasts high performance and low power consumption. A more detailed exploration of this model follows in subsequent sections. Alternatively, the ATMega32u4 from the ATMega family (utilized in Arduino Leonardo and Micro) is noteworthy for its built-in USB port with HID usage possibility, although it needs a Dual In-line Package (DIP) option [47].

The ATMega328 and ATMega328P fulfill comparable tasks, yet the latter leverages ATMEL's PicoPower Features to achieve significantly lower power consumption, where the "P" denotes PicoPower [48].

2.2.1 ATMega328P

As previously highlighted, ATMega328P is underpinned by the improved AVR RISC (Reduced Instruction Set Computer) architecture. This CMOS 8-bit microcontroller showcases exceptional power efficiency [49]. Delivering throughputs approaching 1MIPS per MHz, it empowers system designers to standoff a harmonious balance between processing prowess and power consumption. Accomplished by executing strong instructions within brief clock cycles, this capability provides the means to finely calibrate device power usage and processing efficiency.

The Atmel picoPower enabling operation down to 1.62 V while maintaining full functionality without errors [50]. It excels in waking from sleep mode more swiftly than its AVRmega series counterparts, incorporating diverse Sleep modes to curtail power usage. Consequently, the ATMega328P commands a higher price due to these advanced features, marking a significant distinction while maintaining similar operational functionality [51].

Moreover, the ATMega328P boasts a Pin Count of 28/32, encompassing attributes like 32K Bytes of flash memory furnished with 15-bit addresses, 2K Bytes of Static Random Access Memory (SRAM), and 1K Bytes of EEPROM. With 23 General Purpose I/O (Input/Output) Lines at its disposal, enhances connectivity [52]. ATMega328P block diagram shown in Figure 2.1. The inclusion of a singular TWI (I2C) Inter-Integrated Circuit, coupled with the Analog-to-Digital Converter offering 16-bit precision across 10-bit resolution and a sampling rate of 15kSPS with 8 ADC channels.

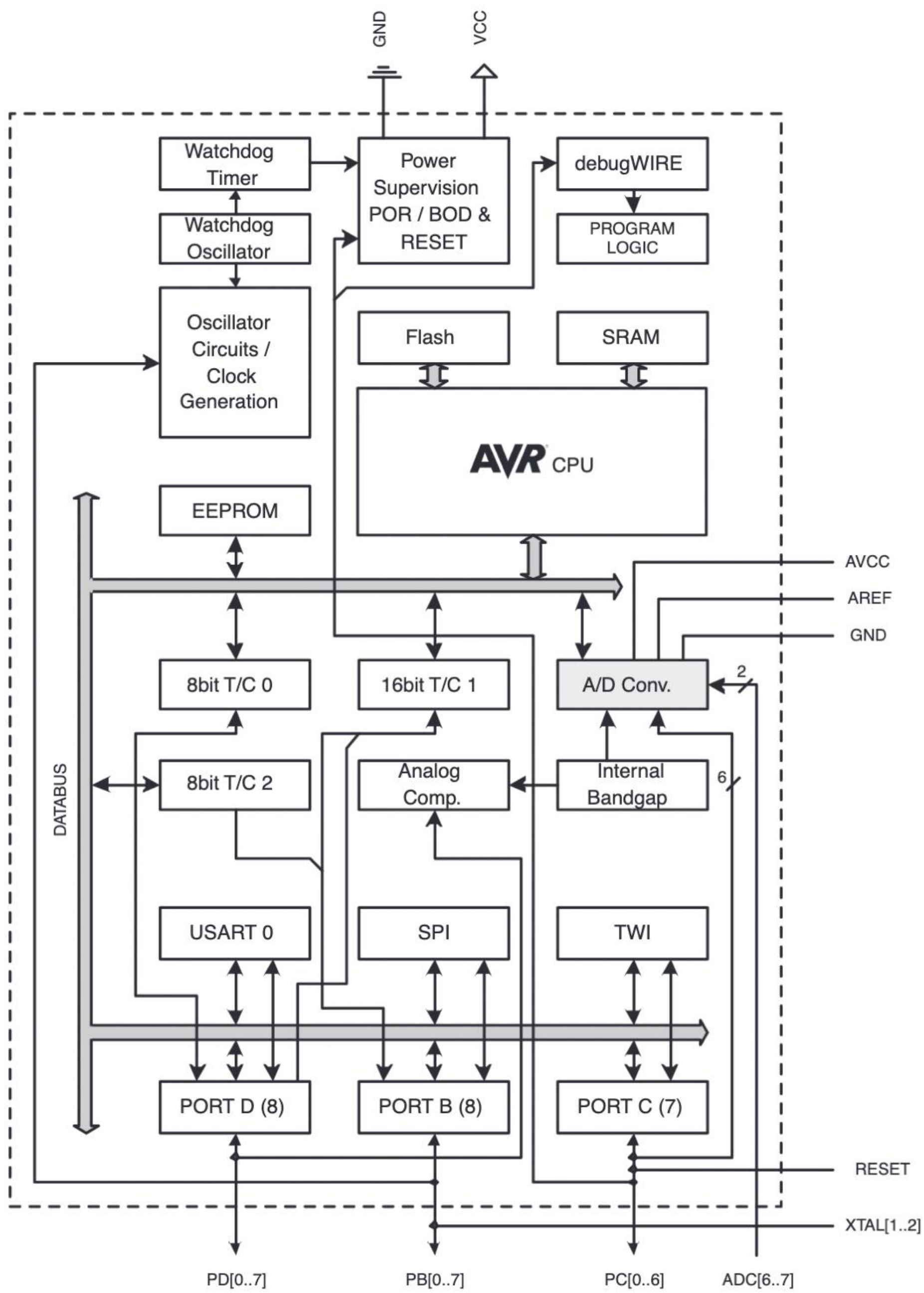


Figure 2. 1: ATMega328P Block Diagram.

Timer/Counters =1, 8-bit Timer/Counters = 2 and Interrupt Vector Size = 2. The AVR core integrates a set of 32 general-purpose working registers and a robust instruction set. This design choice enables the coupling of each of the 32 registers directly to the ALU, facilitating access to two separate registers in a single instruction executed within a single clock cycle [53]. This architecture results in enhanced speed and code efficiency compared to traditional CISC microcontrollers. The chip encompasses instruction words/vector, both internal and external interrupts, a programmable USART for serial communication, an SPI serial port, a Watchdog Timer with an integrated oscillator, and a set of five software-selectable power saving modes for functionality encompasses, these modes are:

1. Idle mode turns off the CPU while keeping the interrupt system, SRAM, Timer/Counters, USART, 2-wire Serial Interface, and SPI interface operational [52].

2. In the Power-down state, the oscillator freezes, halting all other chip operations until the next interrupt or hardware reset, while preserving register contents.

3. Power-save mode lets the asynchronous timer run, maintaining a timing basis while most of the device is in a low-power sleep state.

4. ADC Noise Reduction mode minimizes switching noise during ADC conversions by disabling the CPU and all I/O modules except the asynchronous timer and ADC.

5. Standby mode lets the crystal/resonator oscillator remain active, offering rapid startup and low power consumption[52].

The product is made utilizing high-density non-volatile memory technology from Atmel. The On-chip ISP Flash permits In-System reprogramming of the program memory via an SPI serial interface, a non-volatile memory programmer, or On-chip Boot software executed on the AVR core. While the Boot Flash area operates, the Application Flash part can be updated, facilitating Read-While-Write functionality [54].

The Atmel ATMega48P/88P/168P/328P stands as a potent microcontroller, unifying an 8-bit RISC CPU with In-System Self-Programmable Flash on a single chip. This versatile and cost-effective solution finds relevance in a multitude of embedded control applications. Furthermore, all-inclusive system and program development tools, including C Compilers, Macro Assemblers, Program Debugger/Simulators, In-Circuit Emulators, and Evaluation Kits, are supported for the ATMega48P/88P/168P/328P AVR [54].

2.2.2 Applications of ATMega328P Microcontroller

The integration of microcontrollers into industrial applications has led to remarkable advancements in automation and control systems. Among the notable contenders in this domain are industrial boards based on the ATMega microcontroller series, designed to serve the specific demands of industrial environments. This section highlights some initiating efforts in this direction, showcasing the diverse range of applications and innovations achieved using these industrial boards.

Within the existing system, as outlined in paper [55], the power of microcontrollers becomes evident. Complex Programmable Logic Devices (CPLDs), while limited in function and logic density, take a back seat compared to the versatility of microcontrollers. The proposal envisions the

ATMega328P microcontroller as a central hub, interfacing with an array of sensors to capture parameters like temperature, humidity, gas, pressure, and light intensity. This architecture delivers accuracy, portability, affordability, and efficiency, concluding a user-friendly system adaptable to various scenarios.

Industrial Ethernet Controller Chaudhari and Chopade introduced an industrial Ethernet controller based on the Atmel ATMega328P microcontroller. The design incorporated the ENC28J60 Ethernet controller, positioning the system as a versatile master-to-master controller applicable in both industrial and non-industrial fields. This system boasted attributes such as low power requirements, low latency, and high-speed communication, contributing to its adaptability in diverse scenarios [56].

Wireless Machine Control System Ghodake and collaborators embarked on a wireless machine control system employing the ATMega328 microcontroller and LO-RA technology. The proposed control system, operating on an ON/OFF principle, demonstrated exceptional accuracy, achieving 100% accuracy within 1100 meters and up to 90% accuracy at 1300 meters. The implementation took the form of a printed circuit board (PCB), showcasing a feasible approach for wireless control systems [57].

Industrial Fuzzy Speed Control Alset et al. designed an industrial Fuzzy speed control system for permanent magnet direct current motors using the ATMega328Pu microcontroller. Leveraging a proportional integral fuzzy control mechanism, they achieved improved speed control compared to the conventional proportional integral configuration. Parameters like rise time, peak time, overshoot, and settling time showcased enhancements [58].

A microcontroller comparison study highlights the ATMega328P's advantages in PWM signal generation. This 8-bit microcontroller stands out for its quick reboot time and minimal code requirements, emphasizing the benefits of simplified programming and rapid PWM control response [59].

The ATMega328 microcontroller is pivotal in real-time vital sign monitoring systems. Using XBee communication technology, this system monitors vital signs like heart rate and body temperature [60, 61]. Data integrity is ensured through a memory card in case of radio transmission failures. The system enhances data accuracy and historical tracking, all within a compact wrist-worn device.

CAN Bus Protocol Implementation Iosif's work centered around creating and implementing a CAN bus protocol based on the ATMega328P. Using the ISO-11898:2003 CAN standard as a foundation, a CAN bus controller was built using the MCP2515 chip. The system was put to the test in a car to monitor the brake pedal, achieving a 500kbps baud rate and a 1-second delay [62].

These notable examples represent pioneering endeavors in the realm of industrial open-source boards, equipped with embedded protocols, converters, and communication controllers. These early attempts laid the groundwork for subsequent innovations, leading to the development of prototypes and benefit boards by various manufacturers.

2.1 ATMega Microcontrollers for Industrial Automation

The versatility of the ATMega microcontroller make it a favored choice for industrial applications, boasting a collection of features ideally suited for control systems, sensors, and wider industrial automation activities [63]. With its sizeable memory, potent processing prowess, and an array of integrated peripherals, the ATMega microcontroller model various regarding to diverse needs.

Expressive cases feature the potential within the land of microcontrollers and industrial automation. For instance, reference [64] demonstrates how the ATMega644PA manages complex multidimensional dynamical systems, achieves full processing power for convoluted numerical computations. Additionally, research expounded illuminates the potential of merging PLCs and microcontrollers within traffic control systems [11]. This amalgamation yields enhanced flexibility, security through internal passwords, and resilience against tampering, capitalizing on PLC strengths while thriving in challenging outdoor scenarios. In the following, a number of examples demonstrated in order to highlight the use of ATMega microcontroller in different industrial fields.

In smart home automation and agriculture, M. Hanif et al. [65] propose a dual-pronged approach, leveraging microcontrollers for interior appliances using Grid-eye sensors and reserving PLCs for managing outdoor equipment, aligning with their robustness in harsh conditions and complex scenarios.

As an example in power industry, the ATMega161 microcontroller plays a crucial role in managing an innovative Uninterruptible Power Supply (UPS) system. This advanced system not only offers real-time UPS status updates but also responds to internet queries. It utilizes the I2C communication protocol to interface with auxiliary memory units, improving data coordination [66]. Through SMTP protocol, it can even send email notifications under specific conditions. This solution provides remote monitoring and is a cost-effective alternative for serial setups [67].

As an example in the domain of industrial automation, the ATMega128 microcontroller takes command of the DXDF40 automated powder packing machine [64]. It regulates critical aspects of the packaging process, such as film feeding pace, packaging material tension, and sealing temperature via

PID algorithms. This versatile controller ensures precision, efficiency, and offers features like production counting and system status display.

A wireless home appliance management system, centered around the ATMega16 microcontroller is another example. It simplifies control and remote management [68]. It operates multiple devices via relays, employing PWM regulation for fan speed and light intensity adjustment. Managed through a radio frequency (RF) remote controller, the system integrates with Sim300 GSM modems for device status notifications and LCD panel displays for real-time feedback [68] [69].

Furthermore, the ATMega8535 microcontroller used in controlling a Pulse Electric Field (PEF) pasteurization process, preserving nutritional value by regulating voltage applied to pasteurize apple juice at room temperature. PWM signals enable precise voltage control and process duration, offering an effective and energy-efficient alternative to traditional pasteurization methods [70].

ATMega microcontrollers also find application in underwater robotics and exploration, regulating propulsion control and ensuring safety in demanding underwater environments. Furthermore, they serve as primary controllers for unmanned aerial vehicles (UAVs), stabilizing flight and control in both tri-rotor and four-rotor flying machines [71].

These examples underscore ATMega microcontrollers' innovative applications across industrial and scientific domains. Their ability to simplify programming, enable precise control, and manage complex processes positions them as essential tools, driving efficiency and innovation in a rapidly evolving technological landscape.

2.1 Microcontroller vs PLC

Microcontrollers and Programmable Logic Controllers (PLCs) are integral components in industrial automation, each with distinctive features. Microcontrollers, being versatile and general-purpose, find applications in embedded systems and consumer electronics, catering to small to medium-sized projects [72]. In contrast, PLCs are specialized controllers tailored for industrial settings, excelling in real-time control of manufacturing processes [73].

Programming diverges as well. Microcontrollers are programmed in languages like C/C++, providing fine-grained control over software and hardware [8]. On the other hand, PLCs employ ladder logic or IEC 61131-3 standard languages, designed for simplicity, accessibility, and suitability for engineers with minimal programming experience [74].

Flexibility varies, with microcontrollers offering high customization for specific applications, ideal for prototyping [51]. PLCs, designed for reliability and standardization, lack the same hardware flexibility, ensuring consistency critical for industrial applications [75].

Communication capabilities differ; microcontrollers may require additional hardware for communication, while PLCs come equipped with built-in inputs and outputs, seamlessly integrating into industrial networks using protocols like Modbus or EtherNet/IP [72].

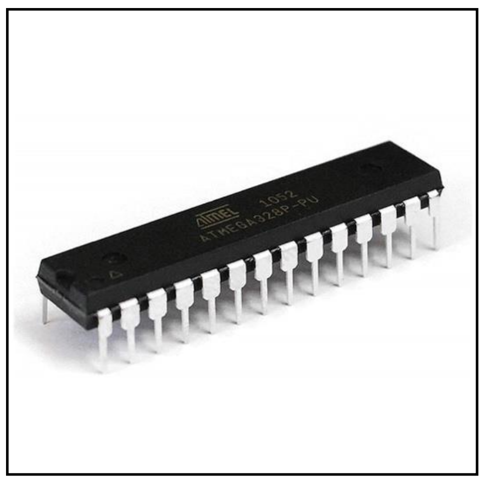
Real-time control is another key distinction. While microcontrollers can handle real-time tasks, PLCs are engineered for precise and deterministic control, crucial in applications demanding high-speed or safety-critical operations [74].

Environmental factors play a role too. Microcontrollers may need additional protection for harsh industrial environments, whereas PLC components are built to withstand extremes like temperature variations, electrical noise, and vibration [73].

Maintenance diverges in complexity, with microcontrollers often requiring more technical expertise and time-consuming troubleshooting. PLCs, designed with diagnostics and maintenance features, facilitate easier monitoring and troubleshooting in industrial settings [75].

Cost considerations complete the comparison. Microcontrollers are generally more cost-effective for small-scale or customized projects, whereas PLCs, though pricier, are considered cost-effective for large-scale industrial automation due to their reliability and dedicated features [51].

As a conclusion, microcontrollers and PLCs serve distinct roles in automation. Microcontrollers offer versatility but may not meet demanding industrial requirements, while PLCs excel in robustness and ease of use for manufacturing and process control. Figure 2.2 represent Programmable Logic Controller and the ATMega328P microcontroller.



a: Programmable Logic Controller **b: ATMega328P MCU**

Figure 2. 2: PLC and ATMega MCU.

2.2 Criteria for Choosing an Industrial Board

Industrial board or Single-board Microcontroller [76], the need for this kind of board came about because microcontrollers are being used in more and more places and by more and more people, and because the need for autonomous control is growing [11].

Engineers face a pivotal decision when it comes to choosing an industrial board from a multitude of alternatives. The primary selection criteria that hold paramount importance include the following: (a) the availability and reliability of sources, (b) the ability to fulfill requirements efficiently and cost-effectively, and (c) the accessibility of software development tools such as compilers, assemblers, debuggers, and the like [77]. When choosing an industrial board, the following procedures should be followed.The selection process flow is shown in Figure 2.3.

