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THE SITUATION OF FREIGHT TRANSPORT AND OTHER LOGISTICS TASKS IN LAOS

[1]Jozsef Gal, [2]Somany Phoymany

[1] University of Szeged, Faculty of Engineering, Mars ter 7., 6724, Szeged, Hungary,
[2]University of Szeged Faculty of Agriculture, Andrassy ut 15., 6800 Hodmezovasarhely, Hungary,
galj@mk.u-szeged.hu

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ABSTRACT

This study aims to analyse the obstacles and constraints in the shipping and logistics in Laos, a landlocked nation in Southeast Asia. Transportation and logistics play a pivotal role in Laos' national economy, acting as the lifeblood for the movement of goods and materials within the country and linking it to the international trade system. This case study highlights the significance of a robust logistics structure for Laos and its essential role in fostering economic development, agricultural growth, and connectivity. It also underscores the challenges faced by the country's logistics sector, such as limited-service frequency and road safety concerns. The study examines Laos transportation infrastructure, encompassing road, rail, and air networks, and sheds light on the obstacles and disparities that hinder value chain development in the country. These issues include disconnected stakeholder participation, the aging vehicle fleet, and financial limitations. Furthermore, the essay emphasizes the need for improved interconnectivity and inter-mobility to enhance the national, regional, and international connectivity of Laos and similar landlocked developing countries in Asia.

Keywords: Laos, Logistics, Transportation Infrastructure, Landlocked Developing Countries

1. INTRODUCTION

Laos is a landlocked country located in Southeast Asia which transport and logistics play an important role in the national economy and in linking the international trade system including road, rail and air. Transportation and logistics are of course an important aspect of Laos economy. It is the lifeblood for the movement of goods and materials. In the context of Laos being situated within the context and surrounded by the country, an efficient logistics structure is necessary and efficient. The ability to move goods across borders without hindrance is essential to a national economy. The transportation and logistics networks in Laos serve as the conduits that bind the nation to the global stage. They are the vital arteries that keep the country integrated into the broader fabric of the world economy. Whether it's the smooth flow of goods across international borders, the seamless movement of people and commodities, or the efficient distribution of resources, the global connectivity fostered by Laos' transport and logistics infrastructure ensures that the country remains an indispensable component of international supply chains. This connectivity opens doors to vast marketplaces, fosters collaboration with international partners, and propels Laos towards a dynamic role in the ever-evolving landscape of global commerce. The exclusive domain in which the Laotian transportation sector fully caters to trucking capacity is the distribution of both domestically manufactured and imported goods. Among the notable distributors in this domain is Beer Lao, an industry giant, responsible for the annual distribution of approximately 200,000 tons of beverages and conducting approximately 15,000

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deliveries every year [1]. This significant undertaking injects an estimated 12 million EUR into the country's economy in terms of transportation expenses (Beer Lao Representative, 2013) (Fig. 1).

Figure1. Beer Lao company shipping products by truck on the road [1]

However, the shipping and logistic in Laos still have a limitation of the number-frequently services in a day, poor road construction cause an accident [2] (Fig. 2). This case study will provide an insight into the growing background of transport and logistics in Laos, and highlighting the importance of this part in the economic development in agriculture and challenge of Laos logistics.

Figure2. The Truck accident during shipping process in Laos [2]

2. TRANSPORTATION INFRASTRUCTURE IN LAOS

Due to its mountainous terrain and historical underdevelopment, Laos has struggled with a dearth of reliable transportation routes. This lack of accessibility has traditionally hindered governments from establishing a presence in remote areas far from national or provincial hubs and has constrained interaction and communication among various villages and ethnic groups
Laos has a rather limited road network, but it does feature some contemporary transportation systems, such as various highways and several airports. Due to its landlocked status, Laos does not have access to sea ports

