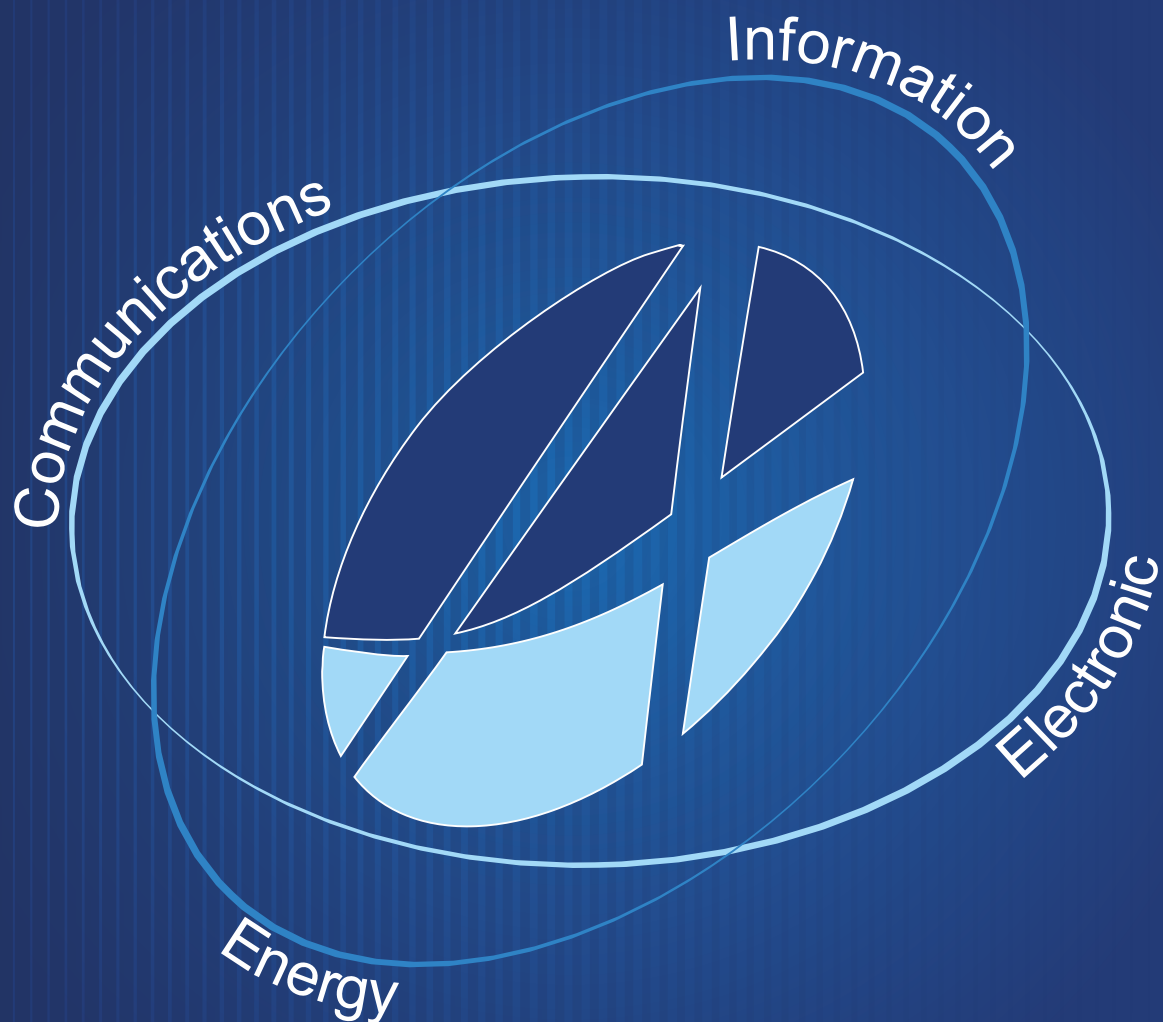


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## **Editorial**

As a result of widening the spectrum of communication, dissemination and implementation of scientific research results, in 2020 was founded the association journal (magazine), issued under the name The Journal of CIEES appearing both in print (ISSN: 2738-7283), and online (ISSN: 2738-7291) format with DOI: <https://doi.org/10.48149/jciees>.

The Journal of CIEES is published in English and it is open access, peer-reviewed international scientific journal publishing papers submitted by authors themselves for publishing and invited by the Editorial Board. The Journal of CIEES covers all the essential branches of theories, technologies, systems, tools, applications, work in progress, and experiences on all theoretical and practical issues arising in telecommunications, electronics, signal processing and applications, information technologies, energy systems and etc.

As always, many people have contributed to this issue including all authors, the anonymous reviewers, the Associate Editors, the Editorial Advisory Board and, of course, our outstanding production team. We wish to acknowledge each individual's contributions, and to also express our gratitude for everyone's commitment. We hope you enjoy this first issue of The Journal of CIEES.

We have had the privilege to publish truly outstanding, quality manuscripts that, judging by the response of our reviewers and readers, are important contributions to their respective fields of research. We want to take this moment to thank all of our reviewers and authors for entrusting us with their discoveries.

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# Bluetooth Low Energy Technology Simulators

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**Abstract:** The growing interest in Internet of Things technologies in modern life requires their active research. This can be done most easily by using a simulation product for the technology in consideration. This article presents the most famous existing simulation products of Bluetooth Low Energy technology, as well as the one developed by the authors, and presents a comparison between the considered solutions.

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**Keywords:** Bluetooth, BLE, IoT, Simulators.

## 1. Introduction

The Internet of Things (IoT) technologies are becoming more and more widespread in modern everyday life, which is leading to their growing worldwide distribution. The active use of IoT technologies in various industries requires the provision of a high-speed data transmission environment. Such an environment provides 4G and 5G technologies, as well as the opportunity for extensive incursion and expansion of broadband technologies for IoT [1].

Among the most common IoT technologies is Bluetooth Low Energy (BLE), which is used to: connect wearable devices such as watches, location devices, health and fitness, body sensors; access to surrounding devices such as access control bracelets, home and office automation; M2M communication with low efficiency as sensors and control devices in homes, offices and factories; communication within a closed system; connecting everything that has data to the Internet. According to statistics and sales forecasts for BLE devices, the number of devices sold is increasing by approximately half a billion per year [2]. This shows that the technology is becoming more and more used.

The widespread use of BLE technology demands offering and researching solutions to improve its performance. Simulators are a suitable tool for researching theoretical improvements to the standard. They allow preliminary study of the proposed solutions before investing resources and time for purchasing, study and configure hardware devices and make efforts to implement new specifications. Implementations of applications to simulate the operation of devices with BLE technology are limited, and most are developed as emulators.

Emulators and simulators allow experiments in software-defined environments. In this way, they ensure that experiments are performed faster than if a real hardware device had to be set up. Although simulators and emulators serve similar purposes, they do not work at

the same way.

The simulator is designed to create an environment that contains all the software variables and configurations that will exist in the actual production environment of the application. However, the simulators are not trying to emulate the actual hardware that will keep the application in use. Because simulators only create a software environment, they can be implemented using high-level programming languages. The emulator tries to mimic all the hardware features of the production environment as well as the software functions.

Simulation products provide an environment for research and study of the main functionalities of the technology in consideration, and the capabilities provided are usually based on existing standards. This allows the simulators to be actively used in the study of new theoretical solutions to improve the technology under consideration. The simplified ability to work with the provided interface, as well as the ability to make modifications to open source solutions makes the simulators an attractive tool with wide application in education. The ability of the simulators to be used on personal machines by the trainees allows for both Onsite and Online work. In addition, the issues addressed during the lesson can exercise at any time.

This article presents several simulation products which examines the basic functionality of BLE technology, as well as their advantages and disadvantages.

## 2. BLE simulation via MATLAB

The BLE interface in MATLAB [3], included in version 2019b [4], provides many features that allow the implementation of simple BLE applications and the ability to transmit and receive ASCII and binary data. For this implementation, it uses a Bluetooth serial port. Any Bluetooth device can be identified, and a two-way connection can be established using MATLAB. To communicate with a BLE device, the computer running MATLAB must have a built-in or external Bluetooth Low Energy adapter. This MATLAB interface is supported by the following platforms:

- macOS 10.13 High Sierra and newer versions;
- Windows 10, version 1709 and newer.



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Once the device is connected, MATLAB is used to read or write data to it (Figure 1). The product allows work with both standard and custom services, features and descriptors, which play an important role in reading from and writing to a peripheral device. The interface provides examples of tracking the orientation of an end device that has a motion sensor, for the Nordic Thingy:52 device, as well as an example of collecting and visualising data from body tone tracking devices of Under Armor during exercises. There are also examples developed for the interface by researchers in the field, for the CC2541 Keyfob and CC2650 Sensor Tag BLE sensor devices [5].



**Fig. 1.** Reading data from a sensor node via the MATLAB interface.

Its functionalities are the following:

- scanning nearby BLE peripherals;
- connecting to BLE peripheral;
- access to a characteristic of the peripheral device with BLE technology;
- access to a descriptor of peripheral device with BLE technology;
- reading characteristics or descriptor data of a peripheral device with BLE technology;
- writing data in a characteristic or descriptor of a peripheral device with BLE technology;
- subscribing for a characteristic notification or indication;
- unsubscribing from a characteristic notice and indication.

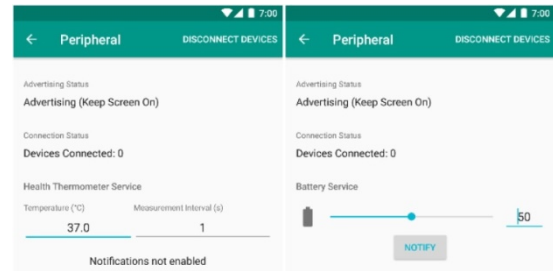
The MATLAB interface requires the use of a real physical device with a Bluetooth module that supports BLE. The actions in the environment are performed with a sequence of commands, as there is a realised graphic visualisation for the provided sample solutions.

### 3. The BLE Peripheral Simulator

The BLE Peripheral Simulator application, written in JavaScript, is for Android (Figure 2) services [6], which allows developers to try out new features of Web Bluetooth without the need for a BLE peripheral. The program code can be used to launch the application and can be compiled or installed from the Google Play Store.

The application can be used to simulate BLE peripherals with one of three services:

- battery service;
- heart rate service;
- thermometer service.



**Fig. 2.** BLE Peripheral Simulator user interface.

The developer can use the new features of Web Bluetooth to connect to the application to read and write characteristics, subscribe to characteristics change notifications, and read and write to descriptors. The developer can also set characteristics values, send notifications, and disconnect. The application must be installed on a device that has a Bluetooth module and supports BLE. It also has limited opportunities to manage only three types of services.

### 4. BLE Simulator of Mikhaylov

The Mikhaylov's simulation tool [7] allows simulate the communication between BLE devices in the constructed network (Figure 3). The simulation environment provides an opportunity to study the network aspects of the BLE protocol.

The MiXiM framework (v2.2.1) based on OMNeT ++ (v4.2.2), used as an application development environment. In order to enable multi-channel communication, the physical layer model (PHY) has been extended. The implementation of the Link Layer (LL) model in the devices is realised with the possibility of their operation in five states (Standby, Advertising, Scanning, Initiating and Connection), based on the BLE specifications.

The simulator does not support HCI (Host-Controller Interface) and host layers of the BLE stack, and packets are generated at the LL layer, which does not affect the accuracy of the communication simulation. All parameters of BLE communication (advertising and connection intervals, timeout tracking, frequency hop change, list of used data and advertising channels) are defined in a simulation initialisation file and remain constant during the simulation. Another limitation is that only one active connection is maintained for each simulated device at a time. The developed version does not include security realisation and Ping command.

The environment allows simulating the functionality of BLE devices in several modes: transmitting advertising packages on one or more advertising channels, listening to one or more advertising channels, establishing a connection, maintaining and terminating the connection. The data collected during the simulations include the number of packets sent/received by each node, the status of each node and the radio channel used at each time, energy consumption, and more. When simulating the power consumption of the radio transmitter, the consumption of the microcontroller for packet preparation and data processing is not taken into account. However, the simulator provides realistic values in terms of throughput and power consumption.

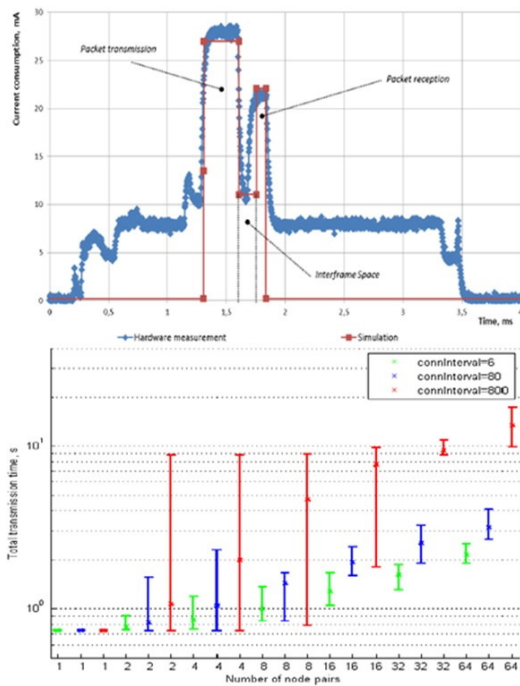


Fig. 3. Results of the Mikhaylov simulator.

## 5. Advantages and disadvantages of the considered BLE simulators

Based on the review of existing solutions for simulating BLE technology, the most common and used ones are presented. Table 1 describes the main advantages and disadvantages of the considered solutions.

In order to overcome some of the disadvantages of the existing solutions for simulating BLE technology and providing a wide range of opportunities for investigation of technology, to the open source simulation product

presented in [8], functionality extensions have been implemented. The product was developed in the Computer Science and Engineering Department at Technical University - Varna, Bulgaria. Extensions are expressed in providing the opportunity to study the measured RSS and RSSI values of the received signal.

## 6. Developed simulator for BLE

The product for simulation of BLE technology [8] developed in the Computer Science and Engineering Department at Technical University - Varna, Bulgaria, provides an easy-to-use user interface (Figure 4) for studying the main functionalities of the standard. Java, Apache Maven, JavaFX & Scene Builder and Lauch4j technologies were used to develop the environment. It has a modular architecture and the operation of all processes is controlled by the application core. The application is open source, free to use and does not require installation (only Java is required on the machine on which it runs).

The functionalities of the environment include: adding a Master and Slave device, with the ability to select and modify the parameters of Slave; visualisation of the connection topology in the network, as well as its modification; research of the used communication channels; tracking of the conducted communication and the transmitted information between the devices; presentation of statistical information on terminal devices; visual presentation of the messages exchanged between Master and Slave when establishing a data transmission connection and its termination. The product provides an opportunity to study the measured RSS and RSSI values of the received signal.

Table 1. Advantages and disadvantages of the considered simulators of BLE technology.

| Simulator                         | Advantages                                                                                                                                                                                                                                                                                                                                                                                                            | Disadvantages                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>MATLAB</b>                     | Allows the implementation of simple BLE applications and the ability to transmit and receive ASCII and binary data. Works with both standard and custom services, characteristics and descriptors of peripherals. The interface provides examples of different applications that have implemented graphical visualisation. There are also examples developed by researchers in the field. Provides easy installation. | Requires Bluetooth serial port. There is a need to purchase a BLE transceiver if it is not built-in. The interface is supported on macOS 10.13 High Sierra and Windows 10 operating systems, as well as their newer versions. Requires physical end devices. The examples provided are applications for Nordic Thingy:52 and Under Armor devices. Requires payment of a license to use. |
| <b>BLE Peripheral Simulator</b>   | Allows operation of Web Bluetooth functions without the need for BLE peripherals. Allows reading and writing of characteristics, subscribing to notifications for changes of characteristics and reading and writing of descriptors, disconnection. The application is easy to install and free.                                                                                                                      | It is a mobile application. Allows operation of a limited number of services (3). It is necessary to use a physical device that has a Bluetooth transceiver and supports BLE.                                                                                                                                                                                                           |
| <b>BLE Simulator of Mikhaylov</b> | Enables simulation of communication between BLE devices in a network. Does not require work with physical devices. Allows research into the network aspects of the BLE protocol. Provides simulation of the operation of end devices in five different states. Allows metering of consumed energy. The application is open source and free access.                                                                    | The simulation parameters are defined in a simulation initialisation file and cannot be changed during the simulation. Provides limited simulation capabilities. There are no operating instructions available. Difficult installation.                                                                                                                                                 |

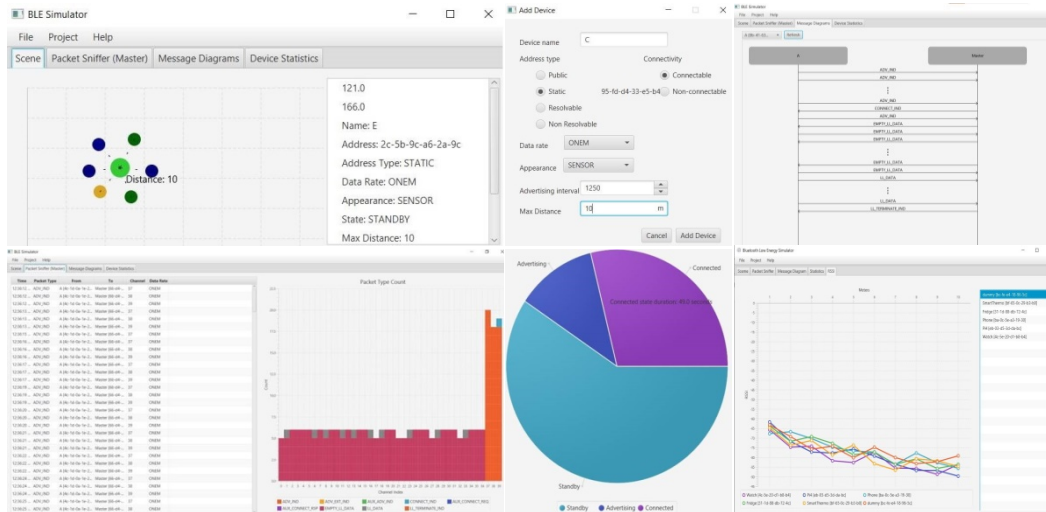


Fig. 4. User interface of the developed product.

## 7. Comparison of simulators for BLE

There are various studies [9, 10] that compare wireless network simulators for IoT. Based on these studies, a comparison made between the considered simulation products for BLE technology. Table 2 presents a compilation of the criteria used in the studies in

consideration, in order to more accurately compare the considered simulators, omitting the criteria that are not applicable.

The presented comparison gives reason to claim that the developed simulation product is not inferior in quality and capabilities to existing ones.

Table 2. Comparison of BLE network simulators.

| Comparison criteria for BLE simulators                     | Researched simulators      |                          |                        |                        |
|------------------------------------------------------------|----------------------------|--------------------------|------------------------|------------------------|
|                                                            | MATLAB                     | BLE Peripheral Simulator | Mikhailov              | Developed              |
| Possibility to build different network architectures       | ✓                          | ✗                        | ✓                      | ✓                      |
| Possibility for implementation and design of protocols     | ✓                          | ✗                        | ✓                      | ✓                      |
| Deriving statistical results for the experiments performed | ✓                          | ✓                        | ✓                      | ✓                      |
| Maintaining a graphical user interface                     | ✓                          | ✓                        | ✓                      | ✓                      |
| Availability of a guide for users and developers           | ✓                          | ✓                        | ✓                      | ✓                      |
| Supported operating system                                 | Linux, MAC OS, Windows     | Android                  | Linux, MAC OS, Windows | Linux, MAC OS, Windows |
| Scalability                                                | ✓                          | ✓                        | ✓                      | ✓                      |
| Possibility for expansion                                  | ✓                          | ✓                        | ✓                      | ✓                      |
| Battery/lifetime evaluation                                | ✓                          | ✗                        | ✓                      | ✗                      |
| Modelling of energy consumption                            | ✗                          | ✓                        | ✓                      | ✗                      |
| Programming language                                       | Matlab script, Python      | JavaScript               | C++                    | Java                   |
| License                                                    | Paid standard and academic | Free                     | Free                   | Free                   |

## 8. Conclusion

This article provides an overview of existing solutions for simulating BLE technology. Some of the most known simulators for the technology are discussed, and their advantages and disadvantages are presented. In order to overcome some of the disadvantages of the considered solutions, improvements have been added to the simulation product for BLE technology developed by the authors. The presented simulators are compared on the example of other researchers, using a compilation of criteria for comparing simulators for wireless networks for IoT. The obtained results show that the developed

simulation product is not inferior in quality and capabilities provided to the existing ones.

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# Nomophobia as a Social Problem- Habits of Using Mobile Phones

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**Abstract:** Nomophobia is a disorder of the modern, technologically advanced and digital world. It is becoming more common nowadays with increased development of mobile devices. In this paper, we can see that more than 60% of the surveyed students admitted that they are addicted to mobile phones, without even being aware of nomophobia itself. The impact of nomophobia is manifold, from the physical and psycho-emotional burden borne by the patient himself to the collective burden, whose influence changes the form of social interactions. The paper will say more about nomophobia itself, the advantages and disadvantages of using the technology itself, the impact on children and society, and the analysis of survey results from students.

