TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Electrical Power Engineering and Mechatronics

TALLINNA TEHNIKAÜLIKOOL

CONTROL AND MONITORING OF SENSORS THROUGH IOT (INTERNET OF THINGS) NETWORK

SENSORITE JUHTIMINE JA MONITOORING (ASJADE INTERNET) VÕRGU KAUDU

BACHELOR THESIS

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Tallinn, 2021

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Hereby I declare that I have written this thesis independently.
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ABSTRACT

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Abstract:

IoT (Internet of Things) is capable of bringing new vision to a variety of technological processes. Even though a production runs for decades, it is possible to improve it dramatically with the help of IoT. A production line with several machines and a conveyer belt will be different if, at any moment, the amount of products on the line is known, workload and capabilities of machines are traceable, and in case of failure, information regarding that will be delivered in a matter of moments. The necessary amount of sensors will allow the creation of very informative dashboards for data analysis. Sufficient datalog help to understand the volume of the production and workload of the machines. Low production demand allows switching machines off with the help of the same IoT possibilities.

The purpose of the work is to show how accessible the world of the Internet of Things can be. The used method is based on the experiment with an induction motor. Motor current was measured externally with the help of current sensors and special measuring equipment. Then, measuring equipment was changed to Arduino, and similar results have been achieved. This result demonstrates how easy it to take something to a new technological level. That might decrease the impact on the environment by prolonging the machine lifecycle.

Keywords: Iot, Arduino, programming, measurement, data monitoring

LÕPUTÖÖ LÜHIKOKKUVÕTE

Autor: Artur Ivlijev *Lõputöö liik:* Bakalaureusetöö

Töö pealkiri: Sensorite juhtimine ja monitooring (asjade internet) võrgu kaudu

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Töö konsultant (konsultandid): -

Sisu kirjeldus:

IoT (Asjade Internet) on võimeline looma uut visiooni mitmesugustele tehnoloogilistele protsessidele. Ehkki tootmine võib kesta aastakümneid, on asjade Interneti abil võimalik seda dramaatiliselt täiustada. Mitme masina ja konveierilindiga tootmisliin saab olema parem, kui igal hetkel on teada toodete kogus liinil, masinate töökoormus ja võimsus on jälgitavad ning rikke korral edastatakse teave selle kohta koheselt. Ettenähtud andurite arv võimaldab andmete analüüsimiseks luuainformatiivseid juhtpaneele. Komplektne andmelogi aitab mõista masinate toodangu mahtu ja töökoormust. Madala tootmisnõudluse korral võimaldab IoT masinate väljalülitamist.

Töö eesmärk oli näidata asjade interneti kättesaadavust maailmas. Kasutatud meetodiks oli katse asünkroonmootoriga. Mootori voolu mõõdeti väliste sensoritega ja spetsiaalsete mõõteseadmete abil. Järgmiseks asendati mõõteseadmed Arduinoga ning saavutati sarnased tulemused. See näitas, kui palju on võimalik midagi uuele tehnoloogilisele tasemele viia. IoT-tehnoloogiaid kasutavate masinate eluea pikendamine mõjub keskkonnale positiivselt.

Märksõnad: IoT, Asjade Internet, programmeerimine, sensorid, monitooring,

THESIS TASK

Thesis title:	**Control and monitor of sensors through IoT(Internet of Things) network**
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____________________ ____________________ ______________________

Supervisor (signature) Student (signature) Head of programme (signature)

____

Co-supervisor (signature)

1. Reasons for choosing the topic

Since we live in the era of 4th industrial revolution, this topic is important and applicable to many areas of our lives. Fact is that we are surrounded with electric motors (water, ventilation, lifts etc) and many of those have no supervision and control over them or it is quite limited. My work will show modern way of supervision for electrical motors as well as control of measurement devices.

2. Thesis objective

The aim of this thesis is to demonstrate the way of data supervision from sensors that are connected to the electric motor (wind turbine) to and control sensors via Arduino controller.

3. List of sub-questions:

1. Learning about IoT devices

2. Integration of Arduino with sensors
3. Monitoring of electrical devices using Arduino
4. Controlling of sensors using Arduino
5. Understanding the working of IoT devices
6. Interpret data inside an IoT network

4. Basic data:

For my research I intend to use Arduino controller and sensors as well as electric motor from TalTech laboratory. Sensors are meant to be used for necessary data collection.

5. Research methods

Research methods are based on measurements, tests and observations. As primary tool, arduino software will be used to read values from arudino controller. We will be interfacing the hardware with system using arduino's own software to check on values form sensors.

6. Graphical material

Graphs and tables with collected data will be part of the main work.

7. Thesis structure

1. Title
2. Table of Contents
3. Introduction
4. IoT devices Overview
5. Arduino Overview
6. Sensors Overview
7. Design Architecture
8. Experiment and Results

8. References

Research articles, books, reports and articles on internet.

9. Thesis consultants

-

10. Work stages and schedule

1. Going through Literature review for Arduino and sensors (14.02.2021)
2. Setting up of Arduino and sensors experimental setup (21.02.2021)
3. Doing calculations and implementation of the method (05.03.2021)
4. Writing of thesis theoretical part (05.04.2021)
5. Compiling results and finishing up first draft of thesis (15.04.2021)
6. Sending to supervisor for review (17.04.2021)
7. Revising first draft with corrections if needed (30.04.2021)
8. Sending revised draft for review to supervisor (30.04.2021)
9. Final version of the thesis (08.05.2021)

CONTENTS

1.INTRODUCTION

Today, induction motors remain their leading positions within the spectrum of industrial applications. Even though those motors have proven their reliability over the decades, there are still many motors that work without proper supervision. A possible result is a motor failure that can be predicted and avoided. The reasons that lead to this situation are quite different, starting from outdated equipment to poor management decisions on the new project. It is essential to mention that such motors might provide valuable and essential needs for the people or production. Its unforeseen breakdown might lead to the loss of money or our most valuable asset - which is time [1]. Especially if the motor is in a very hard reachable space [2]. There have been many studies on motor faults, and they have been narrowed down to three main categories. Some of those categories will be briefly observed, but one of them that is related to electricity will be researched more widely within this thesis.

Primary occurring issues with motors can be divided as follows:

1. **Electrical faults:** This type of fault might be considered the most sophisticated one as it is not visible as a physical danger comparing to the other two. It depends on the quality of the electricity it receives, the balance of voltage or current, and the motors overload situation.

2. **Mechanical faults:** A result of a physical impact on the motor's bad mechanical installation. Quite often, mechanical faults lead to issues that are visible or produce a very distinctive noise that could be observed. For example, broken bearing damage, failure of winding, or unbalance of the mass.

3. **Environmental faults:** Things that are classified under environmental faults are humidity conditions, temperature as well as a vibration that is caused by the surroundings of the motor [2].

Within the current thesis, the author will focus on the threat that is not visible from sight and requires additional observation tools. That would be to control and monitor the motor using the current sensor through the IoT (Internet of Things) network. This technology has rapidly grown and evolved in recent years. It provides remote access to many things as well as access to Industrial automation machines with the help of different terminals [2].

Keywords: IoT, Internet of Things, current, induction motors, supervision.

1.1. Aim and objective of the study

The aim of this study is to connect a sensor to the electric motor, monitor the quality of the electricity, and control the sensor. Here is the list of requirements needed for objective fulfillment.

1. Select a type of current sensor
2. Select a type of Arduino board
3. Select motor for the test bench
4. Calibration and scaling of the selected analog current sensor with Arduino.
5. Monitor current results from the motor and analyzing them.
6. Control sensors from Arduino board.

The amount of equipment suitable for this type of research and application is quite broad. The selection will rely on the options from the university laboratory to provide the best possible result.

1.2. Problem statement

The IoT devices have proven their capabilities in many different areas of data collection and external control. The main focus of this thesis is the possibility of monitoring and controlling the electrical motor's current. As the world is constantly shifting its focus towards a sustainability perspective, ideas of smart resource distribution and usage are constantly evolving [3]. In the industrial automation world, maintenance procedures are not according to schedule but according to the actual need. Another important option is equipment health monitoring possibility and predicting unexpected failures. The idea of motor health monitoring itself is not new. However, we can take a look at that from a new perspective with the help of IoT due to is its price, flexibility, and the option of data transferring to any other location [3].

The structure of the remaining parts of the thesis is divided into the following chapters. Chapter 2 is the overview of IoT, Arduino, sensors, and motors. Chapter 3 is Test bench assembly and preparation for the test. Chapter 4 results of the test. Chapter 4, the conclusion and observation of additional capabilities.

1.3. Introduction to IoT devices

The Internet of Things term was created in 1998 by Kevin Ashton. At that time, he saw the modern and sophisticated technologies that might connect and communicate among themself at any time and any place.

There are many ways of how IoT is described in different literature and publications. One of them is this: "A global network of infrastructure connecting physical and digital devices through the utilization of data capture and communication capabilities." Over the last decades, many companies ranging from startups to large corporations and academic research institutes have been involved in IoT development [4]. The backbone for this interest is the idea of what IoT brings to society. The goal is to connect as many objects as possible and leave communication between those objects to automation with much less human interference. On top of that, self-learning machines are included in the process of analyzing the list of people's needs and work towards the ultimate goal: to create " a better world for human beings" [4].