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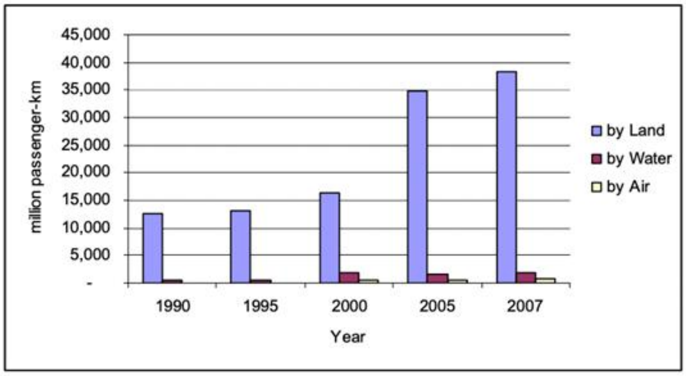
or harbours, and the navigational challenges presented by the Mekong River mean it is not a major transportation route either. Initially established during French colonial rule and expanded from the 1950s onwards, this network has played a crucial role in improving communication between villages, facilitating the movement of goods to markets, and encouraging the establishment of new settlements. Nevertheless, up until the mid-1990s, travel in many areas remained a challenging and costly endeavour, limiting the distance that most Laotians could cover.

2.1. Road transportation

Road is the efficient transportation in Laos which play the important role of logistic. In Laos, there is an extensive road network covering a total of 21,716 kilometres. Of this, approximately 9,673.5 kilometres) are paved, while the remaining 12,042.5 kilometres remain unpaved. The country follows a right-hand traffic (RHT) system for road travel. The low traffic demand, combined with the need to provide access to remote areas, shows that the Lao PDR needs to develop basic two-lane roads at a low cost for the medium term until demand rises to levels requiring significant capacity expansion. Fig. 3 and Fig. 4 show the passenger-km for the Lao PDR and ratio among types of roads. (unfortunately, newer data is not found) [3, 4]



km = kilometer.
Source: Lao People's Democratic Republic National Statistical Center. http://www.nsc.gov.la/Statistics

Figure 3: Passenger-Kilometer Evolution in the Lao People's Democratic Republic [4]

A notable development in Laos' transportation infrastructure occurred in 2007 when a new highway was constructed, linking Savannakhet to the Lao Bao border in Vietnam, with financial support from the Japanese government.

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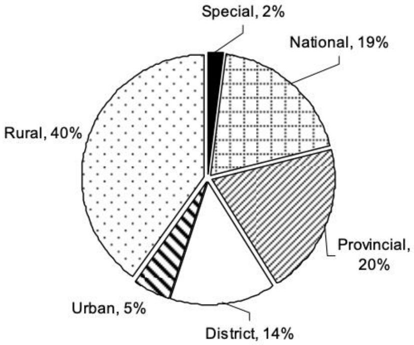

Source: Government of the Lao People's Democratic Republic, Ministry of Public Works and Transport. 2008. *Strategic Plan for Transport Sector Development: Guiding the Sector-Wide Approach*. Vientiane.

Figure 4: Classification of Roads (number of kilometers), 2008 [5]

This significant undertaking has led to a considerable enhancement in transportation within Laos. Previously, the journey from Savannakhet to the Vietnamese border took more than nine hours in 2002, whereas the new highway allows travellers to complete the same route in just a few hours.

2.2. Rail transportation

Laos has 422 km (262 mi) of 1,435 mm standard gauge railways, primarily consisting of the Boten–Vientiane railway, which opened in December 2021. It also has a 3 km (2 mi) metre gauge railway at Thanaleng terminus connected to Thailand's railway system.

In July 2022, the Lao government unveiled plans to conduct a feasibility study for the Laos-Vietnam Railway Project, which entails a two-phase rail line construction. The first phase seeks to link Thakhek with the Vung Ang seaport in Vietnam, spanning a distance of 139 kilometres. Subsequently, the second phase will focus on establishing a 312-kilometer rail connection between Thakhek and the capital city, Vientiane.

The railway was planned to link the capital Vientiane with the town of Boten at the border with China. Construction began at Luang Prabang on 25 December 2016,[16] and the line was officially opened on 3 December 2021. The railway is funded by 60% of debt financing ($3.6 billion) from the Export-Import Bank of China and the remaining 40% ($2.4 billion) is funded by a joint venture company between the two countries, in which China holds a 70% stake. [4]

2.3. Air transportation

Laos possesses 52 airports, of which nine have paved runways. Of the airports with paved runways, Wattay International Airport in Vientiane has a runway length of 3,000 metres. Of the remainder, four have runways 1,524 metres to 2,437 metres length, and a further four have lengths between 914 metres and 1,523 metres.

