

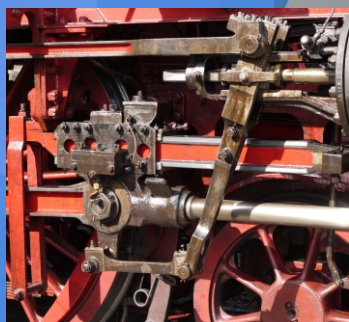
INTERNATIONAL SCIENTIFIC JOURNAL

INDUSTRY 4.0

ISSN (PRINT) 2534-8582

ISSN (WEB) 2534-997X

YEAR IX ISSUE 4/2024



①



②



③



④

PUBLISHED BY
SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING
“INDUSTRY 4.0”, BULGARIA

INTERNATIONAL SCIENTIFIC JOURNAL

INDUSTRY 4.0

YEAR IX, ISSUE 4 / 2024
ISSN (PRINT) 2534-8582, ISSN (WEB) 2534-997X

PUBLISHER
**SCIENTIFIC TECHNICAL UNION OF MECHANICAL
ENGINEERING “INDUSTRY 4.0”**

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90,
tel./fax (+359 2) 986 22 40,
office@stumejournals.com
WWW.STUMEJOURNALS.COM

EDITOR IN CHIEF
Prof. D.Sc. Georgi Popov, DHC, Technical University of Sofia, BG

All articles are published after peer review by two independent reviewers.

EDITORIAL BOARD

Members:

Acad. Igor Bychkov, RU
Cor. member Alexey Belyi, BY
Cor. member Svetozar Margenov, BG
Prof. Alexander Afanasyev, RU
Prof. Alexander Guts, RU
Prof. Andrzej Golabczak, PL
Prof. Bobek Shuklev, MK
Prof. Boris Gordon, EE
Prof. Branko Sirok, SI
Prof. Claudio Melchiorri, IT
Prof. Cveta Martinovska, MK
Prof. Dale Dzemydiene, LT
Prof. Dimitar Yonchev, BG
Prof. Dimitrios Vlachos, GR
Prof. Dobre Runchev, NM
Prof. Dragan Perakovic, HR
Prof. Galina Nikolcheva, BG
Prof. Galina Zhavoronkova, UA
Prof. Gerard Lyons, IE
Dr. Giovanni Pappalettera, IT
Prof. Henrik Carlsen, DK
Prof. Idilia Bachkova, BG
Prof. Idit Avrahami, IL
Prof. Inocentiu Maniu, RO
Prof. Iurii Bazhal, UA
Prof. Jürgen Köbler, DE
Prof. Jiri Maryska, CZ
Prof. Katia Vutova, BG
Prof. Lappalainen Kauko, FI
Dr. Liviu Jalba, RO

Prof. Luigi del Re, AT
Prof. Majid Zamani, DE
Dipl.-Kfm. Michael Grethler, DE
Prof. Michael Valasek, CZ
Prof. Milija Suknovic, RS
Prof. Miodrag Dashic, RS
Prof. Mohammed Taleb Obaidat, JO
Prof. Murat Alanyali, TR
Prof. Nadežda Jankelová, SK
Prof. Nafisa Yusupova, RU
Prof. Nina Bijedic, BA
Prof. Ninoslav Marina, MK
Prof. Olga Zaborovskaia, RU
Prof. Pavel Kovach, RS
Prof. Petar Kolev, BG
Prof. Peter Korondi, HU
Prof. Peter Sincak, SK
Prof. Petra Bittrich, DE
Prof. Predrag Dasic, RS
Prof. Radu Dogaru, RO
Prof. Raul Turmanidze, GE
Prof. René Beigang, DE
Prof. Rozeta Miho, AL
Prof. Salloom A. Al-Jaboori, JO
Prof. Seniye Ümit Oktay Firat, TR
Prof. Sreten Savicevic, ME
Prof. Sveto Svetkovski, MK
Prof. Tomislav Šarić, HR
Prof. Vasile Cartofeanu, MD
Prof. Vjaceslavs Bobrovs, LV
Prof. Vladyslav Alieksieiev, UA

TECHNICAL EDITORS:

M. Sc. eng. Radoslav Daskalov, Bulgaria
M. Sc. eng. Oleg Mihailov, Bulgaria

CONTENTS

TECHNOLOGICAL BASIS OF “INDUSTRY 4.0”

Fabrication and application of internet of things device using sigfox network and at commands

Masaya Watanabe, Hideaki Kanazawa, Satoru Tada, Masayuki Yamauchi, Koji Kakugawa,
Takeshi Tanaka, Katia Vutova 118

Application of convolutional networks to detect the operating phases of energy systems using a biomass boiler as an example

Szymon Podlasek, Piotr Książek..... 122

Deep Eye - Intelligent Device for Creating Digital Models of Underwater Topography

Zuzanna Schab, Marta Żelasko, Krzysztof Lalik, Krzysztof Mamcarz 126

Unified Framework for PdM Algorithm Development: The pdm-tools Architecture

Paweł Knap, Urszula Jachymczyk 130

DOMINANT TECHNOLOGIES IN “INDUSTRY 4.0”

Statistical processing of data from the operation of a photovoltaic power plant

Svilen Rachev, Raul Turmanidze, Vazha Shilakadze 134

Use of precise implantological surgical guides in reconstructions adjacent to teeth with unusual anatomy - use of Dentistry 4.0 technology

Lech B. Dobrzański 138

BUSINESS & “INDUSTRY 4.0”

Performance of digital content distribution channels

Simona Balašćáková 143

Waste logistics in the aspect of a closed loop economy

Maciej Kuboń, Dariusz Kwasniewski, Urszula Malaga-Tobola, Pavol Findura, Miroslav Pristavka, Olivia Kłosowska 145

SOCIETY & “INDUSTRY 4.0”

Energy efficiency measures to reduce the carbon footprint: A case study of Tirana airport.

Artan Hoxha, Ardit Gjeta, Majlinda Alcani, Elona Caushi, Albert Shira 149

Fabrication and application of internet of things device using sigfox network and at commands

Masaya Watanabe¹, Hideaki Kanazawa², Satoru Tada³, Masayuki Yamauchi³, Koji Kakugawa³,
Takeshi Tanaka^{3,*}, and Katia Vutova⁴
HatanoElectric Co Ltd., Hiroshima, Japan¹
Kanazawa Transportation Co., Ltd., Tokyo, Japan²
Hiroshima Institute of Technology, Hiroshima, Japan³
Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria⁴
tanaka@cc.it-hiroshima.ac.jp

Abstract: In this study, the Sigfox network and the Internet were employed to develop an Internet of Things device equipped with temperature, humidity, barometric pressure, and other sensors to measure different physical data. In addition, we attempted to control Sigfox communication by employing AT commands using the Arduino UNOR4 Sigfox module, and social implementation of the proposed system.
Keywords: SIGFOX, ARDUINO, WIFI, MAC ADDRESS

1. Introduction

Knowledge and information have not yet been exchanged in the information society (Society 4.0), which has resulted in issues due to a lack of interdisciplinary cooperation. Society 5.0 is expected to connect all people and things through the Internet of Things (IoT), which will enable the sharing of various types of knowledge and information.

Against From this perspective, using the Sigfox network and the Internet, we have developed an IoT device equipped with temperature, humidity, barometric pressure, and other sensors to measure different physical data [1–5].

In the current study, we attempted to control Sigfox communication using AT commands using the Arduino UNOR4 Sigfox module. In addition, we attempted social implementation using the proposed system.

2. Experimental

2-1 Sigfox module

A Sigfox breakout board (SBB) was used as the Sigfox module (Fig. 1).



Fig. 1 SBB 【BRKLSM100A】 [6]

Key Features - Compact module 14 × 15 × 2.8 mm. (Typ.) - LoRa™ modulation technology. - Sigfox modulation technology. - Sensitivity down to -136dBm@LoRa (BW = 125 KHz, SF = 12) -124dBm@Sigfox (0.6 Kbps) - UART interface. - Low-Power Long Range Transceiver operating in the sub-1 GHz ISM band - Supply voltage range from 1.8 to 3.6 V. - RF interface optimized to 50 Ω. - Output Power Level up to +15 dBm - STM32WLE5CC

A program must be written to run the Sigfox module (Fig. 1) on a microcontroller, and a library for the microcontroller is generally required. To reduce the program's dependence on the

microcontroller, we created the program using AT commands. In the future, we would like to work on creating a microcontroller and dedicated CPU that can run AT commands.

2-2 Arduino UNO R4 Wifi

We selected a highly versatile Arduino microcontroller to run the Sigfox module. In addition, it is necessary to perform Wi-Fi communication to obtain the router's MAC address; thus, we employed an Arduino UNO R4 WiFi device in this study.

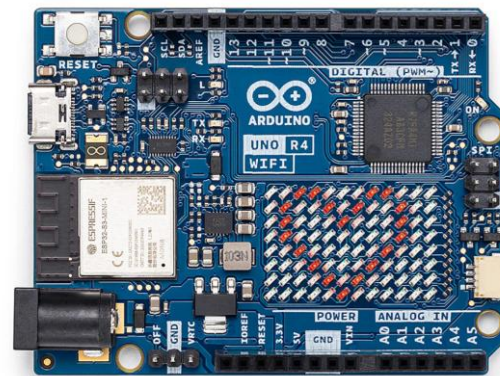


Fig. 2 Arduino UNO R4 WiFi device [7]

The Arduino® UNO R4 WiFi is the first UNO board to feature a 32-bit microcontroller and an ESP32-S3 Wi-Fi® module (ESP32-S3-MINI-1-N8). It features a RA4M1 series microcontroller from Renesas (R7FA4M1AB3CFM#AA0), based on a 48-MHz Arm® Cortex®-M4 microprocessor. The UNO R4 WiFi memory is larger than its predecessors, with 256 kB flash memory, 32 kB SRAM, and 8 kB EEPROM. The RA4M1's operating voltage is fixed at 5 V, whereas the ESP32-S3 module is 3.3 V. Communication between these two MCUs is performed via a logic-level translator (TXB0108DQSR).

Features

The R7FA4M1AB3CFM#AA0, often referred to as RA4M1 in this datasheet, is the main MCU on the UNO R4 WiFi, connected to all pin headers on the board as well as all communication buses.

Overview

48 MHz Arm® Cortex®-M4 microprocessor with a floating point unit (FPU)

5 V operating voltage

Real-time Clock

Memory Protection Unit
Digital-to-analog Converter (DAC)
Memory
256 kB Flash Memory
32 kB SRAM
8 kB Data Memory (EEPROM)
Peripherals
Capacitive Touch Sensing Unit (CTSU)
USB 2.0 Full-Speed Module (USBFS)
14-bit ADC
Up to 12-bit DAC
Operational Amplifier
Power
Operating voltage for RA4M1 is 5 V
Recommended input voltage (VIN) is 6-24 V
Barrel jack connected to VIN pin (6-24 V)
Power via USB-C® at 5 V
Communication
UART (pin D0, D1)
SPI (pin D10-D13, ICSP header)
I2C (pin A4, A5, SDA, SCL)
CAN (pin D4, D5, external transceiver is required)

2-3 Assembling Sigfox module and Arduino

The SBB was placed on a custom manufactured printed circuit board (PCB). Figure 3 shows the IoT device configured by connecting a PCB to an Arduino UNO R4 WiFi device.



Fig. 3 Sigfox module and Arduino device

2-4 Scketch of Arduino UNO R4 Wifi

Using the IoT device with the Sigfox communication function (Fig. 3), we created a sketch to obtain the MAC address of the Wi-Fi antenna and transfer that value using Sigfox (Fig. 4).

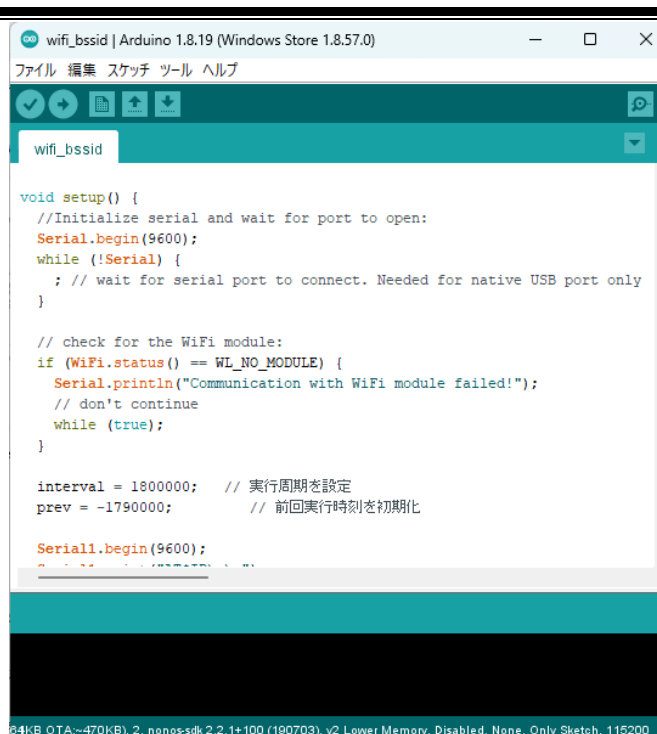


Fig.4 Sketch program using Arduino UNO R4 Wifi

2-5 Sigfox Cloud

Hiroshima Institute of Technology is a Sigfox partner of KYOCERA Communication Systems Co., Ltd., so it can use the Sigfox Cloud[8].

2-5-1 End product certificate and prototype registration[9]

When registering a device in the Sigfox Cloud, an end product certificate must be input. Sigfox compatible commercial devices must obtain device certification, which is referred to as the Sigfox Ready Certification (formerly P2 certification).

Note that the settings for the end product certificate differ depending on whether you are registering a device that has obtained Sigfox Ready Certification or a device that has not been certified.

Device - New

Device information	
Identifier (hex!)	AB12CD
Name	Test Device #00AB12CD
PAC	xxxae2ec3c878975c896ca
End product certificate	P_0006_DAD8_01
Where can I find the end product certificate?	

Fig. 5 Registering a Sigfox device to the Sigfox Cloud

2-5-2 Callback

The advantage of using Sigfox Cloud is that the data obtained from IoT devices can be processed and transferred to the cloud. Here, we show an example where the data obtained from IoT devices are transferred to email via the Sigfox Cloud.

3. Results and Discussion

Communication is performed after setting up the IoT device (Fig. 3) with the Sigfox communication function. The corresponding results are shown in Fig. 6.

Device 30D1222 - Information

Name: brkwls100a001

Protocol: V1

Activable state: ☒ ⓘ

Message modulo: 4096

Sequence number: 43 (2024-05-22 09:23:38)

Trash sequence number: N/A (N/A)

Last seen: 2024-05-22 09:23:38

PAC: AC673C00E944C220

Product certificate: P_0028_4DAF_01

Latitude: 0.000 (degrees)

Longitude: 0.000 (degrees)

Device type: brkwls100a-001

State: OK

Link Quality Indicator:  ⓘ

Communication status: 

Contract: From BUY for 1 devices

Activation date: 2024-02-19 19:27:38

Token validity: 2025-02-19

Fig. 6 Information about device 30D1222

Note that the Link Indicator (Fig. 6) was displaying the strength, indicating that it was receiving data from the IoT device. The corresponding data message is shown in Fig. 7.

Device 30D1222 - Messages

				Base station reception attributes					
Time	Delay (s)	Seq Num	Data / Decoding	Station	RSSI (dBm)	Freq (MHz)	LQI	Callbacks	Location
2024-05-22 09:23:38	< 1	43	d80d17276aac001132916143	D9FC	-127.00	923.2502			
				6969	-121.00	923.2500			
				9A63	-126.00	923.2498			

(a)

Time	Delay (s)	Seq Num	Data / Decoding
2024-05-22 09:23:38	< 1	43	d80d17276aac001132916143

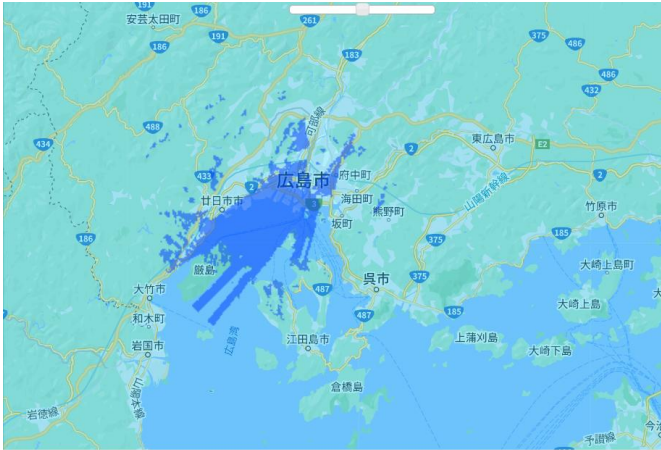
(b)

Base station reception attributes		
Station	RSSI (dBm)	Freq (MHz)
D9FC	-127.00	923.2502
6969	-121.00	923.2500
9A63	-126.00	923.2498

(c)

LQI	Callbacks	Location
		

(d)



(e)

Fig. 7 Data message from device 30D1222. (a) The entire message. (b) Expanded message time, delay, serial number, and data. (c) Base station number, strength, and frequency when receiving the signal. (d) Link quality indicator, callback, and device location. (e) Device location is highlighted in blue on the map. Its width is approximately 20 km.

Figure 8 shows the arrangement of the router and IoT devices. Figure 10 shows the email that was forwarded using this arrangement using the MAC address obtained by the IoT device employing the callback function in the Sigfox Cloud (Figure 9).

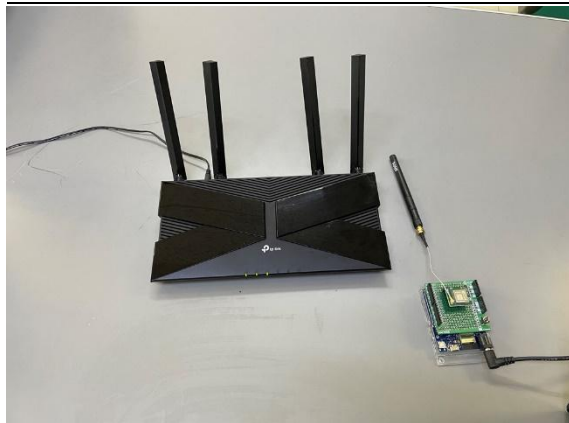


Fig. 8 Callback used to process messages

Device type brkwlsm100a-001 - Callback edition

Callbacks

Type: **DATA** **UPLINK**

Channel: **EMAIL**

Custom payload config: **sls:int:48 big-endian slg:int:48 big-endian**

Recipient: **tanaka@cc.it-hiroshima.ac.jp**

Multiple emails allowed separated by comma,semicolon or new line

Subject syntax: **Subject with device (device)**
 Message syntax: **Message containing time (time), key1 (var1), key2 (var2)...**
 Available variables: **device, time, station, data, rssi, seqNumber, deviceTypeid**
 Custom variables: **customData#sls, customData#slg**

Subject: **kanazawa_test**

Message:

```
{
  "device": "{device}",
  "time": "{time}",
  "seqNumber": "{seqNumber}",
  "data": "{data}"
}
```

Ok Cancel

Fig. 9 Callback function to process messages

```
{
  "device": "30D1222",
  "time": 1716970277,
  "seqNumber": 51,
  "data": "d807b6c70e7b0810868199fc"
}
```

Fig. 10 Email forwarded using Sigfox

Note that the first half of the data (d807b6c70e7b2c1a056815c3), i.e., d807b6c70e7b, is the router's MAC address.

4. Application to society

A router with a known MAC address can be placed at an evacuation center during a disaster, and IoT devices with Sigfox communication functionality can be provided to the evacuees in the area. Then, who is there and when did they get here? Such information is accumulated on the network.

Using such a system, it would be possible to determine who has moved to evacuation centers without human intervention. Thus, it would be possible to obtain useful information about the damage situation, which could be used to support disaster response efforts.

5. Conclusion

Knowledge and information have not yet been exchanged in the information society (Society 4.0), leading to issues due to a lack of interdisciplinary cooperation. Society 5.0 connects all people and things with the IoT to share various types of knowledge and information.

Against this background, using the Sigfox network and the Internet, we developed IoT devices equipped with temperature, humidity, barometric pressure, and other sensors to measure different physical data [1–5].

In this research, we attempted to control Sigfox communication using AT commands using the Sigfox module Arduino UNOR4. We also attempted social implementation using this system.

Acknowledgments

We thank Enago (www.enago.jp) for the English language review.

References

- 1) R. Matsuda, H. Suizu, K. Hiyama, K. Kai, I. Yamasaki, K. Oda, N. Okamitsu, K. Eto, T. Tanaka, Industry 4.0, 3(1), 2018, 11-14
- 2) T. Tanaka, N. Okamitsu, T. Hamada, K. Nishino, Electrotechnica & Electronica (E+E), 55(3-4), 2020, 35-40, ISSN: 0861-4717 (Print), 2603-5421 (Online)
- 3) T. Tanaka, N. Okamitsu, K. Nishino, Electrotechnica & Electronica (E+E), 55(5-8), 2020, 94-98, ISSN: 0861-4717 (Print), 2603-5421 (Online) 304 YEAR VIII, ISSUE 6, P.P. 302-305 (2023) INTERNATIONAL SCIENTIFIC JOURNAL "INDUSTRY 4.0" WEB ISSN 2534-997X; PRINT ISSN 2534-8582
- 4) N. Okamitsu, K. Miyazono, T. Tanaka, Electrotechnica & Electronica (E+E), 55(9-12), 2020, 99-104, ISSN: 0861-4717 (Print), 2603-5421 (Online)
- 5) T. Tanaka, M. Yamauchi, K. Kakugawa, T. Uchida, S. Ishihara, K. Ishihara, Electrotechnica & Electronica (E+E), 57(1-2), 2022, 24-30, ISSN: 0861-4717 (Print), 2603-5421 (Online)
- 6) KYOCERA. Sigfox Breakout Board [BRKLSM100]. <https://www.kccs.co.jp/sigfox/solution/product/device71/> (in Japanese)
- 7) Arduino Cloud. Arduino® UNO R4 WiFi <https://store-usa.arduino.cc/products/uno-r4-wifi?selectedStore=us>
- 8) KYOCERA. Sigfox partner list. <https://www.kccs.co.jp/sigfox/service/pdf/pdf-sigfox-partnerslist-jp-01.pdf>
- 9) KYOCERA. Sigfox: End product certificate and prototype registration. 2018. <https://www.kccs.co.jp/sigfox/blog/technical/2018/1114/>

Application of convolutional networks to detect the operating phases of energy systems using a biomass boiler as an example

Szymon Podlasek^{1*}, Piotr Książek¹
AGH University of Krakow, Poland¹
podlasek@agh.edu.pl

Abstract: The development of neural algorithms opens new perspectives for the analysis of technological processes. Particularly relevant are strongly nonlinear and complex objects, such as power plants. One of the modern solutions enabling data analysis are convolutional neural networks (CNNs). The research presents the application of CNNs to monitor and optimize combustion processes in biomass boilers. The fuel analyzed was gray straw, which is difficult to control due to the nature of combustion. The proposed technique is based on the processing of temporal data, which represent different stages of the combustion process. The work examined the effectiveness of the model in identifying key operating parameters and detecting the stages of firing from ignition initialization to nominal operation. Analysis of images of parameter curves from the time waveforms makes it possible to capture repeatable relationships that enable faster response to future changes in the conditions of the combustion process. Determining the phase of the process, based on data and trends of selected parameters, allows the control system to react faster, without operator intervention. As a result of the study, the efficiency of process stage change detection by the convolutional network, expressed by means of an error matrix, through the F1-score parameter (harmonic mean between precision and sensitivity) was achieved at a level close to 96%. The proposed solution can be effectively applied to a number of technological processes including those that are part of Industry 4.0 effectively influencing technological transformation..

Keywords: RES, COMPUTER MODELING, CONVOLUTIONAL NEURAL NETWORKS, OPTIMIZATION ALGORITHMS, PREDICTION

1. Introduction

Modern biomass boilers play a crucial role in renewable energy production, forming an essential part of strategies to reduce greenhouse gas emissions (Fig.1). Biomass, as an energy source, is characterized by low costs and wide availability, making it an attractive alternative to fossil fuels. However, the biomass combustion process is complex and requires precise management of various variables, such as fuel moisture content, chemical composition, and boiler operating conditions.