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**Keywords:** disorder, addiction, technology, nomophobia, students.

## 1. Introduction

Many of us cannot imagine a day without a cell phone. Those who are older remember the time when it was not in use, but that time has become far away, while the younger generations cannot imagine a world without technology and the Internet. As soon as they wake up and open their eyes, they pick up their mobile phones and check messages, notifications, news, horoscopes and more. Cell phones are probably the biggest addiction of the 21st century. People spend more than 9 hours a day with a mobile phone. This leads to the "paradox of technology", i.e. liberation from the real world and captivity in the virtual world [1].

The burden of this problem is growing globally, especially during a pandemic. Nomophobia refers to the pathological fear of not having a mobile phone, losing signal or running out of mobile phone battery. Women suffer from the phobia more often, but men are the ones who have two mobile phones each. A connection with younger age, low self-esteem, anxiety and impulsivity was established with certainty. Modern society has become more and more antisocial, socially isolated, most of our free time is spent in front of screens, which greatly spoils our vision and motor abilities, and there is less and less live socializing without the interference of mobile phones. Technology has taken over our lives and it is impossible to find some area in which it is not used [2].

However, excessive use of these means of technology is turning against us. Today it can already be encountered and people struggle with many consequences brought by technology.

The aim of the work is to raise awareness and educate students about the problematic phobia that they unconsciously experience every day. Students are encouraged to seek treatment for nomophobia, since with

it they cannot focus on their duties, studies, things that are natural and necessary for our normal course of life, such as hanging out with other colleagues live, exercising, sports.

## 2. Nomophobia

The term nomophobia is used to describe a psychological condition in which people are afraid of being without a mobile phone. Cell phones have effectively filled the void, with the help of social networks through which we are connected. Now we have thousands of friends on social networks (virtual friends), although in reality we may have very few people we really interact with [3].

Anxiety in cases of nomophobia is caused by many factors, such as losing a cell phone, losing signal, and having a low cell phone battery. Nomophobes show some unusual characteristics, such as impulsive use of mobile phones, as a protective mechanism to avoid social communication. Sometimes they carry multiple mobile phones along with a battery charger to avoid disconnection from the virtual world. Nomophobia can also lead to physical problems such as elbow, arm, neck and back pain. Various psychological factors are involved when a person uses a mobile phone excessively: disorders such as social phobia or social anxiety, low self-esteem and panic disorders. It has been documented that victims of anxiety disorders and panic disorders were more susceptible to nomophobia. It is very difficult to distinguish whether a person becomes nomophobic due to cell phone addiction or existing anxiety disorders are manifested by nomophobic symptoms. Therefore, doctors must be careful in establishing a diagnosis. Some mental disorders can accelerate nomophobia and vice versa. The solution is to limit the use of cell phones, rather than ban them, because we cannot escape the influence of modern technology in the 21st century [4].

Indicators of nomophobia are: checking smartphones after waking up in the morning, poor grades among students due to excessive use of mobile phones, young



people going through a crisis of social identity with the pressure of continuous connection to social networks, great extroversion on social networks, and introversion in reality, impulsiveness and a sense of urgency when sending a message or notification (some of those affected often look at the phone screen in order not to miss any notification - ringing anxiety), anxiety, changes in the respiratory system, tremors, sweating, agitation, disorientation, tachycardia [5].

When we talk on the mobile phone, we usually hold it to our ear. In this position, part of the EM radiation is also absorbed by the tissues of the head in the immediate vicinity of the phone. EM radiation has a stressful effect on our health, disrupting the activity of hormones and bodily processes, but the greatest area of interest is the impact of this radiation on the brain and brain nerves (especially the auditory nerve) [6].

### ***2.1. Advantages of using cell phones***

With one click, in a few seconds we can find whatever we need and what interests us. Now we can study without going to the library, looking for literature and bothering to return the book on time. Everything is at our fingertips. On the Internet, we can find everything we need faster and easier, so books are no exception. It also helps us to be constantly informed – aware of what is happening around us. In order to book a holiday, we don't need to visit travel agencies, we don't even have to go shopping. Everything can be ordered and arranged at home from the comfort of your chair, quickly and efficiently, without wasting time. As for contact and communication, it has never been easier to keep in touch with anyone, friends, relatives... Not even hundreds of thousands of kilometers can stop us when there are video calls, voice calls, social networks to share all possible media. We can drink coffee with someone who is on the other side of the world without leaving our armchair. Getting to know and making friends, even romantic relationships, is even less of a problem. It is a preoccupation of young people, but also of middle-aged and older people. They are increasingly reaching for virtual socializing.

### ***2.2. Disadvantages of using mobile phones***

We all see only the benefits because it makes our lives easier. However, excessive use of these means of technology is turning against us. Today we can already meet and struggle with many consequences that technology has brought us. We are all turned to the Internet, we are too lazy to go out to socialize with friends. We become antisocial, lonely, and scientists say that depression is more and more common. Fewer people play sports and everyone loses their motor abilities. Mobile phones, tablets, laptops, computers, all technology radiates, which is dangerous to life because it can cause cancer, and constant radiation worsens vision. In addition, it can have a negative effect on our sleep, or more precisely, disturb our sleep. This automatically reduces our ability to think, learn and concentrate well. It leads to a very high drop in intelligence, people become addicted and forget about their obligations, they just follow the notifications that come to them. Newspapers

and reading materials are read less and less when everything is available, and with that, the wealth of vocabulary and intelligence itself is lost.

The nomophobia levels of students using their mobile phone for 4-6, 6-8 and above 8 hours a day were found to be higher than those of students using it for 0-2 hours a day. Also, students using their phone for 6-8 or above 8 hours a day had higher nomophobia levels than those using it for 2-4 hours a day. Finally, the nomophobia levels of students who used their phone for more than 8 hours were found to be higher than of those using it between 4 to 6 hours per day [7].

### **3. The impact of nomophobia on society**

The social burden of nomophobia is tragically manifested in the growing number of traffic accidents caused by typing on the phone. Although it is questionable what percentage of participants in such accidents is really nomophobic, it certainly belongs to the aspect of impulsive use due to the fact that the possible consequences of such behavior are quite obvious, and in addition, such behavior in traffic is prohibited in a large number of countries. Surprisingly, there has also been an increase in accidents among pedestrians who use mobile phones while walking. This phenomenon is associated with a lower ability to shift attention from one task (typing) to another (walking). There is also an increasing distance between generations, mostly based on the degree of use of mobile phones for social networks [8].

Different age groups within society have different ways of communication, there has always been a certain lack of understanding between the generations because the way of life, different values and a number of other differences.

Social networks are a good way to create a false image of yourself. Some people, in order to gain the approval of the environment, many share unrealistic images of their bodies - there are so-called "influencers", i.e. people who, with their attitudes, habits and individual decisions, shape public opinion on many topics, mostly in relation to products available on the market, which many companies use to promote their own products. "Influencers" are defined as persons who "have the power to influence the consumer decisions of others due to their authority, knowledge, position or relationship with their audience". The last, but by no means less important, consequence was observed in school children and students. It has been shown that they are paying less and less attention to bans on the use of mobile phones during classes, and even that some teachers have begun to give in, thinking that it is impossible to control such a large number of children or because they simply do not consider it worth their effort.

However, a paradox can be observed in the educational discourse. Although a lot is invested in the technical equipment of classrooms and teachers use mobile devices in their everyday life and can hardly imagine life without them, mobile devices are rarely used in class.

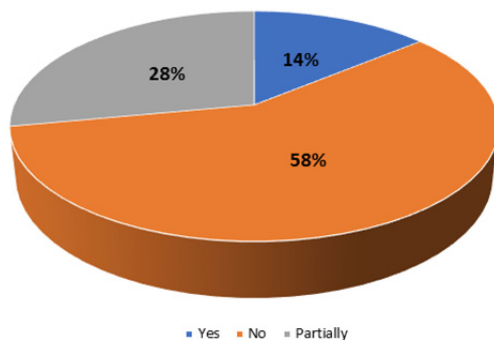
#### 4. Analysis and interpretation of research results

General data- N= 50, 3 groups Operational Management students, years 1-3, May 2022.

Surveyed respondents were 28% male, 72% female, aged- 74%- 20- 25yrs. 70% average (middle) income, 14% lower (and that was to establish brands of mobile phones and how much money they are ready to pay for cell phones).

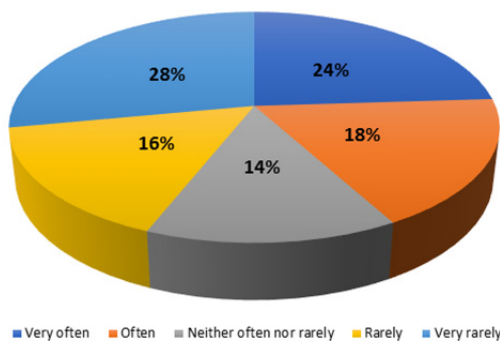
Several hypothesis were placed:

- H0- more than 80% of students are addicted to their mobile phones
- H1- nomophobia has an influence on student's tasks
- H2- students cannot be functional without their mobile phones
- H3- students spend more than 3h daily using their mobile phones



**Fig. 1.** Question: Do you know what nomophobia is?

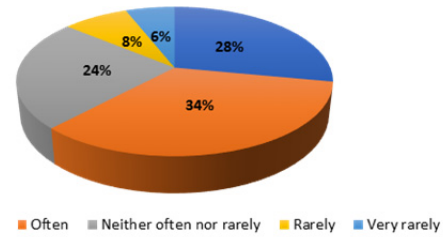
Only 14% of surveyed students are familiar with the term nomophobia, while as many as 58% are not familiar with the term at all, and 28% know it partially (Figure 1).



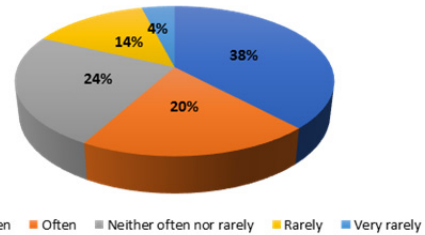
**Fig. 2.** Question: Have you ever forgotten your tasks during the day because of the phone?

As we can see from Figure 2, many students seem to forget their day activities and obligations due to spending time at their cell phones.

It is bad for socializing a human interaction that students spend time constantly checking notifications, even while they are at work, in a lecture or just sitting somewhere with their friends.

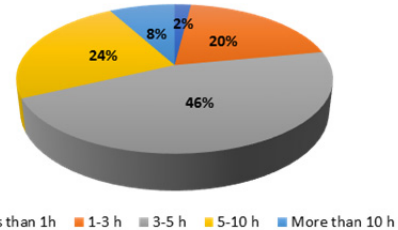


**Fig. 3.** Question: Do you check notifications on your phone while socializing?



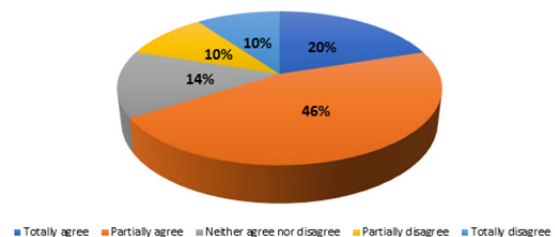
**Fig. 4.** Question: Have you ever had a panic attack if haven't felt phone in your pocket?

The chart from Figure 4 indicates a problem of another sort. It is very troublesome situation that 38% of students have a panic attack if they think they don't have their cell phone with them.



**Fig. 5.** Question: The usage of cell phone per day?

A large number of students spend 3- 5 h using the cell phone (Figure 5).



**Fig. 6.** Question: Are you addicted to your phone?

A lot of students agree or partially agree that they are addicted to their phones. However, none of them want to change that fact and have a different habit in life.

H0- more than 80% of students are addicted to their mobile phones- not confirmed because the research has shown only 20% agree totally and 46% partially. H1- nomophobia has an influence on student's tasks- confirmed while 24% students agree totally. H2- students cannot be functional without their mobile phones- confirmed while 32% of students totally agree.

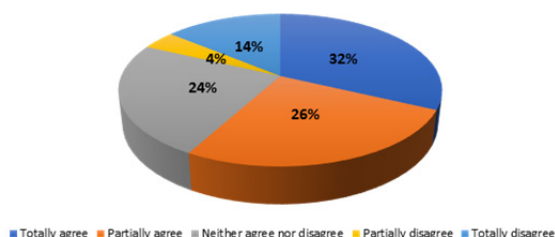


Fig. 7. Question: Do you think that one cannot live without the phone?

H3- students spend more than 3h daily using their mobile phones- confirmed while 46% of students use their phone 3- 5 h.

Students can no longer function without a mobile phone, 88% of those surveyed communicate only via mobile phone and receive the student schedule, homework, grades and everything necessary for studying there. The vast majority of students completely or partially agree (32% and 26%) that you cannot live without a mobile phone, which confirms the very conclusion that people are becoming slaves to the mobile phones themselves.

## 5. Conclusion

It can be concluded that life and society when our grandparents were growing up compared to modern society with all the possibilities offered by technology can be seen as a relationship between heaven and earth. Before, people had one phone at home and it was the only way to communicate with other people outside the home. Whoever had a cell phone in those days was the biggest "face" in the whole school and everyone admired that. The children played and moved a lot more because there were no computers or mobile phones, they had to go outside to have fun. The biggest problem today is that children don't have the kind of childhood that children had twenty years ago, they don't move enough, they grow up in a sedentary lifestyle.

In this way, they only spoil their own motor abilities and disrupt the course of development, and this only increases the dependence on technology. Parents play a big role in this, because if the parent does not allocate enough time for the child and only gives them technology without setting a time limit and explaining what the technology is for, their own child turns into a slave to technology who will not be able to eat, play, meet friends,

all they will focus on is the cell phone, computer and television. An adult who just got a cell phone at the age of 30 can get hooked on a cell phone and won't be able to go anywhere without it. As it is with children who grow up with mobile phones from a young age, we need to find a solution so that technology can be a service to us, and not that we are its slaves.

Just by surveying the students of the Polytechnic Hrvatsko zagorje in Krapina, majoring in operational management, it can be confirmed that nomophobia is clearly present, with the fact that 58% of them do not know about it at all. Most students (46%) use their mobile phones for 3-5 hours a day, 24% of them use their mobile phones for more than 5 hours, and there are even students (8%) who use their mobile phones for more than 10 hours a day, which is a shocking amount. This takes a lot of time that should be used more for student duties and hanging out with friends.

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# An Extensible Model for Turkish Single Document Summarization

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**Abstract:** The development of Automatic Text Summarization systems with the help of a computer is one of the most challenges in two decades. The amount of information currently available and the time problem of those who need information reveal the importance of such summaries. Generally, successful summaries are produced by people. However, it is obvious that human resources will not be enough to summarize the daily flow of information. Today, work is focused on designing and improving systems that automatically extract the abstract from the text. In this study, a summarization system based on a parametric method has been proposed and implemented. It summarizes a single Turkish text. The compression ratio of the summary can be determined by the user. The system also offers title and keyword support to the user. The evaluation reveals an average model however the hardness of the Turkish language considered is promising.

**Keywords:** Document Summarization, Sentence Scoring, Turkish NLP..

## 1. Introduction

The first study in this area is based on the word frequency in 1958 by Luhn [1]. Then Edmundson [2] in 1969 and the Salton [3] in 1989 found work on this topic. In Edmundson's work, he has proposed that we should consider the other facts in addition to vocabulary frequencies, for example expressions giving direct information on the subject (in conclusion, in summary, showing this article, etc.), the words containing the subject heading and the place where the sentence is held (usually the first sentences are more relevant) is also important.

Text summarization can be thought of as a two-stage job. In the first phase, source documents are analyzed and a set of sentences is extracted. However, the document set may contain repeated or conflicting information. Care should be taken when making summaries. More importantly, the documents may not be in a structure suitable to extract sentences directly. In cases where it is necessary to make a semantic or structural analysis, it is necessary to think of a preliminary process before the first stage. The second stage produces a readable summary of this sentence set.

Summarization is a complex task that requires detailed natural language processing capacity [4]. Current investigations for baseline reduction of the problem focus on extractive-summary [5]. Inferential summarization is a simple subset of the original text. This summary does not guarantee clarity, but provides enough content to make decisions about the text.

Erol [6] has worked on summarizing legal texts with keywords and Çetiner[7] has worked on finding similar

cases in civil cases. Aksoy[8] worked to evaluate the answers to the questions asked in his master's thesis and Karaca[9] worked on creating titles for news texts. \*\* In his study, Uslu[10] also found studies on the classification of news texts. Noyan[11] has worked on understanding the natural language of the text written in his study.

[12] This application was developed as a course project within the course of natural language processing. In the study, a weighting method of characteristics was applied with a similar approach.

The rest of the article is organized as follows: text summarization procedure in section 2, method specifications in section 3, evaluation in section 4, conclusion in section 5, and future work in section 6.

## 2. Text summarization procedure

According to Lin and Hovy [13], text summarization consists of 3 stages. These are defined semantically as determining the subject (word frequencies, headings, information expressions, etc.), interpretation (detection of related sentences) and generation (selection of the most appropriate sentence from similar sentences, sentence elimination by summation rate).

Current studies on automatic summarization can be grouped under 3 main headings.

### 2.1. Statistical Methods

It deals with syntactic and statistical properties. Most of these methods are based on the assignment of a weight value to each sentence in the sentence. The weight value is determined by the position of the sentence in the document or the keyword content. The research is mainly focused on the following issues:

- Position of a sentence within the document or paragraph [14].



- The presence of hinted words and expressions are of the "important", "absolutely", "particularly", "ambiguous", "may be", "for example" in unfavourable sense.
- The existence of demonstrative structures, "the purpose of this research", "our research has shown that" [15].
- The number of semantic relations between a sentence and its neighbors [16, 17].
- The presence of words within the title, sub-heading [14] or the source [18].

## 2.2. Speech Methods

These methods are based on speech analysis. It aims to determine a set of POS-tags according to the semantic properties of the sentence. These labels are derived from conjunctive words and superficial clues that link sentences, such as subject matter declaration, causality, and description. The significance of a sentence is obtained from the significance of the semantic label [19].

Other studies reveal the rhetorical structure to determine the sentence [20] and sentence associations [21], taking advantage of the statement representation of the original text. For example, in the method proposed by Teufel, theme units are defined as "past", "subject", "related work", "purpose", "solution", "result" and "product".

## 2.3 Template Extraction Methods

Another approach is to make a detailed semantic analysis of the source text in order to use artificial intelligence techniques, thus creating the meaning of the text with semantic representation. These methods are based on practical knowledge and the use of pre-defined summaries extracted from the original context.

Frequently used text model is vectorial [22]. After each text element is preprocessed - in terms of a sentence text summarization - it is considered to be an N dimensional vector. Some metrics can be used to measure similarity between two text elements. The most commonly used metric is the cosine measurement. The vectors of the x and y texts are subjected to scalar multiplication. If the cosine value is 0, it is completely incompatible. If it is 1, it is completely similar.

The evaluation of the quality of the summary produced is a key point in the summarization work. Classic information fetch precision and recall metrics can be used to evaluate the performance of automated summary generation routines. Precision is the ratio of selected true sentences to the total selected sentences and recall is the ratio of selected true sentences to the total true sentences.

The reference summaries are provided by the human jury and their performances are measured directly against the models. More important than this is the fact that the summaries the same human jury produced in different dates is similar only 55% [23], and the similarity of summaries produced in the jury is 46% [24]. This poses a problem in terms of the consistency of the evaluations.

## 3. Method specifications

### 3.1. Method Schema

Figure 1 and Figure 2 show the operation schema and implementation of the method respectively. Criteria weighting (default values are provided, the user can use these values), if any, keywords and summarization percentage are taken from the user. The user can determine which criteria should be used in sentence weighting. For this purpose, there is a check button next to each scoring criteria. Moreover, only one title (main title) is evaluated in the texts. User approval is required to determine this. The first sentence is regarded as the main title. No method has yet been applied to distinguish subheadings within the text. Later, the user selects the text file they want to summarize and starts the summarization. Up to this point, the process is interactive.

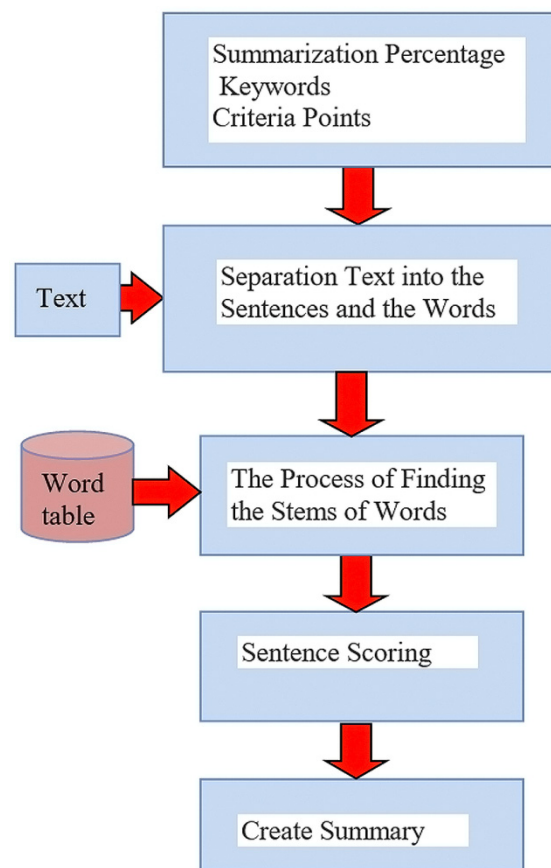


Fig. 1. Method operation schema

Then, the text is divided into sentences (in the direction of punctuation marks of the Turkish Language Society), and the words (tabs, spaces, characters are truncated) are obtained. In the words, the root is found by looking at the word root table (one letter at a time) otherwise the word is treated as root.