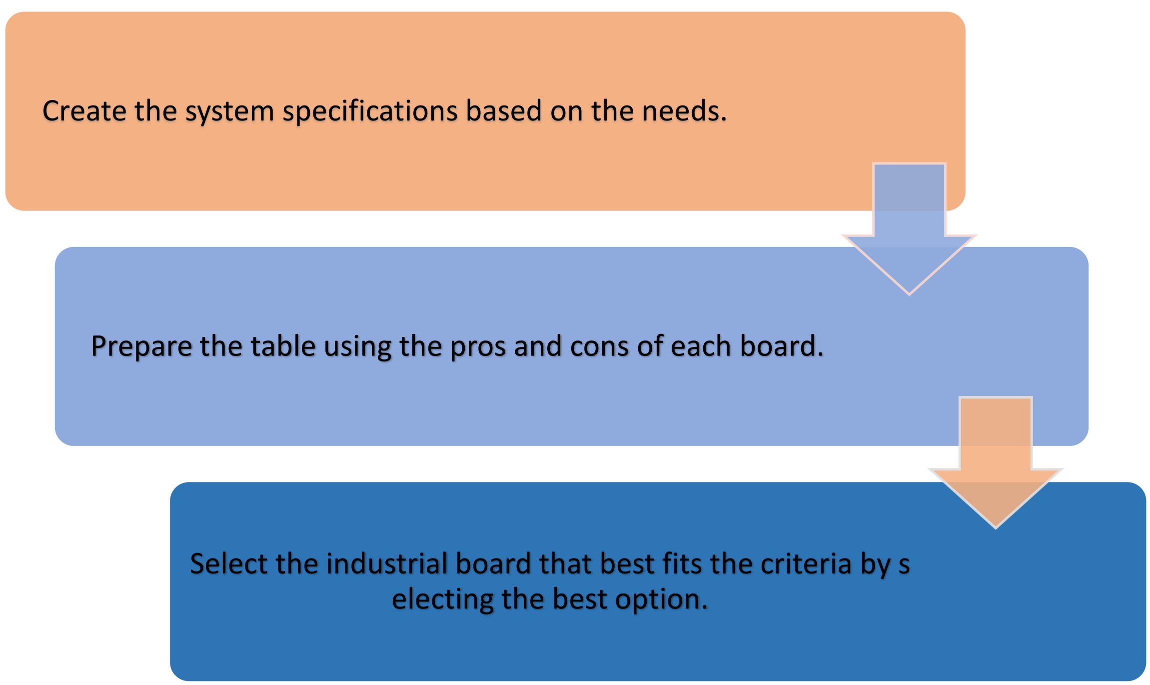


Figure 2. 3: Selection Process Flow.

Selecting an industrial board involves prioritizing key considerations. Beginning with system requirements, environmental toughness, and mechanical specifications take precedence, especially for applications used indoors or outdoors. Microcontroller specifications, ranging from 4-bit to 32-bit, influence code complexity and processing power [48]. Power management, critical for battery life, involves assessing the heat generated by the MCU and peripherals. Robust functionality requires thorough testing of board components in various scenarios. Availability, safety, size, compatibility, and manufacturer support are crucial factors. The cost, a pivotal element, must be balanced with features, and ROM-based devices are preferred for cost efficiency and code security in large-volume applications [78].

2.3 Exploring Industrial Boards Based on ATMega Microcontrollers

After proffering the criteria for choosing an industrial board, the searching about industrial boards based on ATMega microcontroller, which has the compatibility with Arduino boards, results in number of platforms. However, the M-DUINO58 [79], Iono Uno [80], Controllino [81], Arduino Industrial 101 [82], Industruino [83] and Ruggeduino-ET [84], are the best choices representing development boards based on ATMega microcontroller for industrial automation. So, an elaborate Study, analysis and comparison for each one of them is in the next subtitles.

2.4 Comparative Analysis of Industrial Boards Utilizing Microcontrollers:

The industrial boards discussed above have been strategically built upon the foundational advantages of Arduino boards, while implementing specific enhancements to cater to the demands of robust industrial environments.

These enhancements include fortified interfaces, expanded inputs and outputs, protective casing against external elements, output current amplification through relays, and the incorporation of advanced connectivity options like Ethernet and WiFi.

2.4.1 Microcontroller Selection and Comparison

These industrial boards deploy microcontrollers such as the ATMega2560, ATMega328, or ATMega32U4. A comparative analysis of these microcontrollers reveals that the ATMega328P emerges as an optimal choice for several reasons. Rooted in AVR improved RISC architecture, this low-power CMOS 8-bit microcontroller achieves impressive throughputs of nearly 1MIPS per MHz. Its efficient execution of robust instructions in each clock cycle empowers system designers to harmonize power consumption with processing performance. With a Flash memory capacity of 32K Bytes, it strikes a balance between memory and performance.

2.4.2 Robust Connection Strategies

The industrial boards incorporate various connection strategies, including pins, screwless terminals, screw shields, and Tension-spring mechanisms. These diverse options allow for flexible and secure connections tailored to the specific needs of industrial setups. Housed within robust casings, these boards stand poised for operation, further fortified by compatibility with the Arduino IDE for programming.

2.4.3 Addressing Output Current

Addressing diverse power requirements, certain industrial boards employ relays to amplify their output current. These relays bolster the capability to supply higher currents. However, it's important to note that not all boards are equipped to provide substantial amperage, with some offering outputs of less than one ampere.

2.4.4 Voltage Regulation and Challenges

Voltage regulation poses a challenge, as microcontrollers are susceptible to damage when powered by voltages exceeding 20 volts. While none of the discussed boards operate with voltages exceeding this threshold, it remains a significant consideration for safe operation. Additionally, the industrial setting introduces vibrations that can adversely impact sensor readings and overall microprocessor efficiency. Despite this challenge, mitigating strategies aren't explicitly addressed in these designs.

2.4.5 USB Interface and Compatibility

Downloading applications onto the microcontrollers remains reliant on USB interfaces, with variations such as mini-USB, micro-USB, and type A/B connections. While USB interfaces remain standard, their integration must consider industrial environments' specific demands and potential challenges.

2.4.6 Integration with Industrial Sensors and Actuators

A crucial aspect is the compatibility of these boards with industrial sensors and actuators. Industrial components typically adhere to IEC standards, leading to a diverse range of current/voltage specifications and interfaces. These variances may not be directly compatible with microcontrollers and could necessitate additional hardware for seamless integration, potentially elevating costs.

2.4.7 General Benefits of Industrial Boards

As we delve deeper into the realm of microcontrollers and industrial automation, a critical juncture emerges-pitting the capabilities of ATMega microcontroller boards, exemplified by Arduino, against the established regularity of Programmable Logic Controllers (PLCs). This exploration seeks to elucidate the potential of harnessing Arduino as an industrial microcontroller, setting the stage for a comparative analysis that illuminates their respective strengths and weaknesses

Table 2.1 provided compiles comparative overview of the various specifications for each industrial board offers, encompassing aspects beyond just technical specifications.

These Arduino-based industrial boards try to bridge the gap between the versatility of Arduino and the demanding requirements of industrial sectors. While these boards present promising solutions, addressing challenges related to voltage regulation, vibration tolerance, and sensor compatibility is pivotal for ensuring a seamless and reliable transition to industrial applications.

The industrial boards described above were based on Arduino boards and have specific improvements over them, such as robust interfaces, many more inputs and outputs, a case to protect from the outdoor elements, relays to increase the output current, additional connections for ethernet, WiFi, and other things.

Table 2.1, lists also the benefits and drawbacks of each of the aforementioned designing boards by contrasting them and discussing what may be anticipated of such a board.

Comparing the outlined microcontroller boards, a common thread appears with each board utilizing a member of the ATMega family, including the ATMega 2560, ATMega 328, or ATMega32U4. Delving into their specifications, it becomes evident that the ATMega328P microcontroller stands as the most suitable choice due to several factors; it is operating as a low-power CMOS 8-bit microcontroller, it operates on the AVR enhanced RISC architecture. Its ability to execute potent instructions in a single clock cycle yields throughputs approaching 1 MIPS per MHz. This flexibility empowers system designers to tailor the device for optimal power consumption versus processing speed. Furthermore, its Flash memory capacity of 32K Bytes [85] enhances its capabilities. In terms of connectivity, the boards employ diverse mechanisms including screw shields, pins, screwless terminals, and click-on mechanisms. These implementations are accompanied by appropriate protective casings, while programming is facilitated through the Arduino IDE. Power considerations are varied among the boards. While some include relays to enhance output currents, others provide outputs with amperage levels typically lower than one ampere. However, one of them address a crucial issue related to rapid burning that occurs when a power supply exceeding 24 volts is applied - a scenario highlighted in voltage regulator data sheets [86].

Furthermore, the impact of vibration in industrial environments on sensor readings and microprocessor efficiency remains largely unaddressed across the board. Finally, the process of downloading programs to the microcontroller chips is standardized across these industrial boards, utilizing USB interfaces such as mini-USB, micro-USB, type A, and type B. It's important to note that the world of industrial sensors and actuators adheres to the IEC standard, often operating within specific current/voltage ranges and interfaces that may not seamlessly align with microcontrollers. This misalignment necessitates additional supporting hardware, and contributing to increased costs.

Table 2. 1: General specifications of Enhanced Industrial Board.

Item	Microcontroller	Power	Connection	Size	USB Type	Pros.	Cons.
M-DUINO58	ATMega2560	I=1.5A V=12-24 V	Push-in spring connection terminal	101×119.5×119.3	USB type B	Abundant communication interfaces, numerous I/O pins, includes screw shield	Lack of antivibration, low voltage tolerance, requires additional libraries
Iono Uno	ATMega328	I=12A V=12-24 V	Screw shield	160×115×63	Mini USB port	Robust construction, removable terminal blocks, wide compatibility	Limited I/O, large form factor, lacks antivibration features, low voltage tolerance
Controllino	ATMega 328 ATMega 2560	I=30A V=12V or 24V	Screw terminal	107×90×62	USB type A	High I/O current, diverse I/O types, suitable for different applications	Absence of antivibration features, low voltage tolerance, additional library requirements
Arduino Industrial 101	ATMega32U4	I= 130mA V=5V	Pins Header Connectors	51×42	micro-USB connector	Compact size, self-sufficient microprocessor	Requires further libraries, very low current and power, slower processing
Industruino	ATMega 1286 Or ATMega 32u4	I=6.5 A V=6.5-32V	DIN-rail mount, click-on mechanism	72 × 87 × 60	RS485 compatible half-duplex connection	Features 64-pixel graphic LCD, high power capability, secure click-on mechanism, better micro- controller in type (1286), has a better voltage tolerance.	Additional libraries needed, extra interface (RS485) requirement
Ruggiduino	ATMega328P	I=1.85A mAV=7-24V	Screw shield	86×68×23	USB B connector	Improved voltage tolerance, programmable via ICSP or bootloader	Enhanced protection from high power, extra (chips, diodes, and resistors), Low op power
Poposal	ATMega328P	I=5A V=12-30 V	Screw shield	103×106×20	ICSP	High voltage tolerance, high output power, endures harish environment, no extra components.	Need external programmer for reprogramming.

2.5 Classification Based on Architecture

In our exploration of industrial boards based on the Arduino framework, we identified three distinct categories:

1. Arduino with Additional Casing: This group encompasses the Arduino itself accompanied by enhancements like the Iono Uno, which offers extended protection by covering and more durability by utilizing screw shield terminals.
2. Uniform Microcontroller and Timing: The second group features boards like Controllino and M-Duino58, sharing only common microcontrollers, timers, and power attributes.
3. Diverse Microcontroller and Interface: The third category includes boards such as Industruino, Arduino Industrial 101 and Ruggiduino, employing similar principles but varying with different microcontrollers and distinct interfaces or even power supplies.

After presenting a range of improved industrial boards and their basic specifications, a detailed comparison was conducted. These boards were categorized based on their design, and the advantages and disadvantages of each were discussed. This led to the identification of areas for improvement, laying the groundwork for a proposal to develop a new and improved industrial board

2.6 System Design Consideration

In this thesis, we delve into the landscape of system design considerations, where a harmonious blend of electrical issues including (power and board programming interface) and mechanical issues including (wiring system mechanisms, vibration and case box) is meticulously orchestrated.

2.6.1 Electrical Aspect

During the usage of electronic devices, without fail, electrical problems will show up and can have an impact on performance and reliability, and some of them can damage the whole device, in a minor form, which will reduce the efficiency of the device.

DC voltage is supplied from a battery or power supply, power supply is designed to convert high-voltage AC mains electricity to a suitable low-voltage supply for electronic circuits and other devices. the power supply comes in two methods, the first one is by transforming, rectifying, filtering, and regulating an AC line voltage (TRFR), and the second one is by breaking the power supply down into a series of blocks, each of which performs a particular function. Both methods are commonly used in power supply design, and the choice between them depends on the specific requirements of the application, cost considerations, and the level of control and customization needed. The TRFR method is often used in linear power supplies, while the block-by-block approach is more common in switch-mode power supplies and other modern power supply designs, which we don’t need it here. So, the first method is the most suitable for supplying power to an electronic circuit with its micro size components.

In this side, choosing the best regulator is main issue in electronic industries. Electrical concept delves into Power concept and board programming interface concept, which are having the most effect on electronic microcontroller activity.

2.6.1.1 Power

Two primary issues often encountered are related to electrical power and voltage drops. Here, we delve deeper into these issues and explore how selecting the right voltage regulator can mitigate them effectively.

Electrical Power; the amount of power available directly affects the performance, functionality, and overall capability of devices and circuits. To put it simply, enhancing the available power can lead to significantly improve system operation and user experiences.

Voltage Drops; the drop voltage is the minimum voltage applied that regulator must have across it to sustain regulation, voltage drops which are common concern in electronic systems. These occur when there is a reduction in the supplied voltage as it flows through a circuit. Voltage drops can lead to an irregular behavior, reduced efficiency, and even malfunctioning of electronic components.

To address these issues, it's imperative to select a voltage regulator that can provide stable and reliable power to the system. Consider the SPX1117M3-L-5 voltage regulator, which is commonly used in the Arduino Uno.

Table 2. 2: SPX1117M3-L-5 and LD1084V5 Regulators Specifications.

No.	Parameter	SPX1117M3-L-5	LD1084V5
1	Vip	20V	30V
2	Vop	5V	5V
3	Vdrop	1.3V	1.5V@5A
4	Iop	0.8A	5A
5	PSRR	70dB/120Hz	72dB/120Hz
6	T	-40 °C to 125 °C	-40 °C to 125 °C

Table 2.2 provides detailed information about the specifications of the SPX1117M3-L-5 voltage regulator [87]. The SPX1117M3-L-5 voltage

regulator has a maximum input voltage (Vip) of 20V, providing a fixed 5V output voltage (Vop) and supporting a maximum continuous output current (Iop) of 0.8A. With a voltage drop (Vdrop) of 1.3V at 0.8A, it demonstrates good noise rejection (PSRR) with a value of 70dB at 120Hz. Operating within a wide temperature range (-40°C to 125°C), this regulator ensures stability and reliability in various environmental conditions. These specifications are crucial for effective power regulation and protection of electronic components, making careful selection essential for circuit design.

The LD1084V5 is a voltage regulator that offers promising specifications for industrial microcontroller boards showing in table 2.2 [86]. The LD1084V5 regulator is designed for industrial microcontroller boards, offering a safety margin with a maximum input voltage (Vip) of 30V, safeguarding electronic components from overvoltage. It maintains a stable 5V output voltage (Vop), crucial for reliable power supply to connected devices. Under a 5A load, it experiences a limited voltage drop (Vdrop) of 1.5V, requiring consideration of specific device requirements. With a high Power Supply Rejection Ratio (PSRR) of 72dB at 120Hz, it ensures a clean and stable output amidst input voltage fluctuations or noise. Operating within a wide temperature range (-40°C to 125°C), the LD1084V5 excels in various industrial environments, demonstrating versatility and durability.

The LD1084V5 regulator is a robust choice for industrial applications, offering excellent voltage regulation, current capacity, noise rejection, and resilience across a range of operating temperatures. These specifications make it a reliable solution for powering microcontroller boards in demanding settings.

2.6.1.2 Board Programming Interface

In microcontroller communication, the ATMega328, like the '328 variant, relies on TTL serial communication, lacking native USB support. To enable USB connectivity, an external USB to Serial Converter, such as the FT232, is necessary, interfacing with the ATMega328's UART pins and creating a virtual COM port on the PC. For microcontrollers with integrated USB capabilities, like the ATMega32u4, data transmission speeds are limited to around 1.5 Mbit/sec due to clock speed constraints, suitable for applications like keyboards or mice. Connecting an ATMega32u4 to a PC involves configuring its USB interface using libraries like LUFA or Arduino core, compiling firmware code with USB protocols like HID or CDC, and uploading it using a programmer or bootloader. Commonly used microcontroller models with integrated USB interfaces include ATMega16U4, ATMega32U4, At90USB1286, and At90USB1287, widely employed in various USB-based applications. For practical programming and configuration of AVR microcontrollers, the STK500 programmer is a valuable choice. Specifically designed for AVR Flash microcontrollers from Atmel Corporation, the STK500 serves as a comprehensive starter kit, facilitating code development, prototyping, and testing of new designs. Establishing communication with a PC via a USB port, the STK500 is compatible with a range of ATMEL AVR microcontroller variants and popular development environments like AVR Studio and WINAVR(GCC), enhancing its versatility in microcontroller development endeavors.

2.6.2 Robustness By Improving The Mechanical Aspect

Mechanism problems in Arduino refer to issues that can arise when building mechanical systems using an Arduino microcontroller. These issues can range from problems with the physical construction of the mechanism to problems with the software that controls the mechanism.

2.6.2.1 Vibration Resistance

Vibration is the study of oscillatory motions of an object or system, and can be caused by a variety of factors, including mechanical stress, the amplitude of a vibration is the maximum displacement of the object from its reference position. The effect of vibration is shown on the performance and safety of systems since it can cause significant damage to equipment and structures if not properly addressed. Vibration can be measured using accelerometers and vibrometers and can be analyzed using techniques such as frequency analysis and Fourier transforms [88].

Vibration transmission from the shaker to the tested electronic package is explained as the complex problem to solve. Some of the troubles may cause by vibration are: faulty connections, damaged components, or power supply problems; subsequently incorrect readings from sensors and ineffective processing at CPU [89].

It is a difficult task to define the general range of allowable vibrations. The frequency and damping ratios have an impact on how effectively an isolation (antivibration) system works. In the case of rubber components, it is vital to take into account the fact that, for an effect of identical force, strain will vary depending on the type of stress. Torsion, shear, and pressure can be applied to most elements. It is allowed for short-term traction loads to result from shock effects. Constant traction loads are not accepted. The effects of oil, grease, fuel, or other chemical compounds cannot be withstood by NR-based damping elements. Sheathing is necessary to safeguard these components.

Vibration isolation is the process of placing a piece of equipment and attaching it to the environment using isolating components in a way that ensures its proper operation and prevents any disturbances from into or out of the environment. Important conditions for the installation of vibration isolation is a perfect knowledge of the effect of disturbance, the dynamics of the machine, dynamic rigidity and the damping of support elements as well as reciprocal influences [90].