One of the main challenges in biomass combustion is ensuring an efficient and stable combustion process that minimizes the emission of pollutants, such as nitrogen oxides (NO_x) and carbon monoxide (CO) [1-3]. Traditional methods of controlling the combustion process are often not flexible enough to respond to dynamic changes in combustion conditions. Effective management of this process requires advanced technologies capable of processing large amounts of data and adjusting operational parameters in real-time.



Fig. 1 Tested object - biomass boiler fueled by gray straw..

Convolutional Neural Networks (CNNs) are one such technology that is finding increasing application in the energy industry [4]. This method is increasingly used in Renewable Energy Sources (RES) to both forecast and support the operation of solar and wind installations [5, 6]. Also, research has been undertaken on the use of neural networks to reduce emissions from boilers by predicting components of the combustion process [7, 8]. CNNs, a type of deep neural network, are particularly effective in analyzing spatial data structures, such as images [9-11], making them ideal for

analyzing operational data from biomass boilers or prediction of the occurrence of an event such as air pollution [12].

This article presents the application of CNNs for analyzing and predicting combustion processes in biomass boilers. Operational data from actual boilers and numerical simulations were used to train and test the CNN model. The objective of the study was to optimize the combustion process and reduce pollutant emissions. The results show that the application of CNNs can significantly improve combustion efficiency and reduce the negative environmental impact. The approach presented can serve as a basis for future research on the application of advanced machine learning technologies in optimizing industrial processes. Additionally, this solution aligns with Industry 4.0 standards through advanced analysis of measurement data.

2. Prerequisites and means for solving the problem

The work analyzed the possibility of using neural networks to detect the combustion stage. The turbulent nature of straw combustion requires a rapid response to a change in a parameter, which calls for the study of new algorithms for controlling these processes. In the study, it was decided to analyze the time courses of boiler parameters using CNNs.

Convolutional Neural Networks are a special class of deep neural networks particularly effective in processing grid-like data structures, such as images. Convolutional networks can also be used to analyze and interpret time series data, where the dependent variable, such as the intensity of electrical energy flow, is recorded at regular intervals. Such data can be treated analogously to images, where the time axis corresponds to the width of the image, and the variable values represent pixel intensities. By training on historical or simulated data, a CNN can learn to recognize recurring patterns in variable profiles and predict planned changes or anomalies.

The confusion matrix, also known as an error matrix or confusion table, is a tool used in machine learning, such as CNNs, to evaluate the quality of classification. It is a table that allows for the visualization of the performance of a classification algorithm. The confusion matrix shows the numbers of true positive, false positive, true negative, and false negative results (Fig. 2).

These four terms are key to calculating classifier performance metrics, such as Precision, Recall, Specificity, Accuracy, and F1-Score. The formulas for these indicators are presented in equations (r1) to (r5).

$$\text{Precision} = \frac{TP}{TP + FP} \quad (r1)$$

Precision measures what percentage of positive predictions is actually positive.

$$Recall = \frac{TP}{TP + FN} \quad (r2)$$

Recall measures what percentage of actual positive cases was correctly identified.

$$Specificity = \frac{TN}{TN + FP} \quad (r3)$$

Specificity measures what percentage of actual negative cases was correctly identified.

$$Accuracy = \frac{TN + TP}{TN + TP + FP + FN} \quad (r4)$$

Accuracy measures what percentage of all classifications (positive and negative) is correct.

$$F1 - Score = \frac{Precision \cdot Recall}{Precision + Recall} = \frac{\frac{TP}{TP + FP} \cdot \frac{TP}{TP + FN}}{\frac{TP}{TP + FP} + \frac{TP}{TP + FN}} \quad (r5)$$

F1-Score is the harmonic mean of precision and recall, providing a single measure of classifier accuracy.

In the context of change detection, CNNs can be used to analyze data from sensors or time records, identifying patterns that are unusual or indicate potential problems. The confusion matrix in this context would serve to evaluate the effectiveness of models in detecting and correctly classifying these changes.

TRUE NEGATIVES ⇒ Predicted negative result ⇒ Actual negative result	FALSE POSITIVES ⇒ Predicted positive result ⇒ Actual negative result
FALSE NEGATIVES ⇒ Predicted negative result ⇒ Actual positive result	TRUE POSITIVES ⇒ Predicted positive result ⇒ Actual positive result

Fig. 2. Example representation of a confusion matrix for a case with two possible states and the assessment of their proper detection based on actual and predicted values [13].

3. Solution of the examined problem

As part of the work, experimental data from straw combustion were used as input data for analyzing combustion runs. The process was carried out under the same conditions, the only difference was the air feeding point to introduce some variability in the data. In addition, modeling and simulation work was carried out to increase the amount of information for the neural network. A full analysis of the impact of location on the process is available in article [14].

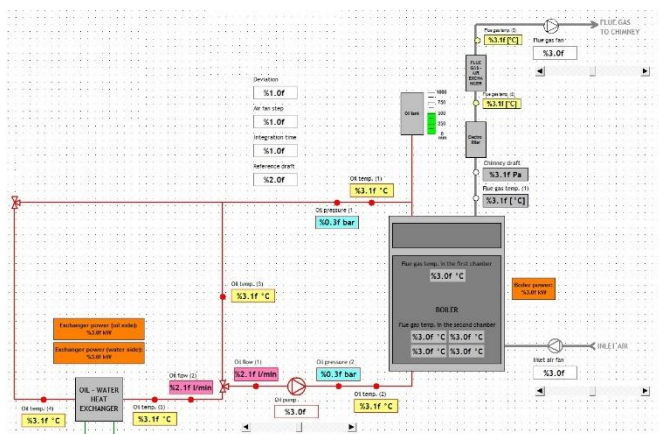


Fig. 3. Visualization of the experimental stand with measurement points [15].

The test stand was equipped with automatic data acquisition from temperature probes and an industrial exhaust gas analyzer (fig. 3). For a detailed analysis of combustion processes in batch boilers, four key operational parameters were identified as the basis for validating the simulation model. The focus was on examining the dynamics of changes in carbon monoxide (CO) and carbon dioxide (CO₂) concentrations, as well as oxygen (O₂) in the flue gases, and monitoring the temperature in the secondary combustion chamber. For components with a high response time (such as an air damper), tripping the system before the information about the need for a shortage is essential to respond in time.

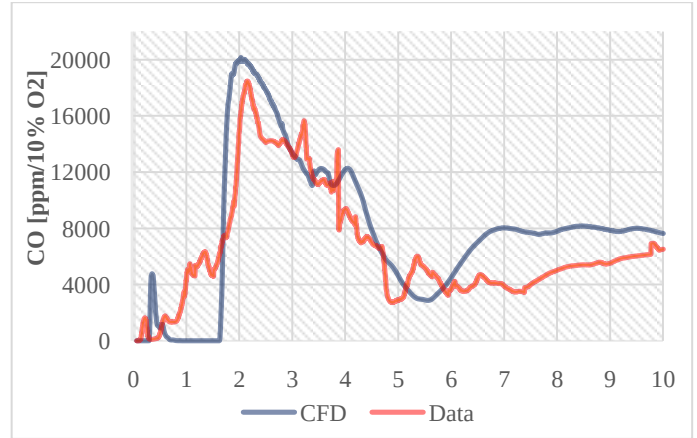


Fig. 4. Comparison of experimental data and CFD simulations, dynamics of concentration changes for selected CO parameter. In red the average measurement, in blue the CFD results.

The entire startup period of the installation – igniting the boiler – lasting 10 minutes can be represented in the form of intermediate states, where the detection of their start and end can serve as a faster signal than direct parameter measurement. The decision scheme for such an algorithm may look as follows:

Initialization: Preliminary Heating: The algorithm starts from an initial state, preparing the system for ignition by monitoring initial parameters such as temperature and chemical composition in the combustion chamber.

- Stage 1: Ignition (up to 60 seconds)

Ignition Detection: The algorithm detects an increase in CO emissions and other chemical products, as well as a temperature rise, indicating local ignition.

Parameter Adjustment: In response to detected ignition, the algorithm adjusts the fan and damper settings to ensure an optimal amount of air for the combustion process.

- Stage 2: Flame Spread (60 – 240 seconds)

Monitoring and Adaptation: During the intensive flame spread phase, the algorithm monitors and analyzes changes in emissions and temperature. It adjusts the fan and damper settings to avoid a rich mixture or suboptimal chemical reaction conditions.

- Stage 3: Stabilization (240 – 360 seconds)

Process Stabilization: When the algorithm detects a decrease in flame spread dynamics, it transitions to maintaining optimal parameters for balanced combustion – i.e., nominal operation.

- Stage 4: Nominal Combustion (360 – 600 seconds)

Maintaining Nominal Combustion: The algorithm maintains stabilized system parameters while being ready to detect and respond to potential anomalies resulting from fuel load fluctuations.

Intervention - Anomaly Response: In the event of anomaly detection, the algorithm immediately responds by adjusting the system parameters to prevent inefficient combustion or potential hazards.

Process Conclusion - Combustion Finalization: After completing the nominal combustion process, the algorithm switches

to a monitoring state, checking whether the residual fuel smoldering process is proceeding correctly.

Continuous Learning: Data Analysis and Optimization: At each stage, the collected data is analyzed, and the algorithm learns and optimizes its actions for the future, increasing efficiency and reducing emissions.

It is also essential to observe that for such complex processes, there is partial overlap of stages, illustrating the process's complexity and the need to provide multiple runs based on models and experimental work to train the state transition detection algorithm.

Analysis of the results of the experimental work makes it possible to observe certain relationships that can serve as flags for subsequent stages of combustion. It is possible to identify common trends and characteristic points that can be used to optimize a control algorithm with a predictive component (Fig. 4). Data from the initial phase of combustion is crucial for quick and efficient process startup. Subsequent phases of combustion require the algorithm to adjust and maintain optimal conditions for full and even combustion. As in the case above, it is possible to analyze a whole range of data and their time courses, such as circulating medium temperature, losses or boiler efficiency. Comprehensive data analysis indicates the need for a flexible algorithm that adapts to changing conditions in real time and predicts next steps to respond more quickly to changing demands, such as air.

4. Results and discussion

The model was trained using a dataset consisting of experimental results and numerical simulations of boiler ignition. Each measurement was labeled by an experienced user and constituted the training dataset. Supervised learning was utilized for training, with cross-entropy as the loss function and the Adam optimization algorithm used to update the network weights based on the calculated loss. To prevent overfitting, cross-validation was employed, where the data was divided into training and validation sets. After each iteration, the model's performance was assessed on the validation set, and the best model was saved and tested on a separate test set. A classic split was applied, with 80% of the input data used for training, 10% for validation, and 10% for the test set.

After the initial training, hyperparameter optimization was conducted, including the number of layers, the size of convolutional filters, and the number of neurons in fully connected layers, to achieve the best possible performance. The model was validated using a previously unseen dataset to evaluate its ability to generalize to new data.

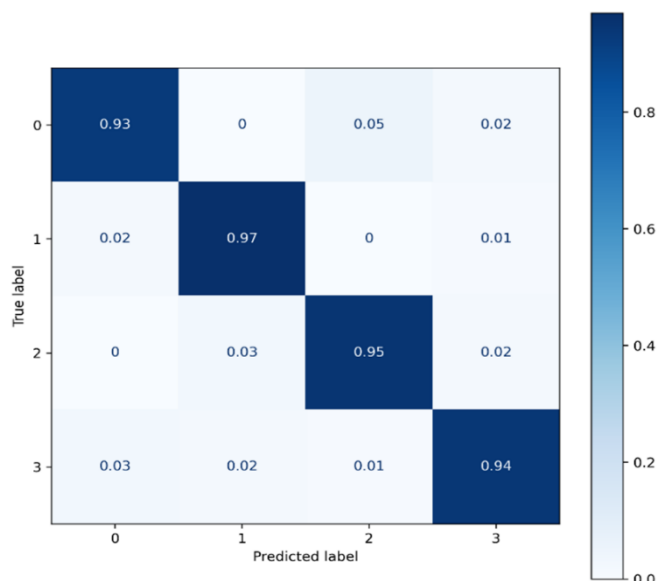


Fig. 5. Confusion matrix for convolution network for classification of combustion stages.

Based on the obtained confusion matrix (Fig. 5) and according to the formulas (r1) to (r5) presented in section 4.3, the following coefficients for the entire system were calculated: Recall: 95.8%, Accuracy: 95.8%, F1-Score: 95.79%, Precision: 95.80%. Additionally, the F1-Score for individual combustion stages was calculated as follows:

- Stage 0 (Ignition): 0.93
- Stage 1 (Flame Spread): 0.97
- Stage 2 (Process Stabilization): 0.95
- Stage 3 (Nominal Combustion): 0.94

Based on the confusion matrix (Fig. 5), it can be concluded that the neural network performs well in classifying the combustion stages. For each combustion stage, the majority of the network's predictions match the actual labels, indicating a high ability to recognize the characteristic features of each stage. For stages "0" and "3", small FP values are observed, where the network incorrectly classified the stage as "3" or "0". Similarly, for stage "2", a small number of FN values were obtained, where the network failed to recognize stage "2" and incorrectly classified it as "1". These low values indicate good specificity and sensitivity of the model.

5. Conclusion

The high F1-Score values for each stage (close to 1) indicate a good balance between precision and recall, meaning that the model performs well in identifying positive cases while avoiding false positives. The high values along the diagonal of the matrix indicate that the network has a high capability for correctly classifying each combustion stage. Based on the conducted training, it can be concluded that the model is capable of predicting the ignition stages based on measurement data, which allows for the automation of the monitoring process and potentially the optimization of the entire process. The designed algorithm can be implemented in a biomass boiler controller, enabling automatic regulation of the combustion process based on continuous analysis of measurement data and identification of combustion stages.

The research confirmed the significant utility of numerical models and their simulation results, which serve as the basis for analyzing the combustion process using neural networks. The application of convolutional neural networks allowed for the determination of combustion phases, even in such a complex process as straw ignition. Identifying the phase of the process based on data and trends of selected parameters enables faster responses in the installation without operator intervention. As a result of the research, the effectiveness of detecting process stage changes by the convolutional network was achieved, expressed using the confusion matrix through the F1-score (the harmonic mean between precision and recall) at a level close to 96%.

6. References

- [1] Liu, Hao, et al. "Control of NOx emissions of a domestic/small-scale biomass pellet boiler by air staging." *Fuel* 103 (2013): 792-798.
- [2] Böhler, Lukas, et al. "Carbon monoxide emission models for small-scale biomass combustion of wooden pellets." *Applied energy* 254 (2019): 113668.
- [3] Szubel, M., A. Dernbecher, and T. Dziok. "Determination of kinetic parameters of pyrolysis of wheat straw using thermogravimetry and mathematical models." *IOP Conference Series: Earth and Environmental Science*. Vol. 214. No. 1. IOP Publishing, 2019.
- [4] A. Le Guennec, S. Malinowski, and R. Tavenard, "Data augmentation for time series classification using convolutional neural networks," in *ECML/PKDD workshop on advanced analytics and learning on temporal data*, 2016.

- [5] Chen, Yaoran, et al. "2-D regional short-term wind speed forecast based on CNN-LSTM deep learning model." *Energy Conversion and Management* 244 (2021): 114451.
- [6] Lim, Su-Chang, et al. "Solar power forecasting using CNN-LSTM hybrid model." *Energies* 15.21 (2022): 8233.
- [7] Li, Nan, and Yong Hu. "The deep convolutional neural network for NOx emission prediction of a coal-fired boiler." *Ieee Access* 8 (2020): 85912-85922.
- [8] Li, Zhenhua, Guanghong Li, and Bin Shi. "Prediction of Oxygen Content in Boiler Flue Gas Based on a Convolutional Neural Network." *Processes* 11.4 (2023): 990.
- [9] P. Bałazy, P. Gut, and P. Knap, "Neural classifying system for predictive maintenance of rotating devices.," in *IOP Conference Series: Materials Science and Engineering*, 2022, p. 12013.
- [10] P. Knap, K. Lalik, and P. Bałazy, "Boosted Convolutional Neural Network Algorithm for the Classification of the Bearing Fault form 1-D Raw Sensor Data," *Sensors*, vol. 23, no. 9, p. 4295, 2023.
- [11] Knap, Paweł, Krzysztof Lalik, and Patryk Bałazy. "Boosted Convolutional Neural Network Algorithm for the Classification of the Bearing Fault Form 1-D Raw Sensor Data." *Sensors* 23.9 (2023): 4295.
- [12] K. Lalik, J. Kozak, S. Podlasek, and M. Kozek, "Self-Powered Wireless Sensor Matrix for Air Pollution Detection with a Neural Predictor," *Energies (Basel)*, vol. 15, no. 6, p. 1962, 2022.
- [13] Macukow, Bohdan. "Sieci neuronowe, historia badań i podstawowe modele." (2020).
- [14] M. Szubel, K. Papis-Fraczek, and S. Podlasek, "Impact of the air supply system configuration on the straw combustion in small scale batch-boiler-experimental and numerical studies," *Renew Energy*, vol. 220, p. 119540, 2024.
- [15] K. Sornek, "Prototypical biomass-fired micro-cogeneration systems—energy and ecological analysis," *Energies (Basel)*, vol. 13, no. 15, p. 3909, 2020.

Deep Eye - Intelligent Device for Creating Digital Models of Underwater Topography

Zuzanna Schab, Marta Żelasko, Krzysztof Lalik, Krzysztof Mamcarz
AGH university of Krakow, Poland
klalik@agh.edu.pl

Abstract: This project endeavors to advance underwater mapping technologies through the development of algorithms tailored for mapping, analyzing, and creating digital models of bathymetry. A key aspect of this research involves the integration of advanced technologies, specifically High-Definition cameras and a purpose-designed sonar system. By leveraging these tools, high-resolution point cloud data and precise representations of submerged geographical structures can be obtained. The project also aims to conduct a waterproof device, operated by a diver, incorporating both HD cameras and sonar sensors. This device will enhance data collection and mapping capabilities in challenging underwater environments, addressing complexities associated with underwater terrains. Several critical questions are central to this research. Primarily, the investigation seeks to understand how artificial intelligence algorithms can be optimized to harness the collective potential of HD cameras and the specially crafted sonar system. Additionally, the research endeavors to evaluate the comparative efficacy and accuracy of the proposed sonar system and HD cameras in underwater mapping, particularly under adverse environmental conditions where visibility is compromised by high particle concentrations. Through these efforts, this project aims to contribute to the advancement of underwater mapping technologies, offering insights into optimizing sensor integration and algorithm development for enhanced mapping accuracy in challenging underwater environments.

Keywords: UNDERWATER IMAGING, UNDERWATER 3D POINT CLOUD, UNDERWATER PHOTOGRAMMETRY, FEATURE MATCHING

1. Introduction

In the realm of marine exploration and resource management, the accurate depiction of underwater terrain holds paramount importance. Submerged landscapes harbor a wealth of ecological diversity, geological features, and invaluable resources, yet their detailed mapping has long presented a formidable challenge to scientists and researchers. Traditional sonar systems, which utilize sound waves to map underwater topography, have been indispensable tools in oceanographic research for decades. However, these traditional methodologies, while providing invaluable insights into submerged terrain, often suffer from limitations such as resolution constraints and an inability to capture fine-scale features. The integration of sonar systems with High-Definition (HD) cameras has emerged as a promising approach to overcome these limitations and revolutionize our ability to unveil the mysteries of the deep.

Recent advances in the field have seen the development and application of sophisticated models and technologies aimed at enhancing underwater mapping capabilities. Authors in [1] presented a theoretical model explaining the imaging mechanism of underwater topography by radar, highlighting the significance of current-induced surface effects. This early work laid the foundation for understanding how underwater features could be detected using surface observations. Building on such foundational theories, a novel framework incorporating deep learning techniques, specifically the Gate Recurrent Unit (GRU) model, to improve water depth inversion in complex marine environments were introduced in [2]. Their study demonstrated significant improvements in accuracy and applicability of inversion models, setting a new standard for underwater topographic mapping.

The integration of mathematical modeling and computational analysis further enriches the field. Authors in [3] utilized GPS and echo sounder data to construct underwater topography models, providing insights into sedimentation changes over time. Such approaches underscore the importance of combining multiple data sources to achieve more accurate and dynamic representations of underwater landscapes.

Enhancements in image processing technologies have also played a critical role in advancing underwater mapping. In [4] an efficient underwater image enhancement method that significantly improved visibility and detail in underwater images were proposed. Similarly, [5] developed a Bayesian retinex algorithm for enhancing underwater images, addressing common issues such as color casts and low visibility. These advancements in image enhancement

techniques are crucial for the effective integration of HD cameras in underwater mapping systems.

Moreover, a multi-view underwater image enhancement method using an embedded fusion mechanism, which further refined image quality and detail retrieval, were introduced in [6]. Their approach demonstrated the potential of combining multiple enhancement algorithms to achieve superior results, particularly in challenging underwater conditions.

The capture and processing of 3D point cloud data have also seen significant advancements. Authors in [7] proposed a methodology for capturing point cloud data in turbid underwater environments, addressing issues such as turbidity and distortion. This method proved effective in obtaining accurate 3D representations of underwater structures, essential for detailed topographic mapping.

Deep learning techniques have been increasingly employed to enhance underwater mapping capabilities. Authors in [8] utilized deep learning methods for multi-dimensional underwater point cloud detection, achieving high accuracy in detecting and classifying underwater objects. Similarly, convolutional neural networks (CNN) with point cloud registration to improve the precision of underwater object pose estimation were combined in [9]. These studies highlight the potential of AI-driven approaches in refining underwater mapping and object detection processes.

Lastly, Authors in [10] explored the use of visual SLAM (Simultaneous Localization and Mapping) algorithms for autonomous underwater robot navigation. The integration of ORBSLAM2 and point cloud processing demonstrated the feasibility of using minimal instrumentation setups for effective underwater navigation and mapping.

This project endeavors to advance underwater mapping technologies through the development of algorithms tailored for mapping, analyzing, and creating digital models of bathymetry. By integrating advanced technologies, specifically High-Definition cameras and a purpose-designed sonar system, this research aims to obtain high-resolution point cloud data and precise representations of submerged geographical structures. The development of a waterproof device operated by a diver, incorporating both HD cameras and sonar sensors, will enhance data collection and mapping capabilities in challenging underwater environments. The key questions central to this research involve optimizing artificial intelligence algorithms to harness the collective potential of HD cameras and sonar systems, and evaluating the comparative efficacy and accuracy of these tools under adverse environmental conditions. Through these efforts, this project aims to contribute to the

advancement of underwater mapping technologies, offering insights into optimizing sensor integration and algorithm development for enhanced mapping accuracy in challenging underwater environments.

2. Design Considerations

In addition to our primary design considerations, we have meticulously engineered the device to withstand the challenging conditions of underwater operation up to depths of 30 meters. Waterproofing is not merely a feature but a fundamental aspect of the device's design, ensuring its functionality and integrity even in the most demanding marine environments. By implementing robust seals and enclosures, we have fortified the device against water ingress, corrosion, and pressure, guaranteeing reliable performance throughout underwater missions.

Buoyancy has been a focal point in our design, as we recognize its pivotal role in facilitating ease of operation and mitigating the risk of device loss. By carefully calibrating the buoyant properties of the device, we have achieved a delicate balance that enables effortless manipulation by divers while preventing the device from sinking to unreachable depths. This buoyancy management system not only enhances user experience but also safeguards against potential accidents or equipment loss, ensuring uninterrupted data collection and mission success.

Furthermore, we have prioritized user comfort, ergonomics, and compactness in the design process, recognizing the importance of seamless integration into the diver's equipment ensemble. Its streamlined form factor and lightweight construction contribute to enhanced maneuverability and agility underwater, empowering divers to navigate complex environments with ease and confidence.

Given the inherent variability of the underwater landscape, we have meticulously optimized the shape of the device to a cylinder, to minimize hydrodynamic resistance and facilitate seamless navigation through confined spaces such as underwater caves and crevices.

3. Sonar System

For our sonar system we use a set of hydrophones and acoustic transducers. Similar to how a microphone captures sound in the air, a hydrophone functions to detect acoustic signals beneath the water's surface.

The majority of the hydrophones operate on a distinctive property of certain ceramics, generating a minute electrical current in response to fluctuations in underwater pressure. When submerged in the water, a ceramic-based hydrophone generates low-voltage signals across a board spectrum of frequencies, reacting to underwater sounds originating from various directions.