At the end, each word and sentence based calculations are made considering the criterion scores. If the user does not want to include some criterion for scoring, he can specify them on the criterion selection screen.

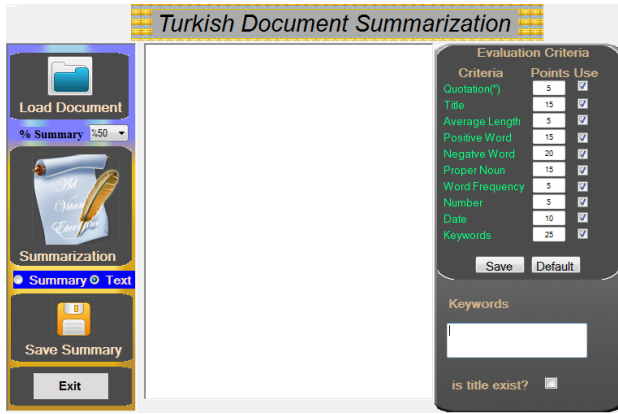


Fig. 2. Model Implementation

Sentences are determined according to the score obtained and the percentage of summarization. In this study, extractive summarization method is used. In other words, there is no semantic analysis module exists.

### 3.2. Method Criteria

Two types of criterion groups are used as in other studies in the system. The sentence-based ones are as follows:

**Quotation Symbol** – The sentences contain this symbol are accepted to be important in the texts.

**Title** - Review whether the phrase contains the words in the title and in the subtitles if any. It is assumed that such sentences are closely related to the subject.

**Average Length** - The average length of the sentences in the document is calculated as words. Assumptions with an average length of  $\pm 1$  are assumed to be significant. This approach is favored as a long-term counterpoint in some studies [25].

The criteria applied on a word-by-word basis are as follows:

**Positive Word** – The sentences are examining whether they contain such resurgent words as a result, in summary, in conclusion and ultimately.

**Negative Word** - The sentences containing the words because and however include detailed information on the subject and do not need to be included in the summary. It is assumed that such details contain unnecessary information [26].

**Special Names** - Special names (starting with capital letters) in the texts about the content, place of the event, person etc. provides important information. So the model should give importance to the specifics of private names.

**Word Frequency** - The frequency of each word in the text is calculated. The words and, or, with, for, et al. are not included (stop words). The words in the first 10% of the list are taken into account in the sentence rating. It examines whether a sentence includes the highest frequency words.

**Numbers** - The sentences containing the numbers are presumed to contain important information indicating the relevant size.

**Dates** - The sentence containing the name of the day or month is examined. Such information is important because it contains historical information.

**Keywords** - The presence of key words given by the user as a clue is perceived as a necessity for those phrases within the desired summary, and is often given a high score.

### 3.3. Word Table

A dictionary containing 49,000 stem words in Turkish is used. Every word in the dictionary also contains information about whether it is a name, an adjective, or a verb. These labels are not used in the model at the moment, but as a sub-structure in terms of subsequent linguistic studies.

Once the words in the text are separated, they are searched in the dictionary. If no word is found while searching the dictionary, the search is continued by subtracting one character from the end. If a stem word can't be found in the dictionary, the original word is regarded as the stem. Thus, the root is found by removing the derivational affixes and inflections.

Due to the linguistic nature of Turkish, if a word ends with one of the letters b, c, d, g, these are replaced by letters p, ç, t, k respectively. The root words are stored in accordance with this linguistic standard.

### 3.4. Parsing

Punctuation marks question mark, point, exclamation and three points are used in order to determine sentence boundary in Turkish. In addition, punctuation marks, single and double quotation, brackets, commas and other symbols (except for numbers and date information) are removed from the text. Words whose initials begin with capital letters are treated as private names.

Paragraph decomposition is not applied because sentence-based extraction is preferred in the model.

### 3.5. Summary Extraction

The summary is extracted using the summary percentage that the user has specified and the weight value assigned to each sentence. First, the sentences are sorted in decreasing order according to the weight values they have obtained from the criteria. Then, by applying the simple formula in (1), it is decided how many sentences will be in the summary.

$$ES = (TS \cdot SP)/100 \quad (1)$$

Here, ES is the number of sentences in the summary, TS is the total number of sentences in the text, and SP is the summary percentage. The result is rounded up.

## 4. Evaluation

The values in Table 1 were provided as default values in the method. These values were given completely intuitively.

Due to the characters in the text, it has been observed that some of the texts can't be properly separated. For the experiments, five texts containing different topics and sentences were used. The properties of the texts used in experiments are given in Table 2.

The experiments are summarized at Table 3. Two types of summaries (20%, 50%) are produced for each sample text. P and R used in the Table 3 are abbreviations of Precision and Recall respectively.

**Table 1:** Criteria default value

| Criterion        | Weight Value |
|------------------|--------------|
| Quotation Symbol | 5            |
| Title            | 15           |
| Average Length   | 5            |
| Positive Word    | 15           |
| Negative Word    | 20           |
| Special Names    | 15           |
| Word Frequency   | 5            |
| Numbers          | 5            |
| Dates            | 10           |
| Keywords         | 25           |

**Table 2.** Corpus properties.

| Sample | Topic      | Title | Sentence Count | Word Count |
|--------|------------|-------|----------------|------------|
| Text 1 | twilight   | no    | 48             | 516        |
| Text 2 | two ships  | yes   | 27             | 335        |
| Text 3 | Istanbul   | yes   | 21             | 440        |
| Text 4 | fashion    | no    | 14             | 202        |
| Text 5 | the system | no    | 4              | 67         |

It can be seen that, whenever the text size gets smaller, the percentage of both recall and precision increases. As the summary percentage decreases, then the percentage of both recall and precision decrease significantly, as a result of increased number of sentences. It is observed that the 50% summarization achieves acceptable success, regardless of the text size.

**Table 3.** Summary percentage and importance of text size

| Sample | 20%  |     | 50%  |      |
|--------|------|-----|------|------|
|        | P    | R   | P    | R    |
| Text 1 | 33%  | 20% | 60%  | 40%  |
| Text 2 | 40%  | 13% | 48%  | 48%  |
| Text 3 | 50%  | 25% | 40%  | 50%  |
| Text 4 | 100% | 30% | 84%  | 84%  |
| Text 5 | 100% | 50% | 100% | 100% |

The results are obtained with the default parameters. The effects of the parameters on the model will be completed during the remainder of the study.

Furthermore, because of no Turkish text corpus exists for summary evaluation, confirming the validity of the experiments is impossible, however the results obtained are promising for future works.

## 5. Conclusion

In this study, an experimental application was developed which will form a summary for a single document written in Turkish. This system is designed with parameter weighting method and has the flexibility to expand with different text features. This study provides an experimental platform in order to train the learners who will meet for the first time with the natural language processing (NLP). In this model based on the weighting method, we have observed how important the document size and the summary percentage to be generated are in

the summary. The effects of selected features and weight values on the model are not addressed in this study.

This system can be further expanded to create an application infrastructure for many NLP applications such as multi-document summarization, document classification, and so on. Similar studies on this subject have been mentioned in the literature section. But none of these are open source applications. The current application was developed with C # and is intended to be translated into Python and to be used by researchers as open source code in the near future.

## 6. Future work

A limited number of criteria were applied in the study. The effects of selected features and weight values on the model are not also addressed in this study. Moreover, the new criterion may be suggested and evaluation of the successes of criterion can be modeled easily.

One other issue is to determine the effects of the criteria for different text groups. Moreover, adaptation and modeling of criterion values can be achieved by machine learning algorithms.

At the moment, semantic analysis is not used for the summarization study. Semantic analysis can be applied so that the sentences follow a semantic sequence with each other and the summary forms integrity. As a simple method for this, a metric can be used that takes into account the distance between the sentences in the summary candidates or the sentence alignment.

The study is developed for a single document summarization. For multi-document summarization in the future, a summarization model can be modelled that uses the results of the each single summarization

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# Problems and Opportunities for Cost-Effective Photovoltaic Systems for Private Use

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**Abstract:** The climate changes, rising world tensions, soaring energy prices and fossil fuel dependencies require an affordable green power solution to be found and applied. The PV systems seem to be such solution, but there are still many obstacles standing on their way, especially in Bulgaria. An analysis concerning the cost-effectiveness of PV systems is done. The results are that they are cost-effective for companies, but not so much for private users yet. There are already breakthroughs in battery technology that are expected to open wide the doors for many types of renewable energy systems. The Bulgarian regulation process is one of the main obstacles standing on the way of PV systems.

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**Keywords:** photovoltaic, solar, system, installation, cost, effectiveness, regulation.

## 1. Introduction

The world is on the brink of global climate changes which require urgent actions, but the rising international tensions and economic wars create even more challenges for humanity. The rising energy prices push many towards poverty and this could stop countries' economic developments. At the same time, the European Commission adopted a package of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, [1]. The renewable energy sources seem to be a good solution for the changing climate and economic war challenges, but there are still many problems that stop their wide adoption. The aim of this work is to analyse the cost-effectiveness of photovoltaic systems in Bulgaria and to propose an affordable setup.

## 2. Methodology

The analysis includes current prices and types of photovoltaic systems more suitable for private use, concerning the overall cost of usage. Certain common parameters are reviewed for different system components. In order renewable energy sources to become widely used an economically viable project should be designed.

The analysis regards and the government regulations concerning new installations of renewable energy sources, because they could be an enormous obstacle standing in the way of their widespread use and often in Bulgaria they are. Clear, simple and cost-effective regulations for private installations should be created, because this is the only way the energy crisis to be solved and our country dependence on fossil fuels to be lowered.

The analysis is done based on widely available to all customers' information.

## 3. Types of photovoltaic systems

All photovoltaic (PV) systems consist mainly of PV panels and some type of smart energy converter. They could be two main types: stand-alone or grid connected, [2]. A typical block diagram of such a system is presented on Fig. 1. Both types could be with batteries or without batteries. The batteries are still too expensive and have many design deficiencies, so often their usage makes the PV systems unprofitable, so systems with less battery storage capacity are often with higher cost-effectiveness. This is about to change because the science society works hard towards improvement of battery technology and there are already declarations for significant achievements in the field. Both, stand-alone or grid connected PV systems, have advantages and disadvantages that affect their cost-effectiveness.

The stand-alone PV systems could be of DC or AC types. The AC type is more common because most electric appliances, people use nowadays, are designed to work with alternating current. They usually need certain battery storage capacity, depending on the usual power consumption, which increases their usage costs, but allows the solar cells to work in their optimal power point and assures more flexibility and power autonomy during temporary poor lighting conditions or in the dark times of the day. The grid connected PV systems are of AC type and often they don't require battery storage systems. In this case the extra generated electricity is being sold to the power grid operator instead of stored in batteries. If the generated power is not enough then additional energy is drawn from the grid which is done automatically and allows high flexibility and convenience for the users. The balance between generated and consumed energy is usually reported at the end of the month and the debtor pays the other party.



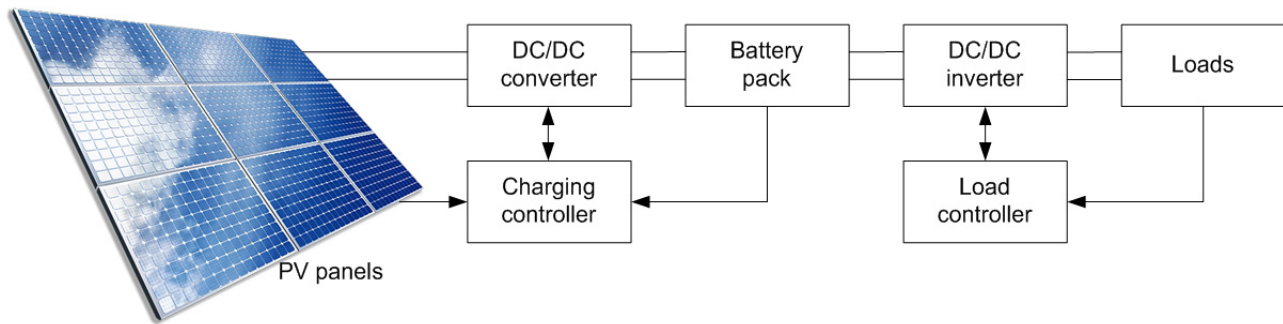


Fig. 1. Block diagram of PV system.

The possible lack of battery storage system improves their usage cost-effectiveness. The drawbacks of the grid connected PV systems usually come from the government regulations. They are often heavily regulated and the preparation of all documents concerning their commissioning is very expensive and time-consuming process. They also require a legal entity to be created because a contract should be created between their owner and the power grid operator. The legal entity has its taxes and maintenance costs. This makes these systems more attractive to companies than to private persons.

#### 4. Photovoltaic systems with lower cost for private use

A good minimum for the average homeowner is a 5 kW PV system, which is enough for covering certain basic needs, at least in sunny days. These needs include entertainment, computer and communication equipment, cooking and certain minimum climatization. It doesn't include winter home heating and any season water heating. Solar thermal collectors for direct water heating are a good option for lower power consumption. If higher level of power autonomy is needed, then a 10 kW PV power should be enough in most weather conditions.

Because of the many regulations, only the stand-alone PV systems have a potential for lower cost for private use. Two types of such systems could be created – hybrid and grid connected without energy returning to the grid. The difference is that the hybrid system works in stand-alone operating mode if the generated power is enough to feed the current energy consumption. If the energy consumption is too high, then the hybrid inverter switches off the battery power and connects the load entirely to the grid power. The grid connected PV system uses the generated PV power and if it is not enough to feed the current load it can draw the difference from the grid. Such type of system should have the capability to detect the grid voltage and if it disappears the inverter must disconnect from the grid automatically, which is required for safety reasons.

One of the main problems for private users is the lack of enough space for the PV panels installation. In this case, PV panels with higher than the average efficiencies should be used for minimization of the required installation space. Panels with efficiencies around 20% are a good choice. The monocrystalline N-type solar cells are often used as they have high efficiencies, but higher prices too, [3]. The hybrid solar cells, consisting of

inorganic and organic materials, seem to offer good price to quality ratio.

The peak power output of standard size high quality PV panels usually varies from 300W to 400W. The standard size is 1 m wide by 1.7 m long, which makes 1.7 m<sup>2</sup> surface area. The higher efficiency panels are usually more expensive, but our research found some good deals. The Solarhouse offers 405 W standard size PV panels, produced by Risen, for the price of €162. The 375 W standard size panels of Longi cost €144. Both producers are Chinese companies. China is the world's largest manufacturer and consumer of PV cells and modules, and offers competitive prices, [4].

The research led to the conclusion that the Solarhouse company offers competitive prices for different sets of PV systems and components. Their 5 kW PV system comes with 14 PV panels Longi with 375 W peak power each. It also includes a grid Huawei inverter that allows stand-alone operations when the grid power is down. The price of the system is €3740 without battery pack and €7811 with 5 kW battery pack. This is a very high price for the average Bulgarian, but there are many people that can afford it.

The first problem is when this investment will pay off for the initial cost. Solarhouse presents data concerning the annual power production of their 5 kW power system, [5]. The energy generation varies from 292 kWh for December to 786 kWh for July. The average energy generation per month is 530.16 kWh. If we accept that the whole generated energy is used, then it could be calculated when this system is going to pay off the invested money. The electricity price per kWh for private Bulgarian users is €0.1045. The annual power generated by the PV system is 6362 kWh, which makes €664.83 per year. The pay off period of the PV system without battery pack is:

$$\text{PayOff} = 3740 / 664.83 = 5.625 \text{ years} \quad (1)$$

The pay off period of the PV system with battery pack is:

$$\text{PayOff} = 7811 / 664.83 = 11.75 \text{ years} \quad (2)$$

If the PV system is without battery pack the panels most likely won't work in their optimal power point and the generated power will be less. If the system is with batteries, they are supposed to be alive for 10 years and most likely by that time they will have to be replaced. The inverter and the PV panels could survive for 20

years. Furthermore, the PV system price doesn't include the installation cost and other additional costs, but at the same time the electricity prices are supposed to grow with time. The electricity prices for private users in Bulgaria have grown with 1.91% per year on average for the last 10 years. The historical data is from the Bulgarian National Statistical Institute. The world tensions and economic wars caused havoc on the energy market and the electricity prices are expected to rise a lot at least in the short term.

From this investigation it could be fairly concluded that the PV system most likely won't pay off the investment, but in the best-case scenario it could guarantee the current electricity price for the next 20 years. For legal companies, which electricity prices are currently 3 to 4 times higher, the system is supposed to pay off for about 2-3 years with all costs included. As of now, the PV system is cost-effective for private use by legal entities only. In this case, it would be better the PV system to be without batteries and the extra generated electricity to be sold to the grid operator.

The investigated 5 kW PV system comes with 14 standard size PV panels Longi with 375 W peak power each. 14 panels by 1.7 m<sup>2</sup> surface area for each, makes 23.8 m<sup>2</sup>. The required surface area allows south roof installation for the average Bulgarian house owner which will save needed space. The space could be optimized if 405 W Risen panels are used instead.

During June 2022 there were powerful hailstorms in Bulgaria and it was reported that the hail broke photovoltaic panels installed in the affected region. Such storms are rare, but the climate changes worsen the weather conditions and the storms are expected to become more powerful in the near future, so a PV panel protective cover might be designed and used in the rare cases of powerful storm forecasts.

As of today, the best type of PV system for private use in Bulgaria is the stand-alone one because soon it is expected its installation to be possible with simple notification. This option will save a lot of installation costs and time. Unfortunately, this is not done yet. This type of system works better with batteries and for each separate case the minimum autonomy needed could be calculated based on the average power consumption. For higher cost effectiveness lower battery pack capacities are needed. The problem is that the batteries are still too expensive. The battery pack capacity could be estimated based on the maximum expected current consumption. The current drawn from the battery shouldn't exceed the recommended one for the types of cells used because this will extend the battery life and will lower the overall usage cost of the PV system. In this case more convenient would be a grid connected inverter to be used that allows entirely stand-alone operation of the PV system, which has an option to stop the battery pack draining when the voltage falls under certain minimum, and allows additional grid power energy consumption. If the price of such controller is too high, a regular battery management controller could be used, which will disconnect the battery when its power is low, and then the grid power must be switched on manually. This could lower the price and the payoff period of the whole system.

The battery problem is expected to be solved in the up-coming years because a lot of money are invested for the development of battery technology. There are already breakthroughs in the field. The NMC532 Li battery cell have been projected to have 100 years of lifetime for 20°C work temperature, [6]. The real lifetime is expected to be lower, but this is amazing achievement considering that the current Li battery technology allows 15 years of calendar lifetime. At the same time the NMC532 Li battery cell shows no sudden failure and no signs of capacity loss after nearly 2000 cycles, [6]. The near future is expected to offer Li batteries with high calendar and cycle lives, which will allow cheaper electric vehicles and PV systems to be designed, that may not require battery change for their lifetime. This will lead to lower costs and higher affordability for greener technologies.

## 5. Photovoltaic systems - problems and opportunities

There aren't many private renewable energy systems in Bulgaria in contrast to other European countries. The main problem is the heavy regulation process that makes them too expensive and stops their widespread use. It takes over a year even for small PV system to be approved. Even if the PV system is for own needs everyone must go through all regulation steps as if registering a photovoltaic power plant for electricity sale. The investor needs even to register his solar power plant as a tax warehouse and pay excise duty to customs for the electricity he produces for himself. The whole legislation in this field is unclear and creates many hindrances, [7]. This problem must be eliminated and the registration of stand-alone systems for private use must be simplified as much as possible. It is enough the installation, registration and preparation of the documentation of such sites to be left entirely in the hands of licensed companies. They could take care of this, but they must have the opportunity to quickly prepare the documentation. This will allow fast and widespread use of PV systems which will create many new workplaces, it will increase the people's standard of life and will improve country's economy.

The companies should be responsible for the safe and reliable installation design of PV systems. They must pay special attention to the risk of fire, because fire accidents involving PV systems during the last few years have shown an increasing trend worldwide, [8]. An effective lightning protection system is also necessary for PV systems, depending on the location, construction type and utilization, [9].

The fast development process of PV systems and battery technologies create many opportunities for safer, greener, healthier and abundant future for everyone. There is a great opportunity to tackle the intensifying climate changes. The rising global conflicts and energy crises revealed the high level of dependence of the free world on fossil fuels coming from militarized dictatorial regimes. This increases their income and power and creates chances for future militarized actions that could destroy the whole world. Now, there are great opportunities for freeing the world from such dependencies. All mentioned problems require all

obstacles to the widespread use of PV systems to be completely eliminated.