Machines with great moving masses, such as a compressor, for example, produce vibrations which can be transmitted to the structures of the building or cause annoying noise or breakage if there are no damping supports. Electrical control apparatus must be mounted onto a transport system. Isolation must be provided in order to prevent problems of electronic nature [90, 91].

Analysis of experimental data has verified that the most effective and simple methods for protection against vibration and hereby providing strength and reliability of enclosed electronic packages subjected to vibration, are: the installation or suspension on the fabric tape with dry friction damper for PCBs; and vibration isolation of the whole electronic package by using dry friction damper.

The anti-vibration mounts can divided depending on the application [92]:

1- Mobile Applications Engines, generators, compressor pumps.
2- Static applications: Engines, generators, hydraulic pumps and compressors.
3- Machine levelling mounts.
4- Rubber blocks and mats.
5- Bushings.
6- Bobbins & buffers.

When undertaking the selection of anti-vibration mounts to effectively mitigate undesired vibrations within an industrial microcontroller platform, a comprehensive assessment of several critical factors is imperative. The considerations governing this selection process encompass a spectrum of pivotal dimensions, each of which contributes to the ultimate choice of anti-vibration mounts. These considerations, grounded in engineering and vibration control principles, guide the selection process and are well-documented in the literature. Figure 2.4 represent different types of vibration mounts.

Type of Vibration Mounts; various categories of anti-vibration mounts have been established to cater to diverse vibration isolation requirements. Rubber mounts, characterized by their exceptional damping properties, are proficient in mitigating high-frequency vibrations and are available in a range of configurations, including cylindrical mounts, bushings, and pads [93].

Figure 2. 4: Different Types of Vibration Mounts.

Spring isolators, utilizing steel coil springs, excel in attenuating vibrations of lower frequencies and are often deployed in heavy machinery and equipment applications [94]. Air springs, relying on compressed air, offer superior vibration isolation capabilities, particularly for very low-frequency vibrations, and their stiffness can be adjusted as needed [95]. A different types of anti-vibration mounts could be used for different applications, we mention number of them [95].

1. Rubber Mounts; Comprised mainly of rubber, these mounts excel in damping high-frequency vibrations, making them suitable for various applications. Configurations include cylindrical mounts, bushings, and pads.
2. Spring Isolators; Utilizing steel coil springs, these isolators effectively dampen lower-frequency vibrations. They find frequent use in scenarios with heavy machinery, thanks to their robust load-bearing capacity.
3. Air Springs; Operating with compressed air, air springs provide superior vibration isolation, especially for very low frequencies. Their load-carrying capabilities are robust, and stiffness levels can be conveniently adjusted.
4. Combination Mounts; Combining materials like rubber and metal springs, these mounts offer a hybrid solution balancing damping and load-bearing capacity. Their versatility allows customization for specific applications, requiring careful consideration during selection.

Combination mounts, blending diverse materials such as rubber and metal springs, provide a versatile solution that strikes a balance between damping and load-bearing capacity. This hybridization affords the adaptability to tailor these mounts to suit specific applications, and the selection of anti-vibration mounts necessitates a meticulous consideration like: frequency of vibration

[96], load capacity [97], environmental conditions [98], cost and maintenance [99], customization [100], and performance testing.

2.6.2.2 Wiring Interface Mechanism

The Wiring System is a versatile device used for converting connections into connectors, allowing for the easy wiring of devices or circuits. This system is employed in various applications and its selection depends on specific service requirements such as durability, safety, appearance, cost, accessibility, and maintenance cost [101]. By converting connections to connectors, it becomes possible to connect and disconnect devices using just the hands or basic tools. One of the common applications for the Wiring System is in printed circuit boards (PCBs) and control cabinets. PCB connectors typically consist of two main components: the header, which is soldered to the PCB itself, and the connector [102]. These connectors are crucial for establishing connections between conductors and printed circuit boards, facilitating the transmission of signals, data, and power. The choice of PCB connectors is influenced by several advantages they offer [103], including:

1. **Compact Design**; PCB connectors are designed to be space-efficient, making them ideal for applications with limited space.
2. **Multi-level Connectors**; these connectors can provide multiple levels or layers for connecting various components, which is especially useful in complex circuitry.
3. **Innovative Locking Systems**; many PCB connectors incorporate innovative locking mechanisms to ensure secure connections, preventing accidental disconnection.

4. **Versatile Combination Possibilities;** PCB connectors offer flexibility in combining various types and sizes of connectors to meet specific needs.
5. **Reliable Panel Feed-throughs**; They provide dependable feed-throughs in control cabinets and other enclosures, ensuring consistent performance.

The Wiring System categorizes connection technologies based on these advantages and their suitability for different applications. In the context of industrial connector units for programmable logic controllers (PLCs), the main types of terminal block conversion units are as follows:

1. **Terminal Blocks with Push-in Connection System**; these terminal blocks allow for quick easy and tool-free wire insertion using a push-in mechanism, simplifying the wiring process [104].
2. **Terminal Blocks with Screw Connections**; screw-type terminal blocks offer a secure connection through the tightening of screws, ensuring a stable electrical connection [105].
3. **Terminal Blocks with Tension-spring Connection**; these terminal blocks utilize tension springs to secure wires, providing a reliable and vibration-resistant connection [106].
4. **Screw Shield With Headers Terminals and Connectors**; these connectors offer various connection options, including screws and pins connections, providing flexibility for different PCB layouts and requirements [107, 108].
5. **Pin Header Connectors;** pin header connectors are used for making connections between PCBs and other electronic components, this category providing flexibility for different PCB layouts and requirements [107, 108].

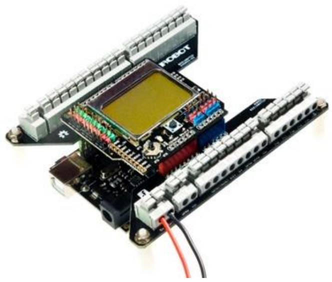
6. **Housings**; housings are used to enclose and protect electronic components, ensuring their safety and functionality in different environments. They can be designed to be dustproof, waterproof, and/or explosion-proof [109].

Using a screw terminal block instead of another kind of connection has the following advantages:

This kind is small and suitable for usage in confined locations. as opposed to push-in connections. A screw terminal block with a diameter of about 5 mm may be soldered onto a circuit board with ease; it also contains side tabs for simple clipping together of several blocks. These connections are most often perfect for electrical purposes. The retention screw is also included to prevent unintentional release of the wires. This makes it a necessary tool for any task requiring the attachment of cables and wires.

This type of wiring is essential for establishing connections with other devices. However, when it comes to components within the same device, such as a WiFi shield or Ethernet shield, it is preferable for them to be integrated into the microcontroller board's enclosure. In such instances, a pin header proves beneficial. Alternatively, if consolidating all wires at a single exit or entry point is desired, a housing solution can be highly suitable. Figure 2.5 illustrates specific terminal blocks within the wiring system. These include:

- **a: Push-in Terminal Block**
- **b: Screw Terminal Board**
- **c: Terminal Block with Spring**
- **d: Screw Shield With Headers**
- **e: Pin Header Connectors**

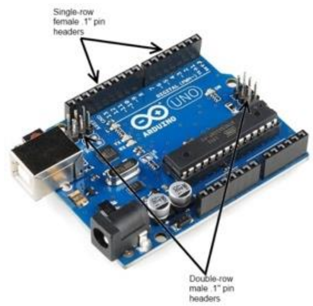


a: Push-in Terminal Block

b: Screw Terminal Board

c: Terminal Block with Spring

d: Screw Shield With Headers



e: Pin Header Connectors

Figure 2. 5: Terminals Blocks Types.

2.6.3 CASE for Outdoor Application of Microcontroller Platform

In the context of outdoor applications for microcontroller platforms, CASE (Casing, Assembly, and Sealing Equipment) refers to specialized enclosures and protective systems designed to house microcontroller-based electronic systems and sensors in outdoor environments. These cases are crucial for ensuring the reliable and long-term operation of microcontroller platforms in harsh outdoor conditions.

Key considerations and features of CASE for outdoor applications of microcontroller platforms include:

1. **Environmental Protection**: Outdoor CASEs are designed to protect microcontroller platforms from environmental factors such as moisture,

dust, dirt, rain, snow, and exposure to UV radiation. They typically feature robust seals and gaskets to prevent water and dust ingress.

2. **Temperature Resilience**: These enclosures are built to withstand a wide range of temperatures, from extreme cold to high heat, to ensure that the enclosed microcontroller and sensors continue to function accurately.
3. **Physical Durability**: Outdoor CASEs are constructed to be rugged and impact-resistant, offering protection against physical shocks, accidental damage, and vandalism.
4. **Corrosion Resistance**: Many outdoor CASEs are made from materials that resist corrosion, such as stainless steel or weather-resistant plastics, to ensure their longevity in challenging outdoor environments.
5. **Mounting Flexibility**: These enclosures often provide multiple mounting options, including wall mounting, pole mounting, or integration with equipment racks or structures.
6. **Ventilation and Cooling**: Some outdoor CASEs incorporate ventilation systems or fans to manage temperature and humidity levels within the enclosure, preventing overheating of microcontroller platforms and sensors.
7. **Security Measures**: Depending on the application, outdoor CASEs may include security features like lockable covers, tamper-evident designs, or even security cameras to protect the enclosed microcontroller-based systems.

2.7 Proposal for Developing an Industrial Board Prototype

Based on our assessment of the results of earlier studies, we proposed a new prototype with the combination of best features, as shown also in Table 2.1. In the followings, the proposed improvements are discussed briefly.

1. To start, the platform starts to burn when we give more than 20 volts of power. To solve this problem, we may install a different voltage regulator that can handle more than 20 volts while producing a consistent output voltage of 5 volts.

2. Secondly, the anti-vibration mechanism, which may be resolved in a number of ways, one of which is by employing dry friction dampers.

3. The third issue is with the wiring system mechanism. The wiring system used will be greatly influenced by the sorts of services needed, such as (Durability, Safety, Appearance, Cost, Accessibility, Maintenance Cost). However, screw terminal shield is a superior option for industrial boards.

4. The fourth issue is while one of the most favored benefits of PLCs is that no one can modify the software since reprogramming them is difficult, employing an external programming tool connected by ICSP, capable of understanding C, and able to work with the Arduino IDE through a bootloader is a wise option for developing industrial prototype boards. If we wish to program without the Arduino IDE environment, it would be very useful where debugging was possible and there was freedom from unneeded libraries. The removal of the USB interface and USB connection, which need an additional microprocessor like the ATMega32U4 in the Arduino board, will result from this.

These are the primary problems that our proposed prototype of an industrial board based on the ATMega328P microcontroller, which is a potential extractor of analysis for explained made industrial boards, would attempt to address.

2.8 Summary

In Chapter Two, an extensive literature review on ATMega microcontroller boards is conducted, examining the development of an industrial ATMega microcontroller platform and innovations in ATMega microcontrollers. The review explores the ATMega328P microcontroller, detailing its applications in industrial automation. A comprehensive comparison between microcontrollers and PLCs is presented, alongside criteria for selecting an industrial board.

The chapter delves into the exploration of industrial boards based on ATMega microcontrollers, including a comparative analysis covering microcontroller selection, robust connection strategies, addressing output current, voltage regulation challenges, USB interface compatibility, and integration with industrial sensors and actuators. General benefits of industrial boards are discussed as well.

Furthermore, the literature review encompasses the classification based on architecture, system design considerations, and an in-depth examination of electrical and mechanical aspects. The chapter concludes by proposing the development of an industrial board prototype, setting the stage for practical implementation and testing in Chapter Three.

Chapter Three

Methodology

Chapter Three: Methodology

3.1 Introduction

The researchers' main goal is to improve the effectiveness of the systems and their efficiency hoping to produce a kind of comfort for humans.The creation of complex devices like this prototype of industrial microcontroller platform necessitates a well-structured methodology. This chapter shows the systematic steps that underpin the entire design process of our system which named “Kerduino” according to (Kerbala-Arduino). The phases that Kerduino platform passed through and the fabrication process will be shown subsequently.

The following sections explore the intricate process by which every aspect of system design is considered and integrated. These considerations are the base upon which the Kerduino Microcontroller is built, maximizing the performance and a long-lasting service.

In the System Design Implementation section, the framework of Kerduino contains a range of components and equipment, purposefully designed to make Kerduino not only functional but adaptable to a wide range of applications. It provides a structured and robust platform for users to explore and harness the full potential of this microcontroller system. The Kerduino Microcontroller transcends its status as a mere product; it's a testament to precision engineering. This chapter explores Kerduino's methodology and system design.

3.2 Methodology of the Kerduino Board Design

The Kerduino industrial microcontroller platform is developed through a systematic approach to achieve an optimal design, minimizing repetitive iterations and saving time/resources. The key phases as represented in Figure 3.1 include:

Study Former System Impairments; Analyze previous industrial microcontroller systems to learn from limitations and weaknesses.

Define Microcontroller Specifications; Based on the study, outline the functionalities, performance benchmarks, and key features of the proposed Kerduino Microcontroller.

Develop Proof-of-Concept (POC) Prototype; Create an initial prototype to evaluate the concept's effectiveness in addressing the intended problem, using readily available components.

Choose Manufacturing Components; Select essential components based on functionalities and intended retail price, creating an initial Bill of Materials (BOM).

Design Schematic Circuit and PCB; Develop a detailed schematic diagram illustrating component interconnections, followed by designing the Printed Circuit Board (PCB) using specialized software.

Implement Proposed Board; Engineers collaborate to design the microcontroller's hardware, software, and additional components, distinguishing it from the initial POC prototype.

Measure Board Performance; Rigorous testing and assessment protocols are employed to evaluate the microcontroller's capabilities against predefined specifications.

Develop Custom Enclosure 3D Model; Create a 3D model for custom plastic components, including the enclosure, using software like Solidworks. Prototypes are crafted using 3D printing, CNC machining, or urethane casting.

By following this methodology, the aim is to create an innovative microcontroller solution that minimizes trial and error, accelerates development, and delivers a robust, efficient microcontroller addressing industrial challenges in the modern technological landscape.

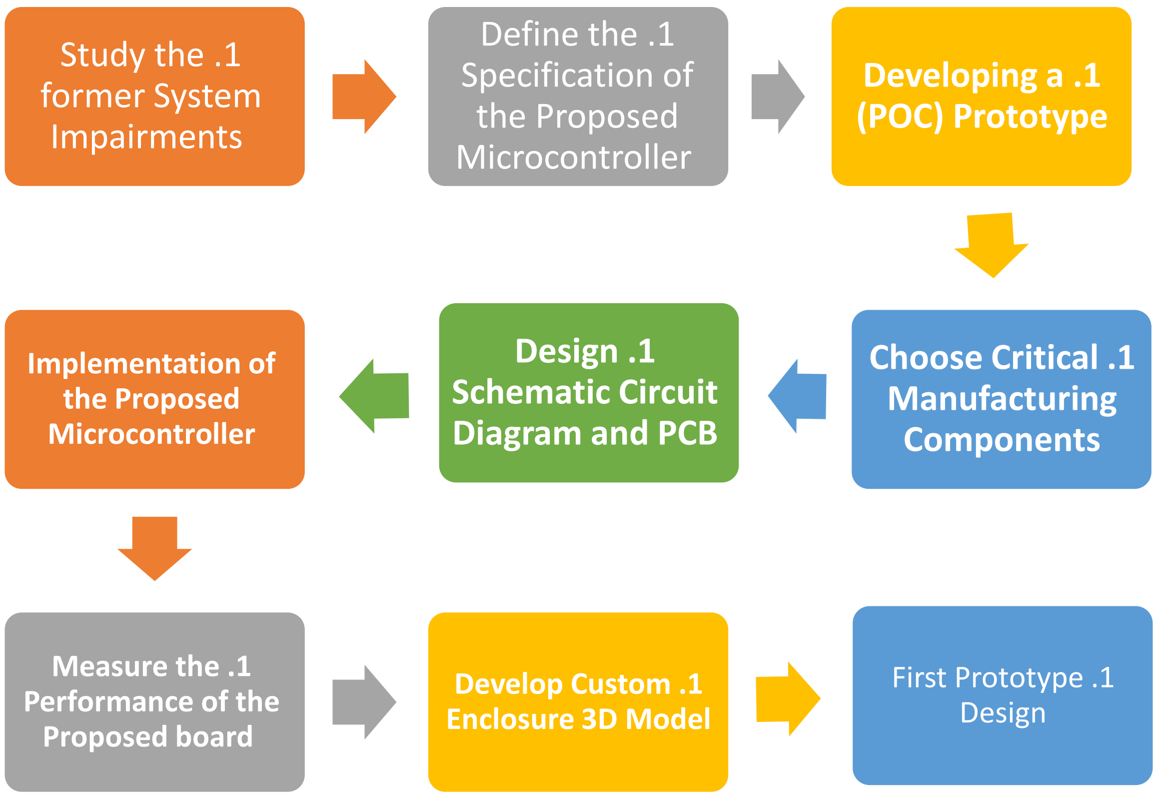


Figure 3. 1: Methodology Steps for Kerduino Microcontroller Design.

3.2.1 CASE for Outdoor Application of Microcontroller Platform

In the context of outdoor applications for microcontroller platforms, CASE (Casing, Assembly, and Sealing Equipment) refers to specialized enclosures and protective systems designed to house microcontroller-based electronic systems and sensors in outdoor environments. These cases are crucial for ensuring the reliable and long-term operation of microcontroller platforms in harsh outdoor conditions.

Key considerations and features of CASE for outdoor applications of microcontroller platforms include:

8. **Environmental Protection**: Outdoor CASEs are designed to protect microcontroller platforms from environmental factors such as moisture, dust, dirt, rain, snow, and exposure to UV radiation. They typically feature robust seals and gaskets to prevent water and dust ingress.
9. **Temperature Resilience**: These enclosures are built to withstand a wide range of temperatures, from extreme cold to high heat, to ensure that the enclosed microcontroller and sensors continue to function accurately.
10. **Physical Durability**: Outdoor CASEs are constructed to be rugged and impact-resistant, offering protection against physical shocks, accidental damage, and vandalism.
11. **Corrosion Resistance**: Many outdoor CASEs are made from materials that resist corrosion, such as stainless steel or weather-resistant plastics, to ensure their longevity in challenging outdoor environments.
12. **Mounting Flexibility**: These enclosures often provide multiple mounting options, including wall mounting, pole mounting, or integration with equipment racks or structures.
13. **Ventilation and Cooling**: Some outdoor CASEs incorporate ventilation systems or fans to manage temperature and humidity levels within the enclosure, preventing overheating of microcontroller platforms and sensors.
14. **Security Measures**: Depending on the application, outdoor CASEs may include security features like lockable covers, tamper-evident designs, or even security cameras to protect the enclosed microcontroller-based systems.