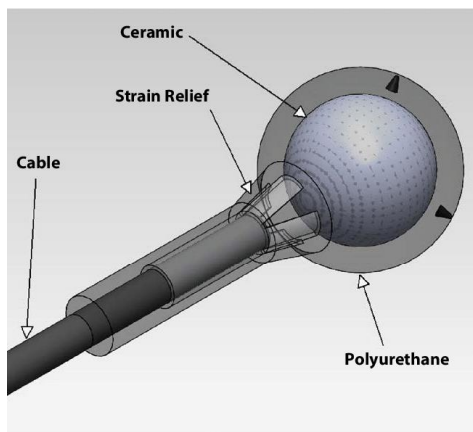


Fig. 1. Schematic of an example ceramic hydrophone

Through the amplification and recording of these electrical signals, hydrophones can accurately measure underwater sounds.

While a single hydrophone has the capacity to capture sounds from all directions, employing multiple hydrophones arranged in an array, yields signals that can be manipulated to enhance sensitivity beyond that of a singular device.

A point cloud comprises myriad data points suspended in space, collectively representing an object or a defined area such as a landscape or specific objects.



Fig. 2. Example of an underwater object

Each of these 3D points possesses a distinct set of X, Y, and Z geometric coordinates, essentially serving as a digital counterpart to corresponding points on the actual object.

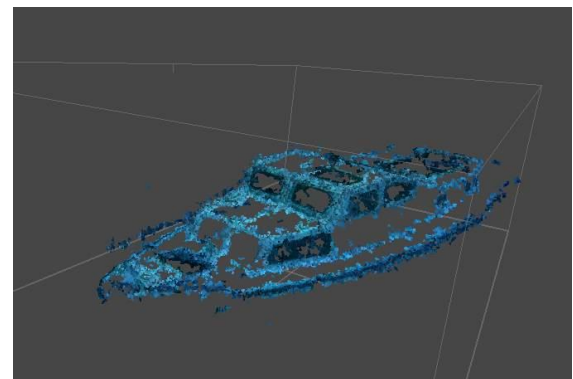


Fig. 3. Point cloud of underwater object

Point clouds are relatively straightforward to create and can be generated using freely available software, capable of storing highly detailed information with ease. Furthermore, their accuracy, particularly in the case of geo-referenced point clouds, is exceptional, enabling precise measurements. In most cases, constructing a point cloud for a landscape involves stitching together numerous high-resolution images captured by drones to produce a detailed output.

The level of detail in the resulting point cloud is directly influenced by the quantity of high-resolution images collected. On presented pictures we can see one of the pictures taken by one of our members. We then created a point cloud of the object which was later used to create a 3D model.

Feature matching is a critical step in many computer vision applications, including object recognition, image stitching, and 3D reconstruction. One widely used algorithm for this purpose is the FLANN (Fast Library for Approximate Nearest Neighbors) algorithm. Before matching features, it is essential to detect and describe these features accurately in each image. The Scale-Invariant Feature Transform (SIFT) algorithm is one of the most effective techniques for this task.

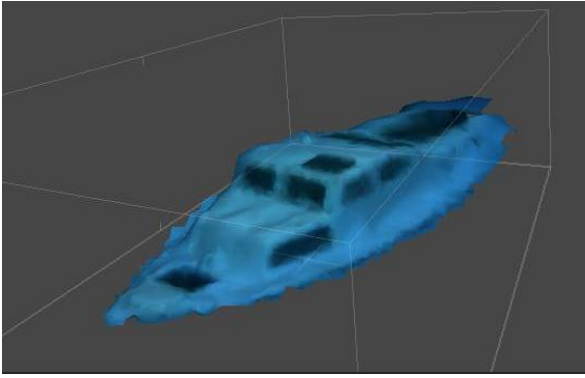


Fig. 4. 3D model created from the point cloud

SIFT is designed to detect and describe local features in images, which remain invariant to scale changes, rotation, and partially invariant to changes in illumination and 3D viewpoint. The first step in SIFT is constructing a scale-space representation of the image. This is done by convolving the image $I(x,y)$ with Gaussian kernels of varying standard deviations (σ), creating a series of progressively blurred images. This process can be described by Equation (1).

$$G(x,y,\sigma)=I(x,y)G(x,y,\sigma) \quad (1)$$

where $G(x,y,\sigma)$ is the Gaussian blur operator with standard deviation σ . This operation results in multiple blurred images at different scales, which help in detecting features that are invariant to scale changes.

The next step involves creating the Difference of Gaussian (DoG) images. DoG is computed by subtracting one blurred image from another, each having a different σ :

$$D(x,y,\sigma)=G(x,y,k\sigma)-G(x,y,\sigma) \quad (2)$$

where k is a constant multiplicative factor. This process results in a set of images that highlight the edges and important features in different scales.

SIFT detects keypoints by searching for local extrema in the DoG images. Each pixel is compared with its 8 neighbors in the current image and its 9 neighbors in the scale above and the scale below. If a pixel is a local extremum (either a maximum or minimum), it is considered a potential keypoint. Not all detected keypoints are equally useful. To refine the keypoints, SIFT uses the Taylor series expansion of the scale-space function to interpolate the location of the extrema accurately. Keypoints with low contrast (below a certain threshold) or those that are poorly localized along edges are discarded. Each keypoint is assigned one or more orientations based on the local image gradient directions. This step ensures that the keypoints are invariant to rotation. The orientation of a keypoint is determined by computing the gradient magnitude and direction around the keypoint and creating an orientation histogram. The highest peak in the histogram indicates the dominant orientation. Finally, a descriptor is created for each keypoint. This descriptor is a vector that describes the local image region around the keypoint. The image gradients are measured in the region around the keypoint, and these gradients are weighted by a Gaussian window. The resulting values are then transformed into a vector that is normalized to enhance invariance to changes in illumination.

Once features have been detected and described using SIFT, the next step is to match these features between images. FLANN (Fast Library for Approximate Nearest Neighbors) performs fast and approximate nearest neighbor searches. It is particularly useful when dealing with large datasets where exact nearest neighbor search would be computationally expensive.

The basic idea behind FLANN is to use a combination of randomized kd-trees and hierarchical k-means trees to organize the data, making the search process much faster.

To match features between two images, FLANN first builds an index of the feature descriptors from one image. For each feature descriptor in the second image, FLANN searches the index to find the closest matching descriptor. This process results in a set of matched feature pairs. To improve the robustness of the matching process, FLANN incorporates techniques to reject outliers. One common method is the ratio test proposed by [11], which compares the distance of the closest neighbor to that of the second-closest neighbor. Matches are accepted if the ratio is below a certain threshold, indicating a good match. By integrating these methods, it becomes possible to accurately match features between images, enabling various advanced computer vision tasks such as 3D modeling, image stitching, and object recognition in underwater environments.

6. Results

Our project aimed to advance underwater mapping technologies by integrating high-definition cameras and sonar systems to create accurate digital models of underwater terrains. The field tests conducted in both controlled and challenging environments provided valuable insights into the effectiveness and limitations of our approach.

Field Testing at Diving Pool

We conducted initial tests at the Diving pool, a controlled environment known for its excellent visibility. The primary objective was to generate a detailed point cloud of an actual boat wreck. The results from this test were highly successful, demonstrating the capability of our integrated system to produce high-resolution 3D models of underwater objects.

Table 1: Point Cloud Accuracy in Pool

Metric	Value
Average Point Density (points/m ²)	500000
Mean Distance Between Points (mm)	1,5
Standard Deviation of Distance (mm)	0,2
Total Number of Points	500000
Coverage Area (m ²)	10
Processing Time (minutes)	45

The results from Pool highlighted the system's ability to capture fine details and produce a dense and accurate point cloud, with an average point density of 500,000 points per square meter and a mean distance between points of 1.5 mm.

Field Testing at Zakrzówek

Subsequent tests were performed at Zakrzówek, an environment characterized by significantly poorer visibility due to high particle concentration. The objective was to assess the performance of our imaging and sonar systems under less ideal conditions.

Table 2: Point Cloud Accuracy in Zakrzówek

Metric	Value
Average Point Density (points/m ²)	120000
Mean Distance Between Points (mm)	5,0
Standard Deviation of Distance (mm)	0,8
Total Number of Points	120000
Coverage Area (m ²)	10
Processing Time (minutes)	60

The results from Zakrzówek indicated a significant reduction in point cloud density and accuracy, with an average point density of 120,000 points per square meter and a mean distance between points of 5.0 mm. This decrease in performance underscores the challenges posed by poor visibility and the limitations of photographic methods in such conditions.

The comparative analysis between the two test sites clearly illustrates the strengths and weaknesses of our system under different environmental conditions. In the controlled environment of Diving Pool, the high visibility allowed for precise and detailed point cloud generation. However, in Zakrzówek, the poor visibility conditions significantly impacted the quality of the point cloud, highlighting the need for complementary data from sonar systems to maintain accuracy.

The data clearly shows that while high-definition cameras can provide excellent results in clear water conditions, their effectiveness diminishes significantly in turbid environments. This finding underscores the importance of integrating sonar data to complement imaging techniques and ensure reliable and accurate underwater mapping across varying conditions.

The results of our tests underscore the critical role of integrating multiple technologies for underwater mapping. The high-definition cameras provided excellent results in clear water conditions, but their limitations in turbid environments highlighted the necessity for supplementary sonar data. Our system's ability to adapt to different environments by combining these technologies ensures robust and accurate mapping, paving the way for advancements in underwater exploration and resource management.

7. Summary

In this project, we successfully advanced underwater mapping technologies by integrating sophisticated sonar systems and high-definition cameras, coupled with advanced image processing and deep learning algorithms. Our efforts focused on developing robust algorithms for mapping, analyzing, and creating digital models of underwater terrains.

We conducted a series of tests at the Diving pool, where we successfully generated a detailed point cloud of an actual boat wreck. This demonstration confirmed the effectiveness of our integrated approach in a controlled environment with good visibility.

Further tests were carried out at Zakrzówek, an area with significantly poorer visibility. These tests revealed a critical limitation: imaging based solely on photographs proved insufficient under these challenging conditions. The reduced visibility highlighted the dependency of photographic methods on clear water conditions, underlining the necessity for supplementary techniques to ensure accurate underwater mapping.

Our findings indicate that the integration of sonar systems with HD cameras is essential for overcoming the limitations posed by adverse underwater environments. The sonar system, comprising hydrophones and acoustic transducers, provided reliable data even in turbid conditions, where traditional photographic methods failed. The use of SIFT for feature detection and FLANN for feature matching between images further enhanced our ability to process and integrate data from multiple sources.

The development of a waterproof device, designed to operate effectively up to depths of 30 meters, was a crucial aspect of our project. This device, incorporating robust seals, buoyancy management, and ergonomic considerations, facilitated efficient data collection and maneuverability in underwater environments. The cylindrical shape minimized hydrodynamic resistance, enabling smooth navigation through confined spaces.

Our research demonstrates that while high-resolution imaging plays a vital role in underwater mapping, it must be complemented by sonar data to address the challenges of visibility and detail capture. The integration of multiple data sources and the application of advanced algorithms ensure a more comprehensive and accurate representation of underwater terrains.

Future work will focus on further enhancing the integration of sonar and imaging technologies, improving the robustness of our algorithms, and expanding the application of our methods to more

diverse and challenging underwater environments. This project has laid a strong foundation for ongoing advancements in underwater mapping technologies, offering significant potential for future research and practical applications in marine exploration and resource management

6. References

- [1]. Alpers, W., & Hennings, I. (1984). A theory of the imaging mechanism of underwater bottom topography by real and synthetic aperture radar. *Journal of Geophysical Research: Oceans*, 89(C6), 10529-10546.
- [2]. Leng, Z., Zhang, J., Ma, Y., & Zhang, J. (2020). Underwater topography inversion in liaodong shoal based on GRU deep learning model. *Remote Sensing*, 12(24), 4068.
- [3]. Iwakami, S., Tamega, M., Sanada, M., Mohri, M., Iwakami, Y., Okamoto, N., & Watanabe, M. (2021). Mathematical modeling and computational analysis of underwater topography with global positioning and echo sounder data. *Journal of Applied Mathematics and Physics*, 9(5), 1171-1179.
- [4]. Zhang, W., Zhuang, P., Sun, H. H., Li, G., Kwong, S., & Li, C. (2022). Underwater image enhancement via minimal color loss and locally adaptive contrast enhancement. *IEEE Transactions on Image Processing*, 31, 3997-4010.
- [5]. Zhuang, P., Li, C., & Wu, J. (2021). Bayesian retinex underwater image enhancement. *Engineering Applications of Artificial Intelligence*, 101, 104171.
- [6]. Zhou, J., Sun, J., Zhang, W., & Lin, Z. (2023). Multi-view underwater image enhancement method via embedded fusion mechanism. *Engineering Applications of Artificial Intelligence*, 121, 105946.
- [7]. Lin, H., Zhang, H., Li, Y., Wang, H., Li, J., & Wang, S. (2020). 3D point cloud capture method for underwater structures in turbid environment. *Measurement Science and Technology*, 32(2), 025106.
- [8]. Tsai, C. M., Lai, Y. H., Sun, Y. D., Chung, Y. J., & Shortis, M. (2021). Multi-dimensional underwater point cloud detection based on deep learning. *Sensors*, 21(3), 884.
- [9]. Wang, X. X., Gao, J., & Feng, L. (2020, August). Recognition and 3D pose estimation for underwater objects using deep convolutional neural network and point cloud registration. In *2020 International Conference on System Science and Engineering (ICSSE)* (pp. 1-6). IEEE.
- [10]. Hidalgo, F. (2020, October). ORBSLAM2 and point cloud processing towards autonomous underwater robot navigation. In *Global Oceans 2020: Singapore-US Gulf Coast* (pp. 1-4). IEEE.
- [11]. Balestrieri, E., Daponte, P., de Vito, L., & Lamonaca, F. (2021). Sensors and Measurements for Unmanned Systems: An Overview. *Sensors*, 21(4). <https://doi.org/10.3390/s21041518>
- [12]. Muja, M., & Lowe, D. (2009). Flann-fast library for approximate nearest neighbors user manual. Computer Science Department, University of British Columbia, Vancouver, BC, Canada, 5, 6.

Unified Framework for PdM Algorithm Development: The pdm-tools Architecture

Paweł Knap^{1,*}, Urszula Jachymczyk¹
AGH University of Krakow, Poland¹
pknap@agh.edu.pl

Abstract: This paper proposes a novel architecture for *pdm-tools*, a dedicated library designed to streamline the development process of predictive maintenance (PdM) algorithms within the Industry 4.0 paradigm. *pdm-tools* tackles the time-consuming nature of PdM algorithm development by encompassing five key components within a unified framework. *pdm-tools* tackles the time challenge by offering a unified workflow: generate synthetic vibration data (gearboxes, bearings, shafts) for rapid prototyping, eliminating initial real-world data collection. Data preparation and feature extraction ensure readiness through scaling, filtering, and extracting diverse condition indicators, empowering robust algorithms. Finally, user-defined model development and evaluation allow training, optimization, and selection of optimal PdM algorithms (machine learning/deep learning). By integrating these functionalities within a single architecture, *pdm-tools* empowers rapid development and evaluation of PdM algorithms, ultimately leading to a more efficient and effective implementation of predictive maintenance strategies within the Industry 4.0 landscape.

Keywords: PREDICTIVE MAINTENANCE, FAULT IDENTIFICATION, ANOMALY DETECTION, REMAINING USEFUL LIFE

1. Introduction

Predictive Maintenance (PdM) is an advanced maintenance strategy that leverages data analysis techniques and condition-monitoring technologies to predict when equipment failure might occur [1]. Unlike traditional maintenance approaches, such as reactive maintenance, which involves repairing equipment after a failure, or preventive maintenance, which schedules regular maintenance based on time or usage, PdM aims to minimize downtime and maintenance costs by performing maintenance activities just in time before a failure happens [2].

PdM relies on real-time data collected from various sensors and historical data to identify patterns and anomalies that indicate potential issues. By applying machine learning algorithms and statistical models, PdM systems can forecast the remaining useful life of machinery and recommend optimal maintenance actions [3, 4, 5]. This proactive approach not only enhances the reliability and efficiency of equipment but also extends its operational lifespan, thereby contributing to overall operational excellence [6, 7, 8].

libraries such as PyTorch, Scikit-learn, and TensorFlow. Although there are numerous repositories on GitHub related to PdM, none of them provide a complete framework that is reusable, adjustable, and scalable, which presents a significant gap in the current landscape of PdM development tools.

To address these challenges, we propose a unified *pdm-tools* framework designed to streamline the development of Predictive Maintenance (PdM) solutions. This framework facilitates the generation of synthetic vibration data for critical components such as gearboxes, bearings, and shafts, thereby mitigating the need for initial real-world data collection and expediting the prototyping process. Comprehensive data preparation and feature extraction methods ensure the data is preprocessed through scaling, filtering, and the extraction of diverse condition indicators, which are crucial for developing robust predictive algorithms. Additionally, the framework supports user-defined model development and evaluation, enabling the training, optimization, and selection of optimal PdM algorithms, encompassing both machine learning and deep learning techniques.

2. Framework overview.

The proposed framework encompasses a comprehensive suite of components designed to facilitate the development of Predictive Maintenance (PdM) solutions. This section provides an overview of the key components comprising the framework architecture (Fig 2.).

The framework includes a robust data generation module capable of producing synthetic vibration data and simulating faults in critical machinery components such as bearings, gearboxes, and shafts. This functionality enables users to generate data representative of real-world scenarios, facilitating the rapid prototyping of PdM solutions.

A critical aspect of PdM solution development involves preprocessing raw data to ensure its suitability for algorithmic analysis. The framework offers a flexible preprocessing module where users can perform tasks such as scaling, filtering, and normalization, particularly crucial when working with real data. This preprocessing step enhances the quality and reliability of the data, laying a solid foundation for subsequent analysis.

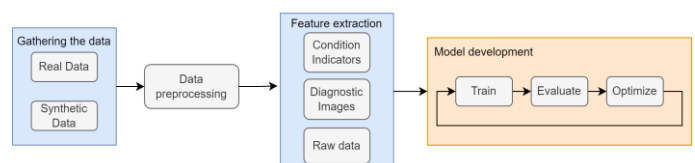


Fig. 2 High-level framework overview.

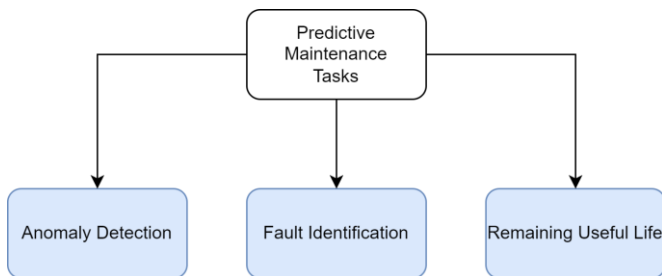


Fig. 1 Predictive Maintenance tasks diagram.

Predictive Maintenance (PdM) encompasses three core tasks (Fig 1.): anomaly detection, fault identification, and estimation of the remaining useful life (RUL). Anomaly detection involves monitoring equipment to identify deviations from normal operational behavior, signaling potential issues before they escalate. Fault identification goes a step further by diagnosing the specific nature and cause of detected anomalies, enabling targeted corrective actions [9, 10]. Lastly, the estimation of the remaining useful life predicts the time remaining before an asset is likely to fail, allowing for optimal scheduling of maintenance activities to prevent unexpected breakdowns and minimize downtime. Together, these tasks ensure a comprehensive and proactive approach to maintaining equipment health and performance.

Currently, most Predictive Maintenance (PdM) solutions are developed using scripts written in MATLAB or Python. These scripts often leverage a variety of MATLAB toolboxes and Python packages to create new algorithms. While MATLAB offers a comprehensive and well-suited solution for PdM, its high cost can be prohibitive. Consequently, in the fields of Deep Learning (DL) and Machine Learning (ML), scientists often prefer open-source

The feature extraction module provides users with a range of options tailored to their specific modeling requirements. Whether utilizing diagnostics images, condition indicators, or raw data, this module offers diverse feature extraction techniques to capture relevant information from the data. By extracting meaningful features, users can enhance the predictive capabilities of their models and uncover valuable insights into equipment health.

Central to the framework is the model development module, where users can design, evaluate, and optimize custom PdM models. Leveraging a combination of machine learning and deep learning methodologies, users have the flexibility to create models tailored to their unique application domains. This module also facilitates the optimization of model hyperparameters, ensuring optimal performance and generalization.

In the final stage of PdM solution development, users can evaluate the performance of their custom models and compare them against pre-existing implementations. This allows for comprehensive benchmarking and validation, enabling users to assess the efficacy of their solutions and make informed decisions regarding model selection and refinement. Additionally, users can leverage pre-existing models as starting points for their own implementations, further expediting the development process.

3. Data Generation

The data generation component of the framework employs sophisticated techniques to simulate various machine malfunctions and generate synthetic vibration data [11]. Through the application of specific amplitude and frequency modulation methods, the framework can accurately replicate fault conditions within machinery components. Certain faults, such as those occurring in shafts and gearboxes, are represented as sinusoidal components, while others, such as bearing faults, are modeled as decaying pulses. Moreover, the framework allows for the application of randomly generated frequency response functions corresponding to the machine under consideration, a technique commonly employed in modal analysis to identify resonant frequencies. This function is characterized by non-periodic and non-monotonic amplitude modulation, reflecting the dynamic nature of vibration signals produced by machines operating at varying speeds. By combining these features and parameters, the framework can simulate a range of faults including:

- shaft imbalance,
- bearing defects,
- and gearbox faults,

thereby enabling the generation of synthetic data representative of diverse operational conditions. This parametrization capability further enhances the versatility of the framework, facilitating the simulation of different fault scenarios for comprehensive testing and analysis.

4. Data preprocessing.

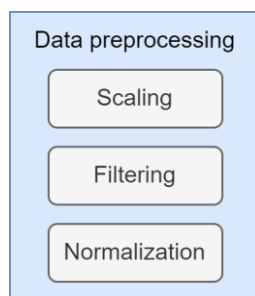


Fig. 3 Data preprocessing component.

The data preprocessing component of the framework is integral to ensuring that the data is suitably prepared for subsequent analysis

and model development. This component is comprised of three key parts (Fig. 3.):

- **Scaler** - The scaler module facilitates the scaling of measured values according to specified measurement parameters, like amplification and sensitivity.
- **Filtering** - The filtering module provides tools to design and apply various types of filters to the data. Users can implement low, high and band-pass filters (Fig. 4.).
- **Normalization** - The normalization module applies z-score normalization to the data, transforming it into a standard normal distribution. This process ensures that the data has a mean of zero and a standard deviation of one, facilitating improved performance and stability in machine learning algorithms.

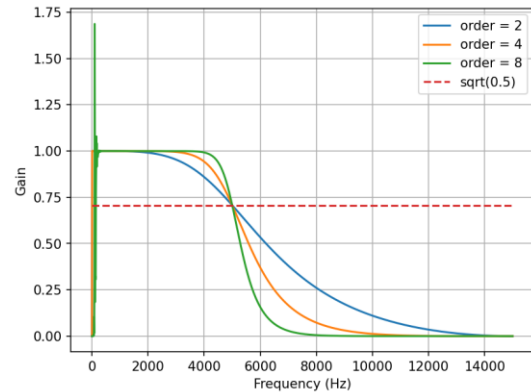


Fig. 4 Example of a band-pass filter (from 2 to 5000 [Hz]).

5. Feature extraction

The feature extraction component of the framework provides a comprehensive suite of tools to calculate various indicators and diagnostic images that are essential for developing robust predictive maintenance models [12]. This component supports the extraction of features in the time domain, frequency domain, and specific envelope indicators related to bearing faults, as well as the generation of diagnostic images.

Time Domain Indicators

The framework allows for the calculation of several time domain indicators, including:

- **Peak-to-peak (PP)**: The difference between the maximum and minimum values in the signal.
- **Root mean square (RMS)**: The square root of the mean of the squares of the values, reflecting the power content of the signal.
- **Crest factor (CF)**: The ratio of the peak value to the RMS value, indicating the presence of peaks.
- **Shape factor (SF)**: The ratio of the RMS value to the mean of the absolute values, providing insight into the waveform shape.
- **Standard deviation (STD)**: A measure of the amount of variation or dispersion in the signal.
- **Kurtosis**: A measure of the "tailedness" of the probability distribution of the signal.
- **Velocity root mean square (VRMS)**: The RMS value of the velocity signal.