## 6. Conclusions

The current PV systems are still too expensive and the investigation based on current energy prices leads to the conclusion that they are not cost-effective for private users. In the best-case scenario, they could guarantee the current energy price for the next 20 years for them. The PV systems are cost-effective for private use by legal entities because their energy prices are 3 to 4 times higher and the investment will pay off for 2-3 years. On top of that the heavy regulation process creates additional hindrances in front of PV systems widespread use in Bulgaria. There are signs that a policy change is coming that could solve partially this problem. The battery technology develops fast nowadays and it is expected the expensive battery problem to be solved in the following 5 to 10 years. The future is bright for PV systems and they are soon expected to offer energy freedom to all countries.

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# Active Learning Community for Upskilling Technicians and Engineers

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**Abstract:** Based on the data of a recent survey in European Union more than 40% of EU employees experienced a recent change in the technologies they use at work. According to the experts new technologies and structural modification in many areas and professions will provide a higher dependence on cognitive and interpersonal skills in future works. Active Learning Community for Upskilling Technicians and Engineers is a project, developed under Erasmus+ programme, KA2 and lasting from 1.09.2020 to 31.08.2022. It offers an alternative solution to address these challenges and needs by developing an active learning platform for engineering and technical staff in the sector of Machine Building and Mechatronics. This article also presents the results from the 2 lesson which realized in Kavala, Greece.

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## 1. Introduction

Without doubt Industry 4.0 is totally transforming the manufacturing sector in European Union imposing its principle of digitalization of industrial processes. Consequently, the new cyber-physical production systems have a high impact on the labour force, especially on technicians and engineers.

Today technicians and engineers should analyze big data, simulate production lines, coordinate robots and diagnose/repair complex automated systems. Unfortunately the real situation is that employees are not ready to face the above new realities since they lack the “right” knowledge/skills demanded by the new industrial environment. According to the data from the @Cedefop’s European skills and jobs (ESJ) survey 43% of adult employees have recently experienced changes in technology they use at work and 47% have seen changes in their working methods. About 1 in 5 considers it very likely that several of their skills will become outdated in the next years [1].

The 2019 Talent Shortage Survey shows an average of 54% shortage of skills in EU: Greece - 77% (engineering and technical skillset shortage is respectively top 2 and 1); Bulgaria - 62% (3 and 5); Poland -70% (5 and 1), and Serbia – 78% (Serbian Employers Union Survey). Therefore, although on different scale, skills deficit of employees appear a European issue, which severely affects the manufacturing sector [2].

Continuous technical and vocational education and training (CTVET) systems are not well developed in the partner countries and mainly targets unemployed, low-qualified workers, etc. It rarely addresses continuous TVET of employees, in particular technicians and engineers and does not respond to the immediate needs of that target group – dedicated time on the clock to learn, high level of support, online learning platforms with open resources, mobile and active learning. VET trainers are mainly skilled in technical areas rather than pedagogy, so teacher-centred approaches are predominantly used.

Taking into account the above needs, their relevance at European level and emergency at regional level, as well as the high demand of flexible continuous TVET on behalf of companies within the partner regions, a consortium of 4 universities, 4 Chambers of Commerce and Industry and a VET provider from Bulgaria, Greece, Poland and Serbia was established so as to develop an Active Learning Community for Upskilling Technicians and Engineers (allCUTE) in the sector of Machine Building and Mechatronics [3-11].

## 2. Methodology

### 2.1. Project partnership

Coordinator of the project is the Technical University of Gabrovo, Bulgaria while the other partners is the Cluster Trakia Economic Zone in Bulgaria, the Gabrovo Chamber of Commerce and Industry also from Bulgaria, the International Hellenic University in Greece, the Kavala Chamber of Commerce also from the Greece, the Gdansk University of Technology and the Regional Chamber of Commerce both from the Gdansk area in Poland and last but not least the University of Nis and the Serbian Chamber of Commerce from Serbia (Figure1).



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Fig. 1. A consortium scheme of the allCUTE project

## 2.2. TVET needs of technicians and engineers in the sector of Machine Building and Mechatronics

According to the new data a worker of the Industry is necessary to have four skills: Adaptive skills (embracing technology, mindset change), Technical skills (automation systems, energy optimization and sustainability, systems engineering), Transversal skills (innovative thinking, decision making, communication and collaboration, respect for the environment, etc.) and Technological skills (smart engineering, smart infrastructure, data analysis, cyber security, integrated platforms).

In order to identify the TVET needs of technicians and engineers in the sector of Machine Building and Mechatronics a report is written within the ERASMUS+ Programme, KA2, project allCUTE. It is based on a survey carried out among 161 companies in the sector of Machine Building and Mechatronics so as to identify the needs of technical and vocational education and training of their technicians and engineers. It covers 5 partner regions:

- Gabrovo region, Bulgaria;
- Plovdiv region, Bulgaria;
- East Macedonia and Thrace region, Greece;
- Pomorskie Region, Poland;
- Nis region, Serbia.

The Report is developed in the context of the demands of Industry 4.0 imposed on today's technicians and engineers (Figure 2). The 4 key elements of Industry 4.0: Internet of Things, Big Data and Analytics, Engineering Simulation and Additive Manufacturing have a significant impact on machine building and mechatronics since they require complete redesign of processes and operations to accommodate those new advancements. Therefore, those industries need forward-thinking technical and engineering staff who can embrace these digital tools and technologies so as to design, repair and maintain the increasingly smart manufacturing facilities. To do that, companies are aware that they should invest in the training of those employees so as to continuously improve their competence and skills in

order to achieve excellence and meet the new demands of both manufacturing and customers.

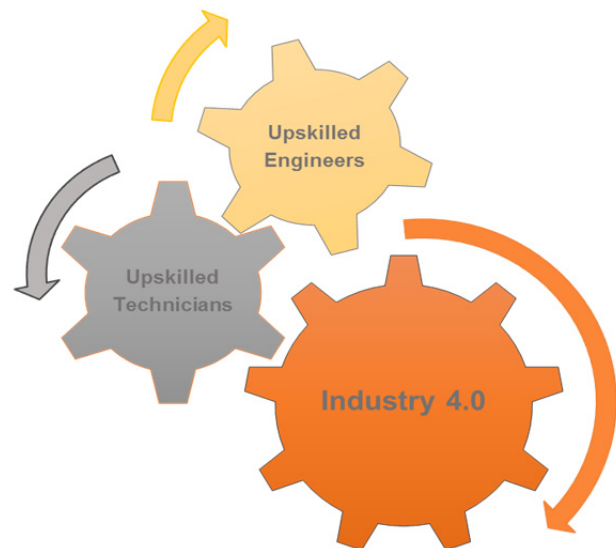


Fig. 2. The central idea of the allCUTE project

This Report aims to:

- present the current situation of the partner regions in relation to TVET provision to technicians and engineers employed in the sector of Machine Building and Mechatronics;
- identify the training needs of the companies in the respective sector by partner region so that they can improve the competence and performance of their technical and engineering staff;
- identify the teaching methodology preferred by the employers;
- compare survey findings across partner regions;
- give recommendations for the elaboration of the follow-up curriculum.

## 2.3. Target Groups

The target groups of the project can be divided in 2 groups: i) the direct target groups which includes both the Technicians in the sector of Machine Building and Mechatronics and the Engineers in the sector of Machine Building and Mechatronics and the indirect target groups in which belongs the VET trainers, the Companies in the

sector of Machine Building and Mechatronics and the VET providers, including universities and Chambers. The benefits will be multiply for each group and more specific:

#### Technicians and engineers

- Upskilled STEM, in particular in particular technology and engineering skills
- Improved generic skills such as analytical/critical thinking, problem-solving, communication
- Easier access to TVET learning platforms (Internet-based and mobile) that best match their learning styles
- Easier access to educational resources to be used for upskilling
- Ability to quickly and adequately respond to Industry 4.0 fast technological changes in the respective industrial sector
- Opportunity for securing their positions within the company and future career development
- Opportunity for building a “culture of learnability” in the long run

#### VET trainers

- Improved teaching competence by mastering active learning techniques and strategically using ICT
- Ability to better motivate learners
- Easier access to TVET resources

#### Companies in the sector

- Better awareness of the specific TVET needs of their engineer
- Upskilled technicians and engineers ready to respond to the fast technological changes in the sector
- Opportunity to adequately meet the demands of Industry 4.0 in the long run
- Potential of higher economic growth in the long run

#### VET providers, including universities and Chambers

- Better awareness of the specific TVET needs of the engineering and technical staff employed in the sector
- Access to TVET learning platforms that best match learning styles of end-users
- Access to educational resources to be used for upskilling
- Opportunity to train their VET teachers on active learning tools
- Opportunity to provide TVET to companies that matches the demands of Industry 4.0 and the specific learning needs of their employees.

### **3. Results and discussion**

To study the needs of additional qualification of technicians and engineers in the mechanical engineering and mechatronics sectors, a questionnaire with several sections was developed: size of the company, need for qualification of technicians, need for qualification of engineers, need to increase the so-called soft skills, as well as those related to the training methodology.

Based on the preliminary study, a certain set of topics for professional training of technicians and engineers was proposed. They cover areas of rapid development of technologies during the recent years, which suppose greater need for trained personnel.

After analyzing the survey results, the following 8 courses for technicians have been identified as a priority of employers in the respective industrial sector [12]:

1. Electricity
2. Electrical Drives
3. Pneumatics and electro-pneumatics
4. Hydraulics
5. Vacuum and vacuum technology
6. Optimal use of compressed air
7. Operating CNC Machines
8. Operating automated production system

While the following 6 courses for engineers have been identified as a priority of employers in the respective industrial sector [12]:

1. Basic schemes in automated pneumatic systems
2. Energy efficiency in pneumatic systems
3. Hydraulics, proportional hydraulics
4. Electrical engines and complex electrical drives
5. Automated manufacturing systems
6. Quality assurance, quality control and testing.

Table 1 shows the topic of each of the courses for technicians while table 2 illustrates the topics for the 6 lessons for the engineers. Each lesson will be available in five languages namely English, Serbian, Bulgarian, Greek and Poland.

The selected topics related to key competencies (soft skills) were:

- Team work (active listening and understanding different viewpoints, ability to respect and trust others, self-evaluation and self-criticism, endurance when working under pressure)
- Communication skills – (ability to communicate and build trust, effective receiving and sending of information)
- Problem-solving (analytical and critical thinking; taking personal responsibility, identifying problems, decision making and response, risk assessment)
- Adaptability and flexibility (accepting and understanding different environment and new and different ideas, compliance with rules, established principles and relationships, ability to accept criticism, positive thinking)
- Work ethic
- Creativity
- Growth mindset (motivation to reach higher levels of achievement by continuously learning new skills in order to move with a changing market).

The companies could choose between 2 types of training:

- Active blended learning – the students get familiar with the learning content by using PP presentations online or through their smart phones, then they discuss the topics with the teacher in the classroom so as to clarify difficult issues and solve problems, after that they do their lab work;
- Traditional – the teacher delivers the learning content in the classroom and then the students do their lab work.

All questions allowed more than one answer (except for the methodology), which is why the total percentage of the answers is over 100%.

**Table 1.** The topics of the each lesson for the training of technicians.

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Course 1 - Electricity</b><br>T1 Introduction to Electricity<br>T2 Electrical Resistance<br>T3 Voltage<br>T4 Electrical Current<br>T5 Inductors<br>T6 Capacitors<br>T7 Oscilloscope<br>T8 Three phase circuit<br>T9 Thermographic testing of electrical equipment<br>T10 Electrical Safety                                                                                                                                                                                                                                                                                                                                                                                                                | efficiency<br>T2 Structure of the pneumatic system<br>T3 Some properties of compressed air<br>T4 Basic problems with compressed air<br>T5 Basic causes of energy losses in the manufacturing plant<br>T6 Potential for savings in pneumatic systems in air production<br>T7 Potential for savings in pneumatic systems in air preparation<br>T8 Potential savings in pneumatic systems for the distribution and supply of air<br>T9 Potential savings in compressed air systems at consumers<br>T10. Energy efficiency in vacuum systems<br>T11 Monitoring and optimization                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Course 2 - Electrical Drives</b><br>T1 Basic concepts of electrical engineering<br>T2 Rectifiers and filters<br>T3 Power converters<br>T4 Constant and variable-frequency control<br>T5 D.C. motors<br>T6 Induction motors<br>T7 Stepper motors<br>T8 Electrical drives<br>T9 Variable-frequency drives (VFD)<br>T10 Servo drives                                                                                                                                                                                                                                                                                                                                                                         | <b>Course 7 - Operating CNC Machines</b><br>T1 CNC machines, introduction, and principles of work<br>T2 Concepts of CNC machine control<br>T3 CNC system programming methods<br>T4 Work Safety<br>T5 Technological preparation for CNC machining<br>T6 G-code structure and syntax<br>T7 Tools calibration and path optimization<br>T8 Introduction to CAM software<br>T9 Program management and execution (Example for lathe training)<br>T10 Program management and execution (Example for milling training)<br>T11 Independent work with supervision and help                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Course 3 - Pneumatics and Electro-pneumatics</b><br>T1 Theoretical basics<br>T2 Compressed air production<br>T3 Preparation of compressed air<br>T4 Pneumatic actuators<br>T5 Sensors for pneumatic cylinders<br>T6 Pneumatic valves<br>T7 Elements for regulating the flow, timers, logic elements<br>T8 Pneumatic and mechanical controlled circuits<br>T9 Electro-pneumatic control<br>T10 Sequence solution methods. Repeat pattern sequence. Non-repeat pattern sequence<br>T11 PLC Pneumatic Circuit Control<br>T12 Pneumatics applications in continuous production processes                                                                                                                      | <b>Course 8 - Operating Automated Production System</b><br>T1 Basic concepts and issues in the field of automation of manufacturing processes and production systems<br>T2 Operation and maintenance of automated production systems<br>T3 Flexible automation means and integration of technological processes; automation of machining processes<br>T4 Computer-aided technological preparation of production<br>T5 Trends and developments in the automation of production systems                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Course 4 - Hydraulics</b><br>T1 Introduction to hydraulic drives<br>T2 Basic parameters of hydraulic drives<br>T3 Pressure valves<br>T4 Directional control valves<br>T5 Cylinders<br>T6 Hydraulic control devices<br>T7 Speed control elements<br>T8 Variable flow control valve<br>T9 Fluids for hydro-systems<br>T10 Basic hydro-schemes for propulsion and control                                                                                                                                                                                                                                                                                                                                    | <b>Table 2.</b> The topics of the each lesson for the training of engineers.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Course 5 - Vacuum and Vacuum Technology</b><br>T1 Vacuum theoretical basics. Expressions and units. Measurement methods. Vacuum quality<br>T2 Compressed air vacuum production<br>T3 Compressed air-driven ejector pumps<br>T4 Vacuum systems for material handling<br>T5 Suction cups (vacuum pads)<br>T6 Vacuum sensors and switches<br>T7 Vacuum valves – types and operation<br>T8 Vacuum, pneumatic and electro-pneumatic controlled circuits<br>T9 Vacuum suction control circuits<br>T10 Integrated applications with pneumatic drives<br>T11 Electronic vacuum regulators<br>T12 Use of vacuum in continuous production processes - freeze drying, filtration, distillation, test equipment, etc. | <b>Course 1 - Basic Schemes in Automated Pneumatic Systems</b><br>T1 Basic steps to air preparation equipment calculation and selection<br>T2 Basic steps to build compressed air piping systems<br>T3 Design complete pneumatic control systems<br>T4 Design of pneumatic and electro-pneumatic control circuits for feeder modules<br>T5 Design of pneumatic and electro-pneumatic control circuits with timers<br>T6 Design of pneumatic and electro-pneumatic control circuits with counters<br>T7 Design of pneumatic and electro-pneumatic control circuits with pressure programmable relay<br>T8 Design of pneumatic and electro-pneumatic control circuits with logic elements<br>T9 Design of pneumatic and electro-pneumatic control circuits with vacuum equipment<br>T10 Pneumatic circuit design using PLC<br>T11 Pneumatic valve actuators and positioners<br>T12 Electronic pressure regulators. Principle of operation, parameters and applications |
| <b>Course 6 - Optimal Use of Compressed Air</b><br>T1 Energy efficiency - essence, purpose and benefits of energy                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Course 2 - Energy Efficiency in Pneumatic Systems</b><br>T1 Reduce pressure drop in the distribution system<br>T2 Turn off the power during downtime of pneumatic systems<br>T3 Involve the OEM in designing more energy efficient machines and compressor air systems<br>T4 Add sensors to high pressure and consumption machines and processes<br>T5 Reduce leakage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

T6 Optimize compressed air systems  
 T7 Incorporate air saving circuits where appropriate  
 T8 Energy savings starts at the top of organizations and relies on all-inclusive teams

**Course 3 - Hydraulics, Proportional Hydraulics**

T1 Elements of hydraulics circuits (pumps, motors and valves)  
 T2 Basic circuits with hydraulic cylinder and motor  
 T3 Control of speed of a motor with the use of throttle valve  
 T4 Volumetric control of motor speed  
 T5 Circuits with flow regulators  
 T6 Pump regulators  
 T7 Proportional valves  
 T8 Electronic control of proportional valves  
 T9 Introduction to systems with servo valves

**Course 4 - Electrical Engines, Complex Electrical Drives**

T1 Definition, functions and features of an electromechanical systems and drives  
 T2 Electromechanical system components and their functions  
 T3 Electrical machines and material technology. Classification of electrical machines  
 T4 Properties and characteristics of motors and generators  
 T5 Structures of electromechanical systems used in industry  
 T6 Electromechanical system development, evolutions and trends  
 T7 Power units used in electric and hybrid vehicles  
 T8 Electromechanical systems with piezoelectric machines  
 T9 Electromechanical energy storage devices  
 T10 Electromechanical drives developed with nanotechnology  
 T11 Basic definition and terms: physical model, mathematical model, simulation, design

**Course 5 - Automated Manufacturing Systems**

T1 Sensors  
 T2 Actuators  
 T3 Numbers and Data  
 T4 Boolean Logic Design  
 T5 Control System Analysis and Design  
 T6 Advanced Control Systems  
 T7 Programmable Logic Controllers - PLC-s

**Course 6 - Quality Assurance, Quality Control and Testing**

T1 Introduction to Quality Control and the Quality Assurance  
 T2 The Concept of Quality Control in Manufacturing  
 T3 Statistical process control (SPC)  
 T4 Introduction to industrial experimentation  
 T5 Guidelines for designing industrial experiments  
 T6 Factorial designs  
 T7 Analysis of case studies – modelling and analysis of a given industrial process/system – working examples  
 T8 Independent work with supervision and help  
 T9 Introduction in FMEA method, definition weight factors and recognition level of risk  
 T10 Sheet metal forming  
 T11 Bulk metal forming

Each partner selected the companies in their region to which the questionnaire was sent.

The topics were discussed and supplemented by all partners. All respondents had the opportunity to suggest other training topics. Totally the project has 5 main outcomes:

- **Survey** on the skills deficit of technical and engineering staff in the sector of Machine Building and Mechatronics.

- **Teacher's ToolKit** on Active and Problem-based Learning. It is an attempt to tackle the transversal skills' gap.

- **Curriculum** for upskilling technicians and engineers in the sector of Machine Building and Mechatronics.

- **14 course materials** (PPT presentations, industry-related problems and additional internet resources) as open educational resources. It is an attempt to tackle the talent and transversal skills' gap.

- **Problem-based platform** – industry-relevant problems; a discussion forum for tutor and peer-to-peer support; assessment area for assessing the gained knowledge. It is an attempt to tackle the transversal and digital skills' gap.

### 3.1. Lessons and results

In International Hellenic University have realized two lessons one for 15 technicians and another for 15 engineers. The relevant lesson for the first group was the "Electricity" while for the engineer participants were the "Energy Efficiency in Pneumatic Systems".

#### Results from the survey among trainees:

Table 3 illustrates the questionnaire which given to the participants after they finished the training. For each of the question 5 was the highest mark and 1 was the lowest. The questionnaire includes 16 questions which are divided in 4 groups namely this is usefulness, course materials and teaching methodology, ALC platform and overall evaluation.

**Table 3.** The results according to the learners answers for each of the lessons

#### I. USEFULNESS

Q1. The training was useful for my better performance at work.  
 Q2. The training helped me improve my technical skills.  
 Q3. The training helped me improve my generic skills (teamwork, critical thinking, problem solving, etc.)  
 Q4. Now I have a better chance for career development.  
 Q5. Now I have easier access to vocational training.

#### II. COURSE MATERIALS AND TEACHING METHODOLOGY

Q6. The course materials are well-structured and attractive.  
 Q7. The course materials are user-friendly.  
 Q8. The training is practice-oriented.  
 Q9. The teaching methodology is active and encourages creativity.  
 Q10. The use of ICT is well incorporated into the learning process.

#### III. ACL PLATFORM

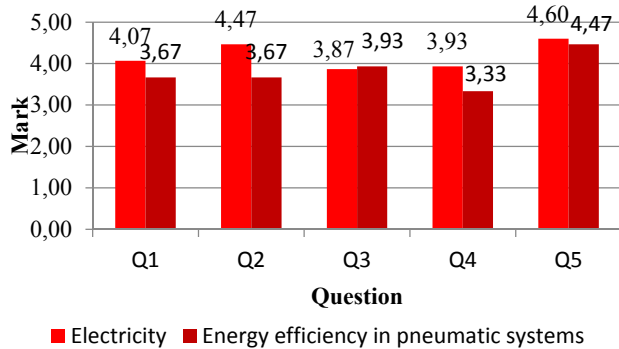
Q11. The Platform is user-friendly.  
 Q12. The Platform is well-structured and attractive.  
 Q13. The Platform facilitated my learning process.