1.4. The benefit of IoT devices

IoT creates a worldwide network of connections that are uniquely accessible from many devices: personal communication gadgets, home appliances, transport, image recording tools, and other things and objects. Nevertheless, it is a technology and here is the list of some reasons behind its functionality:

- **Ubiquitous Connectivity—** connection is possible with or without required licenses that make pervasive networks very affordable and without speed limitations.
- **Widespread adoption of IP-based networking** - IP is the standard of networking, and its possibility to be integrated into any platform or software provides accessibility for IoT.
- **Computing economics** - As it is happening according to Moores's Law, we can observe the rise of computing powers with lower prices.
- **Miniaturization** - Latest manufacturing capabilities along with computing economics already provide impressive small-scaled technologies for IoT. Current small and affordable sensors are

- **Advances in data analytics** - Similar to computing power, the development of data storage, cloud services for larger quantities of data offer new and unique possibilities for the extraction of knowledge and information.

- **Rise of cloud computing** - With the help of cloud computing, there is a way to connect even a small remote access point to powerful data processing resources at any time. That eliminates unnecessary computing power on the field [5].

1.5. IoT architecture

For a better understanding of IoT architecture, it is possible to divide it into several layers:

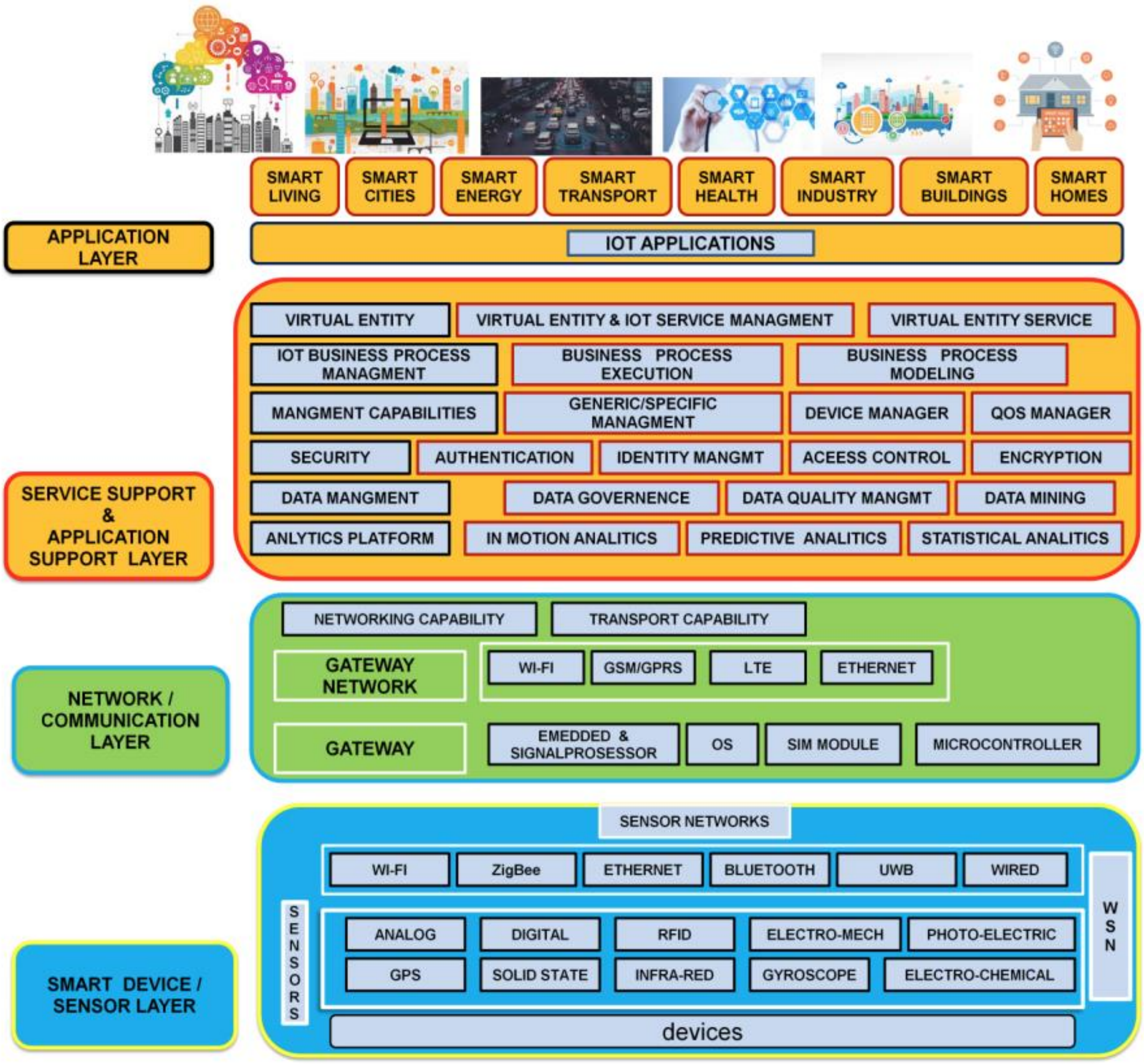

Figure 1.1 IoT layer structure [6].

Smart device/sensor layer - this layer is about data gathering from all types of sources and sensors: digital, analog, electro-mechanical, wi-fi, ethernet, Bluetooth, solid-state, infrared, etc.

Network/communication layer - is about data transferring over wi-fi, GSM, LTE, Ethernet, OS, SIM module, or microcontroller.

Service and support application layer - is about implementing IoT that starts from the virtual entity, IoT business process management, business process execution, security, authentication, condition monitoring, process monitoring, and many more.

Application layer - more general description of implementation areas that can be improved with the help of IoT: Living, cities, energy, transport, health, industry, building, homes [6].

1.6. How the IoT devices communicate

To explain the flexibility of IoT device communication, several most common models are mentioned by the internet architectures: Device to Cloud, Back end Data Sharing, Device to Device, and Device to Gateway.

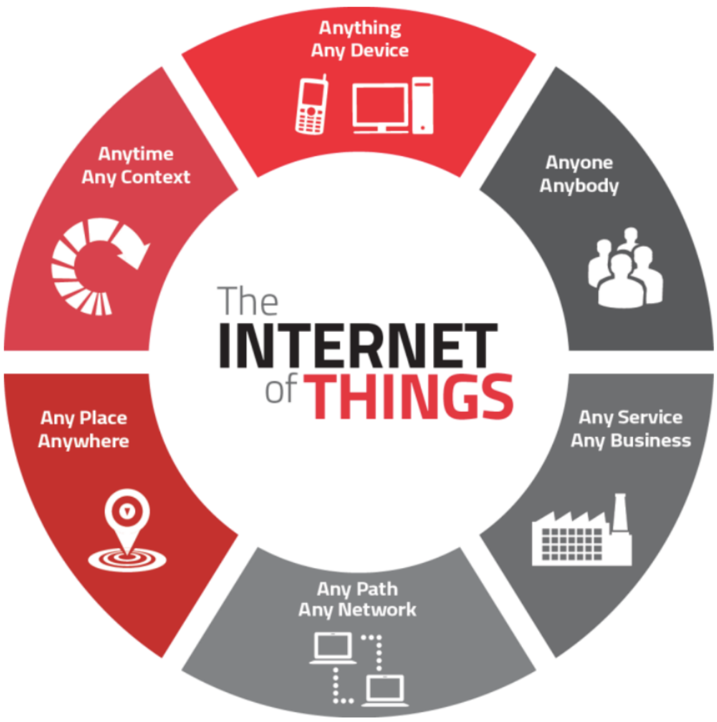

Figure 1.2 IoT device communication diagram [5].

2. ARDUINO AND MOTORS

2.1. Introduction of Arduino boards

Arduino is an open-source platform for constructing electronic projects. It was introduced in 2005 as an easily programmable microcontroller. There is a programmable circuit board with several inputs and outputs (also referred to as a microcontroller) and its software or IDE (Integrated Development Environment) that runs on the computer. Software is needed for writing a computer code and then uploading it to the physical board.

Some intelligent ideas behind Arduino made it very popular for people who just start to learn electronics. A computer with a USB port is more than enough to make it work. For the programming, Arduino uses a simplified version of C++. The standard form factor makes it easy to understand, connect and use with other peripherals [7].

Advantages of Arduino:

- Low cost
- Cross-platform
- A transparent and straightforward programming environment
- Open-source software
- Open-source hardware

2.2. Types of Arduino

During the last 16 years, the Arduino family has expanded from small, entry-level products and starter kits to more complex solutions with advanced functionalities. Especially appealing is the line of products dedicated to IoT. Even if a person is not so familiar with the programming, Arduino products come with a great set of code examples for practice. Here is the list of some popular boards from different categories: [7].

- Arduino UNO
- Arduino Leonardo
- Arduino Zero
- Arduino 33 IoT

2.2.1. Arduino UNO

This is the best choice for beginners to get started with programming and electronics. It is very robust for first tinkering experiences and Arduino UNO established itself as the most used documented board of the Arduino family [7].