Frequency Domain Indicators

In the frequency domain, the framework can calculate:

- **Mean frequency (MF)**: The average frequency content of the signal.
- **Frequency Center (FC)**: The center of mass of the power spectrum.
- **Three maximal amplitude peaks and their corresponding frequencies**: The highest peaks in the frequency spectrum and their associated frequencies.

Envelope Indicators

For bearing fault detection, the framework includes envelope indicators that are related to specific bearing fault frequencies:

- Fundamental Train Frequency (FTF): Related to the cage or train of the bearing.
- Ball Pass Frequency of the Outer Race (BPFO): The frequency at which a ball passes over a defect on the outer race.
- Ball Pass Frequency of the Inner Race (BPFI): The frequency at which a ball passes over a defect on the inner race.
- Ball Spin Frequency (BSF): The frequency at which a ball spins within the bearing.

Diagnostic Images

The framework also provides capabilities for generating various diagnostic images, which are useful for visual analysis and model input:

- Fast Fourier Transform (FFT): Converts the time-domain signal into its frequency components.
- Power Spectral Density (PSD): Estimates the power distribution of a signal over frequency.
- Short-Time Fourier Transform (STFT): Represents the signal in both time and frequency domains.
- Continuous Wavelet Transform (CWT): Provides a time-frequency representation of the signal.
- Kurtogram: A visual tool to identify the frequency bands where kurtosis is maximized, indicating potential faults.

6. Model development

The model development, evaluation, and comparison component of the framework offers users a robust environment to design, optimize, and assess their predictive maintenance (PdM) models. Users can develop their models utilizing popular machine learning libraries such as TensorFlow and Scikit-learn, depending on the specific algorithm requirements [13].

Model Development

The framework supports the creation and customization of models using a wide array of machine learning (ML) and deep learning (DL) algorithms. By leveraging TensorFlow for DL models and Scikit-learn for ML algorithms, users can construct models tailored to their specific PdM applications.

Optimization Algorithms

A key feature of the framework is its integration of advanced optimization algorithms to enhance model performance. Users can utilize:

- Grid Search - A systematic approach to hyperparameter tuning by exhaustively searching through a specified parameter grid.
- Random Search - An alternative to grid search that randomly samples hyperparameters, often yielding comparable performance with reduced computational cost.
- Bayesian Optimization - A probabilistic model-based approach that efficiently navigates the hyperparameter space to find optimal settings.
- Hyperband - A resource-efficient optimization algorithm that dynamically allocates resources to promising hyperparameter configurations, particularly suited for DL models.

Base Solutions and Comparison

The framework provides a set of pre-implemented base solutions that users can employ for benchmarking purposes. These baseline models facilitate a straightforward comparison, enabling users to

evaluate the performance of newly developed algorithms against established standards.

Automated Evaluation

To streamline the evaluation process, the framework automatically generates confusion matrices (Fig 5.) and computes essential performance metrics, including precision, accuracy, recall, and the F1 score, where applicable. These metrics provide a comprehensive assessment of model performance, aiding users in the selection and refinement of their PdM algorithms.

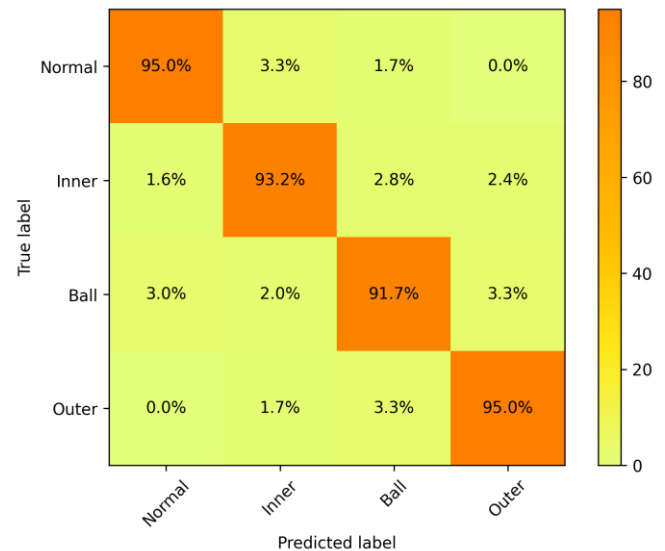


Fig. 5 Example confusion matrix.

7. Conclusions

The proposed architecture allows for the rapid, scalable, and adjustable development of Predictive Maintenance (PdM) solutions. By leveraging well-established packages such as NumPy, SciPy, TensorFlow, Matplotlib, and Scikit-learn, the framework ensures robustness and flexibility in handling specific tasks associated with PdM.

One of the key advantages of this framework is its capability to generate synthetic data, which can be particularly useful in providing additional information to enhance algorithm performance. This feature significantly reduces the initial dependency on real-world data collection, thereby accelerating the prototyping phase.

Furthermore, the framework enables users to benchmark their solutions against predefined baseline models. This comparative capability is a significant advantage, as it allows for an objective evaluation of new algorithms, facilitating the identification of the most effective approaches.

However, it is important to note that the current framework does not address the deployment phase of PdM solutions. Deployment is a critical aspect that involves integrating developed models into real-world systems, ensuring they operate efficiently under actual operating conditions. Future work should focus on incorporating deployment capabilities to provide a comprehensive end-to-end solution for PdM.

Overall, the architecture presented offers a robust platform for the development of PdM solutions, with strengths in synthetic data generation, comprehensive data preprocessing, and advanced model development and evaluation. By addressing the deployment phase in future iterations, the framework can become an even more powerful tool for predictive maintenance applications.

References

1. Hu, Yang, et al. "Prognostics and health management: A review from the perspectives of design, development and decision." *Reliability Engineering & System Safety* 217 (2022): 108063.M.
2. Ran, Yongyi, et al. "A survey of predictive maintenance: Systems, purposes and approaches." *arXiv preprint arXiv:1912.07383* (2019).
3. Krupitzer, Christian, et al. "A survey on predictive maintenance for industry 4.0." *arXiv preprint arXiv:2002.08224* (2020).
4. Tiddens, Wieger, Jan Braaksma, and Tiedo Tinga. "Decision framework for predictive maintenance method selection." *Applied Sciences* 13.3 (2023): 2021.
5. Namuduri, Srikanth, et al. "Deep learning methods for sensor based predictive maintenance and future perspectives for electrochemical sensors." *Journal of The Electrochemical Society* 167.3 (2020): 037552.
6. Lalik, Krzysztof, et al. "Simulation Modeling for Mass Customization Furniture Production: Investigating Production Volume and Machine Load in scope of Industry 4.0 standard." *Industry 4.0* 8.4 (2023): 116-122.
7. Lalik, Krzysztof, et al. "The steam pressure impacts reducing system for a biomass cogenerator based on monitoring of the frequency characteristics of the steam actuator." *Vibrations in Physical Systems* 30.2 (2019).
8. Lalik, Krzysztof, et al. "Self-powered wireless sensor matrix for air pollution detection with a neural predictor." *Energies* 15.6 (2022): 1962.
9. Bałazy, P., Paweł Gut, and Paweł Knap. "Neural classifying system for predictive maintenance of rotating devices." *IOP Conference Series: Materials Science and Engineering*. Vol. 1239. No. 1. IOP Publishing, 2022.
10. Knap, Paweł, Krzysztof Lalik, and Patryk Bałazy. "Boosted Convolutional Neural Network Algorithm for the Classification of the Bearing Fault Form 1-D Raw Sensor Data." *Sensors* 23.9 (2023): 4295.
11. Jablonski, Adam. *Condition monitoring algorithms in Matlab*. Springer Nature, 2021.
12. Oppenheim, Alan V. *Discrete-time signal processing*. Pearson Education India, 1999.
13. Aurélien Géron. „Hands-on Machine Learning with Scikit Learn, Keras, and TensorFlow, Concepts, Tools, and Techniques to Build Intelligent Systems (second edition)”. Sebastopol, CA: O’Reilly Media, Inc., 2019.

Statistical processing of data from the operation of a photovoltaic power plant

Svilen Rachev¹, Raul Turmanidze², Vazha Shilakadze²

¹Technical University – Gabrovo, Bulgaria

²Georgian Technical University (GTU) – Tbilisi, Georgia

srachev@mail.com, inform@gtu.ge, Vazhashilakadze@gmail.com

Abstract: The paper deals with an operating photovoltaic plant in Bulgaria. The wide application of photovoltaic plants in the energy system is known. At the same time, subject matters about their normal functioning are fundamental. The goal of the paper set is to analyze data from the operation of a photovoltaic power plant, which is ultimately related to improving its behavior. Relevant conclusions have been done.

Keywords: SOLAR ENERGY, PHOTOVOLTAIC SYSTEMS, DATA PROCESSING, SYSTEMS OPERATION, STATISTICS

1. Introduction

The development and level of energy resource usage largely determine the standard of living of any industrialized nation. In doing so, the most state-of-the-art technologies, materials, and production methods must be applied.

The use of so-called 'renewable energy sources' (RES) in the world is constantly growing. The goals are to achieve sufficient productivity with rational energy consumption and compliance with environmental pollution norms.

For many years, the usage of solar energy has been a matter of great importance. Standard energy resources such as oil, natural gas and coal are gradually being depleted, and new deposits are being developed less and less, as they either have small estimated reserves and will be very expensive to extract, or are too deep, which also makes extraction more expensive. The other important point is the pressing issue of protecting the environment from technological pollution when using traditional methods of energy extraction [1].

An essential problem of humanity is the production of electricity. Obtaining electrical energy from nuclear power plants (NPPs) is by no means the best alternative to thermal power plants (TPPs), as there is a danger of nuclear contamination, and the life of the NPPs themselves is limited to certain years, after which they must be 'buried' in expensive facilities. Hydroelectric power plants (HPPs), on the other hand, are of limited application due to the specific conditions they require. Moreover, for all these sources of energy, a lot of funds are needed for their maintenance.

Probably most knowledgeable people know that the end of 'petroleum humanity' is approaching. A real shortage of liquid fuels will occur. That is why, in recent decades, scientists from all over the world have focused their efforts on the development and implementation of technologies for the extraction of energy from RES.

One of the developing directions is solar energy usage. The huge amount of solar energy reaching the Earth and its immediate conversion into electricity is not only ecologically clean but also satisfy a significant part of all current and future needs of humanity. The production of electricity from the sun is among the most current directions in the development of modern energy and has many advantages.

In addition, the Renewable Energy Directive RED II (Directive on the promotion of the use of energy from RES) together with the European Green Deal are driving a radical rethink of energy investment across the EU [2, 3].

Bulgaria can be divided into different sunny zones, with the average annual duration of sunshine being about 2150 hours (about 49% of the maximum possible). Although 77% of its territory is occupied by forests, arable land, and nature reserves, the remaining territory could be used for solar power plants under certain conditions.

The geographical conditions of Bulgaria determine a resource of 1300÷1700 kWh/m² average annual radiant flow (amount of radiant energy for all wavelengths falling on a unit area of the country's surface). There are three pretenders for the sunniest city in Bulgaria - Velingrad, Sandanski, Chepelare in the last decade, but it is difficult to say exactly who is the winner.

Regarding the situation in Bulgaria, attention should be paid to several starting points. The energy strategy foresees that in the coming years, the consumption of electrical energy will grow by about 2% per year. In the production of electrical energy for 2023, 39.2% falls on TPPs, 40.2% on NPP 'Kozloduy', 7.7% on HPPs, 8.3% on photovoltaic power plants (PVPPs), and 3.9% on wind power plants (WPPs) [4].

On the other hand, the Energy Act of Bulgaria and the State Energy and Water Regulatory Commission guarantee a premium purchase of all electrical energy produced by RES at a preferential price, higher than the purchase price for the rest of the power plants in the country [5].

In connection with everything mentioned above, the goal of the paper is also set – to analyze data from the operation of a photovoltaic power plant, which is ultimately related to improving the behavior of these energy sources.

2. Basic theoretical statements in statistical processing and data analysis

Statistics is a mathematical subject that studies the extraction of information through the analysis and interpretation of empirical data using probability theory. Statistical activity also includes the planning and organization of data collection through surveys and experiments. Mathematical statistics arose in connection with the needs of empirical science and stand out from most branches of mathematics by its applied orientation. Statistical methods are applied in a wide range of fields, such as the natural and social sciences, public administration, and business [6].

One of the major subfields of mathematical statistics is descriptive statistics, which deals with the summarization of systematized data. It is of particular importance in empirical research and the description of experimental results. Through the methods of mathematical statistics, the data can be analyzed, and, based on this, conclusions can be drawn about the regularities contained in them.

Below are some definitions specific to mathematical statistics given [7].

▪ **Mass phenomenon** – when certain regularities valid for the community of units as a whole are repeated in many individual phenomena.

▪ **Statistical aggregation** – this is a collection of a large number of units (cases) that characterize the mass phenomenon.

▪ **Statistical signs** – express the properties (qualities, manifestations, and relations) of the individual units of a given phenomenon, and in general statistical signs are qualitative and quantitative.

▪ **Statistical units** – these are the individual units (cases, representatives) that form the statistical aggregation. Through statistical grouping, the individual statistical units are distributed into groups, distinguished based on the observed signs characterizing the aggregation.

▪ **Statistical data** – this is the collected, organized, and analyzed information necessary for the study of a given phenomenon.

▪ **Aggregation and sampling** – accumulated data can generally be thought of as measurements of certain properties of objects selected from some large *aggregation*, and information about certain characteristics of items is recorded by *sampling*.

▪ **Characteristics of the location** – there are several characteristics of the location of the empirical data set. The most common is the average (*arithmetic mean*) value, in short, it represents the value about which the entire empirical distribution can be 'balanced'. For raw data (sample values) $x_1, x_2, \dots, x_n$, the *arithmetic mean* value is:

$$\bar{x} = n^{-1} \cdot \sum_{i=1}^n x_i \quad i = 1, 2, \dots, n \quad (1)$$

The *geometric mean* value can also be used as a characteristic of the location. In the case of sample volume n , the *geometric mean* is defined as:

$$(x_1 x_2 \dots x_n)^{\frac{1}{n}} \quad (2)$$

▪ Dispersion characteristics

A commonly used characteristic of the dispersion is the *arithmetic mean deviation* δ , which can be absolute or relative:

$$\bullet \text{ absolute } \delta = \frac{\sum |x_i - \bar{x}|}{n} \quad (3)$$

$$\bullet \text{ relative } V_{\delta} \% = \frac{\delta}{\bar{x}} \cdot 100 \quad (4)$$

One of the most commonly used characteristics of data dispersion is the *root mean square deviation* σ . First, the square of this quantity, called *dispersion* σ^2 , has to be determined:

$$\sigma^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1} \quad (5)$$

The *root mean square deviation* is defined as the positive square root of the *dispersion*:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \quad (6)$$

3. Results obtained

Following the set objective, below are presented processed data obtained from measurements of certain electrical quantities with static electronic electricity meters. Reported: voltage, grid frequency, active power, reactive power, solar radiation, air temperature, module surface temperature. The data is for a PVPP with peak power 25 MWp; location – N42.58674674328831, E25.46936206803762; electrical connection to the power system – 110 kV; 2 pcs available step-up transformers by 16 MVA rated power; a combined module (circuit breaker + disconnector) used to save space by obtaining a small field; single-linear circuit of a switchgear 20/110 kV; solar inverters type PVS800-57 (100÷500 kW); single PV modules type HR-240P-18-Bb with a power of 240 W each.

A general view of the considered PVPP is presented in Fig. 1, and in Fig. 2 – SCADA (control and monitoring system) screen.

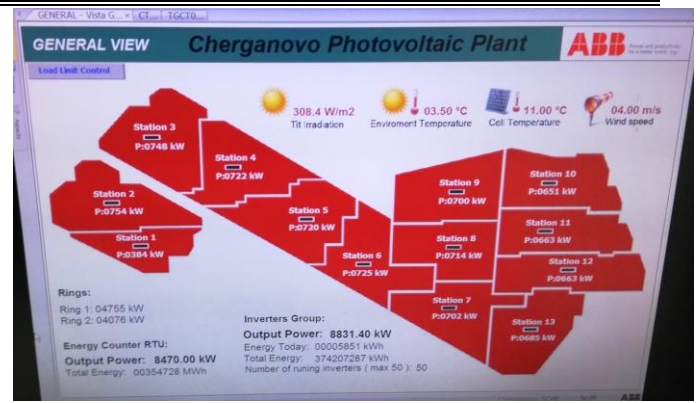


Fig. 1 General view of the PVPP considered.

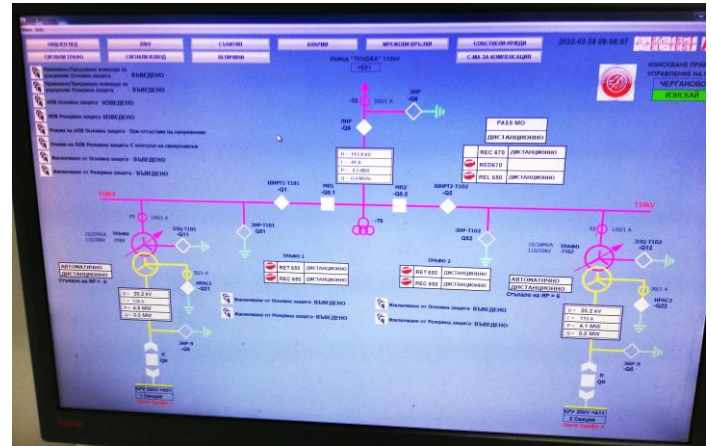


Fig. 2 SCADA screen for the PVPP considered.

Part of the data available for one year is given in the Appendix – only for the daylight part of a particular day, during which generation of electrical energy is possible. The measurement interval (recording or sampling frequency) is 15 minutes, which means a significant amount of data (4 values in 1 hour, 96 values per day).

Table 1 presents the results of the processing reported data during the operation of the PVPP, and the following figures show the graphical change of some quantities. The table and figures prepared, including calculation results, are implemented according to the rules of mathematical statistics [8]. Additionally, analytical expressions for approximating functions (polynomials) are derived, convenient for further calculations.

Table 1: Statistical indicators for the PVPP considered

Month (year 2020)	Total active power, P [MW]	Arithmetic mean value of active power, $\bar{P}$ [MW]	Absolute arithmetic mean deviation of the active power, δ [MW]	Relative arithmetic mean deviation of the active power, V_{δ} [%]	Root mean square deviation of the active power, σ [MW]
V	16124.02	520.13	494.12	94.99	512.69
VI	16915.05	563.84	535.64	94.99	553.02
VII	19020.63	613.57	582.89	94.99	601.46
VIII	19129.22	617.07	586.53	95.05	605.23
IX	16480.39	549.35	521.88	94.99	538.82

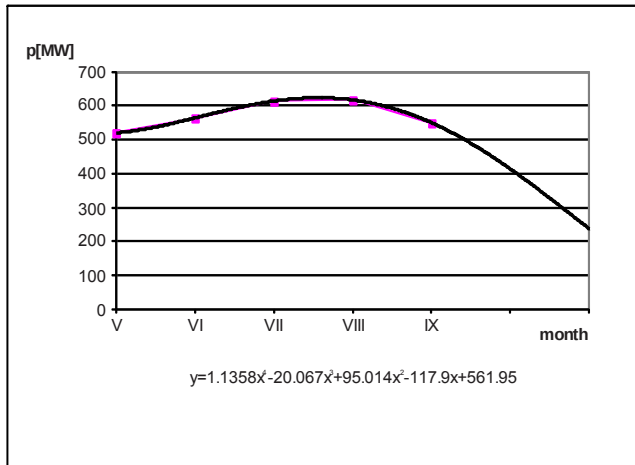


Fig. 3 Change in arithmetic mean value of active power (year 2020).

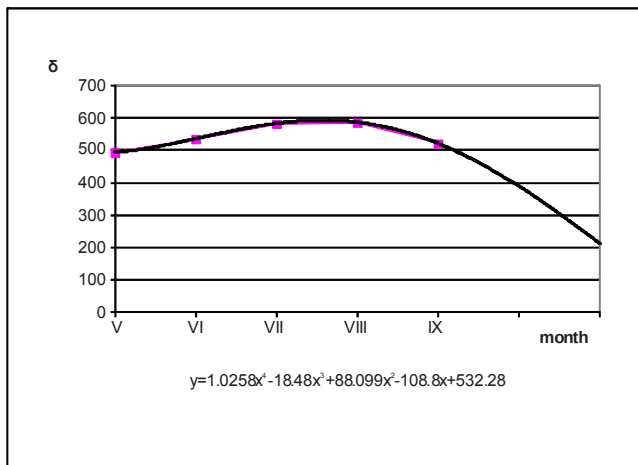


Fig. 4 Change in absolute arithmetic mean deviation of active power δ (year 2020).

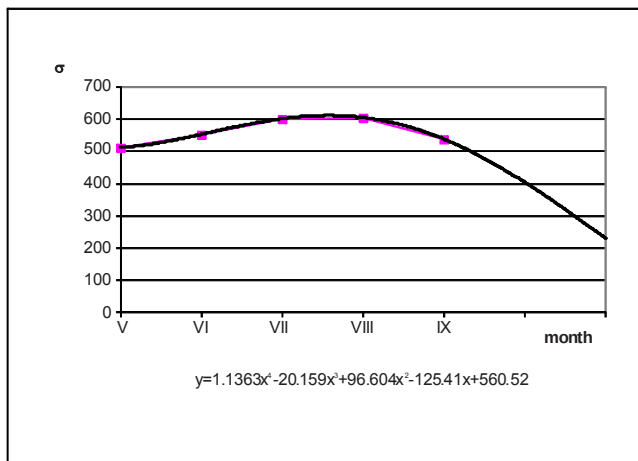


Fig. 5 Change in root mean square deviation of active power σ (year 2020).

4. Conclusions

The treated topic is current, as the results of some developments in this area have not yet been put into practice.

The processed real statistical set of statistical units, which are empirical data on the active and reactive power of a specific PVPP, allows certain regularities to be established based on the analysis.

The dispersion measures *arithmetic mean* and *root mean square deviation* have been determined. It is necessary to clarify that statistical treatments use the data values as they are, and zero is also a value, not the absence of data.

The root mean square and arithmetic mean deviations are the main characteristics of statistical distributions. These are called the parameters of the statistical distribution. The arithmetic mean deviation has the property of underestimating the differences compared to the standard deviation. The root mean square deviation acts as the most accurate and adequate measure of aggregation dispersion and is, therefore, the most widely used. Regarding dispersion, the aim is always to keep it to a minimum.

Despite some inconveniences in the use of RES, the production of 'green energy' and its storage for later use will be at the heart of the sustainable energy of the future.

5. Acknowledgments

The implementation of this paper is thanks to the support from:

- the University Project 2404S 'Applied mathematical research on energy and economic efficiency of electrical equipment in the conditions of energy transition', financed by the Ministry of Education and Science of the Republic of Bulgaria.
- the Project BG05M2OP001-1.002-0023 Competence Center 'Intelligent Mechatronic, Eco- and Energy-Saving Systems and Technologies' financed by the Operational Program 'Science and Education for Intelligent Growth' of the European Regional Development Fund.

6. References

1. <https://bg.wikipedia.org/wiki/>
2. <https://eur-lex.europa.eu/>
3. <https://commission.europa.eu/>
4. <https://www.eso.bg/>
5. <https://www.dker.bg/>
6. Moses, Lincoln E. Think and explain with statistics. ADDISON-WESLEY, 1986. pp. 1-3.
7. Moore, David. Teaching Statistics as a Respectable Subject. // Statistics for the Twenty-first Century. Washington, DC, The Mathematical Association of America, 1992. pp. 14-25.
8. Chance, Beth L. Investigating Statistical Concepts, Applications, and Methods. Duxbury Press, 2005.