3.3 System Design Implementation

The General Framework of Kerduino encompasses a comprehensive set of components and equipment that form the foundation of this microcontroller system. This framework is designed to facilitate the development and functionality of Kerduino, providing a structured and robust platform for various applications. Here is an overview of the key components and their roles within the Kerduino framework:

1. ATMega 328P; this microcontroller serves as the brain of the Kerduino system. It processes instructions and data, controls input and output devices, and executes programmed tasks.
2. LD1085 Voltage Regulator; the LD1085 voltage regulator plays a critical role in stabilizing the power supply to ensure a consistent voltage level for the microcontroller and other components, preventing voltage fluctuations that could lead to malfunction or damage.
3. Resistors (1k); these resistors are used in various parts of the circuit to limit current, divide voltage, or perform other tasks related to signal conditioning, protection and control.
4. Capacitance (22pf); capacitors with a capacitance of 22pf are employed to filter and stabilize high-frequency signals, ensuring a smooth and noise-free operation of the microcontroller.
5. Capacitance (100nf); these capacitors, often referred to as decoupling capacitors, are strategically placed throughout the circuit to reduce electrical noise and maintain stable voltage levels, particularly during rapid changes in current.
6. Capacitance (47µf); capacitors with a capacitance of 47µf are typically used for energy storage and filtering purposes, providing a reservoir of electrical charge and smoothing out voltage fluctuations.

7. ICSP (In-Circuit Serial Programming) Interface; the ICSP interface facilitates the programming and debugging of the microcontroller while it is still connected to the circuit, enabling efficient development and testing of software.
8. 16k Crystal; the crystal oscillator provides precise timing signals to the microcontroller, ensuring accurate execution of instructions and synchronization with external devices.
9. LEDs (Light-Emitting Diodes); LEDs are often used for visual feedback, status indication, or user interface elements. The Kerduino framework incorporates two LEDs for these purposes.
10. Screw Shield; a screw shield is a convenient external ends panel that simplifies the connection of various sensors, actuators, and external components to the microcontroller, enhancing the system's reliability and ease of use.
11. Pins; these are typically female header pins used for connecting extra wires, cables, or components which are nearby to the microcontroller and other parts of the circuit.
12. Diode; diodes are semiconductor devices that allow the flow of current in one direction while blocking it in the other. They can be used for tasks such as voltage regulation, signal rectification, or protection against reverse voltage.
13. Push Button; push buttons serve as user interface elements or input devices, allowing users to trigger specific actions or functions (here for restart action) within the Kerduino system.

The combination of these components within the Kerduino framework forms an adaptable microcontroller system. Depending on the specific application or project requirements, additional sensors, actuators, communication modules, and software can be integrated into this framework to create customized solutions for various tasks and functionalities. The General Framework of Kerduino provides a solid foundation for both beginners and experienced developers to explore and innovate within the realm of microcontroller-based projects.

The schematic design, PCB design, system programming and case printing are discussed in a comprehensive manner in following subsections until the final shape of the implemented proposal prototype.

3.3.1 Schematic Design

By using Fritzing program, version 9.4, the first prototype is implemented. The design is done with the simplest type of microcontroller board. The equipment installed on the board and connected together according to the datasheet of the three chips: ATMega328P microcontroller, ICSP and regulator, the result is shown in the Figure 3.2.

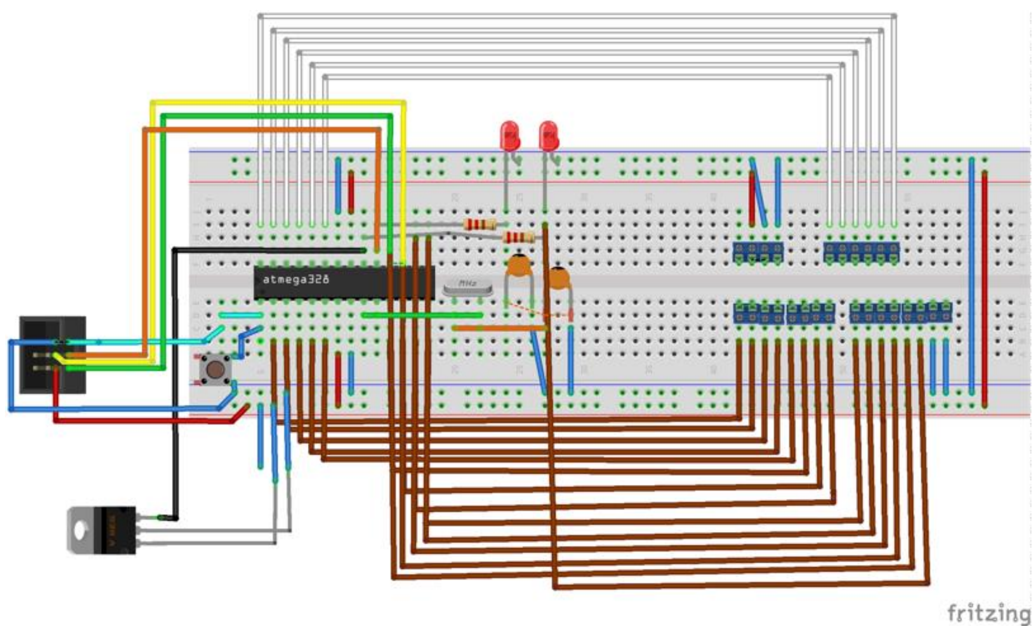


Figure 3. 2: Breadboard Connection.

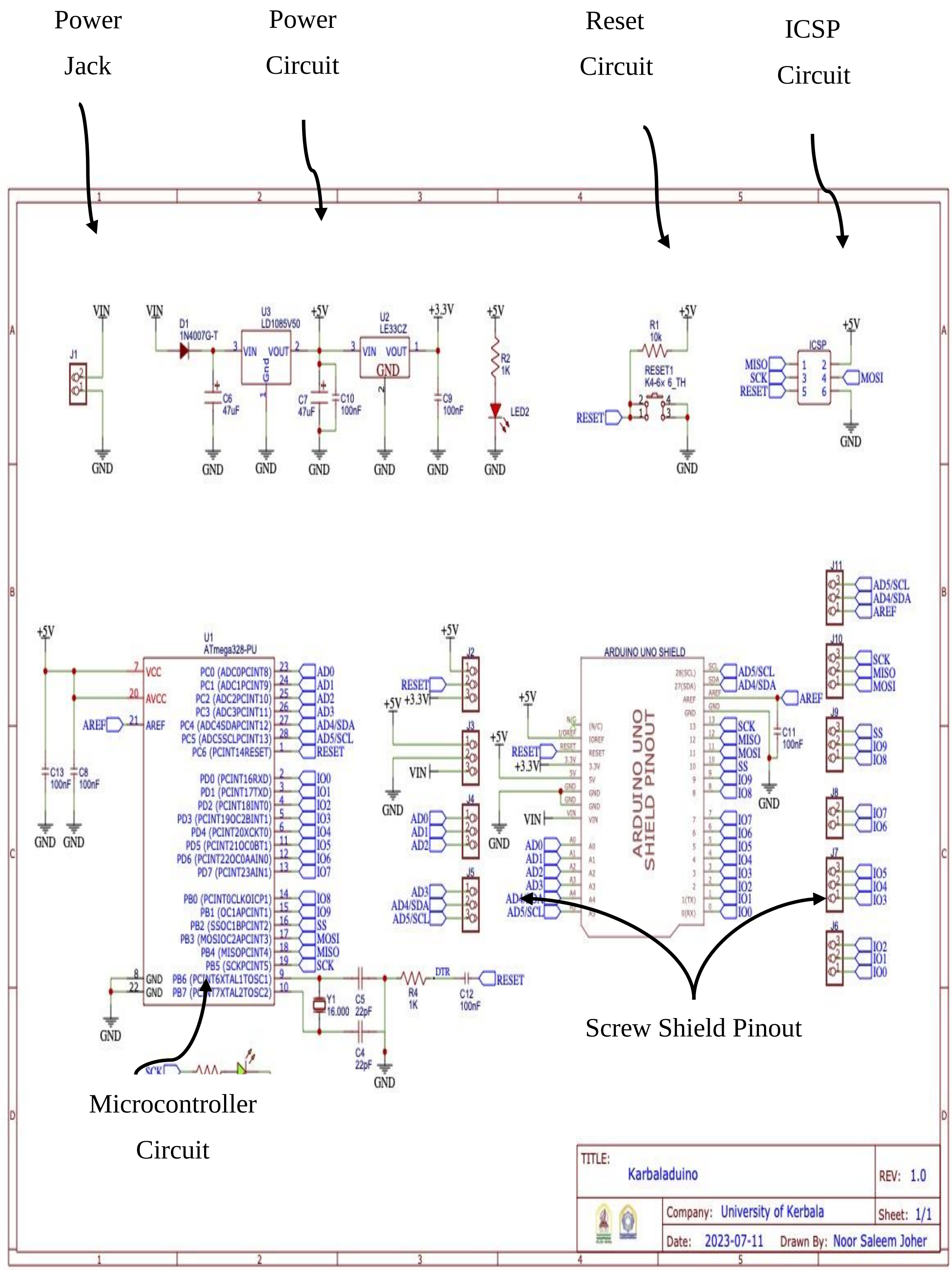


Figure 3. 3: Schematic Design.

Figure 3.3 in the context of the proposed microcontroller system provides a schematic representation that offers a detailed insight into the various key components and circuits that make up the overall microcontroller framework. Each item in this schematic diagram plays a crucial role in the functionality and operation of the microcontroller. Here is an explanation of the components listed in Figure 3.3:

1. **Power Jack**; represents the input port through which an external power source, such as a DC adapter or battery, is connected to supply power to the microcontroller system. It serves as the primary power input point.
2. **Power Circuit**; encompasses the components and connections responsible for regulating and distributing power within the system. It includes voltage regulator, capacitors, diode and any other elements required to maintain a stable and suitable power supply for the microcontroller and connected devices.
3. **Reset Circuit**; designed to control the reset functionality of the microcontroller. It typically includes a reset button that allow users to reset the microcontroller to its initial state when necessary.
4. **ICSP Circuit (In-Circuit Serial Programming)**; facilitates the programming and debugging of the microcontroller while it remains connected to the circuit.
5. **Microcontroller Circuit**; represents the core microcontroller unit, often denoted by the microcontroller's symbol or name. It embodies the ATMega 328p microcontroller and its internal connections, such as input/output pins and communication interfaces, which are integral to the system's operation.
6. **Screw Shield Pinout**; The screw shield pinout illustrates the arrangement of pins and connectors on the screw shield component. This configuration

simplifies the process of connecting external devices to the microcontroller by providing a clear pinout layout.

Figure 3.3 serves a valuable resource for both designing and troubleshooting the microcontroller circuit, ensuring that all elements work together harmoniously to achieve the desired functionality and performance.

3.3.2 PCB Design

The design of power lines and grounding in electronic circuit boards, often referred to as PCBs (Printed Circuit Boards). The provided text discusses two key aspects of PCB design: power lines and PCB grounding.

1. **Power Lines**; power lines on a PCB are designed to deliver electrical power from a voltage regulator to various components on the board. The text mentions that these power lines are made with a suitable format and are designed with a larger size when the application requires handling high current.
   - Suitable Format; the term "suitable format" implies that the layout and width of these power lines are chosen based on the specific requirements of the application. This could include considerations for voltage drop, current-carrying capacity, and heat dissipation.
   - Handling High Current; in applications where a high current is required, it's essential to use power lines with a larger cross-sectional area. Larger lines have lower resistance and can efficiently carry higher currents without overheating or voltage drop issues.
   - Thin Lines for Low Current: Conversely, the text mentions that thin lines may be used for conducting low currents, specifically around 20mA. This is an efficient use of resources since thinner lines are

adequate for low-power components and reduce unnecessary material usage on the PCB with saving space.

2. **PCB Grounding**; PCB grounding refers to the practice of establishing a stable electrical connection between various ground points on the board. The text indicates that this grounding is done using the "common ground plane" method, which is chose over number of grounding methods according to its specific features as will be shown here while presenting the reasons of using this method in PCB grounding.
   - Simplify Connection; in the common ground plane method, a large portion of the PCB, especially the unused or free space, is covered with a continuous ground plane. This ground plane is a conductive layer that connects all ground points on the PCB.
   - Thermal Characteristics Improvement; the presence of a ground plane can improve the thermal characteristics of the PCB. It helps dissipate heat generated by active components and prevents localized overheating, which can affect the performance and reliability of electronic devices.
   - EMI Reduction; additionally, the common ground plane serves as an effective shield against electromagnetic interference (EMI). It prevents unwanted electromagnetic emissions from the PCB, which can interfere with nearby electronic components or devices.

Figure 3.6, which illustrates the PCB design described, showcasing how power lines, ground planes, and components are laid out on the board. Hardware Implementation

In this section, the initial prototype is introduced, with Figure 3.3 in section 3.4.1, illustrating how to assemble the parts till the desired board is obtained. Arriving to the final design, shown in figure (3.9), is a culmination of comprehensive design considerations aimed at addressing inherent design challenges.

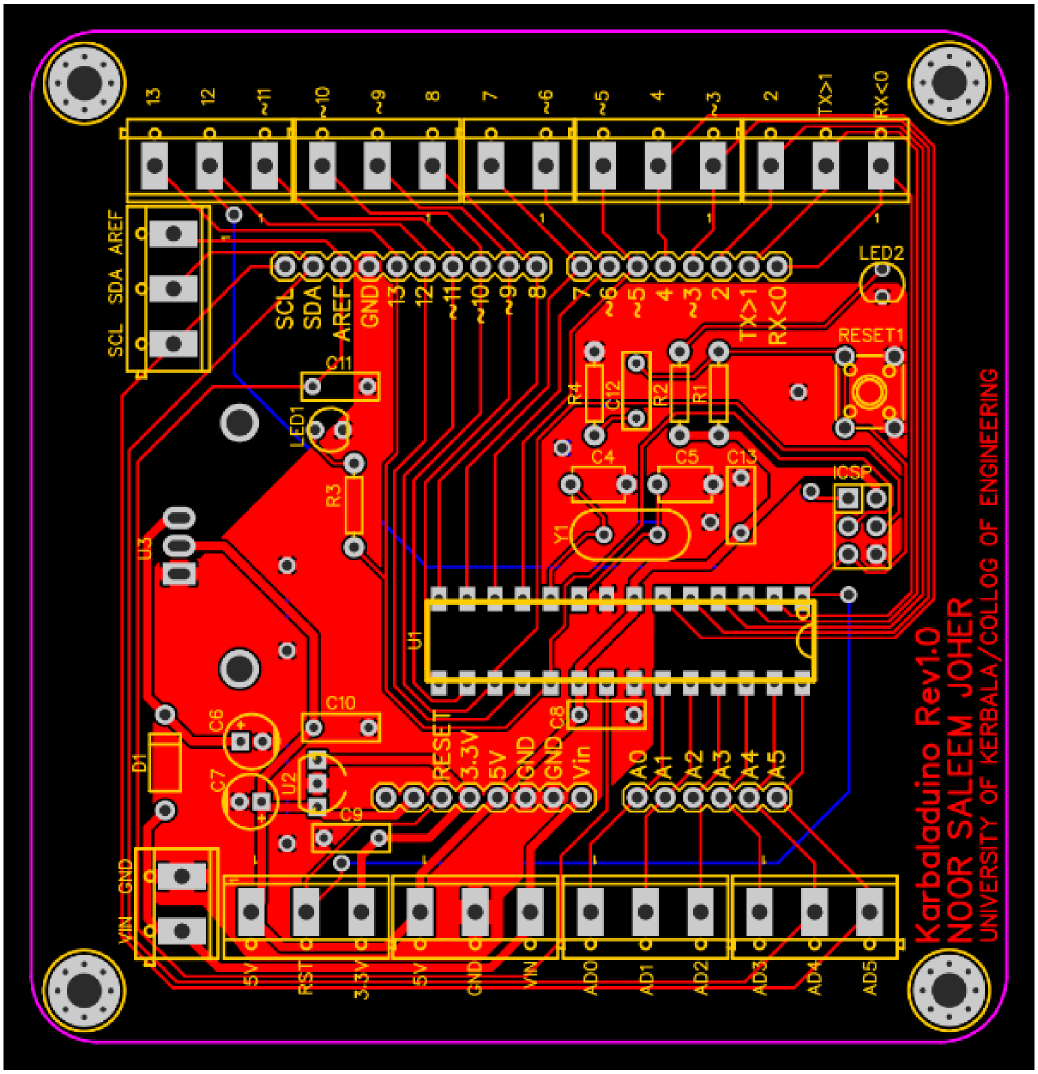


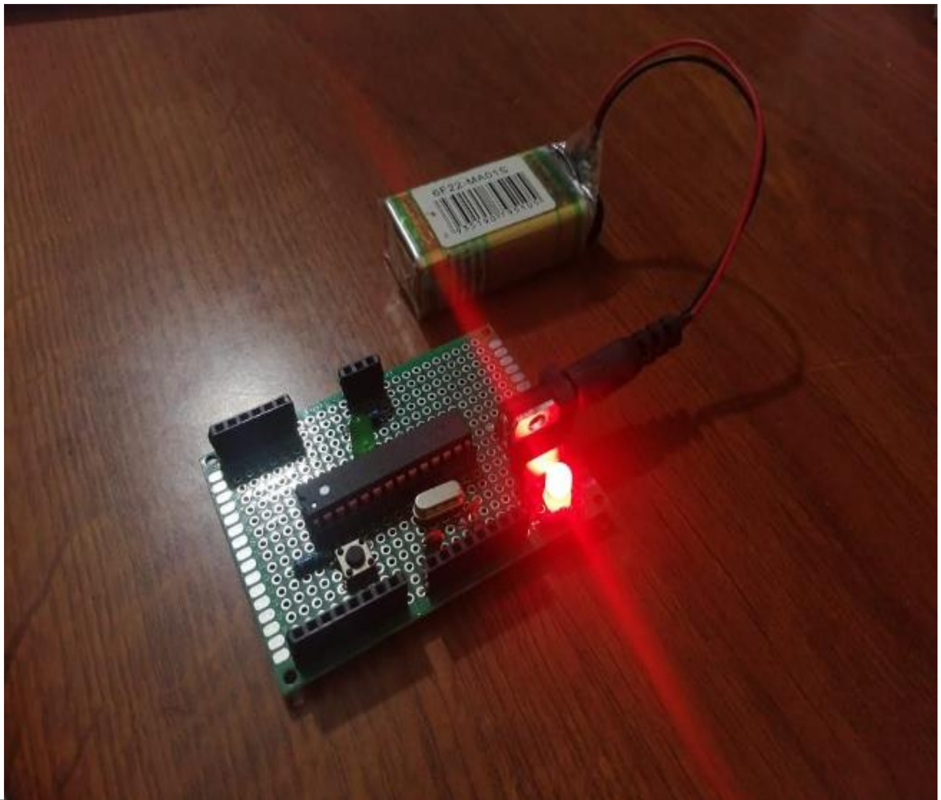
Figure 3. 4: PCB Design.