Figure 2.1 Arduino UNO board [7].

2.2.2. Arduino Leonardo

This is a more advanced microcontroller board base on the ATmega32u4. What sets it apart from others is built-in USB communication, eliminating a need for a secondary processor. While connected to a computer, Arduino Leonardo might appear as a mouse keyboard. There are 20 digital input/output pins and a 16 MHz crystal oscillator [7].

Figure 2.2 Arduino Leonardo board [7].

2.2.3. Arduino Zero

This board is a step towards IoT solutions in wearable technology, hi-tech automation, robotics, and more. Arduino Zero is a powerful 21-bi extension of the platform that was created for UNO. It is powered by Atmel's SAMD21 MCU, which features a 32-bit ARM Cortex. A remarkable addition to the board includes a full debug interface that operates without additional hardware [7].

Figure 2.3 Arduino Zero board [7]

2.2.4. Arduino Nano 33 IoT

This board is a spectacular example of the scenario that describes how little it takes to connect any device to something powerful and remote. Arduino Nano 33 IoT is the most affordable point of entry to enhance existing devices [7].

Figure 2.4 Arduino Nano 33 IoT board [7]

2.3. Arduino work principles on the example of Arduino UNO

Harvard architecture concept is the base of Arduino's processor and its memory and data memory is used for program code and program data. Flash memory capacity for code is 3kb, and Static RAM size is 2kb. The clock speed for the operation is 16Mhz [9].

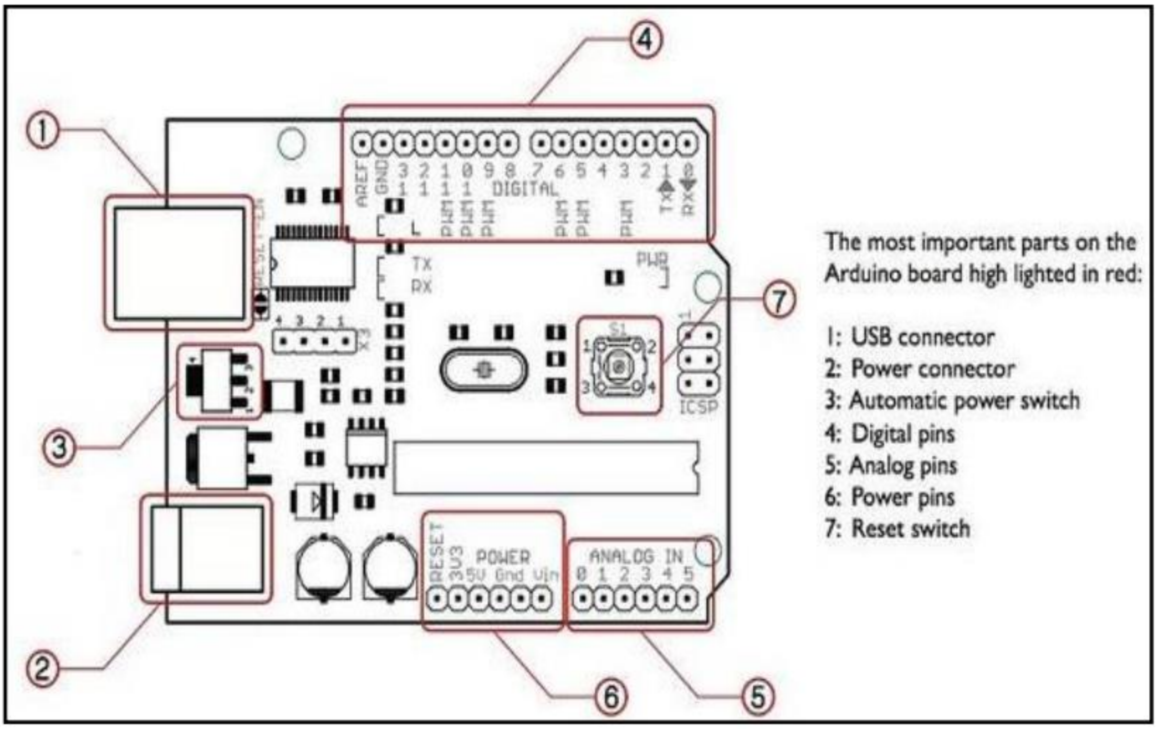

Figure 2.5 Arduino layout scheme [10]

Elements of an Arduino board can be divided into two categories:

- **Hardware**
- **Software**

2.3.1. Arduino Hardware

There are many different components assembled on the small area of Arduino that makes it function [9].

Microcontroller: is the primary component on the board. It is a small computer that exchanges information between other components and devices connected to the board.

The microcontroller is different on every board and selected according to level and functionality [9].

External power supply: it used to power the Arduino board with a voltage raging from 9 to 12 volts [9].

USB plug: Essential component on the board used to upload a program to Arduino Microcontroller, or even power it with regulated 5V. It can also be used to transfer data to connected devices. USB cable can work as a substitute for the power supply unit [9].

Internal Programmer: It is a software code that can be uploaded to the microcontroller if an external programmer is missing [9].

Reset button: It is a physical button on the board itself that resets the Arduino [9].

Analog pins: Those are inputs and outputs of analog signal raging from A0 to A7 [9].

Digital I/O Pins: Ranging from 2 to 16, these pins are used for digital signal input/output [9].

Power and GND Pins: Pins that provide a different voltage of 3.3 and 5 volts and the ground for Arduino.

2.3.2. Arduino Software

Arduino IDE (Internal development environment) is used to create sketches. Sketch - is the name of the program code for Arduino. Here is the list of some parts of this environment [9].

Text editor: A place to be used for code writing using a simplified version of the C++ programming language [9].

Message area: Area that displays errors and works feedback on saving and exporting the code [9] .

Text: Place where it is possible to observe the result of the work and the complete list of error messages in case of issues [9].

Console Toolbar: Window area with main buttons like Verify, Upload, New, Open, Save, and Serial Monitor. As well as other technical information regarding the used board and Serial Port [9].

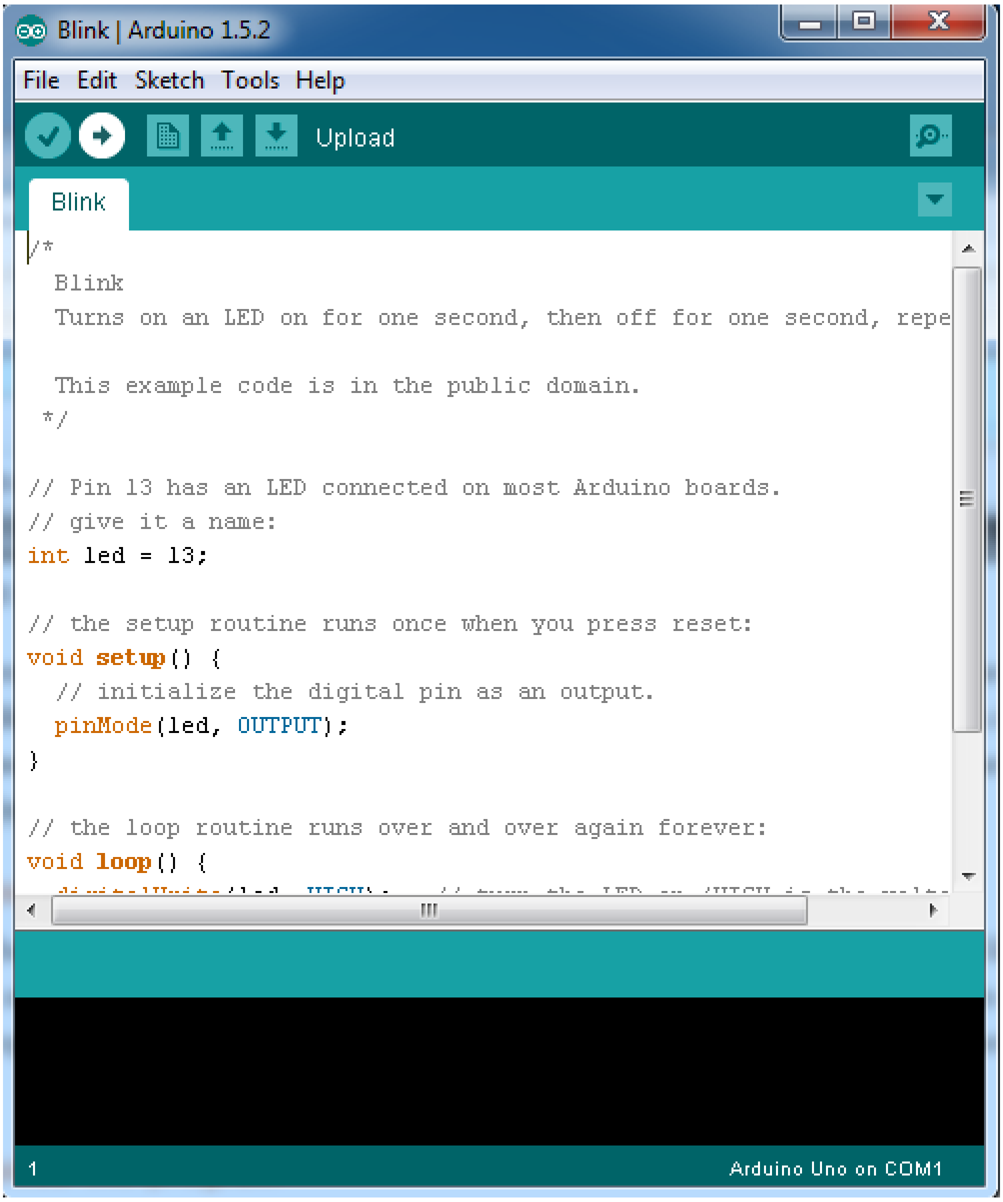

Figure 2.6 Arduino IDE [8]