Appendix**A piece of measured data for a specific time period**

PV Power Plant 25 MWp	Active power					Reactive power				
	Current Value	Average Value	Integral Value	Minimum Value	Maximum Value	Current Value	Average Value	Integral Value	Minimum Value	Maximum Value
02/08/2020 06:30:00	-0.06	-0.07	-0.02	-0.07	-0.06	-0.02	-0.02	-0.01	-0.04	-0.02
02/08/2020 06:45:00	-0.56	-0.28	-0.07	-0.56	0.00	-0.07	-0.02	-0.01	-0.07	-0.02
02/08/2020 07:00:00	-1.06	-0.76	-0.19	-1.06	-0.56	-0.14	-0.10	-0.03	-0.17	0.17
02/08/2020 07:15:00	-2.03	-1.68	-0.42	-2.08	-1.06	-0.11	-0.11	-0.03	-0.15	-0.07
02/08/2020 07:30:00	-3.62	-2.85	-0.71	-3.62	-2.03	-0.12	-0.25	-0.06	-0.43	0.05
02/08/2020 07:45:00	-4.98	-3.99	-1.00	-4.98	-3.61	-0.15	-0.15	-0.04	-0.38	0.15
02/08/2020 08:00:00	-6.12	-4.81	-1.20	-6.12	-3.42	0.01	-0.03	-0.01	-0.33	0.18
02/08/2020 08:15:00	-6.52	-6.67	-1.67	-6.88	-6.12	0.00	0.02	0.00	-0.35	0.20
02/08/2020 08:30:00	-8.00	-7.11	-1.78	-8.00	-5.70	0.00	0.05	0.01	-0.21	0.21
02/08/2020 08:45:00	-9.57	-8.76	-2.19	-9.57	-8.00	0.23	0.07	0.02	-0.22	0.45
02/08/2020 09:00:00	-11.20	-10.30	-2.58	-11.20	-9.57	0.25	0.17	0.04	-0.45	0.50
02/08/2020 09:15:00	-12.37	-11.80	-2.95	-12.37	-11.20	0.38	0.14	0.03	-0.38	0.75
02/08/2020 09:30:00	-13.34	-12.91	-3.23	-13.34	-12.37	0.40	0.30	0.07	0.00	0.89
02/08/2020 09:45:00	-14.51	-14.00	-3.50	-14.51	-13.34	0.42	0.59	0.15	0.00	1.34
02/08/2020 10:00:00	-15.73	-15.05	-3.76	-15.73	-14.51	0.88	1.03	0.26	0.42	1.58
02/08/2020 10:15:00	-16.86	-16.26	-4.06	-16.86	-15.73	1.66	1.46	0.37	0.54	1.83
02/08/2020 10:30:00	-17.78	-17.36	-4.34	-17.78	-16.86	1.91	1.80	0.45	1.47	1.99
02/08/2020 10:45:00	-18.63	-18.26	-4.57	-18.63	-17.78	2.12	2.10	0.53	1.81	2.28
02/08/2020 11:00:00	-19.13	-19.03	-4.76	-19.25	-18.63	2.51	2.39	0.60	2.12	2.64
02/08/2020 11:15:00	-19.77	-19.48	-4.87	-19.77	-19.13	2.54	2.65	0.66	2.43	2.82
02/08/2020 11:30:00	-20.60	-20.08	-5.02	-20.60	-19.77	2.92	2.82	0.70	2.54	2.98
02/08/2020 11:45:00	-21.60	-20.95	-5.24	-21.60	-20.44	3.42	3.09	0.77	2.86	3.42
02/08/2020 12:00:00	-18.68	-20.94	-5.24	-22.23	-18.52	3.88	3.54	0.88	3.16	3.95
02/08/2020 12:15:00	-17.48	-15.11	-3.78	-20.96	-9.65	2.57	3.63	0.91	2.49	4.38
02/08/2020 12:30:00	-22.26	-21.61	-5.40	-23.37	-17.37	2.36	1.61	0.40	0.00	3.59
02/08/2020 12:45:00	-12.02	-19.03	-4.76	-23.18	-10.86	4.35	4.09	1.02	2.18	5.03
02/08/2020 13:00:00	-22.78	-18.72	-4.68	-23.17	-10.83	0.49	3.13	0.78	0.00	4.88
02/08/2020 13:15:00	-23.17	-22.42	-5.61	-23.24	-20.86	4.68	2.99	0.75	-0.41	4.90
02/08/2020 13:30:00	-23.36	-15.53	-3.88	-23.36	-6.07	4.74	4.49	1.12	3.47	4.95
02/08/2020 13:45:00	-7.78	-15.00	-3.75	-23.36	-7.78	4.89	2.29	0.57	-0.22	5.02
02/08/2020 14:00:00	-16.32	-10.11	-2.53	-16.32	-7.51	0.23	1.83	0.46	-0.49	4.98
02/08/2020 14:15:00	-13.14	-19.95	-4.99	-24.06	-12.77	1.96	0.26	0.06	-0.44	1.96
02/08/2020 14:30:00	-19.44	-12.09	-3.02	-19.44	-7.09	0.51	3.53	0.88	0.50	5.62
02/08/2020 14:45:00	-21.94	-15.73	-3.93	-21.94	-12.59	2.89	0.92	0.23	-0.45	2.89
02/08/2020 15:00:00	-9.74	-15.81	-3.95	-23.34	-8.10	4.12	1.71	0.43	0.00	4.12
02/08/2020 15:15:00	-14.18	-11.29	-2.82	-16.53	-7.31	0.25	2.29	0.57	-0.22	4.99
02/08/2020 15:30:00	-18.87	-15.67	-3.92	-22.02	-10.32	1.41	0.64	0.16	-0.43	2.06
02/08/2020 15:45:00	-9.39	-13.71	-3.43	-18.87	-9.39	2.76	1.86	0.46	0.00	4.23
02/08/2020 16:00:00	-4.74	-5.23	-1.31	-9.39	-4.60	0.25	1.15	0.29	0.00	2.76
02/08/2020 16:15:00	-4.90	-4.80	-1.20	-4.95	-4.66	0.00	0.02	0.00	-0.18	0.25
02/08/2020 16:30:00	-4.02	-4.69	-1.17	-5.30	-3.83	0.00	0.00	0.00	-0.35	0.18
02/08/2020 16:45:00	-6.35	-7.47	-1.87	-13.77	-4.02	-0.15	-0.01	0.00	-0.33	0.18
02/08/2020 17:00:00	-4.30	-5.68	-1.42	-8.55	-4.25	0.20	0.17	0.04	-0.35	1.37

Use of precise implantological surgical guides in reconstructions adjacent to teeth with unusual anatomy - use of Dentistry 4.0 technology

Lech B. Dobrzański

Medical and Dental Engineering Centre for Research, Design and Production ASKLEPIOS,
ul. Jana III Sobieskiego 12/1, 44-100 Gliwice, Poland

Corresponding e-mail address: dobrzanski@centrumasklepious.pl

ORCID identifier: <https://orcid.org/0000-0002-4671-3060>

Abstract: This study aims to present the practical application of the Dentistry 4.0 concept based on obtaining data on the patient's intraoral situation and bone base using CBCT, processing them into a digital model, creating a digital twin, and then developing an intra-procedural navigation procedure through a dedicated surgical guide and then designing and manufacturing, using 3D printing, implant-prosthetic restorations. The study describes the results of the author's work, indicating the engineering aspects of implant prosthetic treatment based on the description of cases related to the reconstruction of single missing teeth using dental implants implanted in the case of difficult anatomical conditions of the bone base and/or adjacent teeth, with a discussion of the material selection methodology, technological and structural design, using additive manufacturing.

The technology for the design, manufacture and application of implant-prosthetic restorations developed by the author, preceded by a fully navigated implantation procedure of dental screw implants, illustrates in practice the full application of the Dentistry 4.0 concept, where the latest technologies, including primarily computer-aided design and computer-aided CAD/CAM manufacturing, the use of a digital twin, supporting surgical procedures through the use of templates navigating the operator's actions and additive manufacturing allow for a radical increase in the availability of implant-prosthetic solutions for patients with difficult anatomical conditions, both due to a limited bone base and anomalies of the anatomy of adjacent teeth. Thanks to the latest technology, not only is it possible to perform this type of procedure, but it is also possible to perform the procedure in a short time, with minimal interference in the patient's tissues and ensuring the optimal shape of the prosthetic restoration itself.

Keywords: TITANIUM ALLOY, 3D PRINTING, COMPUTER-AIDED DESIGN, COMPUTER-AIDED MANUFACTURING, SURGICAL GUIDE, DENTAL ENGINEERING, DENTAL IMPLANTS

1. Introduction

Dentistry 4.0 is an original concept [1-4] of using the achievements of the latest technology consistent with Industry 4.0 [5-7] in dental engineering and dentistry to ensure maximum repeatability and predictability of the developed prosthetic solution, optimal use of tissue conditions, and maximum accuracy of the manufactured prosthetic restoration in the shortest possible time available in a specific clinical case (fig. 1).

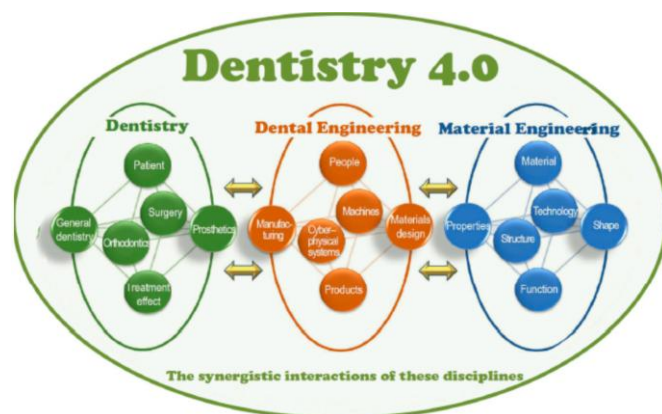


Fig. 1. General diagram of the Dentistry 4.0 model showing synergistic relations between dentistry, dental engineering, and materials engineering [8]

The design of optimal prosthetic reconstruction based on implants should always be started at the consultation visit when the patient presents with a damaged or missing tooth requiring prosthetic reconstruction. Already at this stage, the cooperation between the dentist conducting the treatment and the dental engineer begins, who supports the process of assessing the conditions in the patient's oral cavity to select the appropriate implantological or prosthetic solution properly. The basis for the consultation should be data obtained from CBCT cone beam tomography, which, combined with data obtained from an intraoral impression (made both digitally with an intraoral scanner and

traditional methods using impression materials), will allow obtaining a digital twin of the conditions in the oral cavity [9-11]. On this basis, the patient is qualified for implant treatment. At this stage, decisions are also made about possible regeneration or reconstruction procedures. In this study, the author focuses on the reconstruction of single missing teeth based on screw implants in atypical anatomical conditions of teeth immediately adjacent to the implantation zone, radically limiting the volume of the bone base that can be implanted and the case of maximum use of the natural course of the bone base in the form of the septum of the maxillofacial sinus to avoid the need for procedures to raise the floor of the maxillofacial sinus [12].

Using the Dentistry 4.0 concept, according to the model of the three most important aspects of coincidental horizontal factors (fig.2), particularly concerning CAD/CAM design and 3D printing, allows us to limit the necessary scope of the procedure [13,14]. First of all, accurate, repeatable, and easy-to-install surgical templates allow for limited interference with the patient's alveolar tissue [15-17]. Thanks to this, the doctor performing the procedure does not have to separate these tissues with a large margin, enabling visual control of the insertion of the guide drills. Then, the procedure consists of making one drill, deepening and enlarging with three drills, and creating an implant bed into which the implant is inserted. Additionally, the risk of damaging adjacent teeth or perforating the bottom of the maxillofacial sinus in the case of the upper arch or damaging the dental nerve canal in the case of the lower arch is reduced to an absolute minimum. The procedure also allows you to reduce the duration of the procedure by at least 60% [8]. This also increases the profitability of the dental clinic, which can perform more comprehensive smile reconstructions simultaneously. Additionally, the risk of complications resulting from implantation procedures is reduced by at least 50% [8].

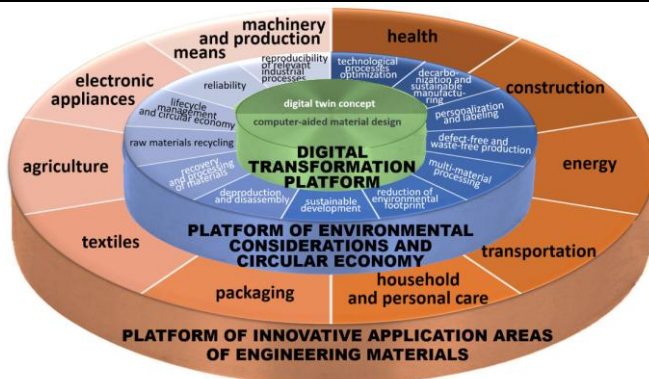


Fig. 2 The Author's model of the three most important aspects of coincidental horizontal factors concerning the development of engineering materials, widespread computerisation of technological processes, and minimisation of the environmental footprint [8]

The use of 3D printing in producing elements necessary for implant prosthetic treatment also brings significant benefits related to a radical increase in the accuracy of the elements made compared to those made using casting techniques or CNC milling technology [18]. Firstly, it is possible to reduce the weight of manufactured elements. The author's research allowed for the conclusion that printed elements are up to 25% lighter than those milled from the same design. This is because prosthetic elements have very complex, irregular shapes, which means that milling requires the use of very thin tools, the diameter of which does not exceed 1 mm. Despite this, some areas, e.g., the prosthetic bridge, are inaccessible to these tools. Additionally, CNC milling technology does not ensure perfect shape repeatability due to the need to ensure tool access in a specific production axis. The main advantage is also a radical reduction in production time, which, in the case of large prosthetic elements, can be reduced by up to 4-5 times [8,13].

All these aspects mean that 3D printing has deep justification for applications in dental engineering, especially implant prosthetic treatment procedures.

This study presents the practical application of CAD/CAM design technology using 3D printing in two technologies: SLA stereolithography using polymeric materials used to produce a surgical template plate and selective laser sintering/selective laser melting SLS/SLM in the case of tool guide elements in surgical templates and prosthetic restorations.

2. Procedure for designing an implantological and implant prosthetic treatment plan

The process of designing a prosthetic restoration begins when the doctor conducting the treatment, after examining with a cone beam computer tomography, turns to our Dental Engineering Center to prepare an implant treatment plan. The first stage of CAD design is to determine the course of the mental nerve canal, which determines the available volume for the insertion of implants, then determine the necessary distance to the neighboring teeth, which is at least 1.5 mm, so as not to damage the tissues of the nerve running to this tooth. Another necessary parameter is to ensure an appropriate distance between the implanted implants, which should be at least one diameter of the implant, thus ensuring proper introduction of prosthetic elements at the following stages and adequate blood supply and nutrition of the bone tissues around the implant. After selecting the appropriate implants, particularly their length and diameter, as well as the finishing of the implant crown, i.e., the polished area and the plan being approved by the attending physician, you can start designing the surgical template. To obtain the exact situation in the oral cavity, it is necessary to take a CBCT

photo with markers visible in x-ray examinations. Combined with a carefully made intraoral impression and a digital model of soft tissues and teeth in the supragingival section, it is possible to provide information about all tissues, including those not correctly visible in X-ray imaging. This also offers the opportunity to test the fit of the surgical template before implantation. Then, a design of the surgical template is made. If the patient has adjacent teeth, there is no need to use osseous templates. We use dental and mucosal templates. The standard fit of the template plate is 100 micrometers. In the family of templates developed by the author, the standard also includes the use of drill guide sleeves made in 3D printing and SLS/SLM technology, individually for each implant inserted. Both printed guide sleeves and sleeves placed on drills are individualized, both on the pilot and subsequent drills. It is also possible to insert the implant through the template. It is also necessary to provide an appropriate method of cooling the bones when drilling.

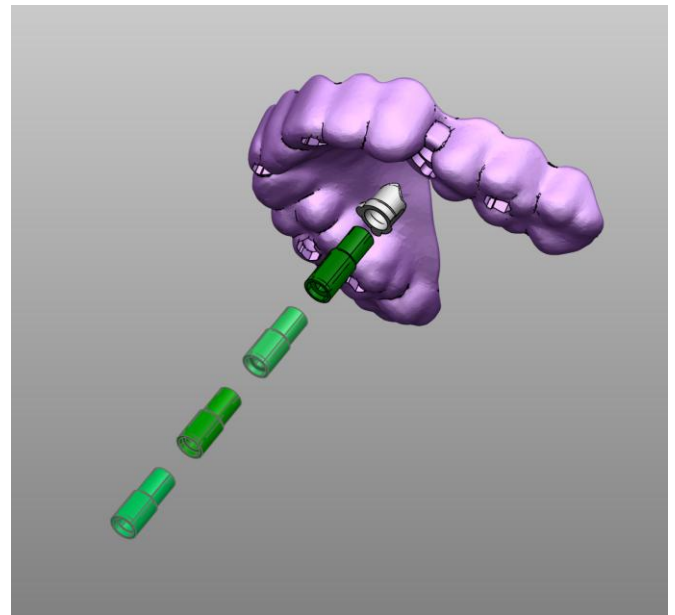


Fig. 3 The entire surgical guide system

After the procedure, a CBCT control photo is taken to assess its effectiveness and the degree of possible deviation from the assumptions.

In the next stage, after a break of 2-4 months, the prosthetic restoration is made. CAD/CAM design based on SLS/SLM 3D printing technology is also used. A design is prepared based on data obtained from the intraoral impression. Information about the patient's bone condition is not required at this stage. If the implant was implanted following the original design, it is possible to make a screw-retained restoration using mono crown and mono bridge technology, where the vectors of occlusal forces acting on the implant-prosthetic restoration system run in the axis of the implant and the mouth of the fixing screw canal are located on the occlusal surface. Thanks to this, there is no need to make an additional element, i.e., an implant connector, which is then glued to the crown. In this way, we eliminate a potential source of complications, which is the incorrect placement of the crown on the abutment during the cementation procedure in the patient's mouth. It is also possible to efficiently service such a prosthetic solution without destroying the crown, which significantly extends the life of the entire solution and minimizes the risk of irreversible complications in the soft tissues surrounding the prosthetic restoration and hard tissues surrounding the implant.

3. Case study

a) CASE 1

The case report concerns 2 cases of implant treatment in patients with single and double missing teeth in the mandible and maxilla's lateral sections.

Patient No. 1, 66 years old, came for the reconstruction of missing pterygoids of the mandible. On the right side, teeth 46 and 47 were missing, and on the left side, tooth 36. The CBCT examination revealed unusual anatomy of teeth 35 and 45, which have a double curved tooth apex, as shown in Fig 4.



Fig 4 Initial condition before starting treatment on the OPG image

The presented anomaly radically reduces the volume of the bone base in the implantation area, which can be used to perform successful implantation.

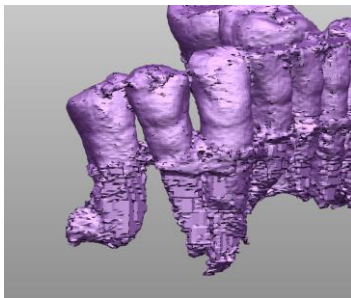


Fig 5 digital model of the patient's isolated teeth

these teeth (fig 5). The procedure failure risk without a surgical guide should be very high. An implant template was designed to consider the shifting of the implantation site to ensure sufficient bone parameters between the teeth and the implants.

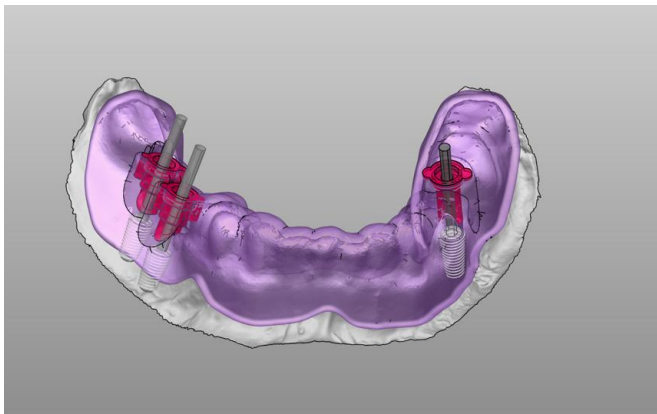


Fig 6 design of implant placement along with a model of the surgical template and all its components

A dental and mucosal template was designed and made using SLA 3D printing technology from a polymer enabling steam sterilization. (fig 6,7)

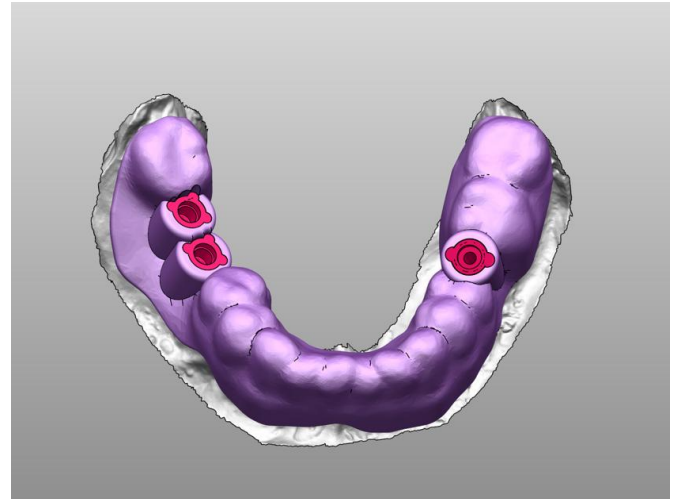


Fig 7 Model of the surgical template on a digital model

The template plate has beds designed to accommodate individual drill guide sleeves made using SLS/SLM 3D printing technology from a titanium alloy. The template was used for implantation. Fig .4 shows the initial clinical situation, and Fig 9 shows the situation after implant insertion. Fig. 8 shows the design of the prosthetic restoration framework. The success of the procedure was verified concerning the project. The design deviation is shown in Table 1

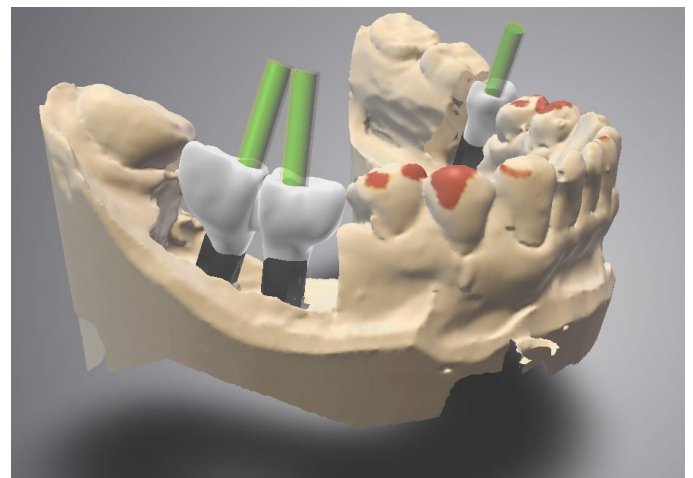


Fig 8 Design of the prosthetic restoration framework

Table 1: table of the difference in the angle of the implant insertion axis in relation to the CAD design after the procedure (in degrees)

ID	36	35	46
36	0	2,9	-
35	2,9	0	-
46	-	-	1,1

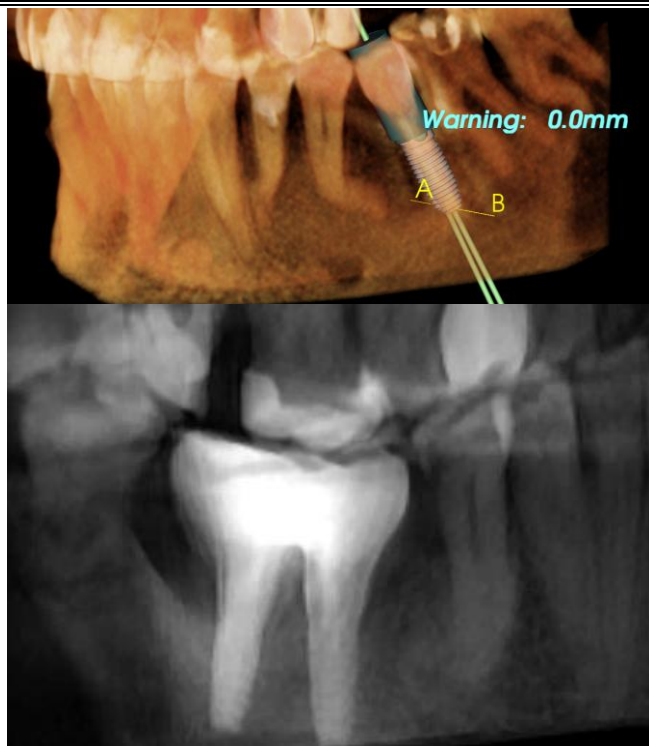


Fig 9 CBCT examination after implantation with a procedure to verify the correctness of implantation concerning the design

b) CASE 2

The design began with selecting an appropriate insertion path and selecting a standard screw implant, also taking into account maintaining a proper margin of bone tissue between the implant and the bottom of the maxillofacial sinus to avoid its perforation. Then, a model of the patient's tissues in the oral cavity was made based on a CBCT image and an intraoral impression (fig 9).