3.3.3 Kerduino Prototype

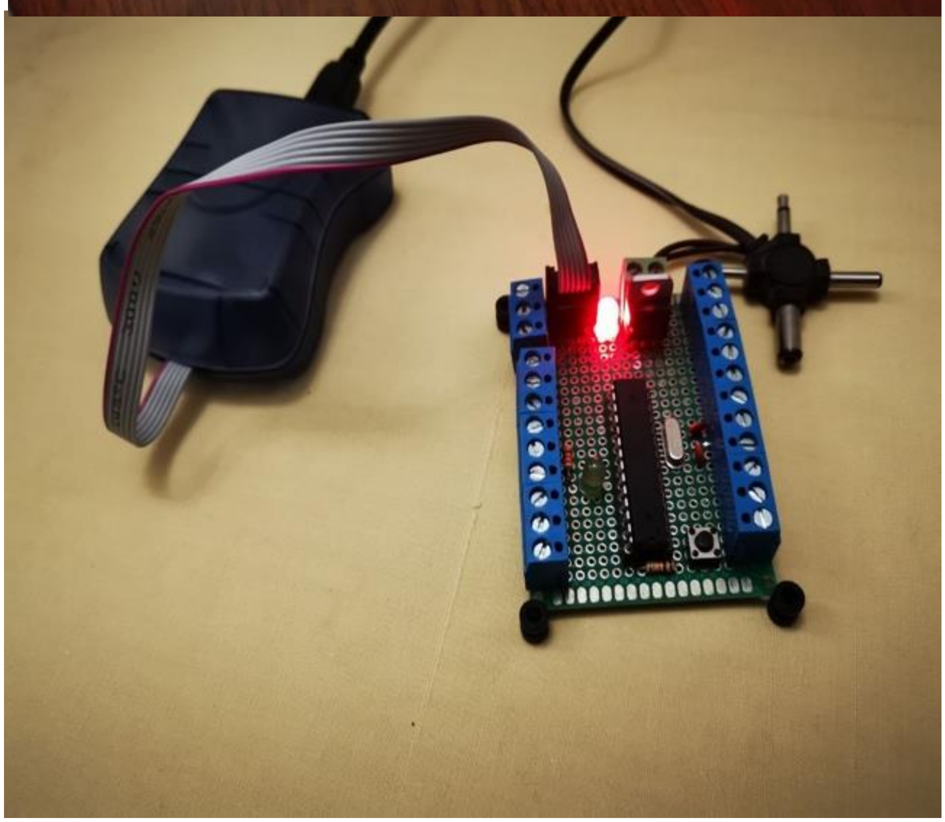
The hardware implementation is done with the following steps, featuring the integration of the ATMega328P microcontroller equipped with 28 pins. As depicted in Figure 3.3, the power supply input is initially routed through a diode before proceeding to the regulator, subsequently undergoing filtration to attain a precise 5-volt output. This regulated 5-volt supply serves as the primary power source for the microcontroller's operation. Capacitors have been strategically incorporated into this design to facilitate the smoothing of current, ensuring that it does not exceed 5 amperes. Additionally, a 16-megahertz crystal oscillator has been employed to support real-time processing. Furthermore, the inclusion of three 1-kilohm resistors connected in series serves a protective function within the circuit. While the push button is used as restart button. The red LED means receive power from Vin, while the green LED is connected on pin 13 in the board as like as Arduino board, to get a test sketch that could use to verify basic functionality.

Many experiments done until reached the final result of the board. The early application has done with bread board for simulating the regular Arduino board with the available equipment shown in figure 3.5.a. After that we use our equipment that we selected after making searches and demanding the unavailable ones from global markets on zero PCB board shown in figure 3.5.b.

More detailed photos for these implemetation phases are in Appendix I. The printed board phase is also done in more than one attempt. The first one is done by us with copper clad laminate sheet FR-4 and PCB etching solution with UV curing paint solder mask shown in figure (3.6.a). Second one is a local industry, the used material for PCB is FR-4, with CNC machine shown in figure (3.6.b). The last one is for more professional industry with efficient paints and better material and more accurate connection lines, its done in China workshop shown in figure 3.7 and there is a procedure for this online ordering for interest put in Appendix II.



a: First simulating prototype.



b: Proposed prototype.

Figure 3. 5: PCB Design.

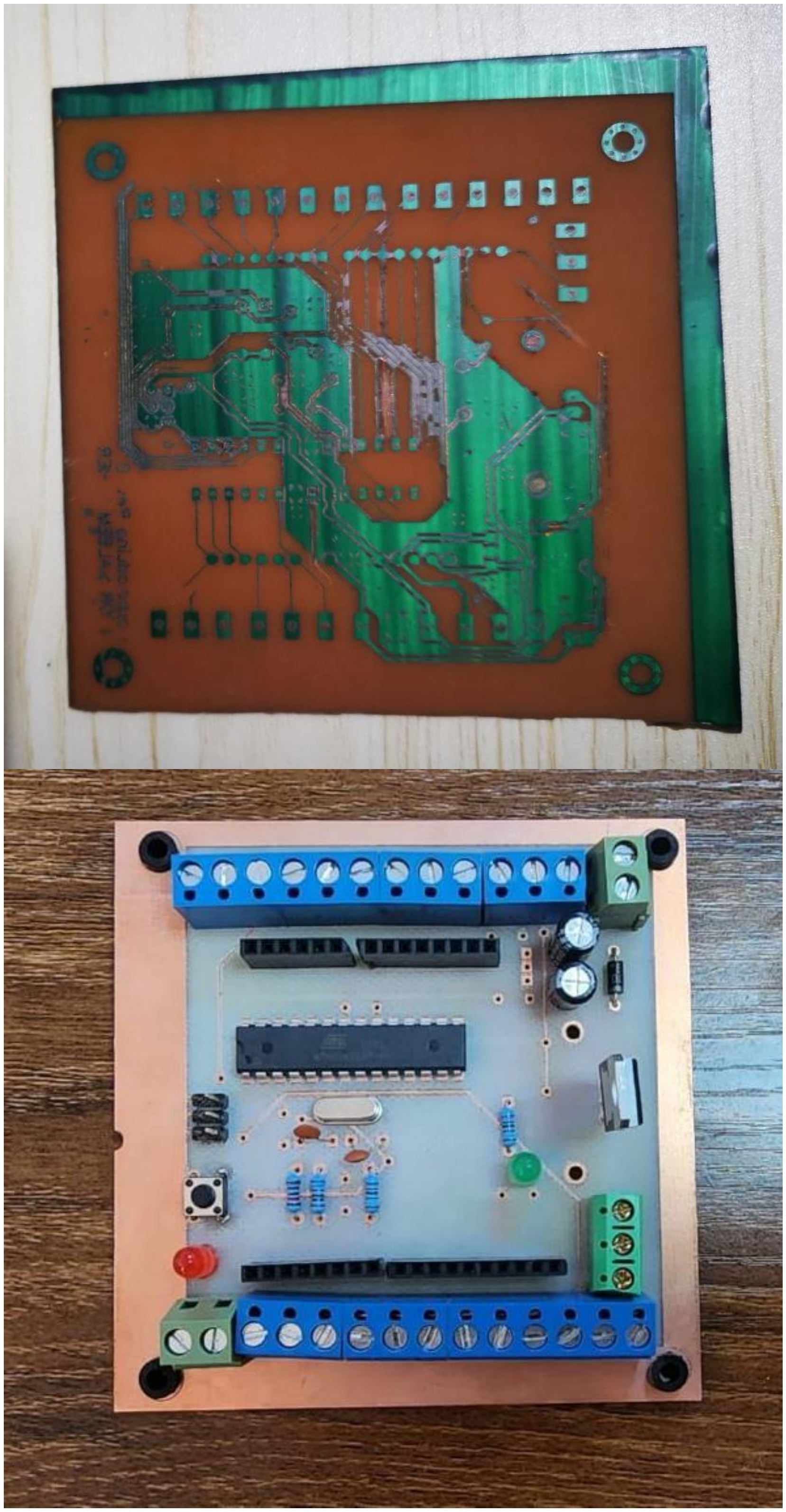


Figure a, First attempt

Figure b, Second attempt

Figure 3. 6: Kerduino first prototypes.

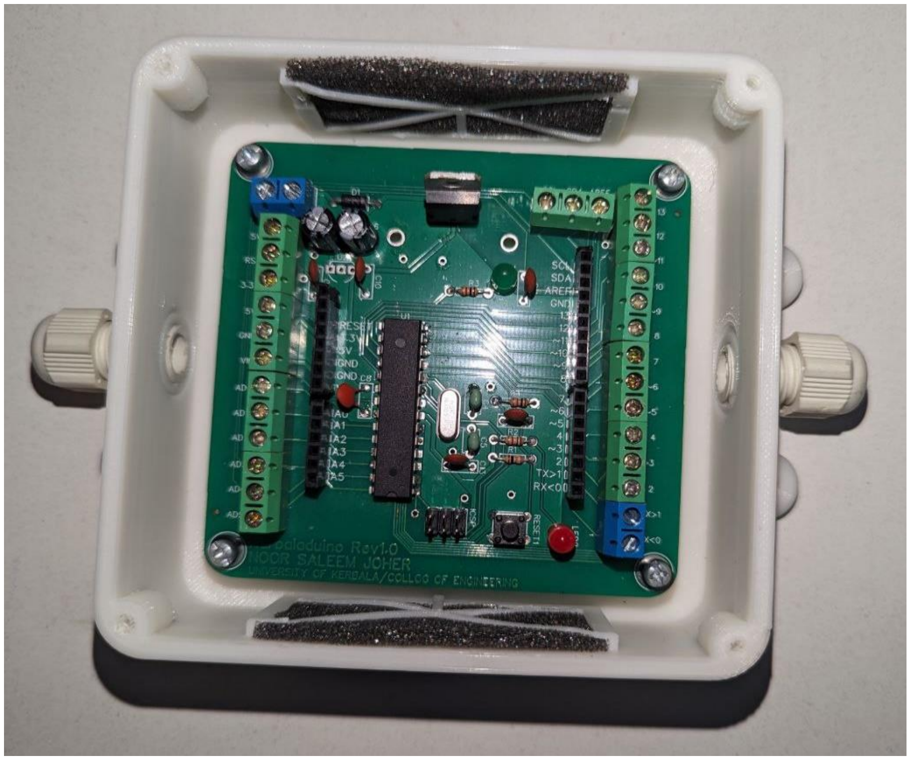


Figure 3. 7: Final Prototype for Kerduino.

3.3.4 Programming

Using the STK500 with ATMega microcontrollers involves employing the STK500 programmer to program, configure, and work with ATMega microcontroller-based projects. The STK500 offers advanced programming control, compatibility with various ATMega models, and versatile capabilities, making it a valuable tool for microcontroller development. Whether in programming, debugging, or customizing the microcontroller projects, the STK500 can enhance controlling and flexibility in working with ATMega microcontrollers.

The most important issue for using STK500 in programming for the industrial board rather than the built-in programmer, is possibility in using different IDE environment, like AVR Studio or WINAVR(GCC) beside Arduino IDE. This give the designer freedom in choosing the simple Arduino available sketches, or for more complicated programming by C language in other environments. The features in using an external programmer is reducing the cost, while there is no need for multitude reprogramming in industrial microcontrollers, and this could reduce program tampering problem, thus, it gives more space in memory for software, and more space on board for hardware.

Arduino IDE Environment

Utilizing the Arduino IDE with the STK500 for ATMega microcontroller programming eliminates bootloader dependency. It ensures robust and customized programming, streamlines development, offers debugging capabilities, and grants low-level access. This support is essential for custom hardware projects, widening the application range from embedded systems to robotics, enhancing control, versatility, and reliability in development.

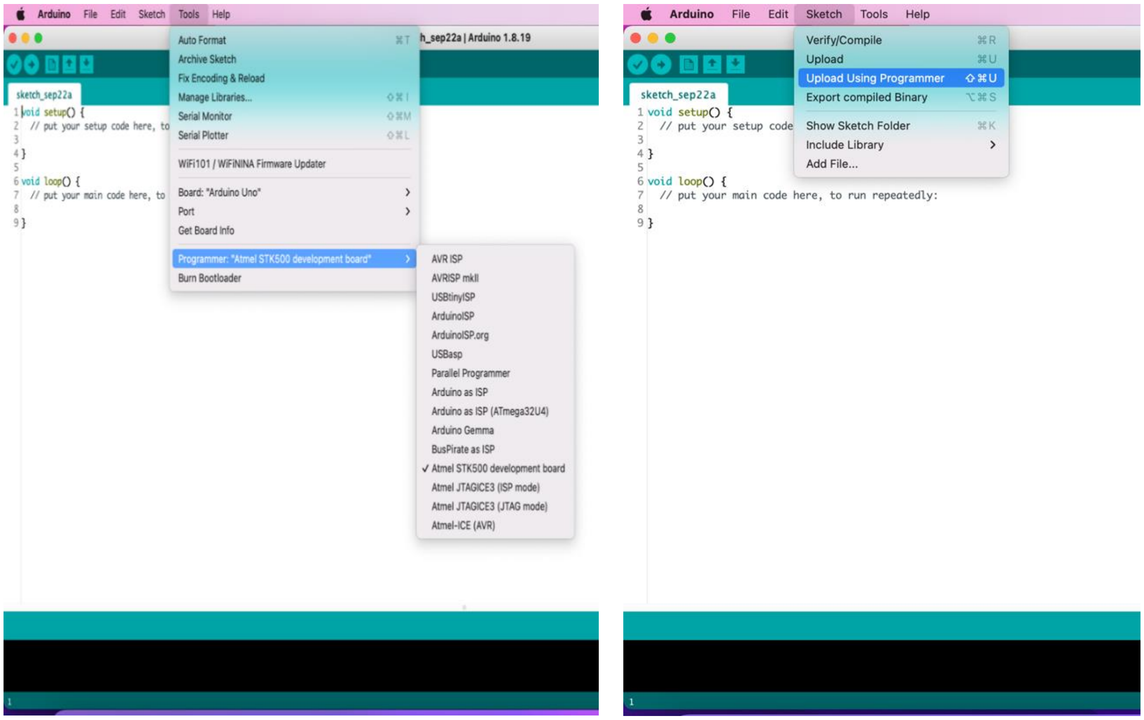
Given our selection of the STK500 programmer for external programming, a streamlined process is imperative. With a focus on precision, this entails just two steps subsequent to uploading the bootloader onto the ATMega328P microcontroller and specifying the port and board. This process commences by choosing the port that corresponds to the programming port of the programmer within the Ports menu. In parallel, within the Boards menu, an appropriate entry should be selected to match the AVR microcontroller or board earmarked for programming. In cases where there are no entries in the Boards menu that align precisely with the target in question, it is plausible that a closely matching entry may suffice. For programming the Kerduino, a configuration featuring an ATMega328P operating at 16 MHz, the

"Arduino/Genuino Uno" entry is suitable since it shares the same processor and clock speed. Subsequently, the board is poised for bootloader uploading, which can be initiated by selecting the "Burn Bootloader" option found within the Tools Menu.

The two remaining procedural stages are as follows:

First stage:-shown in figure (3.8.a)- Within the Tools menu, locate the Programmer submenu and subsequently opt for the Atmel STK500 development board. If the STK500 entry is not visible, it is advisable to perform an update to Arduino version 1.6.5 or a more recent release.

Second stage: -shown in figure (3.8.b)- In the Sketch menu, choose the "Upload with Programmer" option. This particular command variant triggers the Arduino IDE software to execute AVRDUDE, employing the STK500's configurations instead of the conventional bootloader settings associated with the board. This action facilitates the loading of the default template program onto the AVR microcontroller. Successful execution will yield the appearance of the message "Done uploading." within the status bar.



a, First step **b, Second step**

Figure 3. 8: Programming By STK500.

3.3.5 Case Printing

The protective case developed for the Kerduino microcontroller board represents an innovative solution characterized by a fusion of scientifically-informed design features.

Firstly, its composed from two-piece injection-molded construction.

Secondly, the case incorporates insulation properties to mitigate the risk of short circuits when the board is situated on conductive surfaces. This feature aligns with established electrical safety standards, enhancing the case's utility. Additionally, prioritizing panel mounts over DIN rail mounts underscores a better understanding of stability requirements. Panel mounts excel in providing superior installation and setup options, critical for applications susceptible to vibrations. In contrast, DIN rail mounts are primarily intended for suspension and are less conducive to straightforward setup.

A rubber or plastic washers are employed around the exit point of terminal wires and power jack. These elements contribute to reinforce environmental resistance and corrosion prevention.

Moreover, the ventilation design, featuring rectangular holes and spongy filters, facilitates efficient heat dissipation and acts as a barrier against pollutants and humidity. This design ensures both the longevity and reliability of the enclosed microcontroller board.

The choice of PLA+ material for 3D printing underscores the case's durability and resistance to deformation, pivotal attributes for protective enclosures. PLA+, a user-friendly thermoplastic, offers superior strength and stiffness compared to commonly used materials like ABS and nylon. Its low melting point and minimal propensity to warp make it an ideal choice for 3D printing applications.

Lastly, Fusion360 3D design software was used to create an enclosure tailored to the specifications of the Kerduino microcontroller board as shown in Figure 3.9.

This scientifically-driven protective case represents a complete solution that optimizes functionality, durability, and reliability for microcontroller-based projects.