2.3.3. Arduino Programming basics

Here is a brief review of Arduino programming techniques. There are two mandatory steps required for the program at any time, they are:

- **void setup()**
- **void loop()**

1) void setup ():

This function is executed only once and describes the initialization for every pin that will be used through the program, whether it is input or output.

```
void setup()
  {
    pinMode(pin, INPUT);
    pinMode(pin, OUTPUT);
  }
```

Figure 2.7 Arduino pin initialization [9]

To send data through serial to any peripheral device, it is needed to do the initialization of the Serial Port.

```
void setup()
  {
      Serial.begin(9600);
  }
```

Figure 2.8 Arduino Serial Port initialization [9]

Variables that are intended for use must be defined before any function listed above.

2) void loop ():

The current function is the following important function in any program. The difference is that part of the code written there is being executed constantly, unlike the setup function. Here is the example of implementation and explanation to it [9].

```
void loop()
  {
     digitalWrite(pin, HIGH);
  }
```

Figure 2.9 Arduino Serial Monitor initialization [9]

In this example, digital Write is a function that writes high or a low value to the digital pin. The reaction of the pin depends on the initialization from the "setup" part of the code, whether it is set to output or input. Its MODE will determine the voltage value. For HIGH value, it is 5V or 3.3 and 0V for LOW (ground) [9].

2.3.4. Arduino work flowchart

Quite a straightforward example of such a function can be shown within the fire-alarm system. The temperature sensor is constantly working in the loop and comparing its values to limits that the user has set. Once a certain level of temperature is reached, the program will trigger corresponding and preselected action [11].

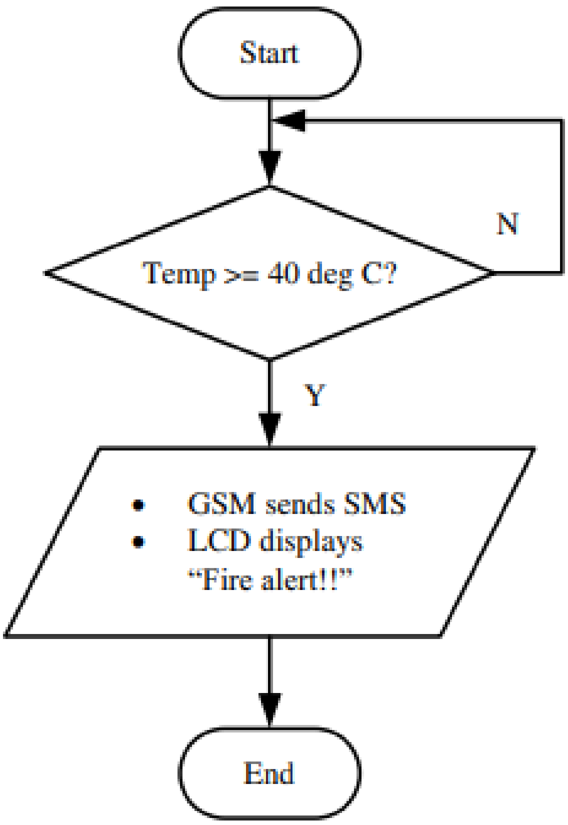

Figure 2.10 Arduino fire alarm flowchart example [11]

2.3.5. Strength of Arduino

Co-founder of Arduino Massimo Banzi has tried to summarize several reasons that make Arduino stand out compared to other microcontroller developers. Here is the list of several of them:

Active User Community: Number of users that are discussing ideas and help with problem-solving is high and constantly growing [11].

Growth of Arduino: Arduino always remained true to its original values of being suitable for total beginners and experienced professionals [11].

Inexpensive Hardware: Despite constant growth and development, prices for the boards remain adequate for corresponding levels, and the open-source platform does not require a payment for the software [11].

Arduino Board as a Programmer: Easy functionality is driven by the idea that only a USB connection is required to power the board and create needed [11].

Multi-platform Environment: Arduino software is ready for the most used platforms, including Microsoft, Linux, and Mac OS X. That expands the user base even more [11].

2.4. Induction motors

2.4.1. Motor construction

Today, around 90% of the need for mechanical power in the various industries is covered with the help of three-phase induction motors. Also named asynchronous motors, they have established their reputation as robust, well build, with reasonable power-factor, self-starting, and low maintenance cost. The popularity of the motor is so high that it is pretty frequent to be the only type of motor in the factory or production. Depending on the size, the motor can be supplied with one or three phases. The construction of the motor is simple and consists of several parts: shield and flange, bearings, stator, stator winding, connecting box, fan with shield and cover. Position if the parts are visible on the picture (Figure 2.11) [17] [18].

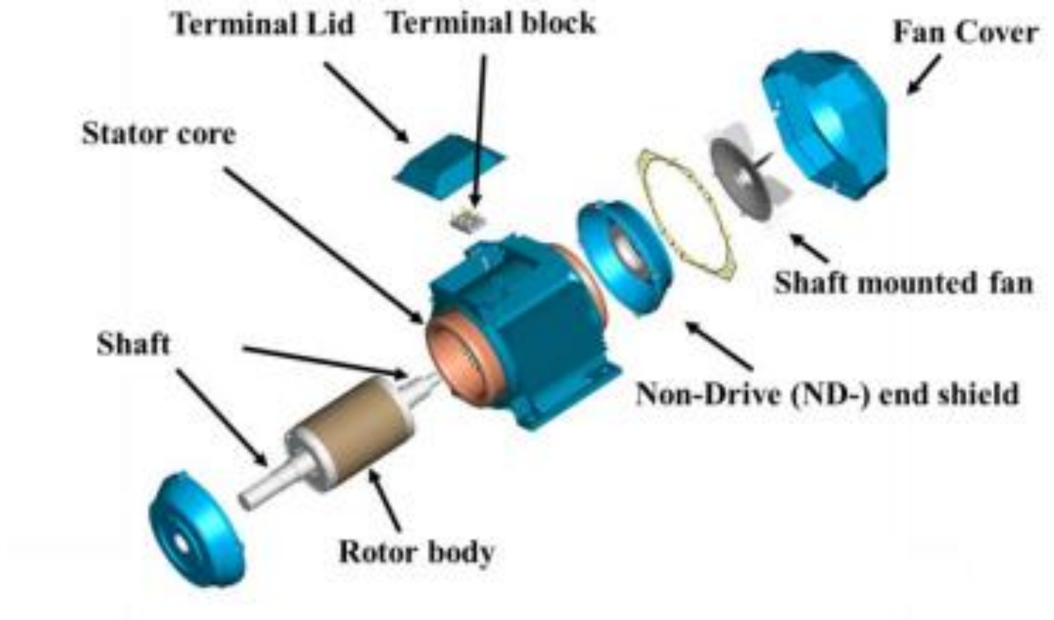

Figure 2.11 Induction motor inner parts [18]

2.4.2. Induction motor operation principle

Once the motor is powered and the 3-phase supply is fed to a 3-phase wound induction stator, a rotating magnetic field with constant angular velocity appears. That is produced in the stator core. On the other hand, shirt-circuited rotor conductors also produce a magnetic field by the current flowing through them. As this field tries to align with the rotating stator field, that produces electromagnetic torque. This electromagnetic reaction produces rotation of the motor.