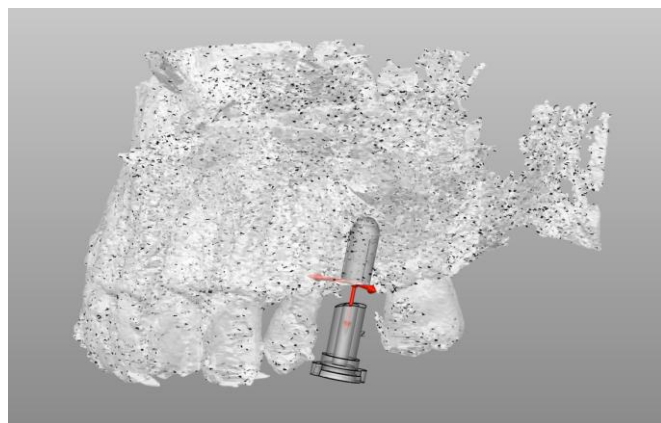


Fig 9 Design of implant placement in the digital twin of the patient's bone base along with the design of the drill guide sleeve

This was done based on a photo taken with a positioning plate, which is part of the template system developed by the Team of which the Author is the leader. After positioning all the collected data in one project,

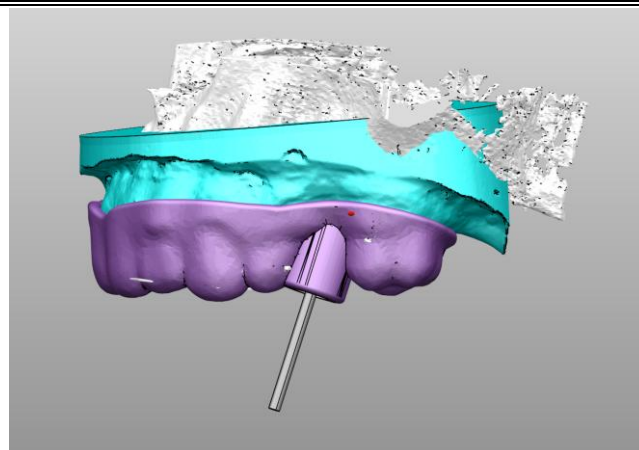


Fig 10 digital assembly of a bone base model, an intraoral scan, and a surgical template model

A template board was made using SLA technology from polymer materials. A bed was designed for a titanium alloy sleeve manufactured using SLS/SLM 3D printing technology. (Fig 10)

The template was made as a dental and mucosal template, so all the components did not encroach on the alveolar tissue zone. The treatment doctor performed the procedure according to the design (fig 11).

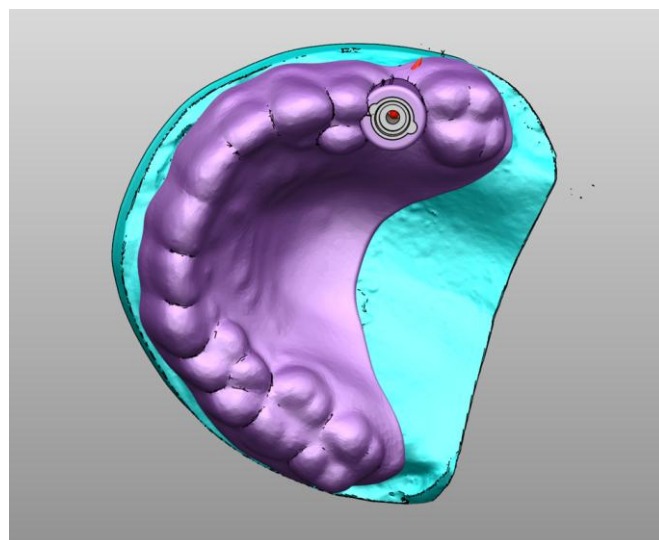


Fig 11 Surgical template digital design



Fig 11 OPG photo immediately after implantation

Then, a mono crown was made using SLS/SLM 3D printing technology, where the individual connector is integrated with the prosthetic crown (fig.12), creating one element, which was then covered with a facing layer of porcelain.

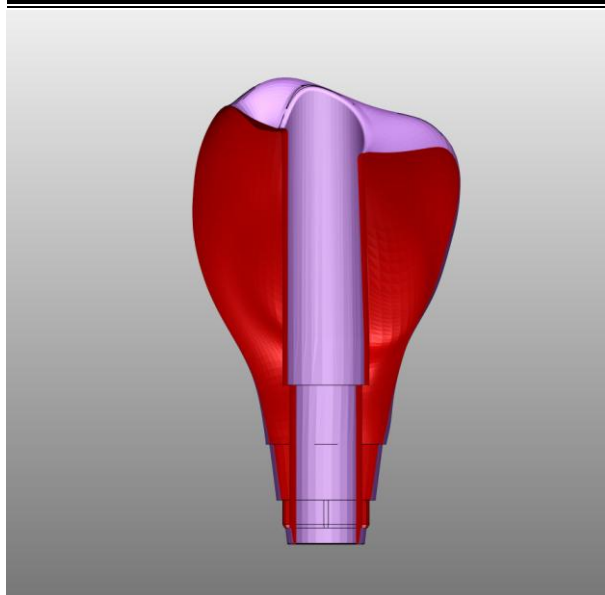


Fig. 12 Cross-section of a prosthetic restoration made as a mono crown with an integrated individual abutment.

The work has been installed and used by the patient (fig 13).



Fig 13 OPG photo immediately after installing the finished prosthetic restoration

3. Summary

According to the Dentistry 4.0 concept, advanced technology allows for a radical change in planning implantological and implant prosthetic treatments. It also enables effective and quick treatment of patients with unusual bone and anatomical conditions for effective implant treatment. Without this technology, the patients in the study would be disqualified for implantation, or the procedure would be burdened with an unacceptable risk of failure. Thanks to the use of surgical templates, not only was the procedure successful, but the procedure was short, and the procedure itself was performed minimally invasively. In addition, patients gain a prosthetic restoration that can be easily serviced. Care was also taken to ensure the correct emergence of the prosthetic crown from the gum. Despite the unusual anatomical conditions, the implants are loaded with occlusal forces along their axis, which is desirable.

Dentistry 4.0, therefore, enables a radical increase in the availability of implantological solutions for patients with difficult bone conditions, ensuring maximum usability of the prosthetic work performed.

4. References

1. L.A. Dobrzański, L.B. Dobrzański, J. Dobrzańska, Chapter 8. Ethical imperatives towards the development prospects of the triad of Dentistry 4.0, dental engineering, and nanoengineering, in: M.H. van de Voorde, G. Jeswani (eds), *Ethics in Nanotechnology: Social Sciences and Philosophical Aspects*, de Gruyter, Berlin, Germany, 2021, 157-248. DOI: <https://doi.org/10.1515/9783110719932-008>
2. L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz, L.B. Dobrzański, Effect of Biomedical Materials in the Implementation of a Long and Healthy Life Policy, *Processes* 9/5 (2021) 865. DOI: <https://doi.org/10.3390/pr9050865>
3. L.A. Dobrzański, L.B. Dobrzański, A.D. Dobrzańska-Danikiewicz, J. Dobrzańska, The Concept of Sustainable Development of Modern Dentistry, *Processes* 8/12 (2020) 1605. DOI: <https://doi.org/10.3390/pr8121605>
4. L.A. Dobrzański, L.B. Dobrzański, Approach to the design and manufacturing of prosthetic dental restorations according to the rules of the Industry 4.0, *Materials Performance and Characterization* 9/1 (2020) 394-476. DOI: <https://doi.org/10.1520/MPC20200020>
5. Rüßmann, M.; Lorenz, M.; Gerbert, P.; Waldner, M.; Justus, J.; Engel, P.; Harnisch, M. *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*; Boston Consulting Group: Boston, MA, USA, 2015. Available online: <http://web.archive.org/web/20190711124617/https://www.zvw.de/media.72e472fb-1698-4a15-8858-344351c8902f.original.pdf>
6. Kagermann, H.; Wahlster, W.; Helbig, J. Recommendations for Implementing the Strategic Initiative Industrie 4.0: Final Report of the Industrie 4.0 Working Group; Federal Ministry of Education and Research: Bonn, Germany, 2013.
7. Hermann, M.; Pentek, T.; Otto, B. *Design Principles for Industrie 4.0 Scenarios: A Literature Review*; Technische Universität Dortmund: Dortmund, Germany, 2015.
8. L.B. Dobrzański, Advanced engineering materials and materials processing technologies in dental implant and prosthetic treatment with clinical cases, *Journal of Achievements in Materials and Manufacturing Engineering* 121/1 (2023) 7-45. DOI: <https://doi.org/10.5604/01.3001.0054.3103>
9. Surovas, A. A digital workflow for modeling of custom dental implants. *3D Print Med* 5, 9 (2019). <https://doi.org/10.1186/s41205-019-0046-y>
10. Garg V, Bagaria A, Kaur G, Bhardwaj S, Hedau LR. Application of Cone Beam Computed Tomography in Dentistry- A Review. *J Adv Med Dent Scie Res* 2019;7(4): 73-76.
11. Khanna, A.B. Applications of cone beam computed tomography in endodontics. *Evid.-based endod* 5, 1 (2020). <https://doi.org/10.1186/s41121-020-00020-4>
12. Nadeem Karimbux, Hans-Peter Weber (eds), *Clinical Cases in Implant Dentistry*, by John Wiley & Sons, Inc, Oxford, 2017
13. L.A. Dobrzański, L.B. Dobrzański, A. Achtelik-Franczak, J. Dobrzańska, Application Solid Laser-Sintered or Machined Ti6Al4V Alloy in Manufacturing of Dental Implants and Dental Prosthetic Restorations According to Dentistry 4.0 Concept, *Processes* 8/6 (2020) 664. DOI: <https://doi.org/10.3390/pr8060664>
14. L.A. Dobrzański, L.B. Dobrzański, Dentistry 4.0 Concept in the Design and Manufacturing of Prosthetic Dental Restorations, *Processes* 8/5 (2020) 525. DOI: <https://doi.org/10.3390/pr8050525>
15. Suresh Sajjan MC, Yekula PS, Kovvuri SS, Venkata Alluri RR. A simple technique for fabrication of a surgical guide for predictable placement of dental implants. *J Dent Implant* 2017;7:11-4.
16. Salem D (2019) Surgical Guides for Dental Implants; a Suggested New Classification. *J Dent Oral Health* 6: 1-8.
17. Revilla-León, M., Sadeghpour, M. & Özcan, M. An update on applications of 3D printing technologies used for processing polymers used in implant dentistry. *Odontology* 108, 331-338 (2020). <https://doi.org/10.1007/s10266-019-00441-7>
18. Melchels, F.P.W.; Domingos, M.A.N.; Klein, T.J.; Malda, J.; Bartolo, P.J.; Huttmacher, D.W. Additive manufacturing of tissues and organs. *Prog. Polym. Sci.* 2012, 37, 1079-1104. [CrossRef]

Performance of digital content distribution channels

Simona Balaščáková
University of Economics in Bratislava
simona.balascakova@euba.sk

Abstract: Digital marketing is currently a key pillar for the success of businesses in an environment of constant changes in online channels. Within this dynamic environment, it is imperative to continually review and analyse the effectiveness of digital content distribution channels. This article aims to systematically review the theoretical background in digital marketing with an emphasis on digital content distribution channels. In order to provide a holistic assessment of the performance of these channels, the thesis combines a critical perspective on existing theoretical framework models with an analysis of current digital marketing trends and practices. The proposed theoretical frameworks provide a basis for further developments in the field of digital marketing. It concluded by further discussing the implications of the findings for marketing managers and proposing recommendations for optimizing the use of digital content distribution channels in order to achieve maximum success in the online environment.

Keywords: DIGITAL MARKETING, DISTRIBUTION CHANNELS, SOCIAL MEDIA, WEBSITE

1. Introduction

Nowadays, the Internet has seamlessly integrated into our everyday lives, evolving into an indispensable component of modern society. We inhabit an era where reliance on the online realm is pervasive, with digital marketing emerging as a cornerstone for business triumph [1]. This form of marketing stands as one of the most potent avenues for engaging existing clientele and enticing prospective customers through the vast expanse of the internet. This prominence underscores the contemporary significance of digital marketing, which has surged ahead, outpacing traditional marketing methods in both efficacy and competitiveness [2, 3].

The landscape of digital commerce is intricately interwoven with the dynamics of distribution channels on the Internet. In recent years, we've borne witness to the swift evolution of Internet technologies alongside shifts in consumer preferences. These transformative forces have precipitated the emergence of novel distribution channels, reshaping the digital commerce landscape. As such, staying attuned to these burgeoning avenues is imperative for businesses seeking to navigate the ever-changing currents of the online marketplace effectively [4].

2. Internet shop

The primary purpose of the Internet was to serve the academic community for research purposes. It was not until 1991 that the government in the United States of America decided to use the Internet for business purposes, and it has grown rapidly in just a few years [5]. An online store or e-shop sells products or services online. The aim is not only to showcase the products but also to sell them [6]. Shopping through online stores is very widespread in the world and in recent years, because of the COVID 19 pandemic, its function has grown considerably. Slovakia is a very important player in this area [7, 8].

The CEO of the website Heureka.sk, Tomáš Braverman, claims that Slovakia, due to the size of the population, is a very strong market for e-commerce. Therefore, diversification of goods and services in the online environment is existentially important for businesses [9]. Janouch argues that one of the main reasons why customers come to brick-and-mortar stores is because they have previously found their products or services online [10].

3. Social media

The next type of website is social media. Almost everyone is registered on at least one of the many social networks that the Internet offers or has at least heard of them. These websites also have a great advantage in areas such as marketing. Social networks have a high potential, for example in discovering new opportunities, establishing business partnerships and new contacts or getting feedback from customers [11, 12].

Social networking can be characterized as a service that allows you to connect with other people with similar interests and backgrounds. It usually includes a profile and diverse ways to

communicate. Often it also includes the possibility to create groups according to the same interests [13].

According to *Statista*, the most used social networks include Facebook, YouTube WhatsApp, and Instagram [14].

4. Survey results

In the practical part of the article, the possibilities of content dissemination on the Internet and their impact on the readability of articles were investigated. The main aim of the research was to find out what impact the different platforms have on the readability of articles on the website www.aktuality.sk [15].

As shown in Table 1, the survey was conducted from 07 February 2023 to 01 March 2023. During this period, data collection, and hence selection of articles based on being found on certain social networks, took place. Initially, articles found exclusively on the website were selected. This means that they are not shared on other social networks (5 articles). Gradually, we searched for articles that are distributed on the website and Facebook (12 articles). Other articles were distributed on social networks such as Instagram and Instagram Bio. These articles are in terms of fulfilling the objective.

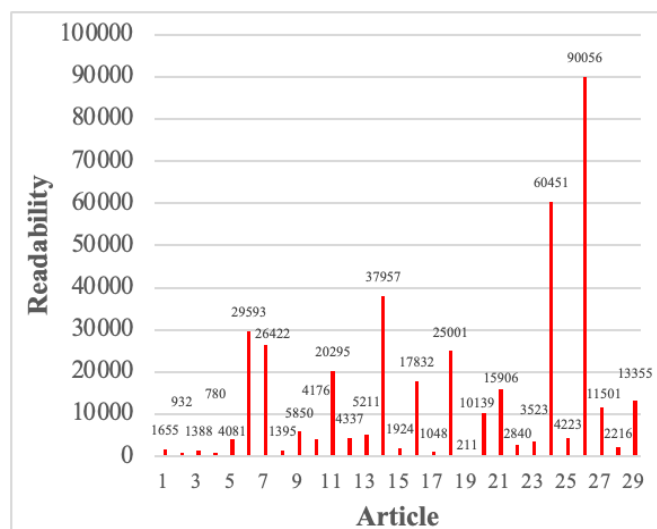


Fig. 1 Overview of the readability of the articles on the website *Грешки!*
Источникът на препратката не е намерен.

Through Figure 1, an increasing trend in readership has been revealed, but with increasing numbers, and therefore readership, come other opportunities for the dissemination of content on the Internet. Articles 1-5 are articles that are found exclusively on the website and are not disseminated on other distribution channels. Based on the data collected, the average readership of articles found on the website is 13,941.3.

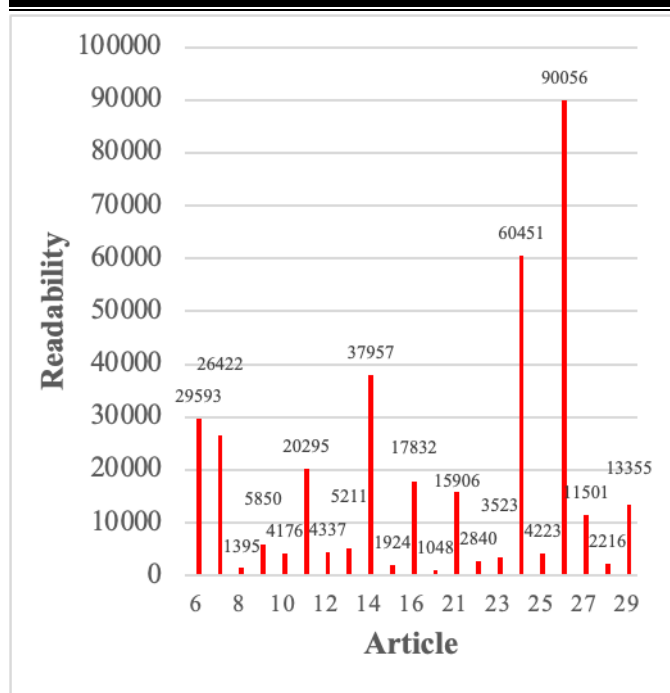


Fig. 2 Overview of the readability of the articles on Facebook ²

Based on the data in Figure 2, we found that although the readership of articles found on the website and Facebook increased compared to the previous ones (found only on the website), it still has lower numbers than articles distributed on other social networks as well. These are mainly articles 6-17, found exclusively on the website and Facebook. The average readership of articles on Facebook is 17,148.1.

Table 1. Average readability values of individual distribution channels

Distribution channel	Average readability
Website	13 941,3
Facebook	17 148,1

Recommendations for aktuality.sk

Based on the analysis of Aktuality.sk and the research conducted for this thesis, we have concluded that although the selected company is taking steps to increase the success rate of its articles, it may share more content related to specific articles with a hyperlink within certain distribution channels (namely Instagram).

Based on the analysis and original research conducted, we make recommendations aimed at improving the distribution of articles on each distribution channel.

5. Conclusion

Recommendations focused on the website

Article sharing on the website, all articles produced by Aktuality.sk are on the main website from which we have drawn data dealing with the readability of individual articles. In terms of the distribution of articles on the website, we do not find any specific ideas that could help to increase its traffic and subsequent readership. specific ideas that could help to increase its traffic and subsequent readership.

Recommendations focused on Facebook

Facebook still ranks first in terms of popularity among social networks in Slovakia. For this reason, the Facebook profile of aktuality contributes largely to the traffic and readership, as the posts contain a direct link to the specific article on the main website.

As in reality, in our conducted research in Figure 2 we can see that Aktuality.sk adds a high percentage of articles from the website to their Facebook profile. However, there are several reasons why

blogs should not share almost all articles on Facebook. These include, for example, redundancy, which can be annoying and people start to ignore the content. Other reasons include loss of credibility, for example, which raises questions about the quality of the content on the blog or accusations of spamming. For these reasons, it is important to share only the most interesting articles and not overwhelm readers.

Based on the average readership shown in Table 1, that is, the average readership of articles shared on Facebook is lower compared to the average readership of articles shared on Instagram, we recommend that the News portal reduce the number of times it adds articles to its Facebook profile.

6. References

1. Beňová, E. (2012). *The Internet in Company Trading* (Bachelor's thesis). Pan-European University. Supervisor: Prof. Ludmila Nagyova, PhD. Bratislava.
2. Rezač, J. (2016). *The Web as Sharp as a Razor* (1st ed.). Brno: Baroque Partners. ISBN 978-80-87923-01-6.
3. Crain, M. (2021). *Profit over privacy: How surveillance advertising conquered the internet*. U of Minnesota Press.
4. O'Connor, P. (2009). Distribution channels and e-commerce. In *Handbook of Hospitality Marketing Management* (pp. 186-208). Routledge.
5. Gagan, S., & Rakesh, P. (2013). Use of internet for research and educational activities by research scholars: A study of DSB campus of Kumaun University-Nainital. *International journal of engineering and management sciences*, 4(2), 193-199.
6. Dewa, O. (2023). Web-based e-shop design (case study of cv. Maju jaya group). *Journal Basic Science and Technology*, 12(2), 41-46.
7. Veselovská, L., Závadský, J., & Bartková, L. (2021). Consumer behaviour changes during times of the COVID-19 pandemic: An empirical study on Slovak consumers.
8. Machová, R., Korcsmáros, E., Marča, R., & Esseová, M. (2022). An International Analysis of Consumers' Consciousness During the Covid-19 Pandemic in Slovakia and Hungary. *Folia Oeconomica Stetinensia*, 22(1), 130-151.
9. WEBNOVINY. (2020, February 12). *Slovaks set a new record on e-shops in 2019 – spent 1.36 billion euros*. Webnoviny. Retrieved April 24, 2022, from <https://www.webnoviny.sk/slovaci-v-roku-2019-na-e-shopoch-vytvorili-novy-rekord-minuli-136-miliardy-eur/>
10. Janouch, V. (2011). *333 Tips and Tricks for Internet Marketing* (1st ed.). Brno: Computer Press. ISBN 9788025134023.
11. 5. Hall, M. (2022, October 18). Facebook American company. *Encyclopedia Britannica*. Retrieved April 24, 2022, from <https://www.britannica.com/topic/Facebook>
12. Weber, L. (2009). *Marketing to the social web: How digital customer communities build your business*. John Wiley & Sons.
13. Performics et al. (2021). *Uspejte v online*. Performics Slovakia. ISBN 978-80-973694-0-8.
14. Dixon, S. (2022, July 26). Most popular social networks worldwide as of January 2022, ranked by number of monthly active users. *Statista*. Retrieved April 24, 2022, from <https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/>
15. Aktuality.sk. (2024, May 1). Latest news. Aktuality.sk. Retrieved May 1, 2024, from <https://www.aktuality.sk/>.

7. Acknowledgement

This work has been supported by the project VEGA - 1/0392/23 „Changes in the approach to the development of distribution management concepts of companies influenced by the impact of social and economic crises caused by the global pandemic and increased security risks”.

Waste logistics in the aspect of a closed loop economy

Maciej Kuboń^{1,2*}, Dariusz Kwasniewski¹, Urszula Malaga-Tobola¹, Pavol Findura³, Miroslav Pristavka⁴, Olivia Kłosowska⁵
 Department of Production Engineering, Logistics and Applied Computer Science,
 Faculty of Production and Power Engineering, University of Agriculture in Kraków¹
 Faculty of Technical Sciences and Design Arts, National Academy of Applied Sciences in Przemyśl²
 Institute of Agricultural Engineering, Transport and Bioenergetics, Slovak University of Agriculture in Nitra³
 Institute of Design and Engineering Technologies, Slovak University of Agriculture in Nitra⁴
 Faculty of Environmental Engineering and Geodesy, University of Agriculture in Kraków⁵
 maciej.kubon@urk.eud.pl

Abstract: The purpose of the study was to analyse and evaluate waste logistics in a large-scale agricultural enterprise in terms of a closed-loop economy. A closed-loop economy was characterised and its significance for the enterprise was defined. The size and structure of the input production means, and their output were established. Based on yardsticks and indicators the degree of implementation of the closed-loop economy into the enterprise was estimated and solutions improving the current situation were suggested. It was found out that in the analysed enterprise it is carried out at a high level which is proved by a high indicator of waste management in the closed loop at the level of 95%.

KEYWORDS: LOGISTICS, WASTE, ECONOMY, CLOSED LOOP

1. Introduction

The global economic and environmental model has become a closed-loop economy (GOZ) [1]. It is a form of regeneration and modernization of the linear system that has functioned until now [2]. The closed-loop economy operates based on the so-called 3R principle "Reduce, Recycle, Reuse", which means reduce waste, recirculate through recovery, and reuse).