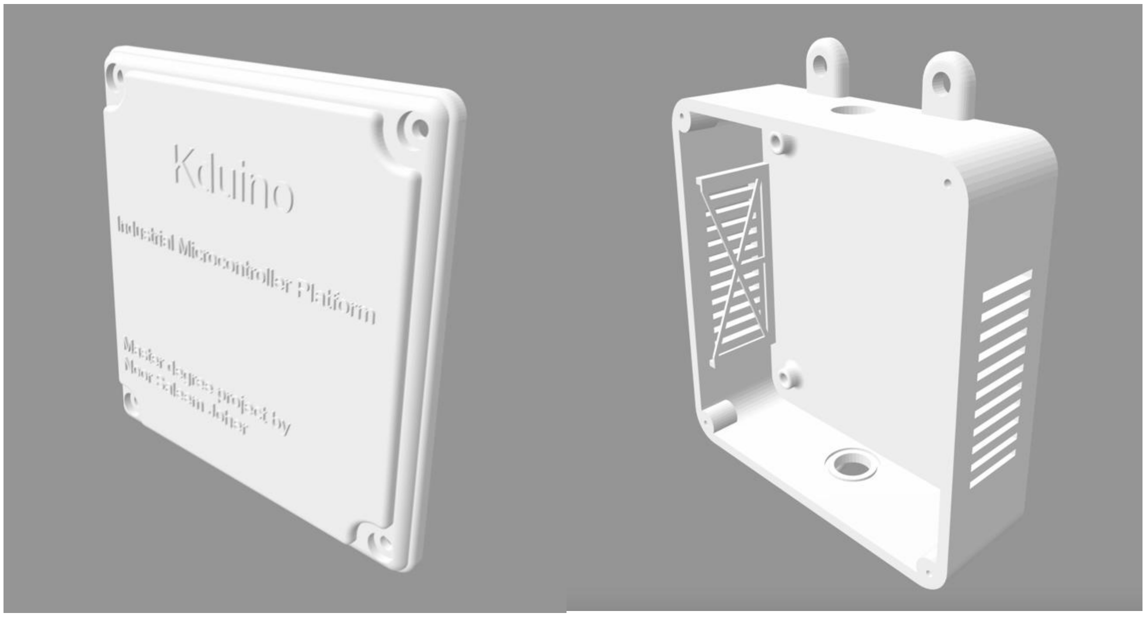


Figure 3. 9: 3D Printing Design for Kerduino.

3.4 Summary

Chapter Three introduces the methodology section, shifting the focus towards the practical implementation of the proposed industrial board prototype, specifically the Kerduino board design. The chapter begins with an overview of the methodology, highlighting the importance of the outdoor application of the microcontroller platform.

The methodology section extensively covers the system design implementation, emphasizing schematic design, PCB design, and the development of the Kerduino prototype. Detailed insights are provided into the programming aspect, utilizing the Arduino IDE environment to configure and control the microcontroller. Additionally, the chapter discusses the critical process of case printing, highlighting its relevance to the overall design and functionality of the industrial board.

A particular emphasis is placed on the robustness of the microcontroller platform, addressing aspects such as vibration resistance and wiring interface mechanisms. The chapter concludes with a comprehensive proposal for the development of an industrial board prototype, setting the stage for the practical testing and validation of the proposed design.

Chapter Four

Results and Discussion

Chapter Four: Results and Discussion

4.1 Introduction

The contribution of the Kerduino microcontroller platform is set with the specified criteria, enabling it to enhance a number of requirements of industrial applications. It is carried out based on a set of criteria. These criteria encompass: programming interface, power, robustness, environmental resistance, and sustainability.

The principal objective of this chapter is to evaluate the proposed industrial board. Full explication of the characteristics and aspects of the proposed board are focal points of discussion within this chapter. Simultaneously, an executed sequence of statistical evaluation procedures are undertaken, accompanied by the application of laboratory evaluation tests.

The experimental outcomes of the statistical data analysis are also expounded upon within this chapter. This systematic examination and reporting serve to clarify the validation of the proposed industrial board.

4.2 Board Programming Interface

The use of external programmer, in our case the STK500, gives our device two main advantages over the existing solutions. The first one is the cost, since on programmer could be used for multiple devices. The second advantage is flexibility, since the use of STK500 gives the possibility to program the device using different IDEs (e.g., like AVR Studio and WINAVR(GCC)) beside the standard programming IDE, which is the Arduino IDE.

Alongside with the main advantages, using an external programmer gives a security advantage. As we mentioned in Section 3.4.4 this method enables stakeholders to adhere to a protocol that minimizes the likelihood of inadvertent interference with the controller during operation. This is achieved by securely storing the STK500, mitigating the prospect of compromising the device unless access to both the programmed data and the device itself is obtained. Alternatively, in many other devices (e.g., the Arduino Uno) both the programmer and the microcontroller are in the same platform which means that the attacker need to access only one item to perform a malicious attack.

4.3 Device Power

A crucial side of our examination centers on the LD1084V5 regulator's ability to manage an output power of up to 25W, which is higher than the one used in regular Arduino boards (i.e., SPX1117M3-L-5), which is limited to 4W. Formula 4.1 is used to calculate the wattage:

Electrical Power (Watts) = Voltage × Current × Power Factor (pf)…4.1

Where the power factor (pf) represents the COS of the angle (θ) between the voltage and current waveforms. Since we are dealing with a DC circuit, the maximum power output corresponds to the maximum values of voltage and current, with the power factor being equal to unity (pf = 1).

For a regular Arduino, the power calculation is as follows: **Power (P) = 5 volts × 0.8 amperes = 4 watts.**

For the proposed prototype, with a voltage of 5V and a current of 5A, the power calculation is: **Power (P) = 5 volts × 5 amperes = 25 watts.**

The difference of powers and Amperes are shown in figure 4.1.

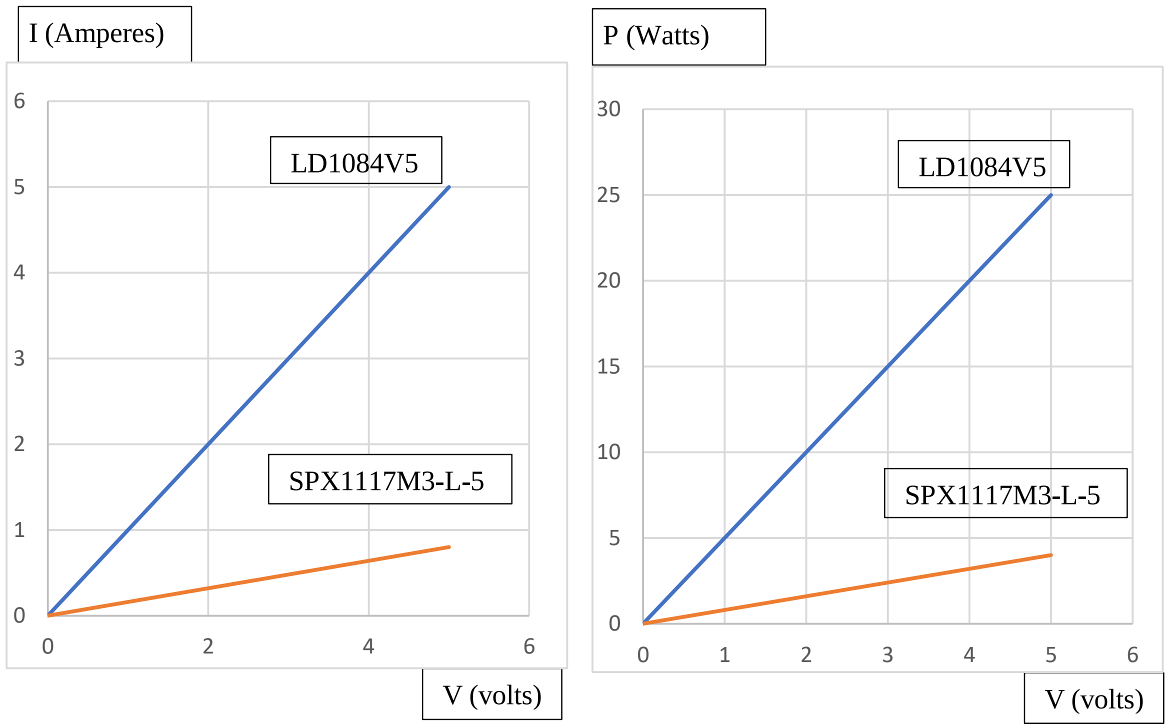


Figure 4. 1: Difference of powers and Amperes between LD1084V5 and SPX1117M3-L-5.

Considering the voltage drop, in the case of the Arduino, there is a voltage drop of 1.3 volts when drawing a current of 0.8A. However, in our prototype, voltage drop at the same current is 0.24 volts only, as shown in formula 4.2.

Voltage Drop (Vdrop) at 0.8A = (1.5 volts × 0.8A) / 5 = 0.24 volts…4.2

However, according to LD1084V5 datasheet, at maximum current (i.e., 5A) the voltage drop is 1.5 volts only.

Table 4. 1: Effecting voltage tolerance on microcontroller.

Item	20 volts	24 volts	30 volts	32 volts	Max. Power	Relay driven output
Arduino	✓	✗	✗	✗	4W	No
Kerduino	✓	✓	✓	✗	25W	No
M-Duino58	✓	✓	✗	✗	7.5W	No
Iono uno	✓	✓	✗	✗	60W	Yes
Controllino	✓	✓	✗	✗	150W	Yes
Industruino	✓	✓	✗	✓	32.5	Yes
Arduino industrial101	✓	✓	✗	✗	0.65W	No
Ruggeduino	✓	✓	✗	✗	9.25W	No

In terms of voltage tolerance, a better solution is also achieved. More specifically, as described in Table 4.1, most of the platforms that are considered in the literature of this thesis, are broke down at voltage exceeds 20V or 24V, except the Industruino that is capable of applying input voltage that reaches 32v. The Kerduino voltage tolerance reaches 30V without any damage or burning in regulator or other chips as shown in Table 4.1, which gives it the advantage over the most boards in the literature.

Note that the output power of the Industruino is relay driven output, i.e., it is not the power provided by the board circuit but by a relay drived by the board. While in the Kerduino case, it is the power provided by the board itself.

4.4 Mechanical Evaluation

In this context, the evaluation of the proposed Kerduino microcontroller delves into the mechanical domain, examining various aspects that impact its operational performance and resilience. In sum, these two dimensions (System Wiring Evaluation and Anti-Vibration Mechanism) two dimensions of mechanical evaluation constitute an integral phase of the overall assessment of the proposed Kerduino microcontroller.

4.4.1 System Wiring Evaluation

Mechanical evaluation primarily focuses on meticulous wiring inspection, vital for seamless microcontroller integration. Engineers prefer screw shield terminals due to their robustness, simplicity, and compatibility with various wire sizes.

Screw terminals are versatile, durable, and cost-effective, making them ideal for diverse engineering projects. They allow easy maintenance and adjustments, meeting engineering demands. Pins are not only essential for integrating certain components like humidity sensors within the enclosure but are also crucial for various shields. On the other hand, housing has demonstrated satisfactory outcomes by effectively organizing wires and minimizing openings in the board case, thereby reducing the effect of environmental factors.

The Kerduino microcontroller outperformed its predecessor in lab tests, showing steady performance under vibration and power load stress. In contrast, the old microcontroller exhibited vulnerabilities, resulting in degraded performance and unreliable outputs. This highlights Kerduino's adaptability to challenging environments.

Figure. 4.2 represents the evidence on effectiveness of using screw shield in strengthen the robustness of wiring since we used an LCD with 12 wire in number of experiments like testing vibration experiment and testing temperature and humidity experiments and the reading was obvious on LCD screen and no error reading shows nor leak or missing in connections.

Figure 4. 2: Testing Wiring Mechanism strength.

4.4.2 Anti-Vibration Mechanism

In the industrial microcontroller field, achieving optimal solutions involves integrating various anti-vibration systems. This approach combines rubber mounts for high-frequency vibrations. This strategy effectively isolates vibrations. This modification optimizes vibration mitigation for specific industrial microcontroller platforms.

Comparing the proposed microcontroller with its predecessors (here Arduino Uno was used) shows a large difference. Former models lack anti-vibration mounts, prompting a detailed evaluation and selection of suitable mounts based on size and effectiveness.

The proposed microcontroller excels in maintaining wiring integrity even under shock and vibration, showcasing its robust design. Conversely, the older microcontroller's performance and wiring system cannot bear under vibration condition.

In the experiment, a Strong Vibration Motor with EVC Material 3-6V DC with frequency reaches to 200 Hz is used with vibration Meter (Fluke 805) to read the effect of vibration, with different statuses by increasing the velocity of motor.

Table 4. 2: Outputs of vibration sensor.

Status	Arduino	Kerduino
Velocity Status1	6.6 rms	1.37 rms
Velocity Status2	8.93 rms	2.72 rms
Velocity Status3	12.81 rms	2.9 rms
Velocity Status4	14.12 rms	2.9 rms
Velocity Status5	17.75 rms	3.86 rms

First status at the lower value of velocity, the root mean square (RMS) of vibration in (mm/s) measurments was 1.37 on Kerduino, while it reaches 6.6 on Arduino as shown in table 4. 2.

The values in RMS because it is an AC amplitude, the steady DC values could be found in the peak value from the formula 4.3.

$$V_{p-p} = V_{rms} \times 2\sqrt{2} \quad \text{…………} 4.3$$

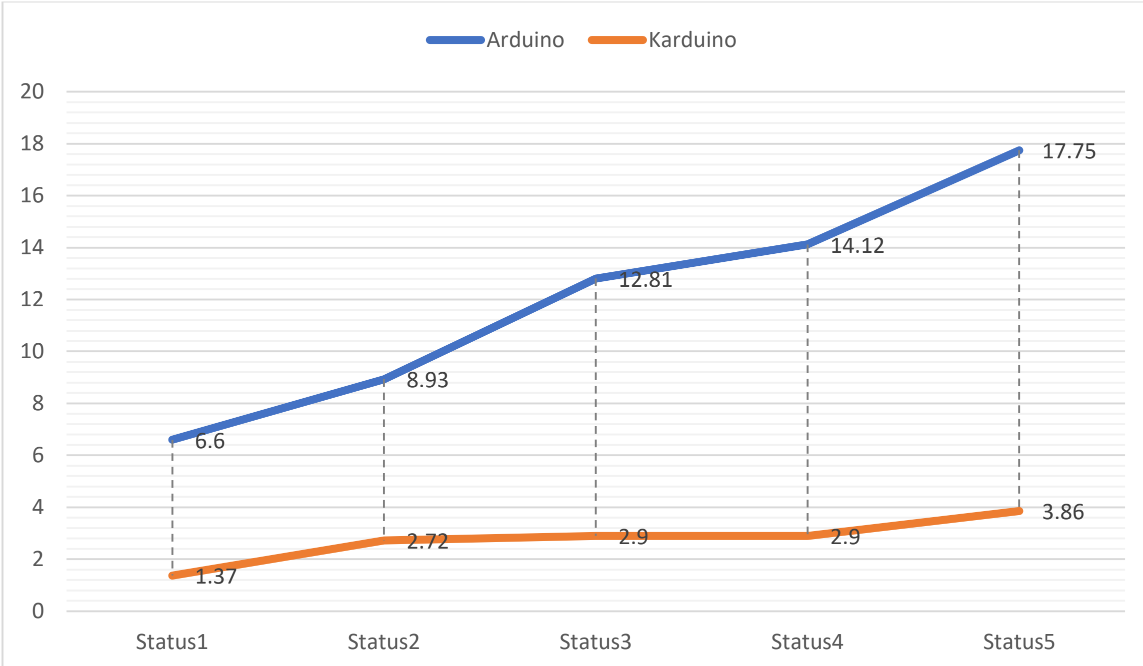


Figure 4. 3: Vibration meter readings of Kerduino and Arduino.

The five statuses of experiment shows the effectiveness of using the rubber mounts in decreasing vibration effect and for further clarification figure 4.3 shows the differences in vibration meter readings between Kerduino and Arduino. During the experiment, one of the wires on Arduino board went out of the pin due to vibration effect. This aspect emphasizes the importance of anti-vibration mechanism as well as the screw shield robustness in industrial microcontroller platforms and highlights the proposed microcontroller's exceptional ability to maintain operational integrity in adverse vibrational conditions.

Figure 4. 4: Testing Vibration Mechanism strength.

4.5 Environmental Protection

To be suitable for industrial deployment, a device must consistently performs reliably across a wide temperature range. Components are typically soldered onto the circuit board, and protective casings or racks are often used. Redundancy measures, including multiple power supply options, are common.

In a comparative evaluation, the proposed microcontroller outperforms its predecessor. Without protective enclosure, the former microcontroller struggles in demanding environments, while the proposed one, explicitly designed for industrial settings, proves resilient.

The proposed microcontroller not only sustains its operational capabilities but excels in challenging conditions. Conversely, the former microcontroller experiences performance degradation and board damage in the absence of protection, vulnerable to dust, temperature fluctuations, and humidity.

In the experiment ran out, two sensor DHT22 used with LCD to compare the humidity inside Kerduino box, with it is environment, outside box. At the beginning they were at the same degree almost, after that when a source of moisture is exposed, the differences show up as in table 4. 3.

While the heat inside the box has no large difference, but when supplying a heat source around the box, comparing with the regular Arduino, one of the chips began to melt, while in the prototype all the chips still safe and the microcontroller work without cutoff or mixed readings.

This assessment highlights the importance of robust design, protective measures, and resilient components for microcontrollers in demanding industrial environments, confirming the suitability of the proposed microcontroller for such conditions. Some photos for this experiment are in Appendix I.

Table 4. 3: Humidity Differences between Inside Box and Outside.

Time (min)	H (outside %)	H (inside %)	H (Difference %)
0 min	58%	56%	2%
10 min	70.4%	62%	7.6%
20 min	87%	66.6%	20.4%
30 min	91.5%	73%	18.5%
40 min	97.6%	80.6%	17%
60 min	99.9%	84%	16%

4.6 Comparative Results

Referring to Table 2.1 in section 2.8.7, the Kerduino boasts distinctive attributes compared to the general specifications of industrial boards. It features a screw shield connection, a chamber, a case box, compact dimensions (103×106×20 mm), and an ICSP programming interface, setting it apart in terms of its robust and well-protected design. In Table 2.1, where pros and cons are detailed, the Kerduino, powered with a 5A current capacity and a tolerance voltage range of 12-30 V, demonstrates significant advantages. These include high voltage tolerance, substantial power output, the ability to endure harsh industrial environments, and its self-contained design that eliminates the need for additional components.