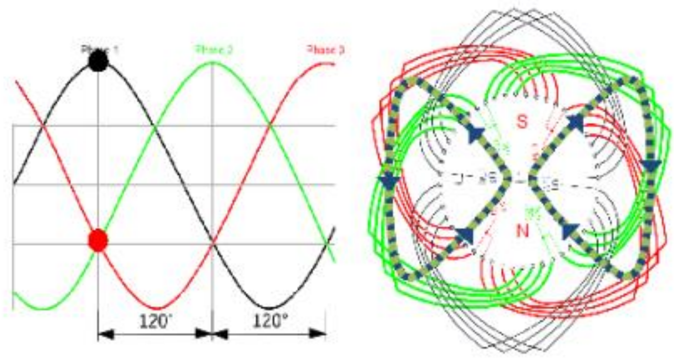

Figure 2.12 Phase coils and magnetic fields. [18]

This type of motor is called asynchronous because the actual speed of the rotation is not the same as the speed of rotating magnetic fields. Depending on the load of the motor, it constantly is a little bit behind the magnetic rotation. This process is called a slip. As there is less load on the motor, that means that the slip is close to zero. Another important motor characteristic that depends on the direction of the current flow is the motor's rotational direction. This rule is called as Right-hand rule (Figure 2.16)

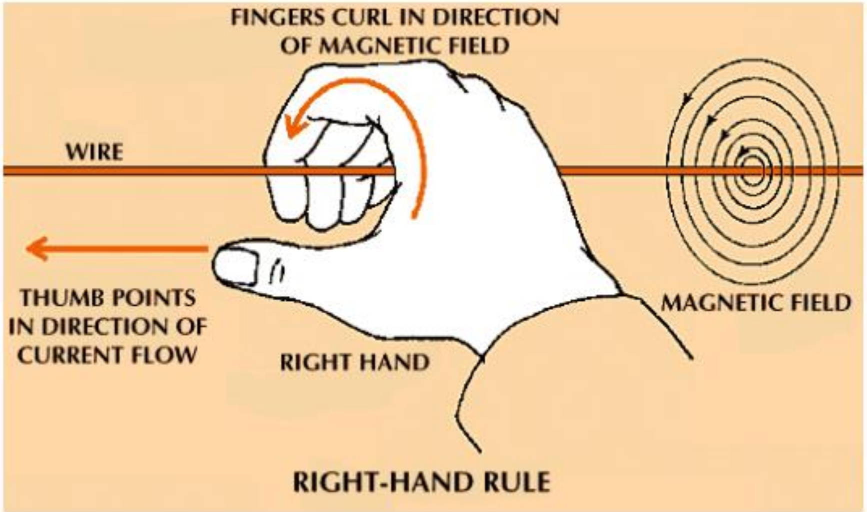

Figure 2.16 Right-hand rule [18]

Quality of electrical characteristics is vital for motor work, and situations, when something is wrong, might appear very quickly. The motor that was powered in the wrong manner might start to work, but very soon might be overheating and then short-circuit.

2.4.3. SIEMENS 1LA7090-4AA60-Z

Figure 2.17 SIEMENS 1LA7090-4AA60-Z [18]

Here is the motor that is used during the test. Such size of the motor is suitable for many applications. Here a some of its characteristics. Electrical data information is divided into two parts for 50 Hz network and a 60 Hz. The part that is applied to the electrical network is 50 Hz, and the motor connection type is Delta since the supply of the motor is three-phase 380V. Rated motor current information is required for analysis and verification of motor health.

Figure 2.18 SIEMENS 1LA7090-4AA60-Z Electrical data [18]

3. SENSORS/MEASURING TOOLS

Current measuring and monitoring play a key role in power converters, while collected current monitoring information can be used for controlling, monitoring and protection. With that, the need for more accurate, lossless, and quick response current sensors is more valuable. Areas of implementation cover solar power electronics, wind turbine systems, motor drives, and hybrid electric vehicles. Today, research in high-frequency current sensing makes controlling, protecting, and monitoring realizable at many levels of electronics. Research focus switches to alternative and contactless measuring options for higher frequency. This part of the thesis aims to review several current sensing methods and challenges that might appear with them. Monitoring techniques can be categorized as resistive-based, filter-based, inductor-based, hall-effect-based [12].

The selection of method usually depends on the aim and type of application or selected monitoring strategy. The list of characteristics that might affect the selection of the sensor is: simplicity, reaction time, accuracy, power consumption, the practicality of implementation for high-frequency converters, sensitivity according to temperature and offset adjustment, and topology dependency [12].

One of the most used methods for measuring AC and DC: Hall effect-based current sensing will be used in this work. The principle of the method is based on the Lorentz force. Once current passes through a conductor that generates a magnetic field, the Hall element is generated during that voltage and represents current as a waveform [13].

3.1. Clamp meters

The clamp meter is one of the devices that is used in the practical part of the thesis. This device is used to measure DC or AC currents and the operational range is quite broad, sometimes reaching 2000A. In the construction of the instrument is a coil that is used for measurements and placed within clamps. Clamps themself can be opened and the wire can be safely placed with the device [13].

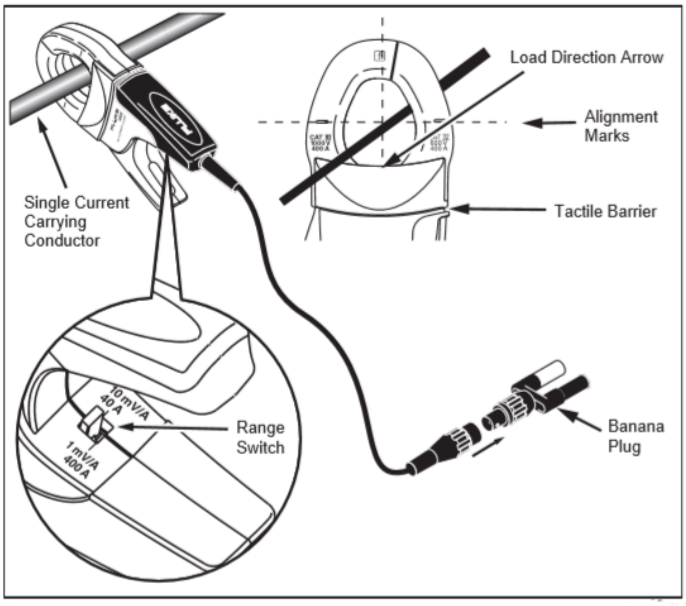

Figure 3.1 FLUKE i400s Setup [14]

The use of the instrument is very advantageous since the current measure does not need the interruption of the measuring conductor. Of course, safety is essential and such a technique provides a very high level of insulation between the instrument and the measurement system and the operator.

3.2. FLUKE i400s AC Current Clamp

Figure 3.2 FLUKE i400s [14]

FLUKE i400s is used in one of the current measuring experiments. It is the part when measurements are performed with high-quality equipment to receive reference values. FLUKE i400 has established itself as a safe and reliable tool. Covered safety ratings are CAT IV 600 V / CAT III 1000V. More specific information is covered in Figure 3.3

	40 A Range	400 A Range
Measurement Range:	0.5 A to 40 A	5 A to 400 A
Output:	10 mV/A	1 mV/A
Accuracy: 45 Hz to 400 Hz	 2 % + 0.015 A	 2 % + 0.04 A
Phase Shift: (45 Hz to 400 Hz) 0.5 A to 1 A 1 A to 5 A 5 A to 10 A 10 A to 20 A 20 A to 40 A 40 A to 400 A	 Unspecified 4° 3° 3° 2° NA	 NA NA Unspecified 2° 2° 1.5°
Crest Factor:	≤3	≤3 to 300 A ≤2.5 to 400 A

Figure 3.3 FLUKE i400s Specifications [14]

3.3. Dewetron DEWE3-RM16 setup

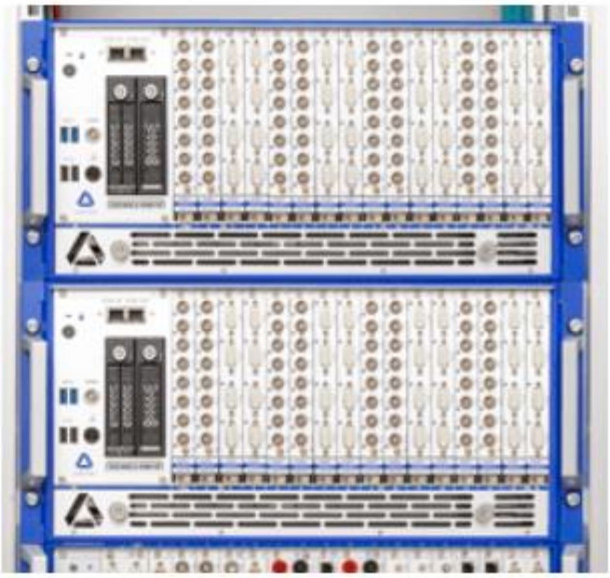

Figure 3.4 Dewetron DEWE3-RM16 [16]

Another essential piece of hardware used during the test is a system created by the company named Dewetron. An Austrian company founded in 1989 focused on measuring instruments since the beginning. At the time PC based measuring systems were just an emerging field. Dewetron quickly expanded into the creation of its measurement systems as well as measurement software. Today this company has a significant portfolio of different instruments and programs. The modular principle is the basis of all Dewetron systems [16].

DEWE3-RM16 is the module that was used during the measurement data acquisition process. (Figure3.4) This is a measuring device that can be installed in the rack along with an external monitor. It contains a powerful CPU inside that allows monitoring signals from a vast range of inputs flawlessly. Transmission speed is up to 10MS/s.

3.4. Measuring software - OXYGEN

The hardware part consisted of the rack with measuring equipment and monitor, and software that is used along with the setup is also from Dewetron company. The program name is OXYGEN and it fitted perfectly with the hardware. Real-time monitoring helped us verify that the current sensor has been connected correctly and to correct phases. The software appeared to be very user-friendly, with the possibility of a custom dashboard [16].