#### IV. OVERALL EVALUATION

Q14. My expectations were met.  
 Q15. I enjoyed the course.  
 Q16. I would join another course in the future if offered.

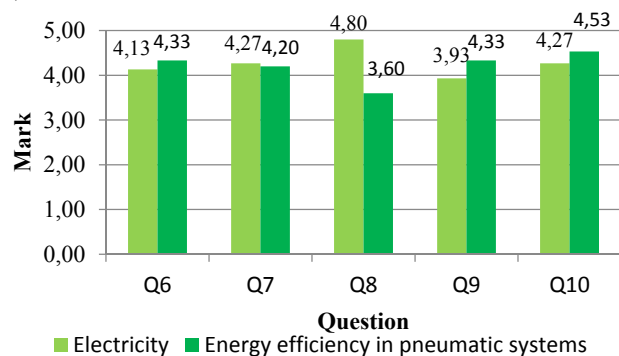
According to the results in the field of **usefulness** the marks fluctuate from 3.87 up to 4.60 for the lessons "Electricity" and from 3.60 up to 4.53 for the lesson "Energy efficiency in pneumatic systems" so is evidence that the learners believe that the training is necessary (Figure 3). In this field for both lessons the highest score occur in the question "Q5. Now I have easier access to vocational training." Which shows that owing to this project the technicians believe that is more close to the

vocational training. In the same filed the minimum is achieved for the Q3 for the lessons “Electricity and for the question Q4, for the lesson “Energy efficiency in pneumatic systems”. These results indicates that the engineers want vocational training however have some uncertainties about how this training is enough in order to find a better job.



**Fig. 3.** The marks for the 5 questions relevant with the USEFULNESS of the lessons

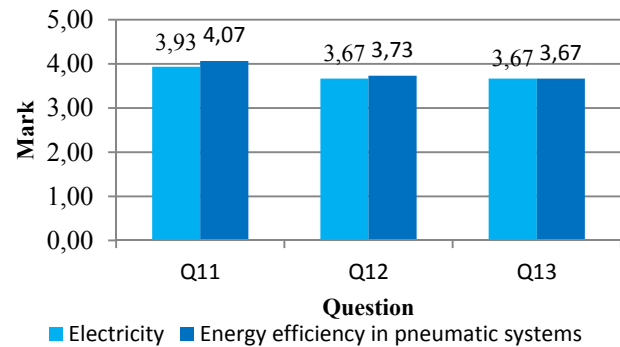
Similar is the results and for the next session **materials and teaching methodology** with marks between to 3.93 up to 4.8 for the lesson “Electricity” and 3.60 up to 4.53 for the lesson “Energy efficiency in pneumatic systems” with the maximum rank in the question Q8 “The training is practice-oriented” for the first lesson and for the question Q10 “The training is practice-oriented” which proves that the technicians want practical and not theoretical training teaching and (Figure 4).



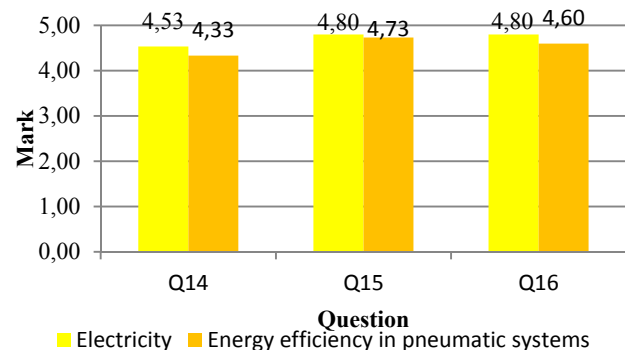
**Fig. 4.** The marks for the 5 questions relevant with the II. COURSE MATERIALS AND TEACHING METHODOLOGY

The next field ALC platform has slight lower grades because during the training only some lessons were uploading in the platform. According to the figure 5 the highest mark in this part was in the question Q11 “The Platform is user-friendly” while the lowest occur for the questions Q13 “The Platform facilitated my learning process”.

Figure 6 shows that in the most important section this **of the overall evaluation** the results prove that learners evaluate positive the course and want participate again in similar projects with the maximum score for the question Q15. I enjoyed the course and Q16.



**Fig. 5.** The marks for the 5 questions relevant with the III. ACL PLATFORM



**Fig. 6.** The marks for the 5 questions relevant with the IV. OVERAL EVALUATION

#### *Results from the survey among companies:*

Table 4 shows the relevant results for the companies, again 5 is the highest mark and 1 is the lowest. From the results is obvious that the companies understand the essentiality of the vocational training for the technicians.

**Table 4.** The results according to the companies answers for the lesson

| QUESTIONS                                                                                                                                    | Electricity | Energy efficiency in pneumatic systems |
|----------------------------------------------------------------------------------------------------------------------------------------------|-------------|----------------------------------------|
|                                                                                                                                              | Mark        | Mark                                   |
| 1. Do you intend to send more engineers and technicians to attend technical courses for upskilling?                                          | 4.33        | 4.73                                   |
| 2. Do you think further vocational training help your engineering and technical staff to perform better?                                     | 4.93        | 5                                      |
| 3. Do you feel your company would be more competitive if your engineers and technicians regularly attend vocational training for upskilling? | 4.87        | 5                                      |

From the results we can say that both the technicians and the companies have very positive attitude relevant with the training especially when this is practice-oriented. The results of the test indicate that the learners have understood the lesson. Last but not least the interest of the technicians for the thermal camera, point at they are open to change and to adapt to new technologies.

#### 4. Conclusions and future work

Significant interest has been shown in improving technicians' and engineers' soft skills such as problem-solving, communication skills, etc. The most preferred teaching methodology is active blended learning. Therefore, the courses should be based on active learning techniques so that they can build not only technical skills but also improve soft skills demanded by employers.

The analysis of the training needs of the employed technicians and engineers in the sector of Machine Building and Mechatronics shows that there is a demand of upskilling those target groups and there are enough potential users of such training. Hence, the material to be developed will be useful for the companies in the above industrial sector.

Companies are aware that they should invest in the training of those employees so as to continuously improve their competences in order to achieve excellence and meet the new demands of both manufacturing and customers in the era of Industry 4.0.

Based on the data from the two lessons derives some common conclusions. First of all, both engineers and technicians estimate that the training can help them and evaluate very positive this training program. Also according to the answer is obviously that both choose practical lessons compared with this with theoretical aspect. Last but not least a really high percentage of workers desire to participate again in such types of project while all the companies believes that further vocational training help both engineering and technical

staff to perform better and hence companies would be more competitive.

#### Acknowledgements

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# Theory and Applications of Fourier, Laplace, and Z Transformations

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**Abstract:** This study presents the mathematics for the implementation of direct and inverse Fourier, Laplace, and Z transformations. This research is at the intersection between signal processing, applied mathematics, and software engineering, and it provides a study guide to implementers. Mathematical concepts and details necessary to transform the math into code are provided as theoretical background. Validation is conducted for the cases when the transforms do intersect, when the transforms do not intersect, and when, in Fourier and Z-transformations, the frequency domain encodes a phase shift which is reconstructed as an image space shift. Coherence between the software implementation of the three transformations is confirmed when: 1. The real component  $\sigma$  of the complex variable  $s = \sigma + i\omega$  is equal to zero, which is the case when Fourier and Laplace transforms are the same. 2. When the magnitude  $r$  of the complex variable  $z = r e^{j\omega}$  is equal to one, which is the case when Fourier and Z transforms are the same. Congruency between software implementation of transformations is confirmed comparing departing image and inverse reconstructed image. The novelty of this research is the presentation style of the theory of direct and inverse Fourier, Laplace, and Z transforms. Details provided in this research make this paper a study guide that is not found elsewhere.

**Keywords:** k-space, L-space, z-space, phase, shift.

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## 1. Introduction

### 1.1. Historical perspective & research objective

The effective and time-saving use of the Fourier transformation had triggered in the past the development of fast Fourier transform, which in its pioneer works benefit of Cooley and Tukey's breakthrough [1, 2, 3], which also facilitated the calculation of Laplace and Z transforms [4]. Numerical Laplace inversion algorithms were reported with a focus on automatic digital computation [5] and algorithmic notation [6]. The relationship between Magnetic Resonance Imaging (MRI) and basic Fourier principles were revealed by Peter Mansfield [7] & Paul Lauterbur [8]. The state of the art in the literature provides well-known and well-established theoretical concepts in relation to direct and inverse Fourier, Laplace, and Z transformations. Nevertheless, the challenge to implement into functional code the transformations, paves the path to a learning experience that starts from the theoretical background and through empirics verifies the correctness of software implementation. Indeed, pioneer work on the numerical inversions of Laplace transforms was carried out long ago by Weeks [9] and Talbot [10]. More recent work provides a description of software implementations of numerical

inversion of a Laplace transform [11-13] and reviews the literature on inverse Laplace transform algorithms [14]. The Laplace transform can be used to solve nonlinear ordinary partial differential equations [15] and fractional differential equations [16]. One aspect of this research is indeed the validation of software implementation of inverse Laplace transform [11, 12, 13]. To this purpose, this paper addresses in the result section a validation paradigm that clarifies, for the dataset of two-dimensional images, when the implementation of the inverse Laplace transform is successful. After Laplace, the basic knowledge of the Z-transform was reintroduced by the Polish mathematician Witold Hurewicz in 1947. The specificity of the Z-transform to model sample data was studied by Ragazzini and Zadeh [17] and later characterized by Jury [18]. Both in nature and in engineering, phenomena can be modelled through differential equations which can determine closed-form solutions [19]. To the extent of the generation of closed-form solutions, Laplace and Z transforms can be successful [14, 19]. More specifically, under a theoretical perspective, the continuity required by Fourier and Laplace is released by the Z-transform allowing the latter to be used to study phenomena regulated by a set of discrete samples while relinquishing the approximation that would be required if Fourier and Laplace transforms would be used for modelling [19, 20]. As far as regards the three transforms treated in this paper, computational evolutions reported in the literature include:

- Fractional Fourier transform [21];



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- Numerical methods for the inversion into the real domain of solutions of differential equations defined in the Laplace domain [22];
- The chirp Z-transform [23].

However, the task of implementing the theory of Fourier, Laplace, and Z transforms is not trivial neither is the validation of the implementation. The motivation of this work is to generate mathematical theory that facilitate code implementation of the three direct and inverse transformations. The generation of code necessitates the translation of the concepts into practical formulations which simplify the implementation. The contribution of this research is hence in the details of theory which are often omitted in the literature to support the introduction of more advanced concepts.

### 1.2. Validation of the theory

There are two approaches undertaken by this research to validate the theory.

The first approach works through intersections. The Laplace transform uses the complex variable  $s = \sigma + i \omega$ . When  $s = i \omega$ , which means when  $\sigma = 0$ , the Laplace transform is the Fourier transform. Similarly, the intersection between Z and Fourier transformations ensues when  $r = 1$  for the complex variable  $z = r e^{j\omega}$ . These aspects are thought of as validation evidence. Validation of the intersection between direct and inverse Fourier and Laplace transformations, and validation of the intersection between direct and inverse Fourier and Z transformations; are evidence of correct implementation for these specific cases.

The second approach is the implementation of the inverse transformations so to pursue validation of direct transformations. This validation approach is used to collect evidence of correct implementation when the intersections are not in place. Which means when  $\sigma \neq 0$  (Laplace transforms) and when  $r \neq 1$  (Z transforms). In this paper the frequency domain calculated with Fourier, Laplace, and Z transforms is termed as k-space, L-space, and z-space respectively.

## 2. Theory

### 2.1. Direct Fourier transformation

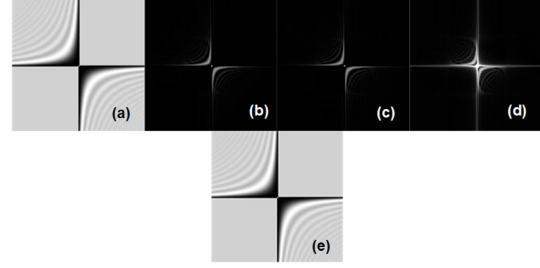
The direct Fourier transformation [24] is

$$f(\varphi) = \int_{-\infty}^{+\infty} f(z) e^{-2\pi i \varphi z} dz \quad (1)$$

The phase is  $\varphi = 2.0 \pi x y / (N_x \cdot N_y)$ ,  $z$  is the complex variable,  $f(z)$  is the signal represented as a complex number,  $f(\varphi)$  is the frequency or so-called k-space. The phase is the unique identifier of the signal component. In Fourier processing and more specifically in Fourier direct and inverse transformations, the phase is like a label to use to map the signal. The digital signal can be viewed as a sequence of samples and each sample can be identified through the phase. Each signal component (sample) is assigned to a different value of phase  $\varphi$  and so it can be identified. The coordinate  $(x, y)$  localizes the pixel of the image to be processed (labelled).

Given the integration between  $-\infty$  and  $+\infty$ , In addition to what reported in the appendix, Eq. (1) requires the following elaboration. We make the approximation that

the signal is discrete and finite. Discrete because represented by a set of samples which we call pixel intensity values (or brightness values). Finite because the signal exists between 1 and  $(N_x \cdot N_y)$ .



**Fig. 1.** Sinc signal image (a), the real component of the k-space (b), the imaginary component of the k-space (c), the k-space magnitude (d). Reconstructed image by inverse Fourier Transformation (e).

Eq. (1) asserts that the signal  $f(z)$  can be decomposed into a convolution of signal intensity values and cosine and sine waves. More specifically: when  $f(z)$  is a real number (pixel brightness), that is  $f_k(z)$  (with  $k = 1, 2 \dots (N_x \cdot N_y)$ ); and when  $2 \pi \varphi z = \text{phase} = 2.0 \pi x y / (N_x \cdot N_y)$ ; from Eq. (1) we can write that the  $s$ -th real component of the k-space is  $(F_s, \text{Re})$ , and the  $s$ -th imaginary component of the k-space is  $(F_s, \text{Im})$ .

$$(F_s, \text{Re}) + i (F_s, \text{Im}) \approx$$

$$\sum_{k=1}^{(N_x \cdot N_y)} f_k(z) \cdot [\cos(\text{phase}_{ks}) + \sin(\text{phase}_{ks})] + \sum_{k=1}^{(N_x \cdot N_y)} i f_k(z) \cdot [-\sin(\text{phase}_{ks}) + \cos(\text{phase}_{ks})] \quad (2)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

The value of the phase changes for each  $(k, s)$  couple determined by  $k = 1, 2 \dots (N_x \cdot N_y)$ , and  $s = 1, 2 \dots (N_x \cdot N_y)$ . Practically, the value of the phase is implemented as  $2.0 \pi k_2 k_3 / (N_x \cdot N_y)$ , and it changes at each iteration of four nested for loops (two outer loops update the value of  $k_2$ , and two innermost loops update the value of  $k_3$ ). The value of the phase is thus always different at each iteration. Thus,  $k_2$  is the same when all of the values of  $k_3$  span in  $[1, 2 \dots (N_x \cdot N_y)]$  ( $k_3$  changes within two for loops selecting each image pixel intensity value). After that, the value of  $k_2$  changes (to target another k-space pixel) and  $k_3$  spans again in  $[1, 2 \dots (N_x \cdot N_y)]$ . The same concept of the phase change applies to inverse Fourier transform and direct and inverse Laplace, and Z transforms. Now let us implement this formula to calculate the direct Fourier transformation. The equation of the  $s$ -th pixel of the real component of the k-space is

$$(F_s, \text{Re}) =$$

$$\sum_{k=1}^{(N_x \cdot N_y)} f_k(z) \cdot [\cos(\text{phase}_{ks}) + \sin(\text{phase}_{ks})] \quad (3)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

The equation of the  $s$ -th pixel of the imaginary component of the k-space is

$$(F_s, \text{Im}) =$$

$$\sum_{k=1}^{(N_x \cdot N_y)} f_k(z) \cdot [-\sin(\text{phase}_{ks}) + \cos(\text{phase}_{ks})] \quad (4)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

Given the departing image in Figure 1a,  $(F_s, R_e)$  is the  $s$ -th pixel of the real component image of the k-space (see Figure 1b),  $(F_s, I_m)$  is  $s$ -th pixel of the imaginary component image of the k-space (see Figure 1c). This means that each pixel  $(F_s, R_e)$  of the real component image of the k-space is calculated with Eq. (3) for  $s = 1, 2 \dots (N_x \cdot N_y)$ . Also, this means that each pixel  $(F_s, I_m)$  of the imaginary component image of the k-space is calculated with Eq. (4) for  $s = 1, 2 \dots (N_x \cdot N_y)$ . Recall that k-space means frequency domain. The frequency domain is also characterized by the k-space magnitude  $M_s = \sqrt{(F_s, \text{Re})^2 + (F_s, \text{Im})^2}$  with  $s = 1, 2 \dots (N_x \cdot N_y)$  (see Figure 1d).

## 2.2 Inverse Fourier transformation

The inverse Fourier transformation [24] is

$$f(z) = \int_{-\infty}^{+\infty} f(\varphi) e^{2\pi i \varphi z} d\varphi \quad (5)$$

Now, in addition to what reported in the appendix, let us consider that  $[(F_s, R_e) + i (F_s, I_m)]$  is the notation of the  $s$ -th term of the k-space (made of real and imaginary component), with  $s = 1, 2 \dots (N_x \cdot N_y)$ . As we are in the discrete domain, we are processing a finite signal. Therefore, the integration between  $-\infty$  and  $+\infty$  can be replaced by the finite sum. Eq. (5) yields

$$\sum_{s=1}^{(N_x \cdot N_y)} [(F_s, \text{Re}) \cdot \cos(\text{phase}_{sj}) - (F_s, \text{Im}) \cdot \sin(\text{phase}_{sj})] + \sum_{s=1}^{(N_x \cdot N_y)} i [(F_s, \text{Re}) \cdot \sin(\text{phase}_{sj}) + (F_s, \text{Im}) \cdot \cos(\text{phase}_{sj})] \quad (6)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

The value of the phase changes for each  $(s, j)$  couple determined by  $s = 1, 2 \dots (N_x \cdot N_y)$ , and  $j = 1, 2 \dots (N_x \cdot N_y)$ . The inverse Fourier transformation uses the k-space to transform back into the departing image (see Figure 1e). Eq. (6) indicates that the  $j$ -th pixel of the real component of the reconstructed signal is

$$\sum_{s=1}^{(N_x \cdot N_y)} [(F_s, \text{Re}) \cdot \cos(\text{phase}_{sj}) - (F_s, \text{Im}) \cdot \sin(\text{phase}_{sj})] \quad (7)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

And the  $j$ -th pixel of the imaginary component of the reconstructed signal is

$$\sum_{s=1}^{(N_x \cdot N_y)} [(F_s, \text{Re}) \cdot \sin(\text{phase}_{sj}) + (F_s, \text{Im}) \cdot \cos(\text{phase}_{sj})] \quad (8)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

And the  $j$ -th pixel of the magnitude of the reconstructed signal is

$$f_j(z) = \sqrt{(f_j(z), \text{Re})^2 + (f_j(z), \text{Im})^2} \quad (9)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

## 2.3 Direct Laplace transformation

The direct Laplace transformation [24] is

$$f(s) = \int_{-\infty}^{+\infty} f(z) e^{-sz} dz \quad (10)$$

The complex variable is  $s = \sigma + i \omega$ . When  $s = i \omega$ , which means when  $\sigma = 0$

$$f(s) = \int_{-\infty}^{+\infty} f(z) e^{-sz} dz = \int_{-\infty}^{+\infty} f(z) e^{-i\omega z} dz \quad (11)$$

Eq. (11) is the Fourier transform of  $f(z)$ . The Laplace transform also bears a straightforward relationship to the Fourier transform when the complex variable is not purely imaginary. To see this relationship, consider  $f(s)$  with  $s$  expressed as  $s = \sigma + i \omega$ , so that

$$f(s) = \int_{-\infty}^{+\infty} f(z) e^{-(\sigma + i \omega)z} dz = \int_{-\infty}^{+\infty} [f(z) e^{-\sigma z}] e^{-i\omega z} dz \quad (12)$$

We recognize the right-hand side of Eq. (12) as the Fourier transform of  $[f(z) e^{-\sigma z}]$ , which means that the Laplace transform of  $f(z)$  can be interpreted as the Fourier transform of  $f(z)$  after multiplication by a real exponential signal  $e^{-\sigma z}$  [24]. Note that  $\sigma \cdot z$  can be called  $\rho$ , so that we use the position:  $e^{-\rho}$ . Moreover, when  $2\pi \varphi z = \text{phase} = 2.0 \pi x y / (N_x \cdot N_y)$ , from Eq. (12) it follows that

$$\sum_{k=1}^{(N_x \cdot N_y)} f_k(z) \cdot [\cos(\text{phase}_{kj}) + \sin(\text{phase}_{kj})] \cdot e^{-\rho} + \sum_{k=1}^{(N_x \cdot N_y)} i f_k(z) \cdot [-\sin(\text{phase}_{kj}) + \cos(\text{phase}_{kj})] \cdot e^{-\rho} \quad (13)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

The value of  $f_k(z)$  is the  $k$ -th image pixel brightness. The value of the phase changes for each  $(k, j)$  couple determined by  $k = 1, 2 \dots (N_x \cdot N_y)$ , and  $j = 1, 2 \dots (N_x \cdot N_y)$ . The  $j$ -th pixel of the real component of the L-space (one pixel of the image in Figure 2b) is

$$(f_j(s), \text{Re}) = \sum_{k=1}^{(N_x \cdot N_y)} f_k(z) \cdot [\cos(\text{phase}_{kj}) + \sin(\text{phase}_{kj})] \cdot e^{-\rho} \quad (14)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

And the  $j$ -th pixel of imaginary component of the L-space (one pixel of the image in Figure 2c) is

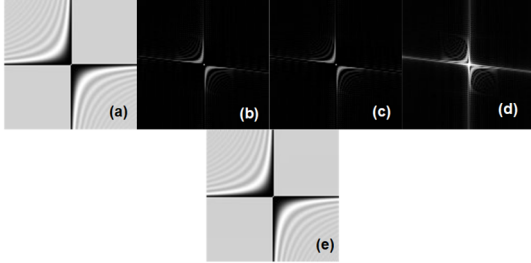
$$(f_j(s), \text{Im}) = \sum_{k=1}^{(N_x \cdot N_y)} f_k(z) \cdot [-\sin(\text{phase}_{kj}) + \cos(\text{phase}_{kj})] \cdot e^{-\rho} \quad (15)$$

with  $j = 1, 2 \dots (N_x \cdot N_y)$

Recall that L-space (or  $s$ -space as many textbooks report) means frequency domain. The L-space magnitude is  $M_j = \sqrt{(f_j(s), \text{Re})^2 + (f_j(s), \text{Im})^2}$  with  $j = 1, 2 \dots (N_x \cdot N_y)$  (see Figure 2d).