However, it is important to note the requirement for an external programmer for reprogramming tasks, which adds an extra step to the programming process. Moreover, the Kerduino's weight, totaling 234 grams, may be a consideration in applications with specific weight constraints. This collocation reveals the Kerduino's strengths and limitations, underscoring its individuality as an industrial microcontroller.

In table 4.4, a comparative result between Kerduino prototype and other boards explained in literature, are presented in binary system where ‘1’ represents the existence of the specific feature, and ‘0’ represents the nonexistence of it.

The table shows that Kerduino platform excels the rest platforms obviously while the ‘1s’ is full in Kerduino row.

Table 4. 4: Binary comparative results between Kerduino and other enhanced industrial boards explained in literature.

Platform	Tough Wire Mechanism	Board Box	Wire-connection Covering	Vibration Dampers	Higher Power	Voltage Tolerance	No need Additional Library	Less Cost	No Need Extra Interface	More I/Os	Open Source
M-DUINO58	1	1	0	0	1	0	0	0	1	1	0
Iono Uno	1	1	0	0	1	0	1	0	0	1	0
Controllino	1	1	0	0	1	0	0	0	1	1	0
Arduino Industrial 101	0	0	0	0	0	0	0	0	0	0	1
Industruino	1	1	0	0	1	1	0	0	0	1	0
Ruggiduino	1	0	0	1	1	0	0	0	1	0	0
Kerduino	1	1	1	1	1	1	1	1	1	1	1

4.7 Kerduino Advantages

The Kerduino microcontroller offers several key advantages that make it well-suited for industrial applications. Some of its notable advantages include:

1. **High Voltage Tolerance;** the Kerduino can operate within a broad voltage range of 12-30 V, making it versatile and adaptable to various power supply conditions commonly found in industrial settings.
2. **High Output Power;** with a current capacity of up to 5 amperes (5A), the Kerduino can deliver substantial power reaches to 25W, which is essential for driving industrial equipment and components that require higher power levels.
3. **Endurance in Harsh Environments;** the Kerduino is designed to withstand challenging industrial conditions, including temperature variations, dust, and humidity. Its robust design ensures reliable performance in adverse environmental conditions.
4. **Self-Contained Design;** unlike some other microcontrollers, the Kerduino is designed to function without the need for additional components. This streamlined design simplifies integration and reduces the complexity of the setup.
5. **Compatibility and Customization;** the Kerduino offers compatibility with a wide range of sensors, actuators, and shields, thanks to its thoughtful choice of components. This flexibility allows for customization to suit specific industrial applications.
6. **Open Source;** one of the standout features of the Kerduino is its open-source nature. This means that users have access to the design, source code, and documentation, fostering a collaborative and transparent development environment as explained in Appendix III.

These advantages collectively position the Kerduino as a robust and adaptable microcontroller for industrial applications, offering reliability, versatility, and resilience in challenging operating conditions.

4.8 Limitations Of the Work

The study faced several limitations:

1. The use of external programmer increases the complexity of re-programming process.
2. Device size (totally including plastic box: 103mm * 106mm * 20mm) still need to be enhanced toward achieving smaller size.
3. Lack of laboratory devices and instruments leads to the fact that the study tested by locally built tools and instruments. It is important to validate this product using more professional instruments.

Chapter Five

Conclusions and Recommendations

Chapter Five: Conclusions and Recommendations

5.1 Conclusions

The development of the ATMega328P-based open-source platform, the Kerduino microcontroller, has successfully addressed a number of critical limitations within current industrial control solutions. More specifically, overcoming challenges related to power constraints, anti-vibration mechanisms, wiring, and sustainability. The Kerduino microcontroller achieves this by offering a unique combination of features and advantages, making it a valuable addition to the field of industrial automation.

The high voltage tolerance of Kerduino, with the ability to operate within a broad voltage range of 12-30 V, sets it apart from many existing microcontrollers. This feature makes it adaptable to the diverse power supply conditions commonly encountered in industrial settings, providing engineers with a versatile tool for a wide range of applications.

Another notable advantage of the Kerduino is its high output power, with a current capacity of up to 5 amperes (5A). This high power output is essential for driving industrial equipment and components that require substantial energy, allowing for more demanding tasks and applications.

The resilience of Kerduino in harsh environments is a critical attribute, as it is designed to withstand challenging conditions, including temperature variations, dust, and humidity. Its robust design ensures reliable performance, even in adverse environmental conditions, making it a reliable choice for industrial applications.

The self-contained design of the Kerduino simplifies integration and reduces the complexity of the setup. Unlike some other microcontrollers, the Kerduino is designed to function without the need for additional components, streamlining the distribution process.

One of the standout features of the Kerduino is its open-source nature. It provides users with access to the design, source code, and documentation, fostering a collaborative and transparent development environment. This open-source approach encourages knowledge sharing and innovation within the scientific community, contributing to the advancement of industrial control solutions.

While the Kerduino offers numerous advantages, it is essential to acknowledge the limitations encountered during the development process. The research faced challenges due to the limited number of available studies in this field and constraints related to the lack of the components and the unavailability of specific industrial sensors and components within the region, as well as the absence of professional PCB printing and 3D printing facilities, posed difficulties during the execution of the project.

5.2 Recommendations

The findings of this study offer valuable insights and recommendations. Given the limited research in this area, it is essential to explore the potential of microcontrollers in diverse industrial sectors while addressing specific challenges. To facilitate microcontroller adoption like the Kerduino, it is improtant to establish training programs for engineers and technicians. Efforts to improve the availability of local components and sensors, invest in local infrastructure (including PCB printing and 3D printing) are essential. These recommendations are based on the assumption of resource availability, collaboration opportunities, market growth, government and industry support, and successful knowledge transfer. These steps can promote microcontroller integration in various industries, advancing industrial science and technology. Additionally, the adaptability of the project extends to global industrial projects and innovation . Simplifying device driver development and further research along with exploring different microcontroller application designs, lecture content, and applications in robotics control and hydraulic systems for example. Evaluating state-of-the-art microcontrollers, such as Raspberry Pi, the BeagleBone Black Development Board, ni6009, and myrio, for inclusion in instructional programs is recommended.

5.3 Future Work

Future work for this research can include the following key areas of exploration:

1. **Transition to SMD Type Microcontroller**: Investigating the feasibility and benefits of transitioning from the traditional DIP (Dual In-line Packaged) ATMega328P microcontroller to the SMD (Surface Mounted Device) variant. This transition may offer advantages in terms of size reduction, reliability, and compatibility with modern manufacturing processes.
2. **Higher Output 3.3V Regulator**: Researching and identifying a 3.3V voltage regulator with a higher output power capacity. This enhancement is crucial to support industrial applications with increased power demands while maintaining stable and regulated voltage levels.

3. **Miniaturization**: Focusing on further reducing the size and footprint of the microcontroller board. This miniaturization effort should consider compact component selection and efficient board layout designs to achieve a smaller form factor, which is advantageous in space-constrained industrial environments.
4. **Comparison with Single Board Computers**: Expanding the scope of the research to include a comprehensive comparative analysis between the developed microcontroller platform and single-board computers (SBCs). Assessing factors such as performance, power consumption, ease of use, and cost-effectiveness will provide valuable insights into the strengths and weaknesses of each platform for industrial applications.
5. **Higher-Frequency Crystal Usage**: Investigating the feasibility and benefits of using crystals with higher frequencies in the microcontroller design. Higher-frequency crystals can potentially enhance processing speed and timing accuracy, making the microcontroller more suitable for specific industrial tasks.

These future research directions aim to advance the capabilities and versatility of the industrial microcontroller platform, addressing size, power, and performance considerations while also providing a comprehensive perspective by comparing it to single-board computer

References

[1] M. Skilton and F. Hovsepian, *The 4th industrial revolution*. Springer, 2018.

[2] K. Schwab, *The fourth industrial revolution*. Currency, 2017.

[3] R. Jayasri, R. Vidya, and J. A. D. Rex, "A survey on industrial automation based on IoT with arduino microcontroller," *Int. J. Cont. Res. Comp. Sci. Technol.(IJCRCST),* vol. 4, pp. 24-27, 2018.

[4] F. Golnaraghi and B. C. Kuo, *Automatic control systems*. McGraw-Hill Education, 2017.

[5] M. M. PAUL, "INDUSTRIAL NETWORKING STANDARDS FOR IMPROVED COMMUNICATION AND CONTROL," 2011.

[6] R. Akkaya and A. Kulaksiz, "A microcontroller-based stand-alone photovoltaic power system for residential appliances," *Applied Energy*, vol. 78, no. 4, pp. 419-431, 2004.

[7] S. Chattopadhyay, *Embedded System Design*. PHI Learning Pvt. Ltd., 2023.

[8] D. Ibrahim, *Microcontroller Projects in C for the 8051*. Newnes, 2000.

[9] T. Willingham and J. De Boer, *Makerspaces in libraries*. Rowman & Littlefield, 2015.

[10] S. Bonfanti, A. Gargantini, and A. Mashkoor, "Design and validation of a C++ code generator from abstract state machines specifications," vol. 32, no. 2, p. e2205, 2020.

[11] H. K. Kondaveeti, N. K. Kumaravelu, S. D. Vanambathina, S. E. Mathe, and S. Vappangi, "A systematic literature review on prototyping with Arduino: Applications, challenges, advantages, and limitations," vol. 40, p. 100364, 2021.

[12] D. M. Rieder, *Suasive iterations: Rhetoric, writing, and physical computing*. Parlor Press LLC, 2016.

[13] N. Zlatanov, "Arduino and open source computer hardware and software," *J. Water, Sanit. Hyg. Dev,* vol. 10, no. 11, pp. 1-8, 2016.

[14] J. M. Pearce, *Open-source lab: how to build your own hardware and reduce research costs*. Newnes, 2013.

[15] V. J. Reddi *et al.*, "Widening access to applied machine learning with tinyml," 2021.

[16] D. Dougherty, *Make: Volume 83*. Maker Media, Inc., 2022.

[17] M. M. Khan, S. Mehnaz, A. Shaha, M. Nayem, and S. Bourouis, "IoT-based smart health monitoring system for COVID-19 patients," vol. 2021, 2021.
[18] A. Mondal, "Building a low cost low power wireless sensor network for agriculture purpose," 2016.
[19] F. Bouquet, G. Creutzer, D. Dorsel, J. Vince, and J. Bobroff, "Enhance your smartphone with a Bluetooth arduino nano board," vol. 57, no. 1, p. 015015, 2021.
[20] A. Biswas, S. Abedin, and M. A. Kabir, "Moving object detection using ultrasonic radar with proper distance, direction, and object shape analysis," vol. 6, no. 2, pp. 99-111, 2020.
[21] D. P. Langis, "Arduino based oceanographic instruments: an implementation strategy for low-cost sensors," 2015.
[22] M. G. Zaragoza and H.-K. Kim, "Comparative Study of PLC and Arduino in Automated Irrigation System," vol. 10, no. 6, pp. 207-218, 2017.
[23] S. Darwin and E. F. I. Raj, "A detailed review on embedded based heartbeat monitoring systems," p. 79, 2023.
[24] S. T. Doherty, C. J. Lemieux, and C. Canally, "Tracking human activity and well-being in natural environments using wearable sensors and experience sampling," vol. 106, pp. 83-92, 2014.
[25] M. F. M. Zain and M. M. A. Jamil, "Arm Rehabilitation Monitoring System using LabVIEW," vol. 2, no. 2, pp. 199-205, 2021.
[26] L. M. Sabogal Guerrero, "Modular kit to support stem-based electronic learning," 2023.
[27] K. Chan *et al.*, "Low-cost electronic sensors for environmental research: Pitfalls and opportunities," vol. 45, no. 3, pp. 305-338, 2021.
[28] A. M. Halawani, "Intelligent Traffic Lights," 2022.
[29] A. Pajankar, *Arduino Made Simple: With Interactive Projects*. BPB Publications, 2018.
[30] G. Dileep, "A survey on smart grid technologies and applications," vol. 146, pp. 2589-2625, 2020.
[31] A. Hardware. (2023, 08/10). *Arduino Uno Rev3 SMD*. Available: https://store.arduino.cc/products/arduino-uno-rev3-smd?queryID=undefined
[32] Arduino LLC. (2023, Aug. 4). *Arduino Uno Rev3*. Available: https://docs.arduino.cc/hardware/uno-rev3
[33] K. Krishna Nandan Kartik, P. Yaswanth Reddy, H. Kalekuri, and P. Kondaiah, "Design and Development of Low-Grade Robotic

Production Platform for Smart Factory Application," in *International Conference on Research into Design*, 2023, pp. 533-548: Springer.
[34] J. A. Enokela and T. O. Othoigbe, "An automated greenhouse control system using Arduino prototyping platform," *Australian Journal of Engineering Research*, vol. 1, no. 1, pp. 64-73, 2015.
[35] S. Goodwin, *Smart home automation with Linux and Raspberry Pi*. Apress, 2013.
[36] M. N. Akhtar, A. J. Shaikh, A. Khan, H. Awais, E. A. Bakar, and A. R. Othman, "Smart sensing with edge computing in precision agriculture for soil assessment and heavy metal monitoring: A review," vol. 11, no. 6, p. 475, 2021.
[37] B. Sudantha, E. Warusavitharana, G. Ratnayake, P. Mahanama, M. Cannata, and D. Strigaro, "Building an open-source environmental monitoring system-A review of state-of-the-art and directions for future research," in *2018 3rd international conference on information technology research (ICITR)*, 2018, pp. 1-9: IEEE.
[38] V. R. Cota, C. Lopes Aguiar, B. d. Souza Neto, and M. Benegas, "Open-source hardware as a model of technological innovation and academic entrepreneurship: The Brazilian landscape," *Innovation & Management Review*, vol. 17, no. 2, pp. 177-195, 2020.
[39] M. Ibrahim, M. Rasel, M. Tuhin, and J. F. Priya, "Design & Implementation of IoT based SMART HOME SYSTEM," Sonargaon University (SU), 2022.
[40] K. Wang and P. Dave, "Implementing an open-source sensor data ingestion, fusion, and analysis capabilities for smart manufacturing," *Manufacturing letters*, 2022.
[41] D. E. Bolanakis, "Historical Review," in *Microcontroller Education: Do it Yourself, Reinvent the Wheel, Code to Learn*: Springer, 2018, pp. 1-10.
[42] M. Singh and S. Goel, "Review of Arduino Microcontroller. 2," 2013.
[43] I. de la Peña Zarzuelo, M. J. F. Soeane, and B. L. Bermúdez, "Industry 4.0 in the port and maritime industry: A literature review," *Journal of Industrial Information Integration*, vol. 20, p. 100173, 2020.
[44] S. F. Barrett and D. J. Pack, *Microchip AVR® Microcontroller Primer: Programming and Interfacing*. Morgan & Claypool Publishers, 2019.
[45] S. F. Barrett, *Embedded Systems Design with the Atmel AVR Microcontroller*. Morgan & Claypool Publishers, 2010.
[46] J. Yiu, *The Definitive Guide to ARM® Cortex®-M3 and Cortex®-M4 Processors*. Newnes, 2013.

[47] D. Mulfari, A. Celesti, M. Fazio, M. Villari, and A. Puliafito, "Using embedded systems to spread assistive technology on multiple devices in smart environments," in *2014 IEEE International Conference on Bioinformatics and Biomedicine (BIBM)*, 2014, pp. 5-11: IEEE.
[48] D. Wheat, *Arduino internals*. Apress, 2012.
[49] H. Reyserhove, W. Dehaene, H. Reyserhove, and W. Dehaene, "Ultra-low voltage microcontrollers," pp. 87-126, 2019.
[50] S. Gadekar *et al.*, "Arduino Uno-ATMega328 P Microcontroller Based Smart Systems," in *Proceedings of the 3rd International Conference on Communication & Information Processing (ICCIP)*, 2021.
[51] M. K. Parai, B. Das, and G. Das, "An overview of microcontroller unit: From proper selection to specific application," *International Journal of Soft Computing and Engineering (IJSCE)*, vol. 2, no. 6, pp. 228-231, 2013.
[52] M. A. Mazidi, S. Naimi, and S. Naimi, *The AVR microcontroller and embedded systems: using Assembly and C*. MicroDigitalEd. com, 2017.
[53] A. Corporation, "8-bit AVR Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash," 2008.
[54] S. M. A. Al-Janabı, "Design and implementing of intelligent anti-theft car security system based on arduino ATMega328P microcontroller," Altınbaş Üniversitesi, 2019.
[55] M. Bharani, S. Elango, S. Ramesh, and R. Preetilatha, "An Embedded System Based Monitoring System For Industries By Interfacing Sensors With ATMega Microcontroller," vol. 3, pp. 1472-1474, 2014.
[56] R. Chaudhari and M. K. Chopade, "Ethernet based field control module for industrial process monitor and control using ATMega328," in *2016 International Conference on Communication and Signal Processing (ICCSP)*, 2016, pp. 2098-2101: IEEE.
[57] M. Y. S. Ghodake, P. S. Parlikar, B. S. More, and B. S. Kulkarni, "WIRELESS INDUSTRIAL AND AGRICULTURAL MACHINE CONTROL USING LO-RA."
[58] U. Alset, A. Apte, and H. Mehta, "Implementation of Fuzzy Logic based High Performance Speed Control System for PMDC motor using ATMEGA-328P-PU Micro-controller," in *2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*, 2020, pp. 1-5: IEEE.
[59] A. M. B. Farouk, "Design and Implementation of a Photovoltaic Power System that Employs “Inverter Technology” to Save electrical Energy," Minia University, 2019.