It was possible to do a perfect visualization of different processes for real-time analysis and the reaction to errors or some unpredicted situation. What was necessary for the test is to record several electrical parameters simultaneously and then export them for further analysis and comparison. This task was successfully performed, and necessary data was collected [16].

Figure 3.5 Measuring software – OXYGEN [16]

Figure 3.6 Measuring software – OXYGEN [16]

4. Measurement process

Nowadays, the need to observe the health of the motors is constantly growing. Such parameters as temperature, current, vibration, and humidity can predict the possible failure of the motor. There are many ways to control such parameter information. The motor can be transported to the laboratory for the test experiments, or it is possible to use complicated and expensive sensors from other companies. To prove that a much more affordable technical solution based on IoT can substitute specialized equipment, a set of experiments will be performed in the following part of the thesis. The selection of equipment is based on the options from the university laboratory. As a first part of the experiment, the motor current of each phase will be measured in laboratory conditions with specialized equipment. For the second part, the measurement will be performed with one of the most affordable Arduino microcontrollers and the result will be compared.

4.1. Experiment with Dewetron setup

All the parts required for the analysis have been introduced, and now the test setup can be introduced. This is the setup needed for reference current measurements. Those results will be compared to result received through Arduino equipment.

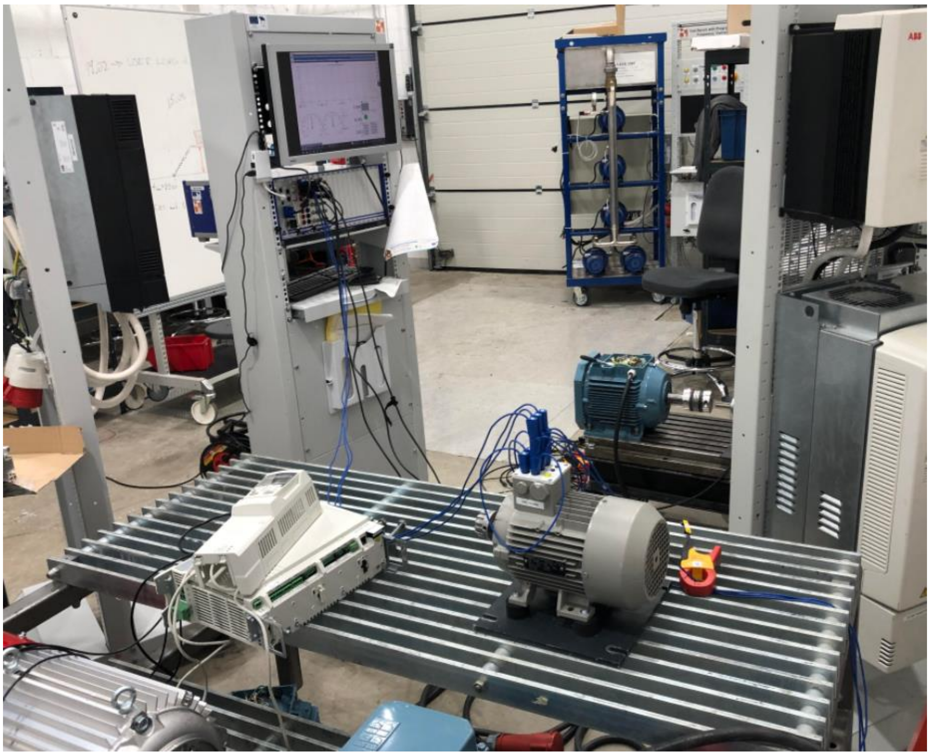

Figure 4.1 Picture of the test setup in the laboratory.

In the picture, it is visible that the motor is on the table, and connection cables go from the socket to the connection box, then to the measurement instrument. Since the motor is supplied with three phases, there is a cable for each phase. After the connection scheme has been assembled, a supervisor verified that everything is fine from the safety point of view. Also, it was verified that nothing is touching the rotating part of the motor. The motor started rotation at nominal speed the moment it was plugged into the wall power socket.

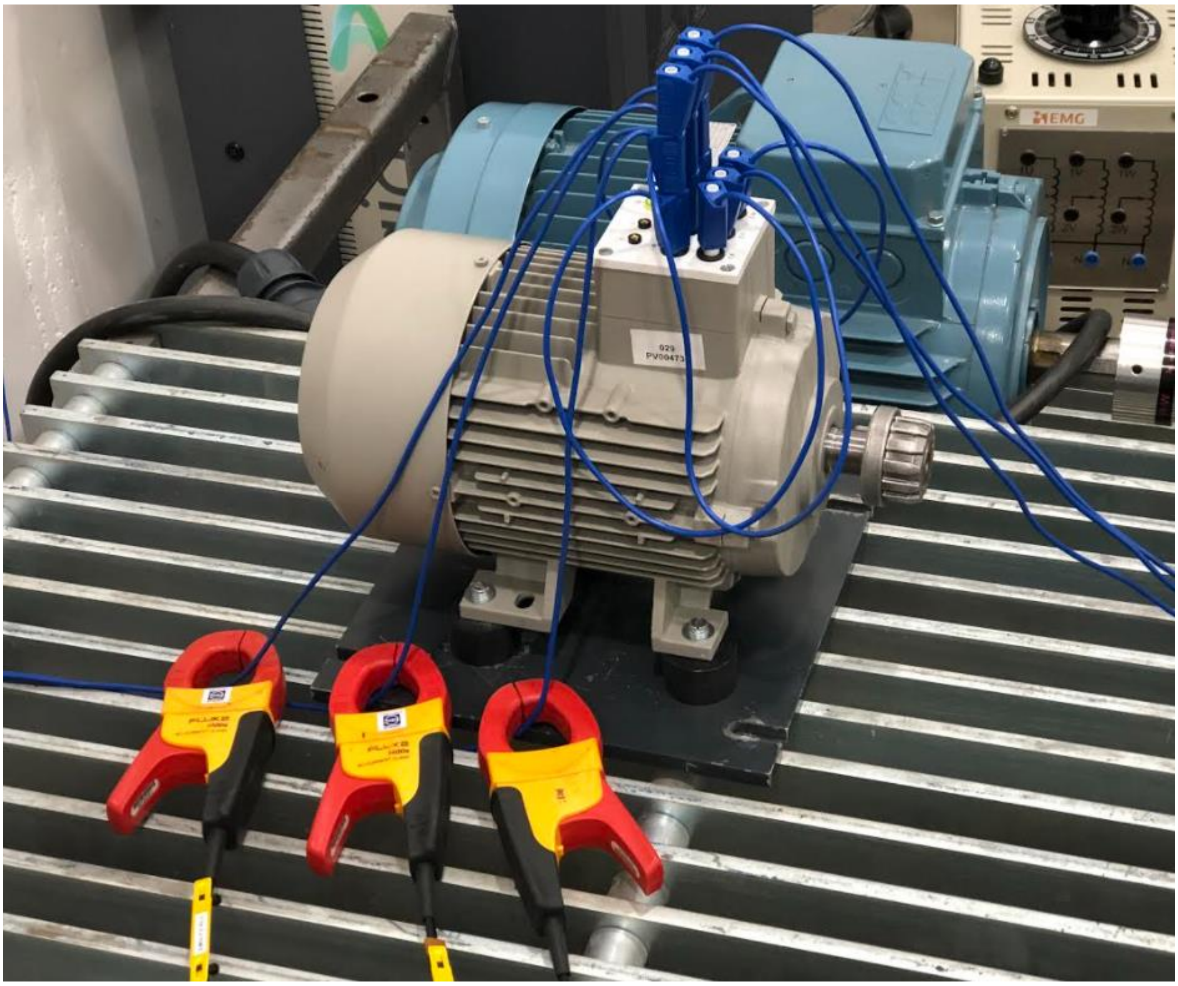

Figure 4.2 FLUKE measurement clamps.

There is a separate FLUKE current measurement sensor for each phase. As the supply voltage is 380V, it is visible that the connection mode is Delta, according to specification.

Once the motor started rotation and all necessary current sensors have been connected. Several dashboards have been assembled in the OXYGEN program that was used for monitoring and data gathering. Right away, it could project all three phases along with voltage and current parameters. In Figures 4.3 and 4.4, dashboard screenshots with real-time parameters can be seen. As data recording speed is tremendously high, it is not always possible to see the precise picture only based on the moment values. With the help of the record function, current values have been collected and saved in CSV format. With this information, it can track the exact values of current for each phase and represent them on the graph on Excel. This test has provided the necessary base for work and further comparison of data from the Arduino sensors.