The concept of the circular economy is to "produce more efficiently and recover value from the materials used" [3], and to sustain products in usefulness for as long as possible, then to allow them to be reused, repaired or refurbished and improved, and only as a last resort to be disassembled and made into a secondary raw material. The circular economy transforms definitions of a product's life cycle, as it creates another product from waste, ready for use and for returning to circulation. It represents a split between the increase in consumption and the excessive consumption of natural resources in recent years [1]. This approach saves available natural goods by not wasting them, but by "using them efficiently and switching to renewable resources" (Jastrzebska, 2019). The circular economy is also the idea of combining the activities of businesses along with preserving the environment undamaged by industry [4].

The basic premise of the circular economy is to focus on "the nature, scope, quality and complexity of available resources" [3]. It has become a business model to link goods and capabilities to achieve and maintain the stability of its benefits. It represents the totality of decisions made that are strategies of operation, which will result in an increase in the value of products inside the business, as well as externally in the relationship between the business and suppliers and consumers [5]. The concept represents a complete transformation in terms of technology. This transformation involves the introduction of new technical [6] and functional solutions, e.g. instead of pure sales additionally offering services to the products in question [2].

The management and control of the life cycle of the products in question, as well as the determination of supply, production and distribution chains, has become an important element of GOZ in corporate policy [7]. Thus, profit can be achieved on an economic level by recovering the previous properties of products, while minimizing the consumption of natural resources [6]. It has been observed that this model can lead to obtain the added value from the waste that has already been created, as well as helps to reduce the risks associated with the lack of rhythmicity of prices, demand and supply [1]. For this reason, the main motive has become the introduction of more and more business models based on new process design and ensuring the cyclicity of materials occurring in companies, and more broadly in the national economy, so that

humans maintain their well-being without disturbing the ecosystem [4].

The idea of a closed-loop economy is to close material flows, while reducing the generation of additional raw materials, as well as minimizing the waste generated in production processes. What is important in this case is the optimization of supply management, so that activities in this direction are both ecological and economically justified [8]. The introduction of the GOZ idea involves managing the entire life cycle of a product through design, supply chain, during production, distribution and returns, up to disposal, i.e. the total loss of value. The idea of the circular economy is becoming a new and sustainable business model that can contribute to economic growth [9].

The purpose of the study was to analyze and evaluate waste logistics in a large-scale agricultural enterprise in terms of a closed-loop economy, and to propose effective solutions in the enterprise to minimize the volume of outgoing waste generated in favor of waste going back into circulation to ensure an efficient flow of goods.

The work covered the process of potato production, along with the entire circulation of both purchased and produced inputs which are raw materials for another production process (internal circulation). The full circulation of packaging as well as waste generated in the production process was also considered. The selection of appropriate yardsticks and indicators allowed an objective assessment of waste management, as well as the selection of optimal solutions for waste prevention.

2. Methodology

The data was obtained directly from the owner based on an interview regarding the size, structure and management of inputs and waste. Among the data collected are:

- the number/mass of seed potatoes purchased in big bags by variety and the size of the fields allocated to potatoes,
- the number/mass of crop protection products used in kilograms, allocated to given fields,
- number/mass of fertilizers used in kilograms, applied to specific field sizes,
- number of bags left over from the previous year, purchased, used and left for the following year, broken down by variety,
- number/mass of exported trailers of potatoes for disposal and their weight,
- the weight of fertilizers left over from the previous year, purchased, used and left over for the following year,

- the number/mass of potatoes sold in a given year, distinguishing their origin from the respective fields,

- the number/mass of harvested potatoes from the respective fields in the form of the number of trailers and the harvested yield.

In order to realize the concept of the work, the following logistics metrics and indicators for a circular economy were used.

Measures for closed-loop circulation of materials and raw materials [10]:

1. Weight of industrial waste to revenue generated (MOO), (kg-PLN-1)
2. Mass of hazardous waste generated (MON), (kg)
3. Mass of reused waste (MPW), (kg)
4. Mass of waste recycled (MR), (kg)
5. Mass of waste subjected to other recovery processes (MIO), (kg)
6. Mass of waste subjected to disposal (MU), (kg) e.g. disposal process
7. Share of recycled packaging in total weight of packaging (UOR), (%)
8. Share of returnable packaging in the total weight of packaging (UOZ), (%) - the ratio of returnable packaging (MOZ) to the total weight of packaging waste (MCOO)
9. Share of secondary materials produced in total production (UOW), (%)
10. Weight of secondary production (MW) to the volume of total production (MPG).

Indicators for a closed-loop economy:

1. Industrial waste reduction rate (**IWR**), (%) - the ratio of the weight of waste landfilled to the weight of waste generated in a given year.
2. Internal waste management efficiency ratio (**WSGW**), (%) - determines the mass of materials put back into circulation, or reuse, to the mass of all materials used in a given year.
3. Potential reuse rate (**WPPW**) - determines the mass of a product used repeatedly, the number of multiples of its use to the total mass of the type of a product in the period under review.
4. Waste indicator (**WO**), (%) - determines the mass of solid waste produced per mass of a primary product, and for a company the mass of waste to the volume of production.
5. GOZ target indicator - determines the state of alignment of the input stream with the return stream into circulation.

3. Object of study

W. O. Watt&Partners Limited is an agri-food company located in Rainham, UK, about 30 km from London. The owner is Harry Fisher. His enterprise mainly produces potatoes and cereals (wheat, spring barley). The farm has a total of 223 hectares of the field area, with about 42 hectares devoted to potatoes, about 52 hectares to wheat and an average of 35 hectares to spring barley. Four varieties of potatoes are currently grown: Cabaret, Maris Piper, Aphrodites, Accord. For 1 ton of potatoes regardless of variety, the buyer pays £168, and £4.5 for a 25 kg bag. Converting pounds into Polish zlotys, the value is £905 for 1 ton and £25 for a bag. This means that the price of 1 kg of potatoes was 1 PLN.

4. Results of the study

Production has varied significantly in recent years (2018-2021), as the entrepreneur used different potato varieties and allocated different areas of the field for planting. Each variety had different productivity and thus different income. Depending on the potato harvesting conditions, that is, wet or dry seasons, had an impact in the value of potatoes sold. The 2021 season was very good, due to the optimum moisture content of the fields at harvest time and the low percentage of waste from the total production.

Table 1: Global, commodity and secondary production from 2018-2021

Yaar	Field Area (ha)	Total Production (kg)	Commercial Production (kg)	Secondary Production (kg)
2018	39,2	1 171 000	1 003 000	168 000
2019	36,9	1 328 000	1 194 000	134 000
2020	34,8	1 245 000	1 085 000	160 000
2021	27,3	1 253 000	1 161 000	92 000

The output included commodity and secondary production. Commodity production included potatoes for sale only. Secondary production was defined as the volume of waste produced (unformed, damaged potatoes), destined for biogas. The highest production volume was obtained in 2019 - 1,328 t, while the lowest in 2018 - 1,171 t. The average yield of potatoes per hectare was in 2018 - 25.6 t·ha⁻¹, and in 2019 - 32.4 t·ha⁻¹.

In terms of closed loop, waste becomes an added value for the company. This means that there is a change in the perception of the life cycle of a product. Not only the performance of materials is considered, but also their usefulness after finished processes, when they become waste [12]. For the most part, packaging is waste after finished manufacturing processes. Improving packaging and thus optimizing its use in logistics increases the "efficiency and reliability of logistics processes," contributing to minimizing costs in the processes that occur. [13]. Cost reduction in the case of a circular economy is the domain of reverse logistics, in which packaging is reused, thus contributing to reduction of its negative impact on the environment [14].

The lowest weight of waste was for recycling - 21 kg and these were paper bags. Then, pallets destined for disposal. The largest volume of waste was sent for reuse - 6,283 kg. Pallets and bags in the "reuse" segment accounted for the largest share and were also the only waste going out of the company and were destined for disposal and recycling. Pallets for disposal accounted for less than 5% of pallets reused. Bags for recycling accounted for approximately 1% to the total bags reused. Big bags of fertilizer and seed potatoes yielded a weight of 309 kg, which is approximately 5% to the total waste.

Table 2: Volume and structure of waste by packaging and total waste

WASTE		Total (kg)	Reuse		Recycling		Utilization	
			(kg)	(pcs)	(kg)	(pcs)	(kg)	(pcs)
SEEDS	Big Bag	192	192	64				
PESTICIDES	Plastic bottles 4l	33	33	222				
FERTILIZES	Big Bag	117	117	39				
WORKS		2 388	2 366	11 832	21	106		
PALETS		3 750	3 575	143			175	7
Total packaging waste (kg)		6 479	6 283		21		175	

Percentage of packaging waste (%)		100	97		0,3		2,7	
POTATO	for biogas plants	92 000	.	.	.	.	92 000	.
TOTAL		98 479	6 283		21		92 175	
% SHARE OF TOTAL WASTE		100	6,3		0,1		93,6	

5. Management efficiency in the aspect of closed cycle

Mass of industrial waste to achieved revenue (MOO), (Mg·PLN⁻¹) - the mass of packaging waste in relation to the revenue. The total weight of packaging waste was 6,479 kg. The value of revenue was determined by multiplying the number of potatoes sold, or 1,161,000 kg, by the value per pallet of 1,000 kg, or PLN 905.

$$M_{OO} = \frac{6\,479}{1\,050\,705} = 0,006 = 6,17 \text{ (Mg} \cdot \text{PLN}^{-1}\text{)}$$

Mass of hazardous waste generated (MON), (kg) - the only waste in this category was plastic bottles, the mass of all bottles was 33 kg.

Mass of reused waste (MPW), (kg) - the sum of packaging left for the next year for reuse, these included: Big Bag'i of seed potatoes, plastic bottles, Big Bag'i of fertilizers, bags and pallets, with the total weight of 6,283 kg.

Weight of waste recycled (MR), (kg) - the only waste in this category was paper bags for wastepaper, with the total weight of 21 kg.

Mass of waste subjected to other recovery processes (MIO), (kg) - the recovery process included potatoes (representing waste) destined for biogas plants, with the total mass of 92,000 kg.

Mass of waste disposed (MU), (kg) - pallets, beyond repair, were subjected to the disposal process and accounted for a mass of 175 kg.

Share of recycled packaging in the total weight of packaging (UOR), (%)

$$U_R = \frac{21}{6\,479} * 100\% = 0,32\%$$

Share of returnable packaging in the total weight of packaging (UOZ), (%) - returnable packaging included big bags of seed potatoes and fertilizer and plastic bottles.

$$M_{OZ} = 192 + 33 + 117 = 342 \text{ (kg)}$$

$$U_{OZ} = \frac{342}{6\,479} * 100\% = 5,28\%$$

Share of secondary raw materials produced in the total production (UOW), (%) - the weight of potatoes destined for biogas plants in relation to the volume of global production.

$$U_W = \frac{92\,000}{1\,253\,000} * 100\% = 7,34\%$$

Waste stream (SO), (%) - Management methods were marked as 1- reuse, 2 - recycle, 3 - dispose, 4 - recover. Packaging waste and secondary production were included.

Reuse

$$S_{O1} = \frac{6\,283}{98\,479} * 100\% = 6,37\%$$

Recycling

$$S_{O2} = \frac{21}{98\,479} * 100\% = 0,03\%$$

Utilization

$$S_{O3} = \frac{175}{98\,479} * 100\% = 0,18\%$$

Recovery

$$S_{O4} = \frac{92\,000}{98\,479} * 100\% = 93,42\%$$

INDICATORS FOR A CIRCULAR ECONOMY

Industrial waste reduction rate (W_{ZO}), (%)

$$W_{ZO} = \frac{10\,842}{92\,175} * 100\% = 11,76\%$$

Internal waste management efficiency index (W_{SGW}), (%)

$$W_{SGW} = \frac{10\,282}{10\,821} * 100\% = 95\%$$

Potential reuse rate (W_{PPW}), (-)

$$W_{PPW} = \frac{2\,500 + 60 + 0,45}{26,35} \approx 97 \text{ (razy)}$$

Wastefulness indicator (W_O), (%)

$$W_O = \frac{92\,196}{1\,373\,083} * 100\% = 6,71\%$$

GOZ target indicator (kg) - the input stream was all production materials such as paper bags, pallets and plastic boxes, and the return stream was paper bags, pallets and plastic boxes that could be reused.

Input stream (S_{WE})

$$S_{WE} = 9\,909 + 3\,750 + 4\,341 = 18\,000 \text{ (kg)}$$

Stream returning to circulation (S_{ZO})

$$S_{ZO} = 2\,366 + 3\,575 + 4\,341 = 10\,282 \text{ (kg)}$$

GOZ TARGET INDICATOR

$$18000 \neq 10\,282 \text{ kg}$$

The closed-loop economy is not provided at an equal level, the input stream is higher than the return-to-circulation stream.

6. Conclusions

1. Waste logistics at the analyzed enterprise is carried out at a very high level, as evidenced by the high efficiency rate of waste management in the internal circulation - 95%.

2. The enterprise generates a small mass of outgoing waste (paper bags for recycling, pallets for disposal, and potatoes for the biogas plant). This is confirmed by the waste rate, which is close to 7%.

3 The idea of a closed-loop economy has not been fully achieved for the use of transport packaging, as evidenced by the GOZ target indicator.

4. To maintain a balance between incoming materials and outgoing waste, it would be necessary to use other materials in the structure of packaging so that it is reusable, as well as to invest in the quality of this packaging to increase its durability and resistance to mechanical damage.

5. Adequate advance planning of demand and consideration of weather conditions would help minimize secondary production.

7. References

1. T. Szczygielski, Wskaźniki obiegu zamkniętego. Podejście do pomiaru obiegu zamkniętego, Politechnika Warszawska, Instytut Badań Stosowanych, Centrum Inżynierii Mineralów Antropogenicznych. Warszawa (2016)
2. M. Esposito, T. Tse, K. Soufani, Why the Circular Economy Matters, European Business Review (2015)
3. M. Pichlak, M. Kruczek, Gospodarka o obiegu zamkniętym - stan obecny i perspektywy, *Ekonomia XXI wieku*, 3 (15) (2017)
4. A. Valavanidis, Concept and Practice of the Circular Economy, National and Kapodistrian University of Athens (2018)
5. K. Połuszyński, Model biznesowy gospodarki o obiegu zamkniętym w obszarze tworzyw sztucznych, N. Iwaszczuk, K. Połuszyński, Gospodarka o obiegu zamkniętym, modele, narzędzia, wskaźniki, Wydawnictwo AGH, Kraków (2021)
6. M. Pichlak, Gospodarka o obiegu zamkniętym - model koncepcyjny, *Ekonomista*, 3, ISSN 0013-3205 (2018)
7. R. Maruszkin, T. Lasecki, T. Tarnecki, M. Biernat-Kopczyńska, Gospodarka o obiegu zamkniętym w przedsiębiorstwie. Przewodnik dla małych i średnich przedsiębiorstw, Polska Agencja Rozwoju Przedsiębiorczości, ISBN 978-83-7633-461-5 (2021)
8. B. Koralewska, M. Sikora, M. Smyk, N. Stępień, Innowacje ekologiczne w sektorze produkcji rolnej jako instrument zrównoważonego rozwoju, Uniwersytet Zielonogórski, Wydział Ekonomii i Zarządzania, *Koło Naukowe Eko-Zarządzania*, 7(6) (2017)
9. A. Bączek, Produktowność w realizacji założeń gospodarki o obiegu zamkniętym w Polsce, J. Kulczycka, Ewolucja gospodarki o obiegu zamkniętym – wyzwania, bariery, korzyści. Kraków, IGSMiE PAN (2021)
10. J. Kulczycka, Wskaźniki monitorowania gospodarki o obiegu zamkniętym, Polska Akademia Nauk, Instytut gospodarki surowcami mineralnymi i energią, IGSMiE PAN (2020)
11. J. Zarębska, Gospodarka o obiegu zamkniętym drogą do zrównoważonego rozwoju, Uniwersytet Zielonogórski, Katedra Zarządzania środowiskiem i Gospodarką Publiczną Wydziału Ekonomii i Zarządzania, Nr 6(7) - ISSN 2391-9361 (2017)
12. D. Woźniak, L. Kukiłka, Logistyka opakowań w transporcie drogowym, *Autobusy, Technika, Eksploatacja, Systemy Transportowe*, 5 (2011)

13. K. Lysenko-Ryba, Logistyka zwrotna jako źródło korzyści konkurencyjnych, *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach*, 249, ISSN 2083- 8611 (2015)

Energy efficiency measures to reduce the carbon footprint: A case study of Tirana airport.

Artan Hoxha^{1,*}, Ardit Gjeta¹, Majlinda Alcani¹, Elona Caushi², Albert Shira¹
Polytechnic University of Tirana, Faculty of Mechanical Engineering¹, Environment Manager, Tirana Airport²
ahoxha@fim.edu.al

Abstract: One of the biggest challenges of our century is climate change. The aviation industry is a major contributor to global carbon emissions, and airports are responsible for a significant portion of this impact. To reduce the carbon footprint of airports, it is necessary to implement energy efficiency measures that can help reduce energy consumption and greenhouse gas emissions.

This study analyzes the impact of the use of photovoltaic panels (PV) and the replacement of boiler burners with oil, on energy efficiency and the reduction of carbon emissions at the airport of Tirana. The electricity produced by these panels is used to power airport buildings, lighting systems and other infrastructure, reducing the need for traditional energy sources.

The reviewed period covers the year 2023, because during this year important investments were made with the installation of photovoltaic panels and the replacement of oil boiler burners with LPG burner, in addition to the improvement of the lighting system and the replacement of diesel vehicles with electric vehicles. Energy consumption data is used to calculate the carbon footprint and key energy performance indicators. The results showed that the use of photovoltaic panels and the change of burners of oil boilers brought a significant reduction of the carbon footprint and a significant economic benefit.

Keywords: AIRPORT, CARBON EMISSIONS, ENERGY EFFICIENCY, CASE STUDY, TIRANA AIRPORT

1. Introduction

Airports are not exempt from the effects of climate change and like other sectors, airports must implement measures to mitigate its impacts. Recognized as nationally critical infrastructure, airports play a pivotal role in enabling both mobility and economic development. The World Bank [1] asserts that the carbon footprint is a vital economic and financial gauge. By reducing the carbon footprint, societies can alleviate the expenses linked to climate change, enhance their ability to adapt to its effects, and stimulate investment in renewable energy and other low-carbon technologies. This reduction not only boosts return on investment but also mitigates risks and generates cost savings. Airports, much like other economic entities, have a responsibility to meet international obligations in addressing climate change while also striving to lower their operational expenses. Contemporary airports are dedicated to optimizing resource and energy usage per passenger served, aiming to enhance their competitiveness and minimize energy consumption, carbon dioxide emissions, and waste. Airports serve as vital hubs within the global air transport network. As airport infrastructures expand, there is often concurrent development of businesses, commercial areas, residential zones, and spatial infrastructure in the airport vicinity. These developments are interconnected by surface transportation infrastructure [2]. Airports play a pivotal role as key stakeholders in the value chain of the global air transport industry. They provide essential landside and airfield infrastructure that facilitates interactions between ground-based transportation and air transport modes for both passengers and air cargo shippers.

Compared to conventional civil buildings, airport terminals are distinguished by their vast, open spaces primarily enclosed with glazing systems. These structures accommodate a large volume of passengers and operate for extended durations daily. These factors collectively contribute to exceptionally high energy consumption for HVAC (heating, ventilation, and air conditioning) systems [3]. Energy consumed by airports can be broadly categorized into two main areas: the energy used for airside activities and the energy utilized in providing landside area activities. The airside refers to the movement area at an airport, including adjacent terrain, buildings, and infrastructure, where access is restricted. Conversely, landside refers to parts of an airport, along with adjacent terrain and buildings, that are not within the airside precinct [4]. The dynamic nature of airports, with their round-the-clock operations and emphasis on safe flight operations, as well as the provision of comfortable conditions for passengers within terminal buildings, often leads to heightened energy consumption. Consequently, energy management has become a crucial priority for airports. They are actively pursuing continuous enhancement of energy

performance, given their status as sites with high and intensive energy usage [5].

Furthermore, airport managers recognize the imperative to not only reduce energy consumption but also optimize its efficiency. Additionally, airports face mounting pressure to adopt energy-efficient systems while ensuring compliance with progressively stringent regulations [6]. Crucially, airports worldwide are transitioning towards the adoption of clean energy technologies and implementing practices to mitigate local emissions. This environmental strategy involves replacing fossil fuel-based operations with electricity-based alternatives at airports [7]. Indeed, in recent years, numerous new energy technologies have been developed and implemented as energy sources for airports. These technologies encompass solar photovoltaic (PV), concentrating solar power, wind power, oil and natural gas extraction, steam-generated power production, and electricity transmission [8]. The primary areas of energy consumption at an airport encompass heating, cooling, lighting, and the energy needed for operating various facilities and systems [9]. Additionally, fuel is utilized for the airport's heating boiler systems and emergency generators [10]. As per [11], reducing the carbon footprint presents a substantial business opportunity for enterprises. By minimizing their carbon footprint, businesses can elevate their return on investment, mitigate risks, and realize cost savings. In a separate study, the International Monetary Fund (2021) [12], scrutinizes the potential repercussions of climate change on the global economy. According to their findings, climate change has the potential to exert adverse effects on the global economy, impeding economic growth. Wongsapai et al. [13] analyze the effects of Thailand's long-term low-carbon energy efficiency and renewable energy plan on energy consumption and CO₂ emissions. Their findings indicate that implementing this plan will decrease energy demand and reduce CO₂ emissions. Additionally, the study suggests that the energy efficiency and renewable energy plan will aid Thailand in attaining its energy and climate objectives. Busu [14] endeavors to assess renewable energy efficiency and its influence on CO₂ emissions across the European Union. The study's results reveal an enhancement in renewable energy efficiency within the EU, correlating with a favorable reduction in CO₂ emissions. These findings underscore the significance of renewable energy and energy efficiency measures in mitigating CO₂ emissions. The overall energy consumption stemming from air transport operations results in the emission of greenhouse gases, including CO₂, NO_x, SO₂, H₂O, and others. The total greenhouse gas emissions generated at airports can be

specifically attributed to and measured separately for various activities occurring in the airside area, landside area, and supporting activities. Within the landside area of the airport, greenhouse gas emissions typically arise from passenger and air cargo servicing activities conducted in the terminals. Additionally, emissions result from the provision of heating, cooling, and lighting in these and other airport buildings [15]. To diminish airports' carbon footprints, there is a growing imperative for airport power systems to transition towards greater utilization of renewable energy sources [16]. Mirza et al. [17] investigate the influence of energy efficiency on CO₂ emissions in developing nations. Their research reveals a notable and adverse impact of energy efficiency on CO₂ emissions, with particularly pronounced effects observed in countries with lower CO₂ emissions. This highlights the effectiveness of energy efficiency initiatives in mitigating CO₂ emissions, especially within developing countries. Additionally, the study identifies a similarly significant negative effect of renewable energy consumption on CO₂ emissions, emphasizing the crucial roles of both energy efficiency and renewable energy in reducing CO₂ emissions.

In their study, Wang et al. [18] explore the comparative effectiveness of energy efficiency, renewable energy, and natural gas in mitigating environmental degradation. Their findings unmistakably emphasize energy efficiency as the most powerful option. Improving energy efficiency reduces environmental degradation by decreasing energy consumption and greenhouse gas emissions. Moreover, the research underscores the effectiveness of renewable energy sources in mitigating environmental harm, highlighting their lesser negative impacts compared to fossil fuel-based energy sources. In recent years, there has been an increasing movement towards airports striving to achieve "carbon neutrality" [19].

The carbon footprint quantifies the environmental impact of a firm's activities on climate change. It encompasses all greenhouse gases emitted by the firm, typically measured in metric tons or kilograms of carbon dioxide (CO₂). It's essential to recognize that a firm's carbon footprint exclusively assesses CO₂ emissions directly and indirectly generated by its activities [20]. The heightened attention on carbon dioxide (CO₂) emissions stems from the significant carbon footprint generated by the global aviation industry [21].

Environmental sustainability in air transport has garnered increased attention recently, given its significant impact on climate change and the environment. Within the global airline industry, the emissions of carbon dioxide (CO₂) from aircraft engines have garnered significant attention due to their detrimental impact on the environment [22]. As awareness of climate change grows, the concept of embodied carbon dioxide (CO₂) emissions, often referred to as the "carbon footprint," has become a common environmental performance indicator for products and production activities [23].