The Laplace transform (see Eq. (15)) is defined for  $\sigma > \alpha$  (real number) [24]. The evidence of the assertion is presented in Figure 3, where it was determined that  $\alpha > -$

5.0. Figure 3 shows the case of the rectangle image. However, the implementation of Laplace transforms was written with the intent to successfully process any input image. Such intent poses a challenge because each image is different. To overcome this challenge  $\sigma$ ,  $\omega$ , were scaled very closely to  $+1.0$  ( $0.99\dots$ ) by means of the sigmoidal function  $1.0/(1.0 + e^{-10 \cdot x})$  with  $x = \sigma$ ,  $x = \omega$ .



**Fig. 2.** Sinc signal image (a), the real component of the L-space (b), the imaginary component of the L-space (c), the L-space magnitude (d).

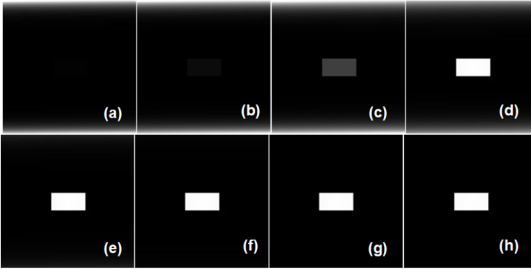
Reconstructed image by inverse Laplace Transformation (e). The warp was obtained scaling the complex variable  $s = \sigma + i\omega$  with sigmoidal function. The effect of the warp is to scale both  $\sigma$  and  $\omega$  to fine fractions of one ( $1.0$ ).

## 2.4 Inverse Laplace transformation

The inverse Laplace transformation [24] is

$$f(z) = \int_{-\infty}^{+\infty} f(s) e^{sz} ds \quad (16)$$

Now let us consider that the notation of the  $j$ -th component of the L-space is  $[f_j(s), R_e] + i[f_j(s), I_m]$  with  $j = 1, 2 \dots (N_x \cdot N_y)$ .



**Fig. 3.** Rectangle image reconstructed with inverse Laplace transform.

The complex variable  $s = \sigma + i\omega$  changes for the value of  $\sigma$  but not the value of  $\omega$ , which was kept equal to one. (a), (b), (c), (d), (e) show the result of image reconstruction using values of  $\sigma$  for which the inverse Laplace transform fails to reconstruct the rectangle image. The values are:  $-9.0$  (a),  $-8.0$  (b),  $-7.0$  (c),  $-6.0$  (d),  $-5.0$  (e). (f), (g), (h) show successful reconstruction obtained using the values:  $-4.0$  (f),  $-3.0$  (g),  $-2.0$  (h). It was confirmed empirically that with the increase of  $\sigma$  from  $-0.1$  to  $1.0$  the image is reconstructed. This result means that for the inverse Laplace transform to be successful in reconstructing the rectangle image  $\sigma$  must be greater than  $-5.0$  (see (f)). Now recall that

$$f(z) = \int_{-\infty}^{+\infty} f(s) e^{(\sigma + i\omega)z} ds = \int_{-\infty}^{+\infty} [f(s) e^{\sigma z}] e^{i\omega z} ds \quad (17)$$

Note that  $\sigma \cdot z$  can be called  $\rho$ , so that we use the position  $e^\rho$ . Thus, in view of Eq. (17) we can write

$$(f_p(z), \text{Re}) + i(f_p(z), \text{Im}) \approx \sum_{j=1}^{(N_x \cdot N_y)} [(f_j(s), \text{Re}) \cdot \cos(\text{phase}_{jp}) - (f_j(s), \text{Im}) \cdot \sin(\text{phase}_{jp})] e^\rho + \sum_{j=1}^{(N_x \cdot N_y)} i [(f_j(s), \text{Re}) \cdot \sin(\text{phase}_{jp}) + (f_j(s), \text{Im}) \cdot \cos(\text{phase}_{jp})] e^\rho \quad (18)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$

The value of the phase changes for each  $(j, p)$  couple determined by  $j = 1, 2 \dots (N_x \cdot N_y)$ , and  $p = 1, 2 \dots (N_x \cdot N_y)$ . The  $\approx$  sign applies to the approximation we make when we work with discrete finite signals. Finally, the  $p$ -th pixel of the real part of the inverse Laplace reconstructed image is  $(f_p(z), \text{Re}) =$

$$\sum_{j=1}^{(N_x \cdot N_y)} [(f_j(s), \text{Re}) \cdot \cos(\text{phase}_{jp}) - (f_j(s), \text{Im}) \cdot \sin(\text{phase}_{jp})] e^\rho \quad (19)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$

And, the  $p$ -th pixel of the imaginary part of the inverse Laplace reconstructed image is  $(f_p(z), \text{Im}) =$

$$\sum_{j=1}^{(N_x \cdot N_y)} [(f_j(s), \text{Re}) \cdot \sin(\text{phase}_{jp}) + (f_j(s), \text{Im}) \cdot \cos(\text{phase}_{jp})] e^\rho \quad (20)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$

And the magnitude of the reconstructed signal is

$$f_p(z) = \sqrt{(f_p(z), \text{Re})^2 + (f_p(z), \text{Im})^2} \quad (21)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$

## 2.5 Direct Z transformation

The z-transform of a general sequence  $x[n]$  [24] is defined as

$$X(z) = \sum_{n=-\infty}^{+\infty} x[n] z^{-n} \quad (22)$$

We express the complex variable  $z$  in polar form as Eq. (23), with  $r$  as the magnitude of  $z$ , and  $\omega$  as the angle of  $z$ .  $z = r e^{i\omega}$  (23)

$$X(r e^{i\omega}) = \sum_{n=-\infty}^{+\infty} x[n] (r e^{i\omega})^{-n} = \sum_{n=-\infty}^{+\infty} \{x[n] r^{-n}\} e^{-i\omega n} \quad (24)$$

We see that  $X(r e^{i\omega})$  is the Fourier transform of the sequence  $x[n]$  multiplied by a real exponential  $r^{-n}$  that is

$$X(r e^{i\omega}) = F\{x[n] r^{-n}\} \quad (25)$$

Now let us write Eq. (24) as

$$X(r e^{i\omega}) = \sum_{n=-\infty}^{+\infty} \{x[n] r^{-n}\} e^{-i\omega n} \approx \sum_{n=1}^{(N_x \cdot N_y)} [\text{Re}(n) \cdot \cos(\omega n) + \text{Im}(n) \cdot \sin(\omega n)] r^{-n} + \sum_{n=1}^{(N_x \cdot N_y)} i [-\text{Re}(n) \cdot \sin(\omega n) + \text{Im}(n) \cdot \cos(\omega n)] r^{-n} \quad (26)$$

Moreover, when  $\omega n = \text{phase} = 2.0 \pi x y / (N_x \cdot N_y)$ ; and when the signal is a real number, which means that  $\text{Re}(n) = \text{Im}(n) = x[n] = f(n)$ ; we can write Eq. (26) as  $(F_p, \text{Re}) + i (F_p, \text{Im}) \approx$

$$\sum_{n=1}^{(N_x \cdot N_y)} f(n) \cdot [\cos(\text{phase}_{np}) + \sin(\text{phase}_{np})] r^{-n} + \sum_{n=1}^{(N_x \cdot N_y)} i f(n) \cdot [-\sin(\text{phase}_{np}) + \cos(\text{phase}_{np})] r^{-n} \quad (27)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$

The value of the phase changes for each  $(n, p)$  couple determined by  $n = 1, 2 \dots (N_x \cdot N_y)$ , and  $p = 1, 2 \dots (N_x \cdot N_y)$ . The equation of the  $p$ -th pixel of the real component of the z-space is  $(F_p, \text{Re}) =$

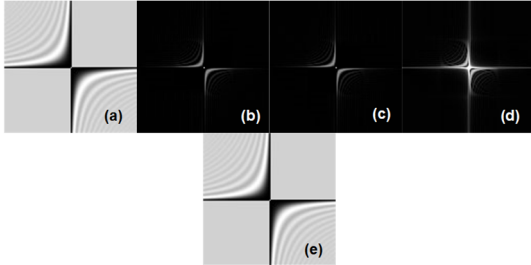
$$\sum_{n=1}^{(N_x \cdot N_y)} f(n) \cdot [\cos(\text{phase}_{np}) + \sin(\text{phase}_{np})] \cdot r^{-n} \quad (28)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$

The equation of the  $p$ -th pixel of the imaginary component of the z-space is  $(F_p, \text{Im}) =$

$$\sum_{n=1}^{(N_x \cdot N_y)} f(n) \cdot [-\sin(\text{phase}_{np}) + \cos(\text{phase}_{np})] \cdot r^{-n} \quad (29)$$

with  $p = 1, 2 \dots (N_x \cdot N_y)$



**Fig. 4.** Sinc signal image (a), the real component of the z-space (b), the imaginary component of the z-space (c), the z-space magnitude (d). Reconstructed image by inverse Z Transformation (e).

$(F_p, R_e)$  is the  $p$ -th pixel of the real component image of the z-space (see Figure 4b),  $(F_p, I_m)$  is the  $p$ -th pixel of the imaginary component image of the z-space (see Figure 4c). Each pixel  $(F_p, R_e)$  of the real component image of the z-space is calculated with Eq. (28) with  $p = 1, 2 \dots (N_x \cdot N_y)$ . Each pixel  $(F_p, I_m)$  of the imaginary component image of the z-space is calculated with Eq. (29) with  $p = 1, 2 \dots (N_x \cdot N_y)$ . The magnitude of the z-space is:  $M_p = \sqrt{(F_p, \text{Re})^2 + (F_p, \text{Im})^2}$  with  $p = 1, 2 \dots (N_x \cdot N_y)$ ; (see Figure 4d).

## 2.6 Inverse Z transformation

The z-space of the signal  $x[n]$  is made of a real  $(F_n, R_e)$  and an imaginary  $(F_n, I_m)$  component, with  $n = 1, 2 \dots (N_x \cdot N_y)$ .

$N_y)$ . Moreover, when  $\omega n = \text{phase} = 2.0 \pi x y / (N_x \cdot N_y)$ , it follows that

$$(f[s], \text{Re}) + i (f[s], \text{Im}) \approx$$

$$\sum_{n=1}^{(N_x \cdot N_y)} [(F_n, \text{Re}) \cdot \cos(\text{phase}_{ns}) - (F_n, \text{Im}) \cdot \sin(\text{phase}_{ns})] \cdot r^n + \sum_{n=1}^{(N_x \cdot N_y)} i [(F_n, \text{Re}) \cdot \sin(\text{phase}_{ns}) + (F_n, \text{Im}) \cdot \cos(\text{phase}_{ns})] \cdot r^n \quad (30)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

The value of the phase changes for each  $(n, s)$  couple determined by  $n = 1, 2 \dots (N_x \cdot N_y)$ , and  $s = 1, 2 \dots (N_x \cdot N_y)$ . Where the  $s$ -th pixel of the real component of the reconstructed signal is  $(f[s], \text{Re}) \approx$

$$\sum_{n=1}^{(N_x \cdot N_y)} [(F_n, \text{Re}) \cdot \cos(\text{phase}_{ns}) - (F_n, \text{Im}) \cdot \sin(\text{phase}_{ns})] \cdot r^n \quad (31)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

And the  $s$ -th pixel of the imaginary component of the reconstructed signal is  $(f[s], \text{Im}) \approx$

$$\sum_{n=1}^{(N_x \cdot N_y)} [(F_n, \text{Re}) \cdot \sin(\text{phase}_{ns}) + (F_n, \text{Im}) \cdot \cos(\text{phase}_{ns})] \cdot r^n \quad (32)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

And the magnitude of the reconstructed signal is

$$f(s) = \sqrt{(f[s], \text{Re})^2 + (f[s], \text{Im})^2} \quad (33)$$

with  $s = 1, 2 \dots (N_x \cdot N_y)$

## 2.7 Fourier-shift and Z-shift

The Fourier shift theorem states that a shift in phase corresponds to a shift in image space. The shift in phase is a shift in the frequency domain. There are two tasks to perform to implement the phase shift. One is to transform the misplacement in image space into a phase shift in the frequency domain and the other one is to encode the shift in the Fourier formulae. The following implementation formulae are used to transform the misplacement in image space into a phase shift in the frequency domain

$$dx = (i - \frac{N_y}{2}) \quad (34)$$

$$dy = (j - \frac{N_x}{2}) \quad (35)$$

$$x = (dy \cdot N_y + dx) \quad (36)$$

$$y = (dx \cdot N_x + dy) \quad (37)$$

$$xshift = 2.0 \pi y \cdot \frac{x Fshift}{N_x} \quad (38)$$

$$yshift = 2.0 \pi x \cdot \frac{y Fshift}{N_y} \quad (39)$$

Where  $i, j, dx, dy$  are the pixel identifiers (integer numbers), with  $i = 1, 2 \dots N_x$  (number of pixels along the X coordinate) and  $j = 1, 2 \dots N_y$  (number of pixels along the Y coordinate). And,  $x$  and  $y$  identify the pixel's coordinate.  $x Fshift$  and  $y Fshift$  are values of the image space misplacement, and  $xshift$  and  $yshift$  are the phase shifts. The phase shifts  $xshift$  and  $yshift$  embed the image space shifts  $x Fshift$  and  $y Fshift$ . The second challenge is to encode the shift in the phase as follows.

$$phase = \frac{(2.0 \pi \cdot k_2 \cdot k_3)}{(N_x \cdot N_y)} \quad (40)$$

$$phase += xshift + yshift \quad (41)$$

$k_2$  and  $k_3$  were defined in section 2.1 titled 'Direct Fourier transformation'. Once we sum the phase shifts to the phase, we have encoded the misplacement in Fourier formulae. Similarly, the Z-transform allows the shift in image space to be encoded in the z-space and this happens through the exponent  $n$ . The image space shifts  $xFshift$  and  $yFshift$  are encoded using the following formulae

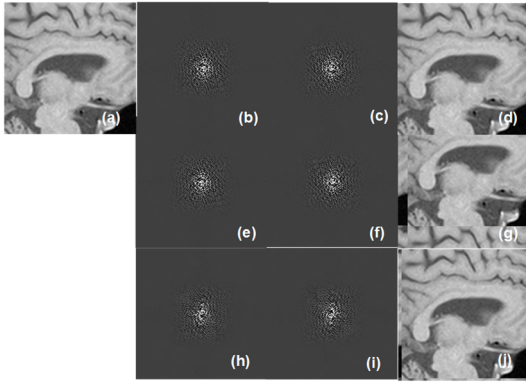
$$xshiftExponent = 2.0 \pi y \cdot \frac{xFshift}{N_x} \quad (42)$$

$$yshiftExponent = 2.0 \pi x \cdot \frac{yFshift}{N_y} \quad (43)$$

The phase then becomes

$$phase += xshiftExponent + yshiftExponent \quad (44)$$

Figure 5 shows an illustration of the Fourier shift theorem and the effect of phase-shifting with the Z-transform so to obtain image space shift after image reconstruction with inverse Z-transform.



**Fig. 5.** Magnetic Resonance Image (a). The real component of the k-space (b). The imaginary component of the k-space (c).

The image was reconstructed with inverse Fourier transform (d). The real component (e) and the imaginary component (f) of the k-space encoding an image space shift of  $(x, y) = (13, 31)$  pixels. The reconstructed image (g) with inverse Fourier transform using (e) and (f), and which shows the image space shift. The real component (h) and the imaginary component (i) of the z-space encoding an image space shift of  $(x, y) = (4, 4)$  pixels. The reconstructed image (j) with inverse Z transform using (h) and (i), and which shows the image space shift.

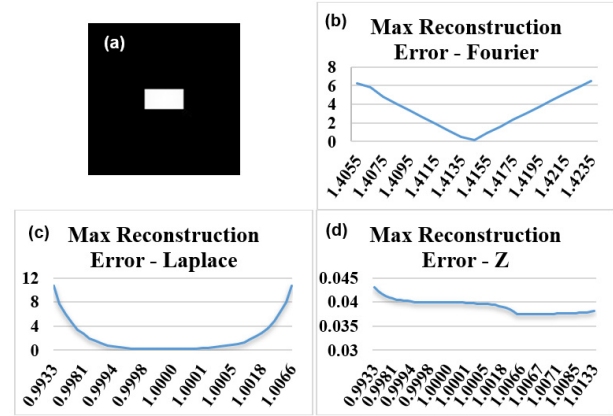
### 3. Results

The dataset used to validate software implementation of theoretical concepts comprises of 30 two-dimensional images: 10 theoretical images and 20 Magnetic Resonance (MR) images. The results reported in this section are a sample of the validation performed using the dataset.

#### 3.1 Maximum reconstruction error

The image reconstructed with the inverse Fourier transform is subject to a scaling factor that adjusts the pixel

intensity values to match the values of the departing image. The scaling factor is constant across pixels. After reconstruction, the difference image is calculated by subtracting the reconstructed image from the departing image. The maximum reconstruction error is the maximum pixel intensity absolute value of the difference image. As extension to earlier work [25], a calibration study was developed so to determine the evolution of the maximum reconstruction error (inverse Fourier transform) versus the scale factor (see Figure 6b).



**Fig. 6.** Rectangle image (a). (b) Evolution of the maximum reconstruction error of the inverse Fourier transform versus the scale factor (the minimum is 0.203 with a scaling factor equal to 1.4145). (c) Evolution of the maximum reconstruction error of the inverse Laplace transform versus the complex variable (the minimum is 0.199 for  $s = 0.999864 + i 0.999864$ ). (d) Evolution of the maximum reconstruction error of the inverse Z transform versus the complex variable (the minimum is 0.0375 for  $z = 1.006989 + i 1.006989$ ).

The rectangle image showed in Figure 6a was used in this study. The plot in Figure 6b reveals that the minimum of the maximum error is 0.203 for the value of the scaling factor equal to 1.4145. This value of the scaling factor was used to determine the evolution of the maximum reconstruction error of Laplace transform (see Figure 6c) and Z transform (see Figure 6d) versus the value of the complex variable. Real and imaginary components of the complex variable had the same numerical value (plotted along the abscissa in (c) and (d)). The minimum of the maximum reconstruction error was: 0.199 for the Laplace transform with  $s = 0.999864 + i 0.999864$ ; and 0.0375 for the Z transform with  $z = 1.006989 + i 1.006989$ .

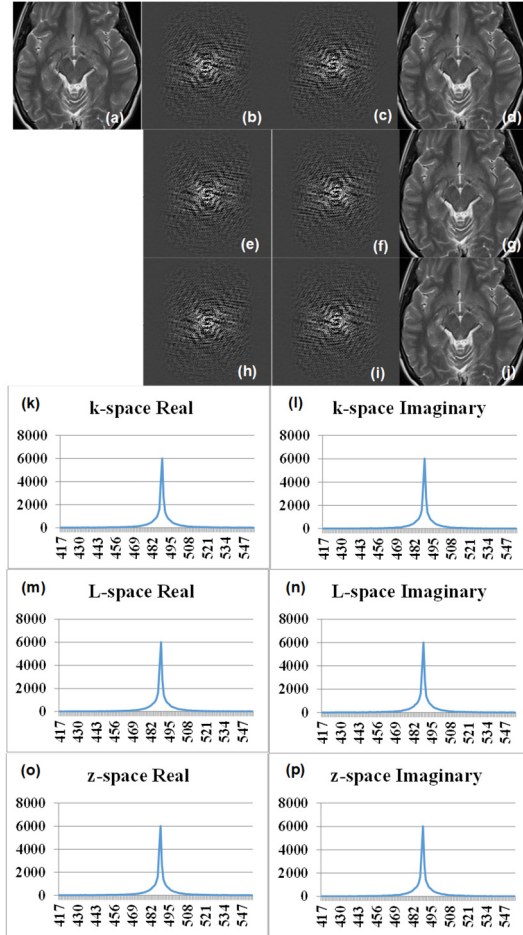
#### 3.2 Laplace and Z transforms: coherence to Fourier theory

This section presents results that show that both Laplace and Z transforms are the same as the Fourier transform when the following conditions are met.