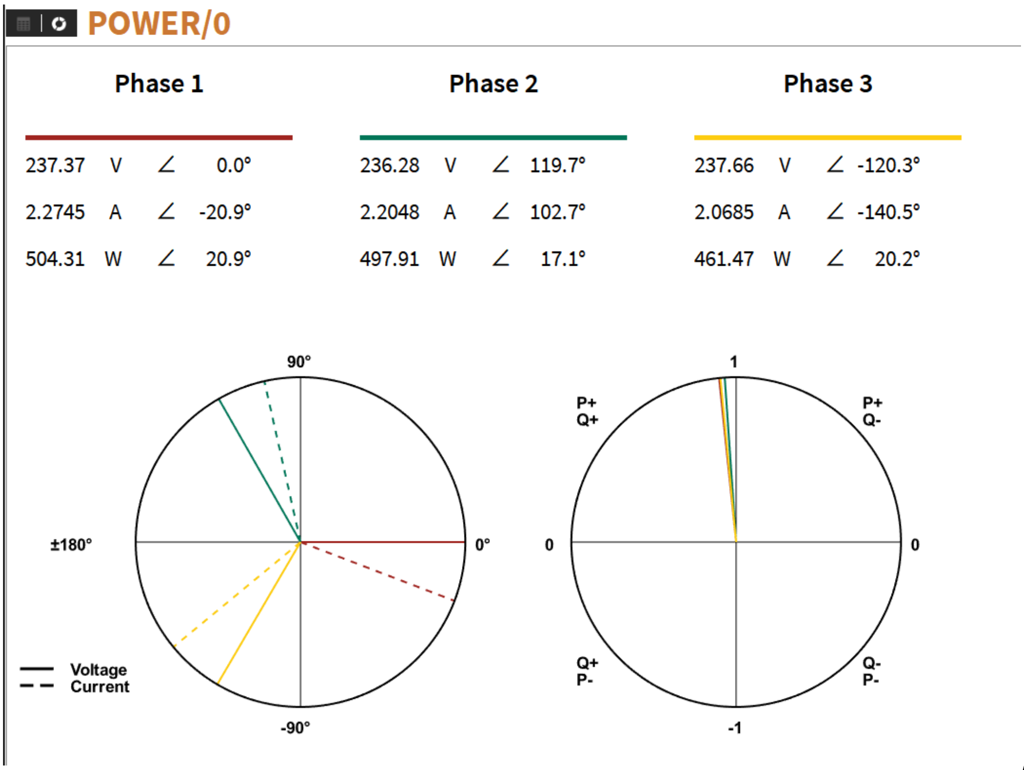

Figure 4.3 OXYGEN Voltage, current, power parameters.

POWER/0

	Phase 1		Phase 2		Phase 3		Total	
U_tRMS	237.13	V	236.00	V	237.41	V	236.85	V
I_tRMS	2.2744	A	2.2065	A	2.0680	A	2.1829	A
P_t	503.29	W	496.72	W	460.36	W	1.4604	kW
Q_t	193.80	var	156.32	var	170.60	var	522.43	var
S_t	539.32	VA	520.74	VA	490.95	VA	1.5510	kVA
PF_t	0.9332		0.9539		0.9377		0.9416	
F_fund							49.965	Hz
U_fundRMS	237.06	V	235.95	V	237.35	V	236.79	V
I_fundRMS	2.2721	A	2.2018	A	2.0662	A	2.1801	A
P_fund	502.96	W	496.34	W	460.11	W	1.4594	kW
Q_fund	192.79	var	153.44	var	169.72	var	515.94	var
S_fund	538.64	VA	519.51	VA	490.42	VA	1.5486	kVA

Figure 4.4 OXYGEN more parameters.

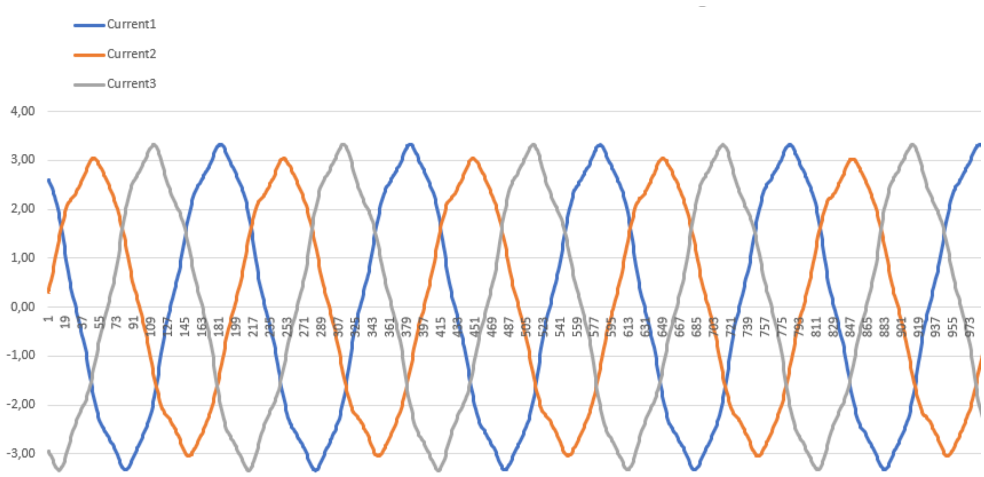

Figure 4.5 Excel current diagram.

4.2. Experiment with Arduino setup

The previous chapter's current measurement results have been acquired with a specific and quite expensive set of hardware and software within the experiment. As the Arduino is one of the most important representatives of IoT, in this part of the experiment, the goal would be to achieve a similar result with the help of Arduino. Now it is possible to exclude Dewetron, along with its software OXYGEN. Instead of this equipment, it is possible to use the most popular Arduino - Arduino UNO, along with its free, open-source software. (Figure 3.5)Current sensors will remain the same since the are several analog inputs on the Arduino board and it is possible to connect Fluke sensors directly there. (Figure 30) The same motor is used within this part of the experiment.

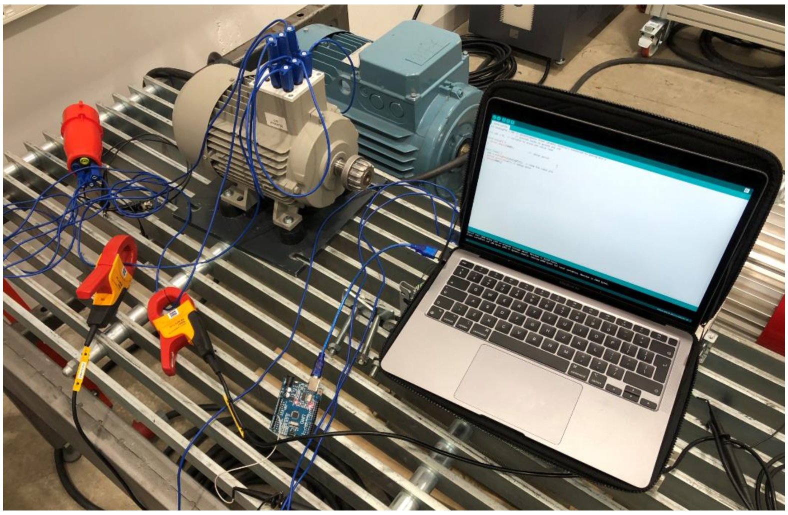

Figure 4.6 Test setup with Arduino**.**

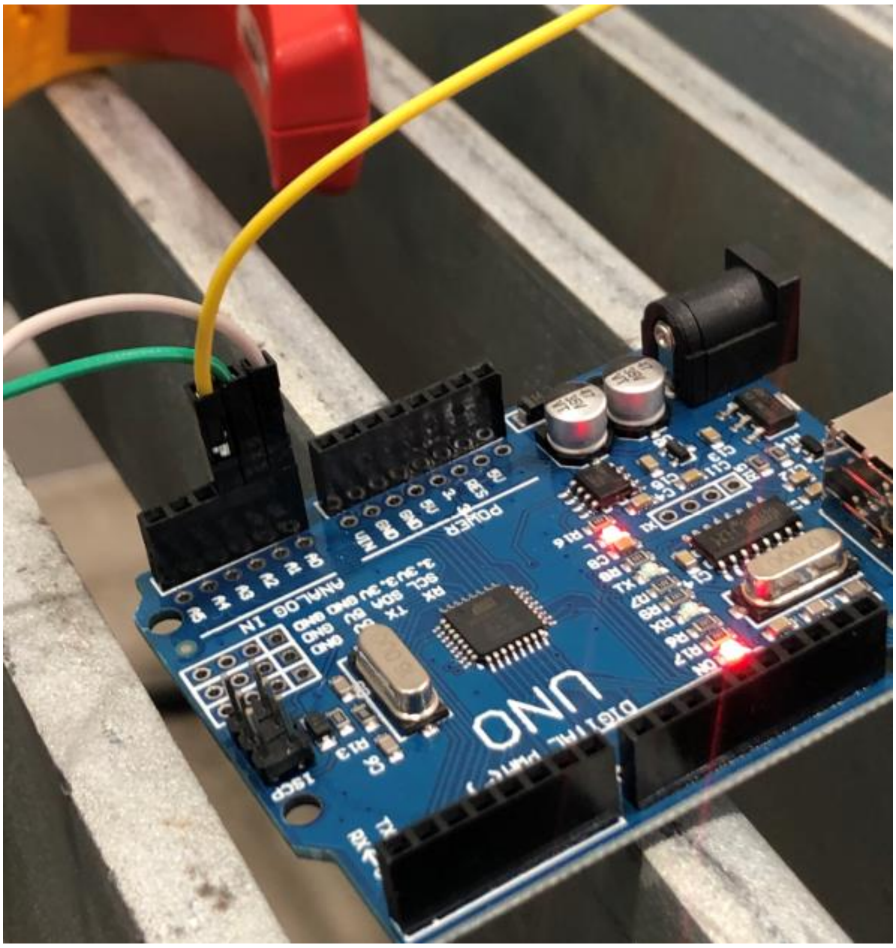

Figure 4.7 Current sensors connected to Arduino**.**

The further process required some programming in Arduino integrated development environment (Figure 3.7). It started with three commands that receive analog values. Then three variables have been assigned to those phases. At the end of the program, it was required to create three more commands the would show our results in the monitor window. The system started to work and the observed but not scaled values from sensors can be seen on the serial monitor (Figure3.8). After calibrations have been performed, the values for the sensors became very similar to the values from the first experiment that used Dewetron (Figure 3.9). On the Figures from the experiments (Figure 4.5) and (Figure 4.10) it is visible that in both cases values go from -2.5A to 2.5A +- 10%.