[60] V. Vippalapalli and S. Ananthula, "Internet of things (IoT) based smart health care system," in *2016 International Conference on signal processing, communication, power and embedded system (SCOPES)*, 2016, pp. 1229-1233: IEEE.
[61] L. Priya, R. Hariprasad, and R. Raghul, "Real time monitoring of vital signs using wireless technique," in *2014 International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE)*, 2014, pp. 1-7: IEEE.
[62] C. Iosif, "Design and Implementation of a Can Bus Protocol using ATMega Microcontrollers," pp. 181-186, 2017.
[63] A. Weimer, M. Kohlstedt, D. C. Volke, P. I. Nikel, and C. Wittmann, "Industrial biotechnology of Pseudomonas putida: advances and prospects," vol. 104, pp. 7745-7766, 2020.
[64] W. Kunikowski, E. Czerwiński, P. Olejnik, and J. Awrejcewicz, "An overview of ATMega AVR microcontrollers used in scientific research and industrial applications," vol. 19, no. 1, pp. 15-19, 2015.
[65] M. Hanif, N. Mohammad, and B. Harun, "An effective combination of microcontroller and PLC for home automation system," in *2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT)*, 2019, pp. 1-6: IEEE.
[66] D.-g. Zhang, D.-c. Dong, and H.-t. Peng, "Research on development of embedded uninterruptable power supply system for IOT-based mobile service," *Computers & Electrical Engineering,* vol. 38, no. 6, pp. 1377-1387, 2012.
[67] M. A. Naiel, S. A. Khamis, and M. E. Nasr, "Flexible realization scheme for streaming voice signals over IP networks," in *2008 National Radio Science Conference*, 2008, pp. 1-8: IEEE.
[68] S. Aliyu, A. Yusuf, U. Abdullahi, and M. Hafiz, "Development of a low-cost GSM-bluetooth home automation system," 2017.
[69] R. Ramani, S. Valarmathy, N. SuthanthiraVanitha, S. Selvaraju, M. Thiruppathi, and R. Thangam, "Vehicle tracking and locking system based on GSM and GPS," vol. 9, pp. 86-93, 2013.
[70] I. N. Syamsiana and R. I. Putri, "High voltage pulse generator design with voltage control for pulse electric field (PEF) pasteurization," in *Proceedings of the 2011 International Conference on Electrical Engineering and Informatics*, 2011, pp. 1-5: IEEE.
[71] U. Papa and G. Del Core, "Design and Assembling of a low cost mini UAV quadcopter System," *Technical Paper,* 2014.

[72] G. Gridling and B. Weiss, "Introduction to microcontrollers," *Vienna University of Technology Institute of Computer Engineering Embedded Computing Systems Group*, p. 25, 2007.
[73] C. Parrot and G. K. Venayagamoorthy, "Real-time implementation of intelligent modeling and control techniques on a PLC platform," in *2008 IEEE Industry Applications Society Annual Meeting*, 2008, pp. 1-7: IEEE.
[74] W. Bolton, *Programmable logic controllers*. Newnes, 2015.
[75] M. G. Hudedmani, R. Umayal, S. K. Kabberalli, and R. Hittalamani, "Programmable logic controller (PLC) in automation," *Advanced Journal of Graduate Research*, vol. 2, no. 1, pp. 37-45, 2017.
[76] S. Jin, F. Ye, Z. Zhang, K. Chakrabarty, and X. Gu, "Efficient board-level functional fault diagnosis with missing syndromes," vol. 35, no. 6, pp. 985-998, 2015.
[77] M. K. Parai, B. Das, and G. Das, "An overview of microcontroller unit: From proper selection to specific application," vol. 2, no. 6, pp. 228-231, 2013.
[78] T. Noergaard, *Embedded systems architecture: a comprehensive guide for engineers and programmers*. Newnes, 2012.
[79] O. Filló Claret, "Study of an innovative SCADA system," Universitat Politècnica de Catalunya, 2016.
[80] S. Labs. (August 4). *Iono Uno Datasheet* Available: https://www.sferalabs.cc/
[81] C. library. (2023, Augast 4). *DATASHEETS*. Available: https://www.controllino.com/wp-content/uploads/2023/05/CONTROLLINO_MEGA_Datasheet.pdf
[82] A. LLC. (2023, Augast,10). *Arduino Industrial 101*. Available: https://docs.arduino.cc/retired/boards/arduino-industrial-101
[83] Industruino. (2023). *Datasheets, Guides and Diagrams*. Available: https://industruino.com/page/techcentre
[84] R. C. LLC. (2023, Augast, 4). *Ruggeduino-ET "Extended Temperature" -40C - 85C*. Available: https://www.rugged-circuits.com/microcontroller-boards/ruggeduino-et-extended-temperature-40c-85c
[85] N. Dunbar and N. Dunbar, "ATMega328P Configuration and Management," pp. 341-416, 2020.
[86] ALLDATASHEET.COM. (2023, Augast, 11). *Electronic Components Datasheet Search*. Available: https://www.alldatasheet.com/view.jsp?Searchword=LD1084V5&sField=2

[87] DigiKey. (2023). *SPX1117M3-L-5-0/TR*. Available: https://www.digikey.com/en/products/detail/maxlinear-inc/SPX1117M3-L-5-0-TR/2472292
[88] F. S. Tse, I. E. Morse, and R. T. Hinkle, *Mechanical vibrations*. Allyn and Bacon Boston, 1963.
[89] I. Kovtun, J. Boiko, S. Petrashchuk, and T. Kałaczyński, "Methods for Vibration Reduction in Enclosed Electronic Packages," in *MATEC Web of Conferences*, 2019, vol. 302, p. 01008: EDP Sciences.
[90] C. Beards, *Engineering vibration analysis with application to control systems*. Elsevier, 1995.
[91] A. P. Engineering. (2023). *Technique Guide*. Available: https://www.angst-pfister.com/
[92] A. Mecanocaucho. (2023, 27/09). *AMC'S ACCURATE CALCULATIONS PROVIDE INDUSTRY LEADING SOLUTIONS*. Available: https://www.mecanocaucho.com/en-GB/
[93] D. Konstantinidis, N. Makris, and J. M. Kelly, "In-situ condition assessment of seismic fluid dampers: experimental studies and challenges," vol. 50, pp. 323-340, 2015.
[94] Y. Liu, L. Xu, C. Song, H. Gu, and W. Ji, "Dynamic characteristics of a quasi-zero stiffness vibration isolator with nonlinear stiffness and damping," vol. 89, pp. 1743-1759, 2019.
[95] V. S. Saji, "Temporary rust preventives—A retrospective," vol. 140, p. 105511, 2020.
[96] A. Emadi, *Handbook of automotive power electronics and motor drives*. CRC press, 2017.
[97] S. Pokharkar Mayur, R. Borkar Rupali, S. Thite Archana, and L. Jogdand Varsha, "Wireless Automated Drone Tank Control."
[98] C. Q. Howard, "Recent developments in submarine vibration isolation and noise control," in *Proceedings of the 1st Submarine Science Technology and Engineering Conference*, 2011, vol. 17, pp. 1-7.
[99] A. D. Nashif, D. I. Jones, and J. P. Henderson, *Vibration damping*. John Wiley & Sons, 1991.
[100] J. Krüger *et al.*, "Innovative control of assembly systems and lines," vol. 66, no. 2, pp. 707-730, 2017.
[101] T. Candela, *Automotive wiring and electrical systems*. CarTech Inc, 2009.
[102] A. Tan and L. Chin, "Board-to-board Connector Solutions for Pagers."
[103] I. Baylakoglu and S. Kyeong, "Selecting the Right Connector," *Electrical Connectors: Design, Manufacture, Test, and Selection*, pp. 207-249, 2020.

[104] A. Brem and K.-I. Voigt, "Integration of market pull and technology push in the corporate front end and innovation management—Insights from the German software industry," *Technovation,* vol. 29, no. 5, pp. 351-367, 2009.
[105] S. Selvaraj and M. Madhavan, "Criteria for selection of sheathing boards in cold-formed steel wall panels subjected to bending: Construction applications and performance-based evaluation," *Practice Periodical on Structural Design and Construction,* vol. 26, no. 1, p. 04020044, 2021.
[106] T. Fukuoka, *The Mechanics of Threaded Fasteners and Bolted Joints for Engineering and Design*. Elsevier, 2022.
[107] P. Seneviratne, *Building Arduino PLCs: The essential techniques you need to develop Arduino-based PLCs*. Apress, 2017.
[108] J. Stanley, J. A. Hunt, P. Kunovski, and Y. Wei, "A review of connectors and joining technologies for electronic textiles," *Engineering Reports,* vol. 4, no. 6, p. e12491, 2022.
[109] F. Suli, *Electronic Enclosures, Housings and Packages*. Woodhead Publishing, 2018.

Appendix I

The following pictures is for more clarification for Kerduino prototype manufacture which described in chapter three.

The picture of figure 1, represent first proposed prototype with zero board.

The second one in figure 2, represent the PCB board which has been made locally.

The third one in figure 3, represent the PCB board which has been made internationally.

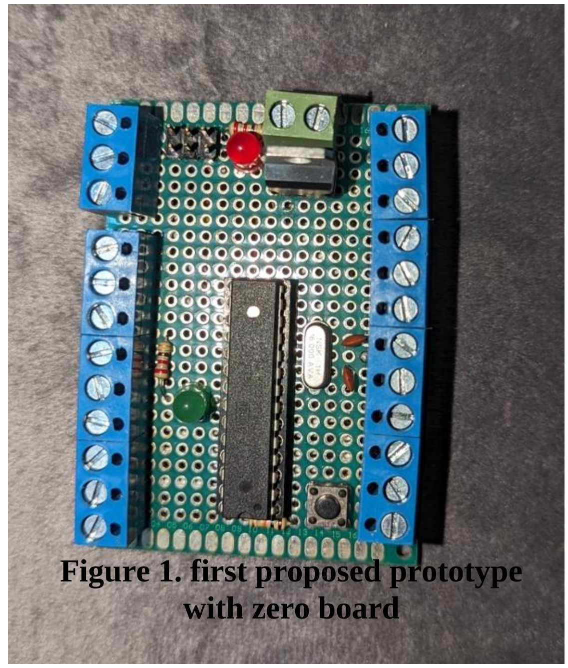


Figure 1. first proposed prototype with zero board

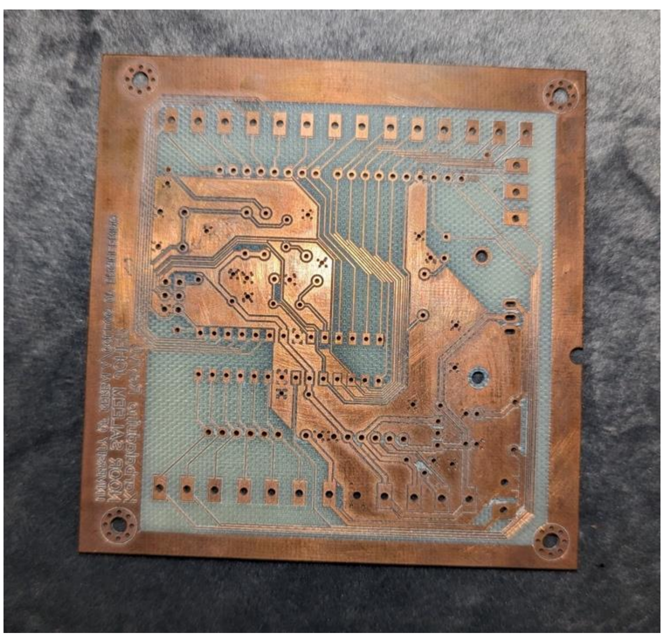


Figure 2. PCB board which has been made locally

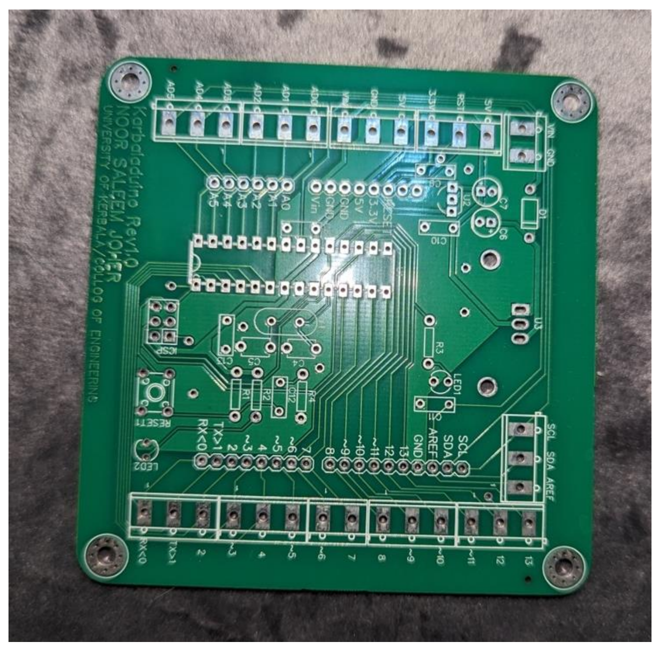


Figure 3. PCB board which has been made internationally

Figure 4. The Final Shape of Kerduino Platform with its enclosure

While figure 4 represent the final shape of Kerduino platform with its enclosure. Figure 5 and 6 from the experiment of measuring humidity and temperature in section 4.5.

Figure 5. Expirement of humidity and temperature

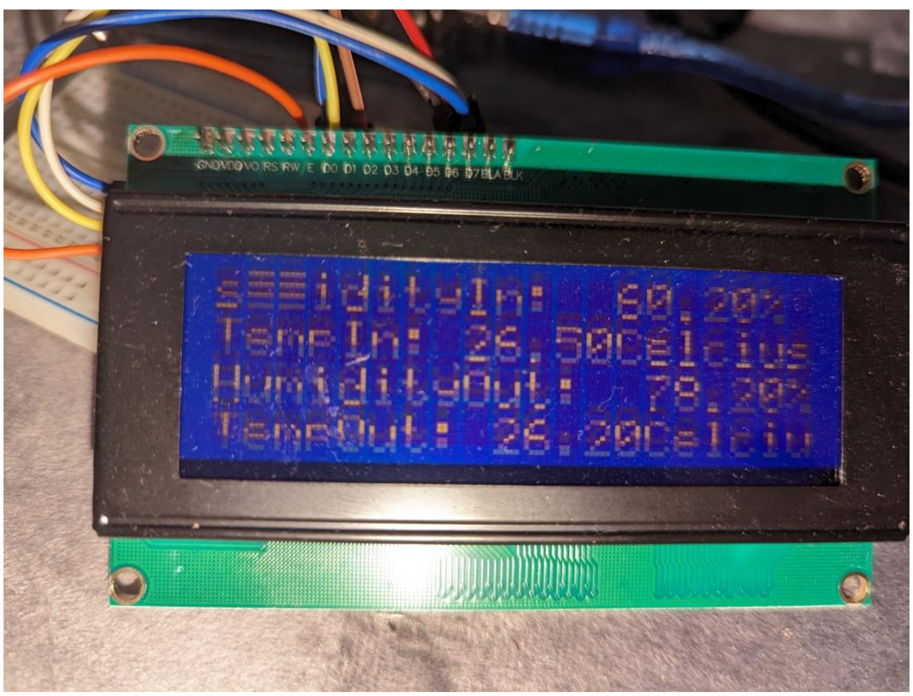


Figure 6. LCD results of the same experiment

Appendix II

This appendix explaining the process of ordering the PCB board from JLCPCB.com website. First 2 layers PCB is selected. The base material should be FR-4 and the dimentions of the PCB is entered and 1.6 thickness is selected. Other options can left untouched.

Then gerber file of the PCB should be uploaded. PCB Assembly service also could be ordered by activaiting it below and clicking on confirm. Next BOM file and CPL file should be uploaded to the website to be processed. Samples are available on the upload page. Next the materials that was not matched automatically must be searched for and matched.

Finally component placement on the board should be checked and corrections should be made as needed. If everything is correct, order can be placed and wait for its processing and production.

Appendix III

Kerduino microcontroller platform is licensed under the MIT license. All the sources and design files for the project can be found in the Github repository at the link below:

https://github.com/NoorJoher/Kerduino

This repo consists the schematic and PCB design of Kerduino board. They can be found in board folder in two types, Altium and EasyEDA. The encloser stl files also can be found in encloser folder. Gerber files, pdf exports and other related files for this and for future releases could be found in releases page which can be accessed from the link below:

https://github.com/NoorJoher/Kerduino/releases

الخلاصة

تُستخدم المتحكمات الدقيقة على نطاق واسع في الوقت الحاضر في تطبيقات متنوعة، مثل أتمتة المنازل والتحكم في السيطرة على الأجهزة وشبكات الاستشعار اللاسلكية، و أيضا تستخدم في التطبيقات الصناعية. بشكل عام، يتوجب أن تتوفر في المتحكمات الدقيقة المستخدمة في التطبيقات الصناعية مجموعة من الخصائص لتكيفها مع بيئة العمل الصناعية، مثل الموثوقية والصلابة.

إحدى أكثر منصات المتحكمات الدقيقة شيوعًا هي منصة الأردوينو، التي تعتمد على متحكم ATMega. وهناك مجموعة من منصات المتحكمات الصناعية التي تعتمد على الأردوينو أو شرائح ATMega. من بينها نذكر، M-Duino58 ، وIono Uno، وControllino، و Arduino 101 Industrial، وIndustruino، وRuggeduino-ET.

بالتأكيد هناك مجموعة من الإيجابيات والسلبيات في المنتجات المذكورة، ما يجعلها تسلط الضوء على خريطة بيان المشكلة و كذلك عرض اقتراح حل المشكلة هذه الرسالة. تقوم هذه الرسالة بتحليل المنتجات الحالية وتقديم مراجعة شاملة لأفضل الخصائص في هذه المنتجات وأيضًا لمعالجة مقوضاتها. فيجعلها تُستخدم كدليل لاقتراح منصة جديدة للمتحكمات الدقيقة من نوع ATMega مع أفضل مجموعة من الميزات.

نتيجة لذلك، تم تصميم وتنفيذ منتج عبارة عن منصة مفتوحة قابل للتكيف بشكل كبير، وقد أطلق عليه اسم "كردوينو". تم تصميم هذا المنتج كمصدر مفتوح لجذب المجتمع في عملية التطوير المستقبلية ودعم استدامته.

تُظهر النتائج المقارنة السمات المميزة لمنصة "كردوينو" مقارنة بمواصفات اللوحات الصناعية الأخرى. على وجه الخصوص، تم تحسين الطاقة الكهربائية للجهاز، كما تم تحسين الخصائص الميكانيكية للجهاز أيضًا، مثل مقاومة الاهتزاز وموثوقية الربط و التوصيلات والصمود في الظروف الخارجية، وأخيرًا، كان عامل التكلفة عاملًا معتبرا في تصميم "كردوينو."

توفر النتائج والرؤى التي تم الحصول عليها من خلال هذا البحث معرفة قيمة لتحسين تصميم المتحكمات الصغيرة في التطبيقات الصناعية. بالإضافة إلى ذلك، يُعد هذا البحث خطوة أولى نحو استكشافات وتطورات مستقبلية في مجال التحكم الصناعي وأنظمة التحكم.

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة الكهربائية و الإلكترونية

تطوير منصة صناعية مفتوحة المصدر باستخدام المتحكم الدقيق ATMega328P

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة الكهربائية و الإلكترونية

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