1. Laplace transform. The complex variable is  $s = \sigma + i \omega$ , and so when  $s = i \omega$ , which means when  $\sigma = 0$ , the Laplace transform is the Fourier transform. This case is presented in Figure 7.

2. Z transform. The complex variable  $z$  in polar form is  $z = r e^{j\omega}$ , and so when  $r = 1$ , the Z transform is the Fourier transform. This case is also presented in Figure 7.

Points 1 and 2 are well-known, and fundamental and they offer the opportunity to validate the implementation of direct and inverse Fourier, Laplace, and Z transforms. Figure 7 shows that k-space, L-space, and z-space are identical, and this is evidence that the three direct transforms were designed with the correct theoretical background presented in the theory section and were also correctly implemented into software. Figure 7 also shows that images reconstructed through inverse transformations (d), (g), (j) are the same as (a).

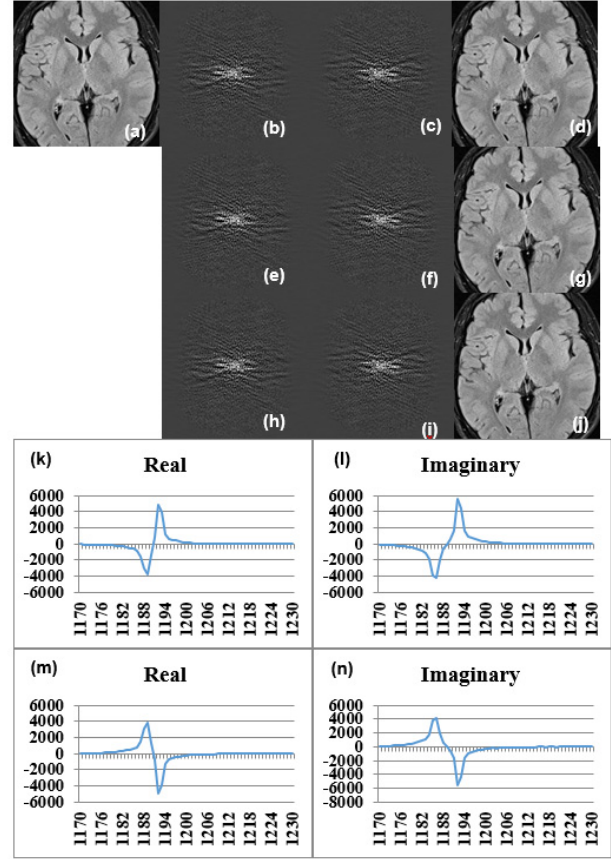


**Fig. 7.** MR image (a). Fourier k-space real component (b), Fourier k-space imaginary component (c), reconstructed signal through inverse Fourier transformation (d). Laplace L-space real component (e), Laplace L-space imaginary component (f), reconstructed signal through inverse Laplace transformation (g). Z-space real component (h), z-space imaginary component (i), reconstructed signal through inverse Z transformation (j). (k), (l), (m), (n), (o), (p), Histograms of the images in (b), (c), (e), (h), (f), (i), respectively.

### 3.3 Laplace and Z transforms versus Fourier transform

This section presents results that show the comparison of both Laplace and Z transforms versus the Fourier transform (see Figures 8, 9). The assumption is that if the

inverse transformation yields to the departing image, then the direct transformation is correct, and so is the inverse transformation. These results were obtained using  $\sigma \neq 0$  and  $r \neq 1$ . The histograms in Figures 8, 9 show that k-space and L-space differs, and L-space and z-space also differs, both in their real and imaginary components. In Figure 8, the complex variable of the Laplace transform is  $s = \sigma + i\omega = 0.999877 + i 0.999877$ ; and the complex variable of the Z transform is  $z = (R_e + i I_m) = 0.999877 + i 0.999877$ . In Figure 9,  $s = 0.999665 + i 0.999665$ ;  $z = 0.999665 + i 0.999665$ .



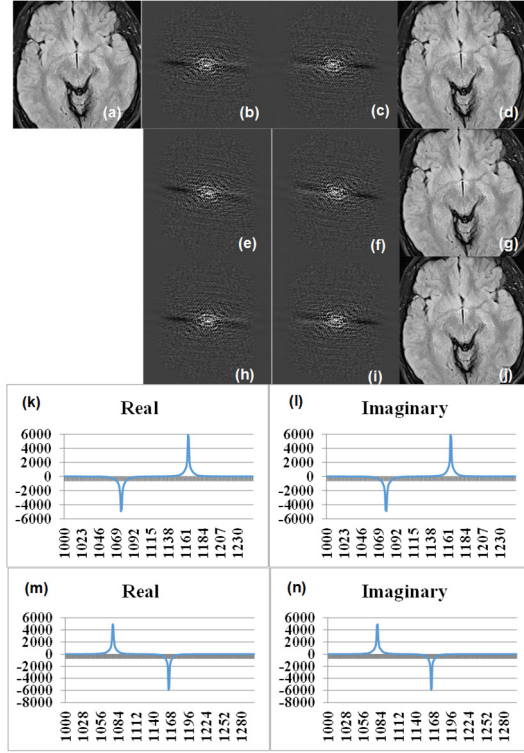
**Fig. 8.** MR image (a). Fourier k-space real component (b), Fourier k-space imaginary component (c), reconstructed signal through inverse Fourier transformation (d). Laplace L-space real component (e), Laplace L-space imaginary component (f), reconstructed signal through inverse Laplace transformation (g). Z-space real component (h), z-space imaginary component (i), reconstructed signal through inverse Z transformation (j). (k) Difference between the histogram of k-space real (b) and the histogram of L-space real (e). (l) Difference between the histogram of k-space imaginary (c) and the histogram of L-space imaginary (f). (m) Difference between the histogram of L-space real (b) and the histogram of z-space real (h). (n) Difference between the histogram of L-space imaginary (c) and the histogram of z-space imaginary (i).

### 3.4 Comparison of Fourier-shift and Z-shift transforms

Another well-known and fundamental property of Fourier theory is the effect of a phase shift in the frequency

domain. Such effect is visible as an image space shift after inverse transformation.

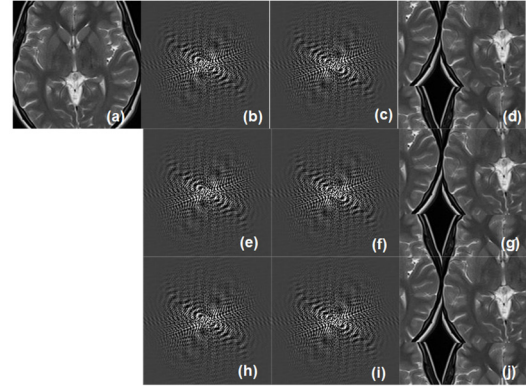
The verification of this property through implementation was adopted as test paradigm of the theoretical background presented in section: ‘2.7 Fourier-shift and z-shift’; and it is presented in Figure 10d, which shows the result of inverse Fourier transformation; and in (g), (j), which show the results of inverse Z transformation.



**Fig. 9.** MR image (a). Fourier k-space real component (b), Fourier k-space imaginary component (c), reconstructed signal through inverse Fourier transformation (d). Laplace L-space real component (e), Laplace L-space imaginary component (f), reconstructed signal through inverse Laplace transformation (g). Z-space real component (h), z-space imaginary component (i), reconstructed signal through inverse Z transformation (j). (k) Difference between the histograms of k-space real (b) and L-space real (e). (l) Difference between the histogram of k-space imaginary (c) and the histogram of L-space imaginary (f). (m) Difference between the histogram of L-space real (b) and the histogram of z-space real (h). (n) Difference between the histogram of L-space imaginary (c) and the histogram of z-space imaginary (i).

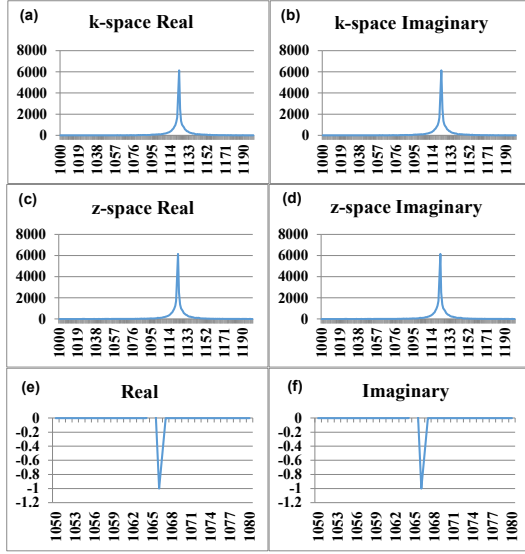
Figure 10 also shows that when  $r = 1$  for the z transform, Fourier-shift and z-shift yields to same frequency domain (see k-space in Figures 10b, 10c, and z-space in Figures 10e, 10f) and same reconstructed image (see Figures 10d, 10g). Figure 11 extends the analysis of Figure 10, presenting histograms of k-space images and z-space images seen in Figure 10. As visible in Figures 11a, 11b (histograms of k-space) and Figures 11c, 11d (histograms of z-space), the frequency domain is the same. Figures 12, and 13 shows the case of a T2 MRI processed with Fourier-shift and z-shift when  $r = 1$ . The frequency domain encodes the same image space shift for the two

transforms (various magnitude of the shift as quantifiable in pixels along the two Cartesian coordinates). K-space and z-space were the same (not shown) and so were the reconstructed MRIs (see Figures 12, and 13). As far as regards the comparison between the z-space when  $r = 1$  (Figures 10e, 10f) and when  $r \neq 1$  (Figures 10h, 10i;  $z = (Re + i Im) = 0.998178 + i 0.998178$ ); the histograms presented in Figures 11e, 11f reveal the difference.



**Fig. 10.** MR image in (a). Fourier k-space real component (b), Fourier k-space imaginary component (c), reconstructed signal through inverse Fourier transformation (d). In (b), (c) the k-space encodes an image space shift of 60 pixels in the x direction and 60 pixels in the y direction. In (d) the shift is reconstructed in the image space. Z-space real component (e), z-space imaginary component (f), reconstructed signal through inverse Z transformation (g). In (e), (f), (h), (i) the z-space encodes an image space shift of 60 pixels in the x direction and 60 pixels in the y direction. In (g), (j) the shift is reconstructed in the image space. In (e), (f) the complex variable is  $z = r e^{j\omega}$  (with  $r = 1$ ). In (h), (i) the complex variable is  $z = (Re + i Im) = 0.5 + i 0.5$ .

In summary, Figures 10, 11, 12, 13, present three main results: 1. The effect of a phase shift in the frequency domain is an image space shift visible through Fourier and Z inverse transformations (Figures 10d, 10g, 10j, 12, and 13). 2. When  $r = 1$ , and when the frequency domain encodes the same image space shift, z-space and k-space are the same (see Figures 11a, 11b, 11c, 11d). 3. The evidence that when  $r = 1$  and  $r \neq 1$ , the z-space encoding the same image space shift (60 pixels along x and y directions) is not the same (see histograms in Figures 11e, 11f).



**Fig. 11.** (a), (b) Histograms of the real and imaginary components of k-space presented in Figures 10b, 10c, respectively. (c), (d) Histograms of the real and imaginary components of z-space presented in Figures 10e, 10f, respectively. The complex variable is  $z = r e^{j\omega}$  (with  $r = 1$ ). Hence, k-space and z-space are the same as visible in Figures 10b, 10c, 10e, 10f, and in the histograms. (e) Difference between the histogram of z-space real when  $r = 1$  (see Figure 10e) and the histogram of z-space real when  $z = (Re + i Im) = 0.5 + i 0.5$  (see Figure 10h). (f) Difference between the histogram of z-space imaginary when  $r = 1$  (see Figure 10f) and the histogram of z-space imaginary when  $z = (Re + i Im) = 0.5 + i 0.5$  (see Figure 10i).

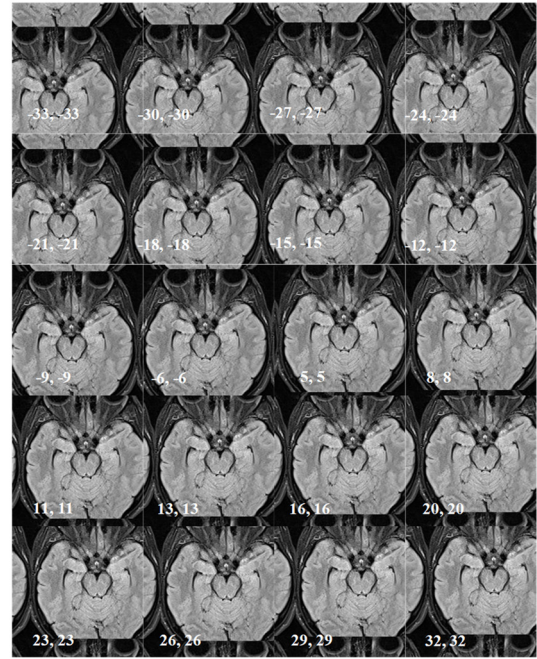
Figures 12 and 13 show the effect of the Fourier and Z shifts (with  $r = 1$ ) on a T2 MRI. The magnitude of the shift (measured in pixels) changes at each experimental session and takes the following values:  $(-33, -33)$ ,  $(-30, -30)$ ,  $(-27, -27)$ ,  $(-24, -24)$ ,  $(-21, -21)$ ,  $(-18, -18)$ ,  $(-15, -15)$ ,  $(-12, -12)$ ,  $(-9, -9)$ ,  $(-6, -6)$ ,  $(5, 5)$ ,  $(8, 8)$ ,  $(11, 11)$ ,  $(13, 13)$ ,  $(16, 16)$ ,  $(20, 20)$ ,  $(23, 23)$ ,  $(26, 26)$ ,  $(29, 29)$ ,  $(32, 32)$ . Through exact inverse image reconstruction, Figures 12, and 13, reinforce on congruency of transforms, and coherence between transforms.

## 4. Discussion

### 4.1 Recent trends in Fourier theory & validation procedure

In recent years computation of fractional Fourier transform (FRFT) has been under the attention of the scientific community and FRFT was demonstrated to be an extension of the classic Fourier transform [26] through a parametrization that makes the FRFT a framework encompassing FT and inverse FT too. A review of existing methods lists a survey of FRFT applications and provides a listing of existing software for FRFT calculation [27]. Cornelius Lanczos did pioneer work on the Fast Fourier transform (FFT), while the pioneer paper was published by Cooley & Tukey in 1965 [1], and the most comprehensive FFT implementation is currently recognized to be the one reported by Frigo & Johnson [28].

However, with the advent of big data disciplines, sparse Fourier transform (SFT) has become a recent trend. SFT allows the calculation of the Fourier transform in a short time using a subset of data, hence focusing on the non-zero frequencies [29]. Recent applications of Fourier theory include: 1. Approximation of Gaussian filters through the Fourier transform [30]; 2. Fourier burst accumulation, which removes image blurring by weighted average in the Fourier domain when the blur is time-invariant [31, 32]. 3. Non-linear Fourier transform which decomposes a periodic signal into nonlinearly interacting waves [33] and finds applications in fiber optics processing and transmission [34]. 4. Non-uniform sampling methods in Nuclear Magnetic Resonance imaging [35], or fast Fourier transform (FFT) methods based on non-equally spaced nodes located on polar and pseudo-polar grids [36]. 5. Calculation of probability cumulative distribution functions through inverse Laplace transforms [37-39]. 6. Wiener-Hopf factorization of a complex function using Hilbert and Z-transforms [40-42]. 7. Improved convergence of Fourier, Hilbert, and Z-transforms [41]. 8. Inverse Fourier transform-based MRI k-space filtering techniques using the intensity-curvature functional [43].



**Fig. 12.** Reconstructed MRIs with inverse Fourier transform. For each of the cases presented in this figure, the frequency domain encodes a phase shift, which is reconstructed as image space shift. The shifts are measured in pixels (see white labels) along x and y directions.

The present research provides both theoretical and applied aspects along with the most significant effort which is the validation procedure. Validation of the code was performed using two approaches. The first approach looks at the intersections between: 1. Fourier and Laplace transforms; 2. Fourier and Z transforms. When the value of the complex variable of Laplace transform is  $s = \sigma + i\omega$  with  $s = i\omega$  and  $\sigma = 0$ ; the Laplace transform is the

Fourier transform. When the value of the complex variable of Z transform is  $z = r e^{j\omega}$  with  $r = 1$ ; the Z transform is the Fourier transform too. It follows that for  $\sigma = 0$  and  $r = 1$  k-space, L-space and z-space are the same. This was documented in Figure 7 and extensively observed across the whole dataset of 30 images. The second approach uses the inverse transform to validate the direct transform. The latter was used to validate separately Fourier, Laplace, and Z transforms. Implicitly, this approach yields: 1. to confirm that direct and inverse transforms are correct; and 2. to investigate the difference between k-space, L-space, and z-space when  $\sigma \neq 0$  and  $r \neq 1$ . This second result is documented in Figures 8, 9 and it was confirmed across the test set of 30 images.



**Fig. 13.** Reconstructed MRIs with inverse Z transform. The frequency domain encodes the same phase shifts as per Figure 12. The phase shifts are reconstructed as image space shifts exactly as per Fourier shifts because the magnitude of the complex number in the Z-transform is  $r = 1$ .

## 5. Conclusion

This research reports three main results obtained studying direct and inverse Fourier, Laplace, and Z transformations: 1. theory, 2. implementation, and 3. testing. The theoretical background is reported as a study guide. Software implementation was accomplished in C++. Testing was performed with two-dimensional images by seeking for coherence and congruency among the three transforms. Coherence between the software implementation of the three transformations is investigated when: 1. the real component  $\sigma$  of the complex variable ( $s = \sigma + i\omega$ ) is equal to zero, which is the case when Fourier and Laplace transforms are the same; and 2. When the magnitude  $r$  of the complex variable ( $z = r e^{j\omega}$ ) is equal to one, which is the case when Fourier and Z transforms are the same. Congruency between software implementation of transformations is assessed comparing departing image and inverse reconstructed image.

Hence, the contribution of this research is within the following three areas.

1. The theoretical background presentation style. Presentation of the concepts is given to simplify the notation, include details, and make possible software implementation of Fourier, Laplace, and Z direct and inverse transforms.

2. Validation paradigm used: (a) to test the coherence of Fourier transforms with Laplace and Z transforms; (b) to compare the frequency domain of Fourier, Laplace, and Z transforms; (c) to compare frequency shifts (which effect is to create image space shifts) between Fourier and Z transforms.

The novelty of this paper consists of details of theory that are not discernible reading the literature. Hence, the focus of the paper is to provide well-tested mathematical guidelines for the implementation of direct and inverse Fourier, Laplace, and Z transformations. Literature on these three transforms is huge, nonetheless, mathematical details are not clearly stated, because of the presentation of advanced concepts, which take basic concepts for granted.

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## Appendix

### 1. Direct process

$$e^{-2\pi i \varphi z} = \cos(-2\pi \varphi z) + i \sin(-2\pi \varphi z) =$$

$$\cos(2\pi \varphi z) - i \sin(2\pi \varphi z) \quad (1)$$

$$f(z) = [\operatorname{Re}(z) + i \operatorname{Im}(z)] \quad (2)$$

$$[\operatorname{Re}(z) + i \operatorname{Im}(z)] \cdot [\cos(2\pi \varphi z) - i \sin(2\pi \varphi z)] =$$

$$\operatorname{Re}(z) \cdot \cos(2\pi \varphi z) - i (\operatorname{Re}(z) \cdot \sin(2\pi \varphi z)) +$$

$$i (\operatorname{Im}(z) \cdot \cos(2\pi \varphi z)) + (\operatorname{Im}(z) \cdot \sin(2\pi \varphi z)) =$$

$$(\operatorname{Re}(z) \cdot \cos(2\pi \varphi z)) + (\operatorname{Im}(z) \cdot \sin(2\pi \varphi z)) +$$

$$i [(-\operatorname{Re}(z) \cdot \sin(2\pi \varphi z)) + (\operatorname{Im}(z) \cdot \cos(2\pi \varphi z))] =$$

$$f(z) \cdot e^{-2\pi i \varphi z} \quad (3)$$

### 2. Inverse process

$$e^{2\pi i \varphi z} = \cos(2\pi \varphi z) + i \sin(2\pi \varphi z) =$$

$$\cos(2\pi \varphi z) + i \sin(2\pi \varphi z) \quad (4)$$

$$f(\varphi) = [(F_k, \operatorname{Re}) + i (F_k, \operatorname{Im})]; k = 1, 2 \dots (N_x \cdot N_y) \quad (5)$$

$$f(\varphi) \cdot e^{2\pi i \varphi z} =$$

$$[(F_k, \operatorname{Re}) + i (F_k, \operatorname{Im})] \cdot [\cos(2\pi \varphi z) + i \sin(2\pi \varphi z)] =$$

$$(F_k, \operatorname{Re}) \cdot \cos(2\pi \varphi z) + i (F_k, \operatorname{Re}) \cdot \sin(2\pi \varphi z) +$$

$$i (F_k, \operatorname{Im}) \cdot \cos(2\pi \varphi z) - (F_k, \operatorname{Im}) \cdot \sin(2\pi \varphi z) =$$

$$(F_k, \operatorname{Re}) \cdot \cos(2\pi \varphi z) - (F_k, \operatorname{Im}) \cdot \sin(2\pi \varphi z) +$$

$$i [(F_k, \operatorname{Re}) \cdot \sin(2\pi \varphi z) + (F_k, \operatorname{Im}) \cdot \cos(2\pi \varphi z)] \quad (6)$$

# Machine Building and Mechatronics Field in The Industry 4 for 5 Regions in Europe

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**Abstract:** The article presents the needs for professional training of technicians and engineers in mechanical engineering and mechatronics was conducted in two areas of Bulgaria - Gabrovo and Plovdiv, Kavala, Greece, Pomorskie Region, Poland and Nis region, Serbia. These regions are very different, both in area and population and the most developed sectors of the economy. The survey was realized under an Erasmus+ KA2 programme which duration from 1.09.2020 up to 31.08.2022 with title Active Learning Community for Upskilling Technicians and Engineers. This works presents the basic data about the training proposals both for engineers and technicians. Last but not least illustrates the preferences of companies about the most suitable training method.