Of the airports without unpaved runways, one has a runway length of more than 1,524 metres, Seventeen have runway lengths between 914 metres and 1,523 metres, leaving 25 with a lengths below 914 metres. [4]

3. RESULTS AND DISCUSSION, CHALLENGES AND OBSTACLES FOR VALUE CHAIN DEVELOPMENT

The Lao transport and logistics sector faces a multitude of challenges and hindrances that hinder its development and engagement with international markets. One major issue lies in disconnect between the key players and stakeholders in the industry. The majority of major players, represented by LIFFA, predominantly function as freight forwarders and customs brokers, with limited involvement in asset-based

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truck ownership. The reluctance to invest in transport assets stems from the belief that they are of little use beyond Laos' borders, where demand is insufficient. Furthermore, there's a lack of awareness among transport operators regarding opportunities and international agreements, a shortage of trained drivers and mechanics, and an absence of qualified managers. Additionally, there's a limited ability to market services to international customers, a scarcity of suitable vehicles for international operations, and difficulties in securing vehicle financing. These barriers highlight the need for a comprehensive strategy to address these challenges, enhance the sector's capacity, and capitalize on the opportunities available for Laos in the rapidly evolving transport and logistics landscape. [6]

In terms of natural channels for significant boat transportation, the Mekong and Nam Ou rivers are the primary options. However, their use is often limited due to low water levels from December through May. For residents of lowland villages situated along smaller rivers, traditional modes of travel have involved using canoes for fishing, trading, and limited river journeys. Otherwise, transportation largely relies on ox-carts over level terrains or traveling by foot. The rugged mountainous landscape and the absence of roads have compelled upland ethnic communities to depend solely on pack baskets and horse packing for their transportation needs.

The degradation of rehabilitated paved roads in Laos is primarily attributed to the lack of consistent maintenance, including both routine and periodic upkeep. While the Road Maintenance Fund (RMF) has been established and operational for national roads and highways, its capacity to allocate just 10% of its revenues to provincial and rural roads has led to the neglect of maintenance in rural areas. This is further exacerbated by the insufficient funding provided by provincial governments.

Laos faces challenges in institutional capacity, with a shortage of technically trained personnel across the board, including within the Ministry of Public Works and Transport (MPWT). The nation lacks the necessary capacity to effectively plan, execute, monitor, and maintain transport projects, a concern that persists despite the implementation of capacity development programs. Gaps persist in various areas, such as project management, safeguard monitoring, rehabilitation and maintenance planning, and procurement. Tab. 1 shows the comparison between Laos and Thailand its Transit Neighbor by Overall Score LPI Components, based on LPI 2014 if Score 5= best [7]

LPI 2014 (Score 5= best): Comparison between Laos and its Transit Neighbor (Thailand) by Overall Score LPI Components

Country	Customs	Infrastructure	International shipments	Logistics quality and competence	Tracking and tracing	Timeliness
Thailand (Transit C.)	3.2	3.4	3.3	3.1	3.5	4.0
Lao PDR (LLDC.)	2.4	2.2	2.4	2.3	2.2	2.6

Table 1: Overall Score LPI Components, Source: sustainabledevelopment.un.org [7]

The improvement of roads, while beneficial, may inadvertently exacerbate economic disparities among ethnic groups, as the benefits are not always distributed evenly. Addressing these differential impacts requires a thorough assessment during the appraisal phase, accurate identification of proclivities for differential economic development, and the implementation of appropriate mitigation measures. In some instances, these assessments have been rudimentary.

Another challenge is road safety, with road improvements often linked to higher vehicle speeds, leading to an increase in road accidents, injuries, and fatalities. Over the period from 2002 to 2007, Laos experienced a 4% average annual growth in the number of accidents, with motorcycles having the highest accident rates,

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followed by cars and pickups. Road safety is further compromised by vehicle overloading, notably by logging trucks and international traffic on certain road sections, resulting in road damage and reduced road lifespan. Weigh stations on national roads struggle to effectively enforce vehicle axle controls, and provincial and rural roads lack such facilities. The hilly terrain and susceptibility to landslides pose additional challenges for road construction, with slope stabilization techniques often proving costly and impacting the economic viability of projects.