Carbon dioxide (CO₂) emissions are directly linked to jet fuel consumption, as each kilogram of fuel consumed by aircraft produces more than three kilograms of carbon dioxide (CO₂) [24].

European airports are highly engaged in the Airport Carbon Accreditation program, with Tirana Airport being among the participants. According to data from 2022 [25], the airports enrolled in the program account for 73.1% of the total air passenger traffic in Europe.

Multiple factors, including weather conditions, building envelope efficiency, energy systems, and occupancy behavior, influence building energy demand [26]. Solar energy systems, encompassing technologies like solar thermal collectors and photovoltaic (PV) modules, along with wind energy, have emerged as pivotal solutions for clean and sustainable energy production on a global scale. Lee and Baek [27] pioneered a method to compute solar collector efficiency based on heating load, proposing several parameters to enhance the assessment of collector efficiency.

Solar heating presents numerous advantages, such as decreased fuel consumption, diminished pollution, and minimal maintenance needs [28]. Hansen and Vad Mathiesen [29] examined the influence

of solar thermal energy on carbon dioxide emissions resulting from both technological advancements and fuel substitution. Their research revealed that solar heating yields greater carbon savings, particularly during the summer months, owing to its higher solar ratio. Integrating solar thermal systems can curtail overall fuel consumption, thereby reducing reliance on this heavily sought-after energy source in the future.

2. The case study

Tirana International Airport, also known as Mother Teresa International Airport (TIA), is the primary airport of Albania and serves as the main air gateway to the country. It is located approximately 17 kilometers northwest of the capital city, Tirana. The airport officially opened in 1958 and has undergone several phases of modernization and expansion to accommodate the growing air traffic and to meet international standards. The airport features a large passenger terminal offering a range of services and amenities for travelers, including duty-free shops, restaurants, cafes, banking services, and currency exchange points. The terminal is equipped with modern baggage handling technology and has the capacity to manage a high volume of passengers. Future plans include further expansion of the terminal and runway infrastructure to improve capacity and meet the increasing demands of travelers and airlines. Tirana International Airport continues to play a crucial role in connecting Albania with the world and in promoting the country's economic and tourism development.

TIA is now the airport with the highest flow in the region, with over 2.8 million passengers only during the first 4 months of 2024. This is also thanks to the new lines and the possibilities for connections to countries that were not easily accessible before. In 2023, Tirana International Airport has welcomed 40% more passengers, reaching a figure of 7,257,574 passengers.

Tirana International Airport (TIA) employs an integrated environmental, energy, and quality management system in accordance with international standards ISO 14001, ISO 50001, and ISO 9001. This means that the company meticulously follows a comprehensive process that encompasses everything from policy statements to improvement actions.

TIA has continued implementing its Energy and Carbon Reduction Action Plan to achieve objectives and targets for reducing energy consumption and increasing energy efficiency.

As part of the European airport industry's response to the challenge of climate change and in recognition of its efforts to optimize energy management and reduce CO₂ emissions, TIA has been a participant in the CO₂ movement since 2011/2012.

TIA achieved Level II Reduction accreditation from Airports Council International Europe, which was last renewed in January 2020. TIA has reviewed its Carbon Management Plan with the aim of increasing energy efficiency to best practice benchmarking. This includes improving processes and meter readings, investing in new energy-efficient technologies such as LED lighting, and evaluating the use of alternative renewable energy sources. TIA also emphasizes strong collaboration and leadership with all airport stakeholders to raise awareness and implement common initiatives, setting a long-term action plan for Energy and Carbon Reduction.

TIA considers taking action to reduce its carbon footprint especially important, regardless of the size of its contribution. As part of the airport industry's response to the challenge of climate change, TIA has been part of the initiative since 2011. Currently, TIA holds a Level 2 - Reduction airport carbon accreditation certificate, recognizing its efforts to manage and reduce CO₂ emissions.

TIA can produce both direct emissions (Scope 1) and indirect emissions (Scope 2). However, together, these sources account for a small part of the total emissions at the airport. Most emissions fall within Scope 3, primarily attributable to aircraft. In 2022, TIA's total calculated and validated carbon footprint was 1,682 tons of CO₂.

The emissions for the years 2011–2022 are given in Figure 1&2.

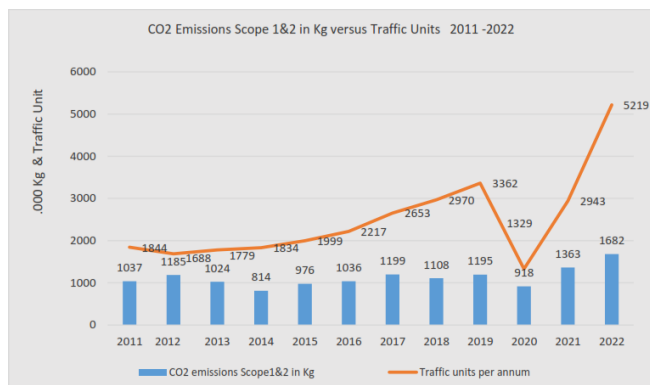


Fig 1. Total CO₂ emissions, 2011-2022

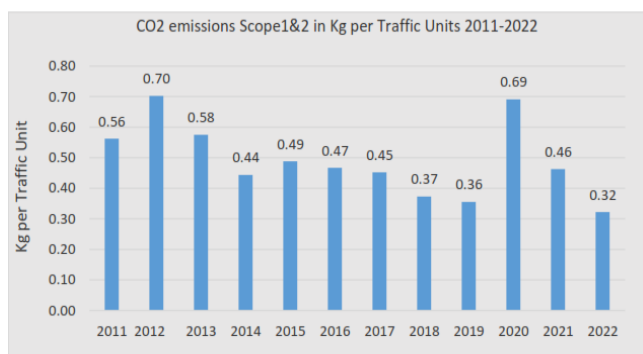


Fig 2. Emissions per traffic unit, 2011-2022

The largest CO₂ emission sources at TIA are Scope 1, which is owned and controlled sources of direct emissions. These include heating boilers, TIA ground support equipment, emergency power, and fleet vehicles, accounting for 96 percent of the total emissions. In comparison, Scope 2 emissions, which are indirect emissions such as purchased electricity, account for just four percent, primarily due to the very low emission factor of hydropower electricity in Albania.

TIA is currently revising its Carbon Management Plan, aiming to set targets of an average of 0.35 kg CO₂ per traffic unit, for TIA scope 1 and 2 emissions. This is a significant improvement compared to the baseline year of 2011, when the first carbon footprint calculation took place and recorded 0.56 kg of CO₂ per traffic unit. The graphs show that the trend in the Airport's total footprint in the last three years is in the range of 9,00–1,700 tons and the carbon footprint per traffic unit is in the range of 0.69–0.32 kg. Emissions per traffic unit average 0.49 kg CO₂ per passenger, 20-40% reduction with the base year. Emissions according to scope are given below.

Table 1 Emissions according to scope 1&2

Airport Operator Source Break Down:			
Mobile Sources	Scope 1	(t CO ₂ e)	905.0
Stationary Sources	Scope 1	(t CO ₂ e)	414.0
Process Emissions	Scope 1	(t CO ₂ e)	-
Process Emissions	Scope 2	(t CO ₂ e)	44.2
Total Scopes 1+2		(t CO₂e)	1,363.2

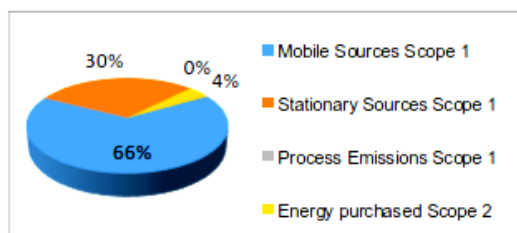


Fig 3. Emissions according to scope 1&2

Table 2 Emissions according to scope 3

Scope 3 Source Group Break Down:		
Aircraft LTO cycle, APU usage and engine testing	(t CO ₂ e)	20,451.4
Landside ground access	(t CO ₂ e)	12,214.6
Staff Commute	(t CO ₂ e)	385.5
Waste Municipality	(t CO ₂ e)	2,165.4
Construction works	(t CO ₂ e)	317.7
Third party electricity	(t CO ₂ e)	2.9

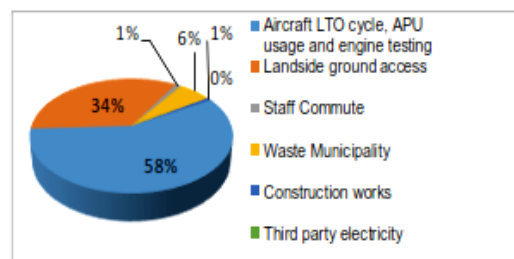


Fig 4. Emissions according to scope 3

Table 3 Total emissions

Airport Total Scope Break Down:		
Airport Operator Scope 1	(t CO ₂ e)	1,405
Airport Operator Scope 2	(t CO ₂ e)	44
Airport Scope 3	(t CO ₂ e)	35,539
Total Gross Emissions		(t CO₂e)

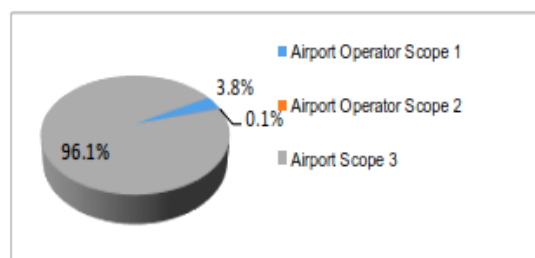


Fig 5. Total emissions

TIA has continued with implementation of its Energy and Carbon Reduction Action Plan for achievement of objectives and targets for energy consumption reduction and energy efficiency.

Energy measures for the scope 1&2 are: Reducing the consumption of conventional fuels, reduction of energy consumption (thermal insulation in buildings, layers of film for protection from the sun, double doors at the arrivals, air curtains at all entrances of the passenger terminal), reduction of electricity for lighting (LED lighting installations, Sensor), design of new buildings in category B (new passenger terminal, panels with hydro and thermal insulation, windows for natural lighting with triplex thermal glass), energy control identification program by consumption units (installation of meters for sub-consumers and third parties), production of renewable energy (installation of photovoltaic panels). Energy measures for the scope 3 are: expansion of urban transport (adding new destinations and frequencies), bus transportation service (for TIA staff and third parties), waste minimization program and separation at source, installation of bins with separation in public areas and waste collection points.

2. Results and discussion

One of the most important measures for improving energy efficiency and reducing the carbon footprint is the installation of photovoltaic panels. In 2023, Tirana Airport installed two sets of photovoltaic panels: one in the airport parking lot with a capacity of

519.42 KWp and another on the terminal roof with a capacity of 594 KWp.

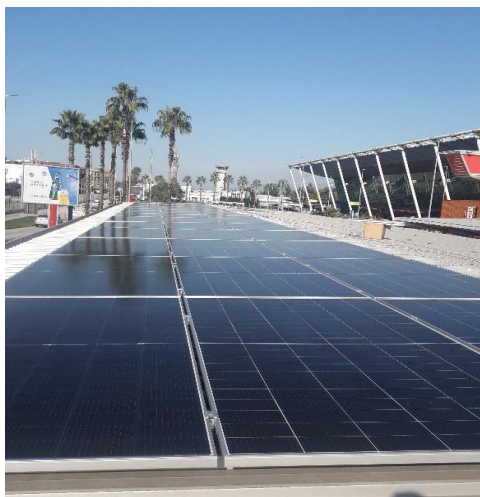


Fig 6. Photovoltaic panels at Tirana International Airport

The annual output of these panels and economic benefit varies based on when they were commissioned, as shown in Table 4&5.

During this year, two sets of photovoltaic panels (PV) with a power of 1 MW will be installed in the airport of Tirana in the new parking lots of the airport, which will affect the further reduction of the carbon footprint and increase the economic benefit.

Table 4 Production and annual profit of PV in the parking lot (T1)

Energy production, T1-Parking 519.42 KWp		Value
2023		
	KWh	ALL
January		0
February	77008.86272	1447766.619
March	116725.4797	2194439.018
April	148043.6785	2783221.156
May	156173.9426	2936070.122
June	148930.2337	2799888.393
July	92092.61081	1731341.083
August	76880.02713	1445344.51
September	59253.09701	1113958.224
October	44063	828384.4
November	21150	397620
December	16842	316629.6
TOTAL	957,162.9322	17,994,663.13

Table 5 Production and annual profit of PV in the terminal roof (T2)

Energy production, T2-Terminal 594 KWp		Value
2023		
	KWh	ALL
January		0
February	0	0
March	0	0
April	0	0
May	0	0
June	7182.445216	135029.9701
July	108593.1803	2041551.789
August	90421.50427	1699924.28
September	69314.84541	1303119.094
October	52043	978408.4
November	25070	471316
December	24413	458964.4
TOTAL	377,037.9752	7,088,313.933

The amount of CO₂ that will be emitted by a diesel power plant to produce a certain amount of electricity will depend on the efficiency of the power plant and the characteristics of the oil used. However, according to the US Environmental Protection Agency (EPA), the average CO₂ emission from the production of one MWh of electricity from power plants that use oil as an energy source is about 623.7 kg of CO₂ and power plants that use natural gas is 400 kg of CO₂.

According to this, a diesel power plant producing 957.16293 MWh of energy will emit about 596,982.52 kg (or about 596.983 tons) of CO₂ into the atmosphere and a natural gas power plant will emit 382,865.17 kg (382.865 tons) of CO₂ into the atmosphere.

A diesel power plant producing 377.03797 MWh of energy will emit about 235,158.8 kg (or about 235.159 tons) of CO₂ into the atmosphere and a natural gas power plant will emit 150,815.19 kg (150.815 tons) of CO₂ into the atmosphere.

In total a diesel power plant will emit 832,141.1 kg (832.14 tons) of CO₂ into the atmosphere and a natural gas power plant will emit 533,680.36 kg (533.68 tons) of CO₂ into the atmosphere.

The use of clean and sustainable energy sources, such as the energy produced by photovoltaic panels, helps reduce greenhouse gas emissions such as CO₂, reduces the carbon footprint and provides an economic benefit.

The heating-cooling system for the terminal is based on: Heating during the winter season is done with three boilers, Hover brand 2x410 Kw and 1 boiler 360 Kw. During the summer season, cooling is done with 2 chillers. The ventilation system also works during the 2 seasons.

The heating-cooling system for the new terminal extension will be with heat pumps, for heating and cooling with air. There will also be AHU air handling units for the ventilation system. This system is under construction.

One of the measures to improve energy efficiency and reduce the footprint at Tirana airport is the replacement of oil boiler burners with LPG (liquefied petroleum gas) burners.

From the data of 2023, oil boilers have consumed the amount of oil according to the following table:

Table 6 Annual oil consumption in boilers

Month	Consumption (l/month)
October	Ventilation
November	9300
December	18800
January	28900
February	32900
March	19600
April	15200
May	9000
Total	133700 liters

Based on these data, the amount of CO₂ emitted during the winter season from the operation of the boilers will be: From calculations, 1 kg of oil produces approximately 3.15 kg of CO₂, and 1 liter of oil produces 2.62 kg of CO₂.

In our case during the heating period, we will have the production: 133700 liters of oil x 2.62 kg CO₂/liter = 350.254 kg CO₂ = 350.24 tons of CO₂.

LPG has a composition of 40% propane and 60% butane. Propane (C₃H₈): Amount of CO₂ produced by burning 1 liter of propane: about 1.51 kg CO₂. Butane (C₄H₁₀): Amount of CO₂ produced by burning 1 liter of butane: about 1.71 kg CO₂.

The amount of CO₂ for each LPG component: - For propane: 40% of 1 liter of LPG is propane: 0.40 * 1.51 kg CO₂ = 0.604 kg CO₂; For butane: 60% of 1 liter of LPG is butane: 0.60 * 1.71 kg CO₂ = 1.026 kg CO₂. So, burning 1 liter of LPG with 40% propane and 60% butane produces about 1.63 kilograms of CO₂.

In the case of LPG, the total CO₂ output based on the boiler manufacturer's data is 137,396 liters x 1.63 kg CO₂/liter = 223,955.48 kg CO₂ (223,955 tons CO₂).

The reduction of carbon emissions because of replacing the burners will be: $350.24 - 223.955 = 126.285$ tons of CO₂.

Economic benefit:

In Albania, 1 liter of oil costs 184 ALL and 1 liter of LPG costs 62 ALL.

Total value of oil 24,600,800 ALL. The total value of LPG based on the data of the boilers received from the manufacturer is 8,518,540.84 ALL. The economic benefit of replacing the boiler burner, regardless of the initial cost, will be approximately 16,082,259.2 ALL (160,822.59 €).

CONCLUSIONS

This study investigated energy efficiency measures at Tirana International Airport (TIA) to reduce the carbon footprint and realize an economic benefit.

Tirana International Airport (TIA) uses an integrated environmental, energy and quality management system in accordance with international standards ISO 14001, ISO 50001 and ISO 9001.

TIA has achieved Level II Reduction accreditation from the International Council of Airports in Europe. The results show that the trend in the total carbon footprint of the airport in the last three years is in the range of 9,00-1,700 tons and the carbon footprint per traffic unit is in the range of 0.69-0.32 kg. Emissions per traffic unit average 0.49 kg CO₂ per passenger, 20-40% lower compared to the base year.

During the study period, two sets of photovoltaic panels with a capacity of 519.42 KWp and 594 KWp were installed at Tirana airport. As a result, the reduction of greenhouse gas emissions was 832.14 tons of CO₂ in the atmosphere, if the energy will be produced by the diesel power plant and 533.68 tons of CO₂ if the energy will be produced by the natural gas power plant with an economic profit of approximately 250,000 euros.

Replacing the oil burners with an LPG burner at the three boilers reduced 126.28 tons of carbon emissions and the economic profit was about 160,822 euros.

References

- World Bank. (2022). The Economic and Financial Implications of Carbon Footprints. World Bank Group. Accessed October 19, 2023. <https://openknowledge.worldbank.org/handle/10986/36704>.
- Ferrulli, P. (2016). Green airport design evaluation (GrADE) – Methods and tools improving infrastructure planning. *Transportation Research Procedia*, 14, 37813790. <https://doi.org/10.1016/j.trpro.2016.05.463>
- Kotopoulos A, Nikolopoulou M. Evaluation of comfort conditions in airport terminal buildings. *Building and Environment*. 2017; 130:162-178. <https://doi.org/10.1016/j.buildenv.2017.12.031>.
- Rossi Dal Pozzo, F. EU Legal Framework for Safeguarding Air Passenger Rights; Springer International Publishing: Cham, Switzerland, 2015.
- Akyuz, M.K., Altuntas, O., Sogut, M.Z., & Karakoc, T.H. (2019). Energy management at the airports. In T. Karakoc, C. Colpan, O. Altuntas & Y. Sohret (Eds.), *Sustainable aviation* (pp. 9-36). Cham, Switzerland: Springer International Publishing.
- Taber, C., & Steele, B. A. (2020). Impact of HVLS fans on airplane hangar air destratification. *ASHRAE Journal*, 62(4), 26-32.
- Sajed Sadati, S.M., Cetin, K., Ceylan, H., Sassani, A., & Kim, S. (2018). Energy and thermal performance evaluation of an automated snow and ice removal system at airports using numerical modeling and field measurements. *Sustainable Cities and Society*, 43, 238250. <https://doi.org/10.1016/j.scs.2018.08.021>
- Barrett, S., Devita, P., Ho, C., & Miller, B (2014). Energy technologies' compatibility with airports and airspace: Guidance for aviation and energy planners. *Journal of Airport Management*, 8(4), 318-326.
- Radomska, M., Chernyak, L., & Samsoniuk, O. (2018). The improvement of energy-saving performance at Ukrainian airports. In T.H. Karakoç, C. Ozgur Colpan & Y. Söhret (Eds.), *Advances in sustainable aviation* (pp. 189-203). Cham, Switzerland: Springer International Publishing.

- Ortega Alba, S., & Manana, M. (2016). Energy research in airports: A review. *Energies*, 9(5), 349. <https://doi.org/10.3390/en9050349>
- McKinsey & Company. (2021). The Business Case for Reducing Carbon Footprints. New York: McKinsey & Company. Accessed October 19, 2023. <https://www.mckinsey.com/capabilities/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring>
- International Monetary Fund. (2021). The Economic Impacts of Climate Change. Washington, D.C: International Monetary Fund. Accessed October 19, 2023. <https://www.imf.org/en/Topics/climate-change/climate-and-the-economy>.
- Wongsapai, W., C. Ritkrerkkrai, and J. Pongthanaisawan. 2016. "Integrated Model for Energy and CO2 Emissions Analysis from Thailand's Long-Term Low Carbon Energy Efficiency and Renewable Energy Plan." *Energy Procedia* 100:492-495. <https://doi.org/10.1016/j.egypro.2016.10.208>
- Busu, M. 2019. "Measuring the Renewable Energy Efficiency at the European Union Level and Its Impact on CO2 Emissions." *Processes* 7 (12): 923. <https://doi.org/10.3390/pr7120923>.
- Janić, M. *Greening Airports: Advanced Technology and Operations*; Springer: London, UK, 2011.
- Zhou, Y. (2022). Low-carbon transition in smart city with sustainable airport energy ecosystems and hydrogen-based renewable-grid-storage-flexibility. *Energy Rev.* 1, 100001. doi: 10.1016/j.enrev.2022.100001
- Mirza, F. M., A. Sinha, J. R. Khan, O. A. Kalugina, and M. W. Zafar. 2022. "Impact of Energy Efficiency on CO2 Emissions: Empirical Evidence from Developing Countries." *Gondwana Research* 106:64-77. <https://doi.org/10.1016/j.gr.2021.11.017>
- Wang, Q., Z. Sun, J. Guo, and R. Li. 2023. "The More Effective Option to Combat Environmental Degradation: Energy Efficiency Vs. Renewable Energy Vs. Natural Gas?" *Energy* 283:128512. <https://doi.org/10.1016/j.energy.2023.128512>.
- Falk, M, and Hagsten, E. (2020) Time for carbon neutrality and other emission reduction measures at European airports. *Business Strategy and the Environment*, 29(3), 1448-1464. Retrieved from: <https://doi.org/10.1002/bse.2444>.
- Wiedmann, T. and Minx J. (2007) A definition of 'carbon footprint'. In: Pertsova, C.C. (Ed.). *Ecological Economics Research Trends*. New York: Nova Science Publishers, p. 1-11.
- Filimonau, V., Mika, M., & Pawlusinski, R. (2018). Public attitudes to biofuel use in aviation: Evidence from an emerging tourist market. *Journal of Cleaner Production*, 172, 3102-3110. <https://doi.org/10.5194/acp-13-429-2013>
- Olsen, S.C., Wuebbles, D.J., & Owen, B. (2013). Comparison of global 3-D aviation emissions datasets. *Atmosphere Chemistry and Physics*, 13, 429-441.
- Laurent, A, Olsen, S.I., & Hauschild, M.Z. (2010). Carbon footprint as environmental performance indicator for the manufacturing industry. *CIRP Annals*, 59(1), 37-40. <https://doi.org/10.1016/j.cirp.2010.03.008>
- Mrazova, M. (2014). Sustainable development – The key for green aviation. *INCAS Bulletin*, 6(1), 109-122.
- Airport Carbon Accreditation. (2022). "Airports addressing their CO2 emissions," <https://airportco2.org/airportsacross-the-world.html>.
- Yang T, Bandyopadhyay A, O'Neill Z, et al. (2022). From occupants to occupants: A review of the occupant information understanding for building HVAC occupant-centric control. *Building Simulation*, 15, 913-932.
- Lee KH, Baek NC. A modified efficiency equation of solar collectors. *Energy Procedia* 2014; 48:145-9. <https://doi.org/10.1016/j.egypro.2014.02.018>.
- Cristofari C et al (2015) Innovative alternative solar thermal solutions for housing in conservation-area sites listed as national heritage assets. *Energy Build* 89:123-131. <https://doi.org/10.1016/j.enbui.2014.12.038>
- Hansen K, Vad Mathiesen B (2018) Comprehensive assessment of the role and potential for solar thermal in future energy systems. *Sol Energy* 169:144-152. <https://doi.org/10.1016/j.solener.2018.04.039>
- Ahamd M. State of the Art Compendium of Macro and Micro Energies. *Advances in Science and Technology Research Journal*. 2019; 13, 88-109.