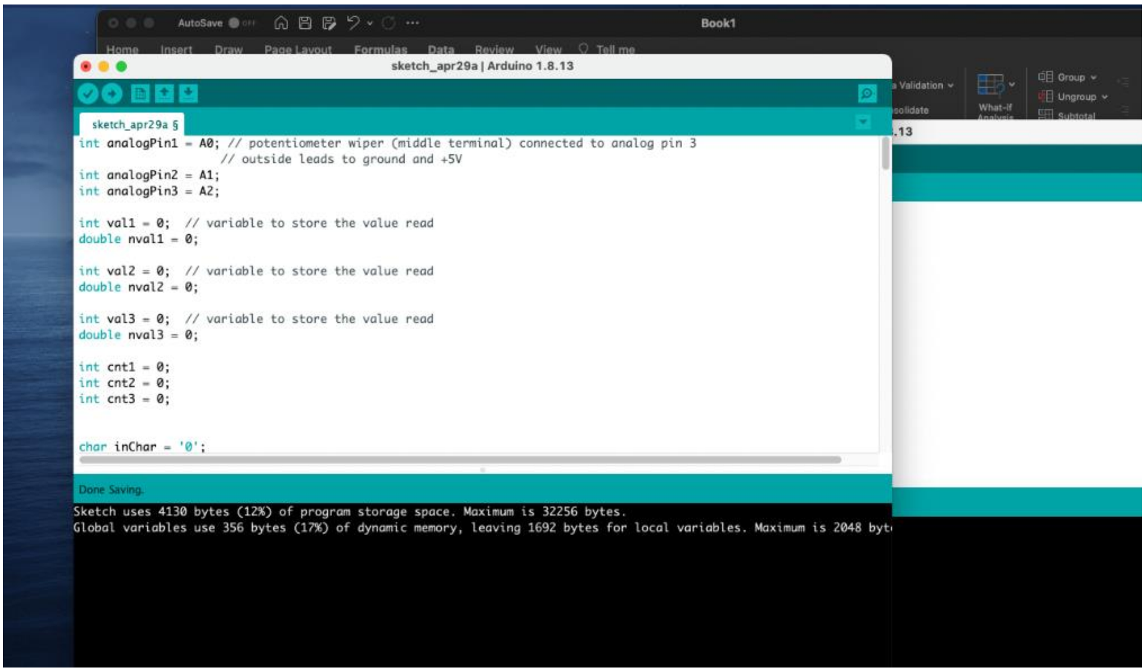

Figure 4.8 Arduino integrated development software.

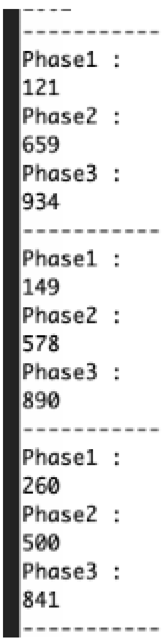

Figure 4.9 Not calibrated values from Arduino.

```
-----------
Phase1 :
-0.50
Phase2 :
-2.50
Phase3 :
-2.50
-----------
Phase1 :
0.50
Phase2 :
-2.50
Phase3 :
-2.50
-----------
Phase1 :
1.50
Phase2 :
-1.50
Phase3 :
-2.50
-----------
Phase1 :
2.50
Phase2 :
0.50
Phase3 :
-0.50
-----------
```

Figure 4.10 Calibrated Amp values from Arduino**.**

Now, the values that Arduino is showing are understandable and measurable. During the next step of the experiment, a reaction to specific changes has been created. In this case, the idea was to monitor each phase and in the case of data from the phase is missing for more than 5 seconds, a warning message would appear. So during the monitoring process, one phase has been disconnected from the board (Figure 3.11). Part of the experiment that required monitoring and reaction was performed successfully.

The last part of the experiment required testing of the control function. The idea was to send a command that will turn one sensor, which is visible on the monitor window (Figure 3.12). And that action was performed by typing number "3" to the "Send command" window (Figure 3.13)

```
0.00
Phase1 :
2.50
Phase2 :
0.50
Phase3 :
0.00
Phase1 :
1.50
Phase2 :
1.50
Phase3 :
No current in Phase 1 for 5 seconds, please check connections or there might be a problem!!
Phase1 :
0.50
Phase2 :
-2.50
Phase3 :
No current in Phase 1 for 5 seconds, please check connections or there might be a problem!!
Phase1 :
-2.50
Phase2 :
0.50
Phase3 :
No current in Phase 1 for 5 seconds, please check connections or there might be a problem!!
```

Figure 4.11 Disconnected phase from the board.

```
-----------
Phase1 :
0.50
Phase2 :
-1.50
-----------
Phase1 :
1.50
Phase2 :
-1.50
-----------
Phase1 :
2.50
Phase2 :
-0.50
-----------
```

Figure 4.12 Phase 3 is not monitored after the command.

```
3
```

```
Phase3 :
3.50
-----------
Phase1 :
0.50
Phase2 :
2.50
Phase3 :
3.50
-----------
```

Figure 4.13 Number three as a command for Arduino

CONCLUSION

Within the scope of this thesis work, a review of areas where the IoT has been implemented and used daily has been made. Already today, IoT covers many areas of our life. The benefits of IoT are apparent. However, the question was how accessible is this technology? For the experiment, it was decided to work with an essential electrical machine like an induction motor and observe its vital parameter like current, using a very affordable representer of IoT family - Arduino UNO. Those motors are essential and their life span usually stretches for years. For the final result verification, the initial data was gathered using dewetron. In the second part of the experiment, the same result has been achieved with a very affordable Arduino UNO board and free open-source software that comes along with it. The experiment showed how to monitor data, react to unusual situations, and control sensors over the network.

The benefit of this work is to show, that with the small amount of modern technology it is possible to modernize machines to a new level. For example, if the motor is very important or in case of its malfunction, it might take some time to get there, with different sensors and Arduino it is possible to look after the motor. Information from vibration, temperature, and current sensors, might predict changes in motor health. This information helps to analyze the motor conditions and prepare for the service in time.

As a possible further development, it is proposed to add more sensors and control of motor using Arduino along with sensors.

KOKKUVÕTE

Antud bakalaureusetöös uuriti valdkond, kus asjade internet on rakendatud ja kasutatakse igapäevaselt. Tänapäeval on asjade internet igapäevaelu lahutamatu osa. Küsimus seisneb järgmises, kui kättesaadav antud tehnoloogia on? Motor voolu kontrollimise katse jaoks otsustati kasutada asünkroonmootorit. Ning jälgitaval parameetril kontrolliti voolu taset ühe kõige enam kättesaadavama Arduino perekonna esindaja abil – Arduino Uno. Need mootorid on enamus tootmistegevustes väga populaarsed ja mootori töö tähtaega arvestatakse mitmeks aastaks. Selleks, et veenduda katse edukuses, olid esimesed voolumõõtmised teostatud spetsiaalsete mõõteseadmete abil. Katse teine osa seisnes selles, et saada sarnased tulemused olemasoleva Arduino Uno abil. Programm, millele kood kirjutati, on tasuta ning on varustatud mikrokontrolleriga. Mõlemal juhul kasutati samu sensoreid juhtmete voolu ja pinge mittekontaktseks mõõtmiseks. Lisaks tavapärasele voolu väärtuste jälgimisele, igas faasis, suutis süsteem ebatavalistele olukordadele reageerida sõnumiga ning teostas andurite juhtimist võrgu kaudu. Antud töö väärtus on järgmine – näitab, et väikse osa kaasaegsete tehnoloogiatega saab masinaid moderniseerida ja viia need uuele tehnoloogilisele tasemele. Näiteks, taoline mootor võib olla väga oluline ja asuda raskesti ligipääsetavas kohas ning rikke korral võib selle parandamine võtta väga kaua aega. Arduino abil saab jälgida mootori olekut. Kui lisada juurde vibratsiooni, temperatuuri, voolu ja pinge sensoreid, saab jälgida mootori tehnilist seisukorda. Selline teave aitab mõista, millistes tingimustes mootor töötab ning valmistada ette õigeaegset hooldust. Bakalaureuse töö edasiarendamiseks pakun välja kasvatada sensorite arvu ja kaugseiret.

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