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## 1. Introduction

The article presents the basic results for the project Active Learning Community for Upskilling Technicians and Engineers (allCUTE) which funded within the ERASMUS+ Programme, KA2. It is established on a survey carried out among 161 companies in the sector of Machine Building and Mechatronics in order to recognize the requirements of technical and vocational education and training both for technicians and engineers. The survey realized at the same time at 5 different partner regions:

- Gabrovo region, Bulgaria;
- Plovdiv region, Bulgaria;
- Kavala, Greece;
- Pomorskie Region, Poland;
- Nis region, Serbia.

This survey is established according to the demands of Industry 4.0 imposed on today's technicians and engineers. Industry 4.0 includes four different modules i) Internet of Things, ii) Big Data and Analytics, iii) Engineering Simulation and iv) Additive Manufacturing. All these concepts have an important effect on machine building and mechatronics because have as a result to impose a whole redesign of processes and operations to fulfill those new developments. With intention to fit in the new data companies are aware that they are essential to invest in the training of their employees and always improve their competence and skills until to achieve their goals and meet the new demands of both manufacturing and customers.

The aims of this work are fivefold:

- to show the existing situation of the five aforementioned regions relevant with TVET provision to technicians and engineers employed in the area of Machine Building and Mechatronics;
- to detect the training needs of the companies in the relevant sector and improve the competence and performance of their technical and engineering staff;
- to recognize the teaching methodology preferred by the employers;
- to associate survey findings among partner regions;
- to give recommendations for the elaboration of the follow-up curriculum.

## 2. State in Partner Regions

### 2.1. Gabrovo region (Bulgaria)

The economy in the Region of Gabrovo is predominantly driven by the industrial sector. In 2018 the worth of the produced goods was nearly 1.25 billion € with over 1.6 billion € of which - produced by the production industry. The processing industry has a main share in the total economy of the region and constitutes about 60% of the total production, twice the average at a country level. Manufacturing of machinery, equipment and fabricated metal products has a leading role in the processing industry with the highest added value per employed person. Almost half of the income generated by the industry in the region comes from the above mentioned manufacturing. The Region of Gabrovo is also the central hub for the production of tools for the machine building industry with more than 20 companies operating



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in this field. Economic center "Gabrovo-Sevlievo" having a strong industrial profile comprises the municipalities of Gabrovo and Sevlievo. It is rated among the 20 most important economic centers in Bulgaria. The industry of the region is predominantly export-oriented with more than 50% of all goods produced being exported. For the machine building industry products the export rate is even higher – about 66% [1].

### **2.2. Plovdiv region (Bulgaria)**

Plovdiv is the biggest industrial centre in Bulgaria. The total production is about € 8.75 billion in 2018, and that in industry is nearly B€GN 4.75 billion. The structure of the local economy is strongly dominated by manufacturing, which, according to NSI data, occupies 39.9% of it, which is 12% more than the second largest sector. Regarding to the produced production the share of the production is 55% while in relation to the incomes from the activity it is 36.3 %.

In the Plovdiv area is found Trakia Economic Zone (TEZ) - the major and most sustainable industrial zone not only in Bulgaria but also in Southeast Europe. It unites 6 industrial zones in the region of Plovdiv - "Maritsa", "Rakovski", "Kuklen", "Plovdiv", High-tech park "Innovations" and Agro park "Kaloyanovo". The area is over 10,700,000 square meters, half of which is already occupied. In the last twenty four years more than 3 billion euros have been invested in it. TEZ employs over 180 companies, half of which are foreign and is one of the most significant companies in Bulgaria - KCM 2000 AD [2].

### **2.3. Kavala region (Greece)**

The area of Kavala spreads in an area of approximately 2,111 km<sup>2</sup>, at the north part of Greece. Most of its people live in the city of Kavala (54,000) and has population of about 133,000. The region has an economy based heavily on the service sector (77%) while the secondary (12,5%) and primary (10,5%) contribute less to the local GDP. Tourism, agriculture, fishing and quarrying alongside an important public sector are the main activities of the residents. The area of Kavala affects the role of the gateway to the trans-European axes for the Aegean Sea and the center of international trade routes for the Balkans. It has also been accepted as an interregional-gateway with an international role through its airport, the Egnatia Motorway and the vertical axis from Bulgaria via the Exohi border station and its harbours [3].

### **2.4. Pomorskie region (Poland)**

Pomeranian region is one of the most dynamically developing regions in Poland. Many companies in this area playing significant part in the national economy. Pomeranian Voivodship is one of sixteen administrative regions of Poland. It is located in the northern part of the country, at the coast of the Baltic Sea. Based on the data of 2019, there were 26,574 commercial companies in the region, including 3,335 with foreign capital participation. Foreign firms make up 12.5% of all companies in the region [4-5]. The traditional industries of the area are related with the sea and include the petrochemical,

shipbuilding, electromechanical, construction, wood and furniture, tourism and food industries. While the food industry traditionally belongs to the leading sectors in the region's economy, it is of marginal importance. The agriculture, forestry, fishing and hunting sector supplied only 2,5% of the regional gross value added in 2017 [4]. Consequently, the priority sectors from the point of view of investment potential are electronics, logistics, maritime, modern business services, ICT, biotechnology and light chemistry, and food processing [6].

### **2.5. Niš region (Serbia)**

Based on the estimation of the Republic Bureau of Statistics in mid-2018, the number of inhabitants in the Regional Chamber of Commerce of Nisava, Pirot and Toplica administrative districts was 531,410, of which 48.25% live in the City of Nis, 10.23% in the City of Pirot. 8.95% in the municipality of Aleksinac, and 7.94% in the City of Prokuplje. Estimates were made on the basis of the 2011 Census of Population, Households and Dwellings and data on natural and mechanical population movements. In the structure of GDP of the RCC Nis, the most represented - services are 46.5%, which is below the national average, industry 40.3%, which is above the national average and agriculture, which participates with 8.1%, which is at the level republican average. Construction participates with 5.1%, which is slightly above the national average.

In the Sector of industry within CCIS RCC Nis consists of six associations: Association for metal and electrical industry, Association for construction industry, Association for chemical, rubber and non-metal industry, Association for textile, clothing, leather and footwear industry, Association for energy and mining and Association for pharmacy and medical activity, with 147 different business codes and 1,129 companies, which is 4.93% more than in the previous period (1,076). Operating income of all companies in the Industry Sector, according to the latest data for 2018, was 199,116,115,000 dinars, or 10.87% more than in the previous year (179,601,492,000 dinars). The foreign trade of the economy of CCIS RCC Nis reached ~ 2.7 billion EUR in 2019, with exports amounting to 1.591 billion EUR and imports of 1.116 billion EUR. The realized trade surplus at the level of RCC Nis amounted to 475 million EUR [7].

## **3. Results and discussion**

In order to identify the needs of additional qualification of technicians and engineers in the mechanical engineering and mechatronics sectors, a questionnaire with several sections was developed: size of the company, need for qualification of technicians, need for qualification of engineers, as well as those related to the training methodology. Based on the preliminary study, a set of topics for professional training of technicians and engineers was suggested. They cover sections of rapid development of technologies during the recent years, which suppose greater need for trained personnel.

For technicians:

- Pneumatics and electro-pneumatics

- Energy efficiency in pneumatic systems,
- Optimal use of compress air
- Vacuum and vacuum technology
- Hydraulic
- Electricity
- Electrical drives
- Automated manufacturing system
- CNC machines.

For engineers:

- Basic schemes in automated pneumatic systems, design of pneumatic and electrical pneumatic systems, diagnostics, maintenance, optimization
- Hydraulics, proportional hydraulics – design, diagnostics, maintenance
- Vacuum engineering and technology, vacuum systems, various capture methods in vacuum engineering
- Electrical engines
- Complex electrical drives
- Automated manufacturing systems - diagnostics, maintenance, troubleshooting
- Energy efficiency in pneumatic systems – measurement, maintenance, optimization.

The topics were discussed and supplemented by each partner; in addition each respondent had the capability to suggest other training topics.

The companies could select between 2 types of training:

- Active blended learning – the students get familiar with the learning material by using presentations online or through their smart phones, then they discuss the topics with the teacher in the classroom so as to clarify difficult issues and solve problems, after that they do their lab work;
- Traditional – the teacher delivers the learning material in the classroom and then the students do their lab work.

All questions allowed more than one answer (except for the methodology), which is why the total percentage of the answers is over 100%. Each partner selected the companies in their region to which the questionnaire was sent.

In relation with the survey of the needs for vocational training, contacts have been made with 1002 companies from the five areas in the field of mechanical engineering and mechatronics. 161 companies or 16.07% of all companies answered. The relatively low response rate can be easily explained owing to the survey period - November and December 2020 - the strongest second wave of the COVID-19 in Europe and worldwide. Table 2 shows the statistics about the size and the number of each company regarding to the five regions while figure 1 illustrates the total data according to the type of companies according to number of employees.

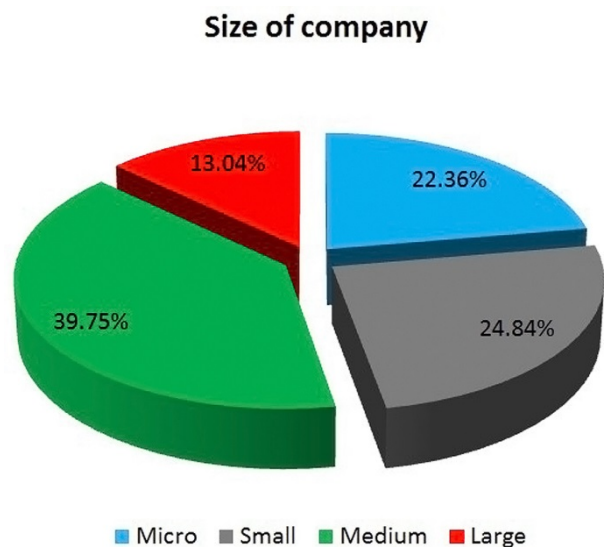
The highest percentage of respondents is among medium-sized enterprises - 64 (39.75%). This is broadly consistent with the structure of enterprises in this sector. The small enterprises follow - 40 (24.84%) and micro enterprises - 36 (22.36%). The percentage of large enterprises is 13.04% (21 companies) with the largest

number of technicians and engineers is also significant. Their percentage is much higher than their share of the total number of enterprises.

Regarding to the large enterprises the biggest numbers that have responded are from Plovdiv (Bulgaria) region because there a number of large enterprises from this sector in the Thrace Economic Zone, followed by Gabrovo (Bulgaria). Another interesting information is the fact that no large companies from Greece replied, this owing to the characteristic of the Kavala region which characterized by micro and small enterprises.

**Table 1.** The size of the participated companies

| Size of company | Region  |         |        |     |           |
|-----------------|---------|---------|--------|-----|-----------|
|                 | Gabrovo | Plovdiv | Kavala | Nis | Pomorskie |
| Micro           | 5       | -       | 8      | 14  | 9         |
| Small           | 8       | 5       | 7      | 8   | 12        |
| Medium          | 11      | 15      | 16     | 7   | 15        |
| Large           | 6       | 10      | -      | 1   | 4         |
| Total           | 30      | 30      | 31     | 30  | 40        |



**Fig. 1.** Category of companies along with number of employees

### 3.1. Training needs of technicians

When studying the needs of technicians in different regions, we have obtained different results. The most wished training in Gabrovo Region is "Operating CNC machines" (22 companies), which has been selected by all types of companies. For Plovdiv Region the most desired trainings for technicians are "Electricity" (20 companies) and "Operating automated production system" (20 companies). For Kavala Region the most preferred training is the "Pneumatics and electro-pneumatics" with 48% of the companies have selected this training. The most chosen training for technicians in Pomeranian region is "Operating automated production system" (19 companies) and in Nis Region "Operating CNC machines" and 40% of companies expressed their interests in this type of training.

The summarized statistics shows that there is no training option, which has not been selected at least by one company.

The top three most preferred trainings for all regions are:

- Operating CNC machines, selected by 62 companies;
- Operating automated production systems, selected by 58 companies;
- Pneumatics and electro-pneumatics selected by 57 companies.

According to the size of companies, their preferences are distributed as follows:

- Micro enterprises: Operating CNC machines is the most chosen in 3 of the 5 regions namely Gabrovo, Pomeranian Region and Nis. In Greece the most preferred is Pneumatics and electro-pneumatics.
- Small companies: Pneumatics and electro-pneumatics in Kavala and Nisa, Operating CNC machine“ in Gabrovo, Electricity and Hydraulics“ in Plovdiv; Operating automated production systems in Gdansk.
- Medium-sized companies: Pneumatics and electro-pneumatics is the most preferred training in two regions Nis and Plovdiv; Operating automated production systems in 2 areas, Gdansk and Kavala; Electrical engines, complex Electrical drives - in Gabrovo; Operating CNC machines in Nis, Electricity in Plovdiv
- Large companies: Operating CNC machines in Gabrovo, Gdansk and Nis region, Operating automated production systems in Plovdiv.

### 3.2. Training needs of engineers

Similar are the result and for the needs of engineers in the five regions. The most preferred training for engineers:

- in Gabrovo area is Programming and maintenance of CNC machines; 25 of the companies selected this training ;
- in Plovdiv area is Automated manufacturing systems; 23 of the companies selecting this training;
- in Kavala region is Automated manufacturing systems with 52% of the companies choosing this training;
- in Gdansk is Automated manufacturing systems - diagnostics, maintenance, troubleshooting.
- in Nis are Hydraulics, proportional Hydraulics and Automated manufacturing systems with 23%.

The summarized information shows that there is no training option, which has not been chosen at least by one company.

The top three most preferred trainings for all regions are:

- Automated manufacturing systems by 64 companies;
- Basic schemes in automated pneumatic systems, design of pneumatic and electrical pneumatic systems, diagnostics, maintenance, optimization by 47 companies;
- Hydraulics, proportional Hydraulics by 42 companies.

The least chosen training is: Vacuum engineering and technology, vacuum systems, various capture methods in vacuum engineering by 20 companies.

Consistent with the type of companies, their preferences are spread as follows:

- Micro enterprises: Automated manufacturing systems – diagnostics, maintenance, troubleshooting - in Kavala and Gdansk. Programming and maintenance of CNC machines in Gabrovo. Energy efficiency in pneumatic systems with 25% in Kavala, Hydraulics“, proportional Hydraulics in Nis with 21%.
- Small companies: Automated manufacturing systems – diagnostics, maintenance, troubleshooting with 80 % in Plovdiv and in Nis and Gdansk with lower percentage. Programming and maintenance of CNC machines with the impressive 88.88% in Gabrovo; Hydraulics, proportional Hydraulics“ with 80% in Plovdiv. Basic schemes in automated pneumatic systems in Kavala with 71%
- Middle-sized companies: Automated manufacturing systems – diagnostics, maintenance, troubleshooting – in Kavala region with 81% and also in Plovdiv and Gdansk with a little lower percentage, Programming and maintenance of CNC machines with 81.81% in Gabrovo, Basic schemes in automated pneumatic systems selected by 67% from companies in Plovdiv, Hydraulics, proportional Hydraulics which is chosen by 43% of companies in Nis.
- Large companies: Automated manufacturing systems – diagnostics, maintenance, troubleshooting was chosen from every large companies in Nis, by 83.83% companies in Gabrovo and by 90% companies in Plovdiv. Programming and maintenance of CNC machines is selected by 83.83% in Gabrovo. Basic schemes in automated pneumatic systems with 90% in Plovdiv and Gdansk regions.

Based on the preliminary study, a certain set of topics for professional training of technicians and engineers was proposed. They cover areas of rapid development of technologies during the recent years, which suppose greater need for trained personnel.

### 3.3. Training methodology

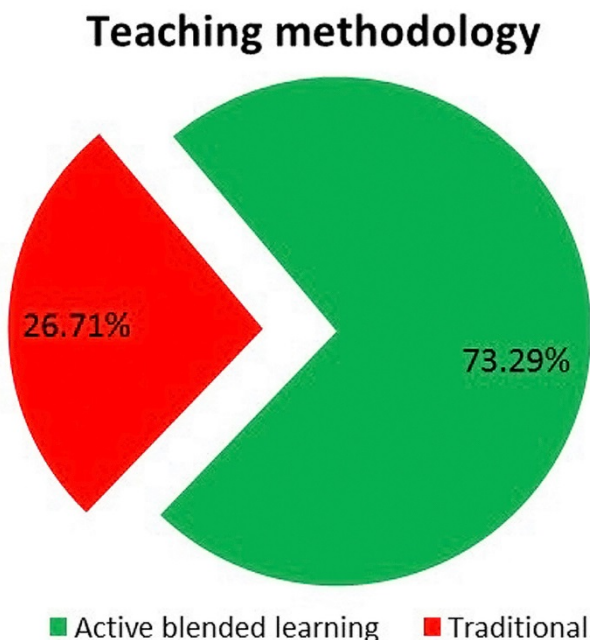
The companies had the option to select between 2 training methods:

- Active blended learning where the learners get familiar with the learning content by using presentations online or through their smart phones, then they discuss the topics with the teacher in the classroom so as to clarify difficult issues and solve problems, after that they do their lab work;
- Traditional which means the teacher delivers the learning content in the classroom and then the learners do their lab work.

In all regions, all types of companies have predominantly supported Active blended learning, with percentages ranging between 65% (in Kavala) and 83% in Gabrovo and Nis (Table 2). Support among all types of companies is between 57% and 100%, with the lowest percentage among small companies (57%) in Kavala area. Figure 2 shows the total results and according these more than 73% from companies prefers the active blended learning.

**Table 2.** The preferred teaching method for each of the investigated region.

| Type                    | Region  |         |        |     |           |
|-------------------------|---------|---------|--------|-----|-----------|
|                         | Gabrovo | Plovdiv | Kavala | Nis | Pomorskie |
| Active blended learning | 25      | 24      | 20     | 25  | 24        |
| Traditional             | 5       | 6       | 11     | 5   | 16        |



**Fig. 2.** The collective results about the training method.

#### 4. Conclusions and future work

The survey reveals that there are many differences between each of the five investigated regions. There is a dissimilar degree of industry development and more specifically of mechanical engineering and mechatronics in the different regions. The least developed in this respect is Kavala (Greece), while these industries occupy the highest portion of economy in the areas of Gabrovo and Plovdiv (Bulgaria). There are also well-developed production sectors both in the Pomeranian and Nis areas. Nevertheless of those differences, the partnership region covered has the potential to boost the sector of Machine Building and Mechatronics. Furthermore, there are universities that train students for mechanical engineering and mechatronics industries in all surveyed regions.

According to our estimations, it can be said that there is an adequate number of potential users of the project outputs in all regions. It is estimated that the total number of engineers and technicians is about 52,000. The training suggestions for engineers and technicians have been chosen by different number of companies in the survey in the different areas, which is directly dependent on the production of the companies that participated in the survey. To the basis of the survey findings, the following courses are highly recommended to be developed:

Courses for technicians:

- Operating automated production system
- Pneumatics and electro-pneumatics
- Electrical Drives
- Operating CNC Machines
- Hydraulics
- Electricity

Courses for engineers:

- Automated manufacturing systems
- Basic schemes in automated pneumatic systems
- Hydraulics, proportional hydraulics
- Electrical engines, complex electrical drives
- Energy efficiency in pneumatic systems

The most preferred teaching methodology is active blended learning. Therefore, the courses should be based on active learning techniques. The analysis of the training needs of the employed technicians and engineers in the area of Machine Building and Mechatronics shows that there is a demand of upskilling those target groups and there are enough potential users of such training. Hence, the courses to be developed will be useful for the companies in the above industrial sector. Companies are alert that they should invest in the training of those employees so as to uninterruptedly enhance their competences with the purpose of achieve excellence and meet the new demands of both manufacturing and customers in the era of Industry 4.0.

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