Transport services in Laos face various challenges, including empty return haulage, high logistics costs, limited transport volume, constrained business opportunities in a small market, financial limitations hindering reinvestment, an aging fleet, the absence of a transport hub, inadequate infrastructure investment, and a lack of institutional coordination; similar challenges are experienced by landlocked developing countries (LLDCs) in Africa and Asia, leading to lower economic performance due to their geographical distance from the coast, complicated transport services, insufficient infrastructure, and limited private sector involvement, emphasizing the need for improved interconnectivity and inter-mobility through the development of transport logistics facilities and ICT, supported by technical and financial assistance, and the provision of international road transport services in LLDCs to enhance their national, regional, and international connectivity.

4. CONCLUSIONS

In summary, Laos is a landlocked country in Southeast Asia, and its transportation and logistics sector plays a vital role in its economy. While the country has made progress in improving its transportation infrastructure, there are still challenges to overcome.

One major issue is the lack of coordination and investment in the sector. Most key players are focused on freight forwarding and customs, rather than owning and expanding transportation assets. This leads to a shortage of trained drivers and mechanics and makes it difficult to market services to international customers. Maintaining and upgrading roads is another challenge, with insufficient funding and a lack of technical expertise. This can lead to deteriorating road conditions and safety issues, including accidents.

To address these challenges and fully benefit from its strategic location, Laos needs a comprehensive strategy to enhance its transportation and logistics sector. This will ensure it remains a significant player in the global trade system and continues to grow economically.

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DIELECTRIC MONITORING OF MICROWAVE EXTRACTION PROCESSES

[1*]**_Réka Dobozi_**, [2]**_Zoltán Péter Jákói_**, [2]**_Sándor Beszédes_**

[1]Department of Food Engineering, Faculty of Engineering, University of Szeged, H-6725, Szeged, Hungary
[2]Department of Biosystems Engineering, Faculty of Engineering, University of Szeged, H-6725, Szeged, Hungary
dobozireka@mk.u-szeged.hu

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ABSTRACT

Our research investigated the dielectric traceability of microwave and ultrasound intensified extraction processes of plant by-products. For the experiments, I used plant by-products from beetroot, carrot and raspberry, which were extracted in 5% suspensions. The dielectric behaviour of the extracts was investigated in the frequency range 300-2400 MHz using an open-ended coaxial probe. For both the ultrasonic and microwave intensified procedures, the reported energy was 30, 45 and 60 kJ, respectively. Based on my research results, I found that the dielectric constant measured in the frequency range 700-900 MHz is closely related to the yield of total polyphenol and pectin regardless of the feedstock and treatment used, but the method has limitations due to the presence of components that affect the physical structure and the concentration of target components below the limit of detection.

Keywords: microwave, extraction, dielectric properties, dielectric measurements

1. INTRODUCTION

A significant proportion of agricultural and food by-products and wastes of plant origin contain valuable components (bioactive substances, heteropolysaccharides, etc.) that can be recycled for industrial use through appropriate recovery, separation and purification technologies, thus fitting into the concept of circular economy [1]. One of the most commonly used methods for recovering the various components that can still be used is extraction, whereby the target components are introduced into the liquid phase extract using a solvent, usually a selective solvent, and under suitable reaction conditions [2]. In order to improve the efficiency of extraction, novel, complementary methods are nowadays being used to achieve higher product concentrations with significantly lower solvent requirements and operation times. Examples of such intensification operations are microwave-assisted or ultrasound-assisted extraction, where the thermal effects generated by the microwave field in the former and the mechanical shear forces and cavitation phenomena in the liquid phase caused by ultrasound in the latter result in the destruction of the structure of the material to be extracted, which facilitates the recovery of the components. In the extraction of plant by-products of agro-food origin, the concentration of the target components to be extracted can be many times higher than the maximum concentration achievable in conventional extraction processes due to the plant cell wall disintegration induced by these intensification operations [3].

At the same time, the complexity of the processes justifies the need for real-time monitoring and control of the extraction operations to detect possible errors and improve the efficiency of each extraction operation. Monitoring techniques based on the dielectric behaviour of materials are becoming more and more widely used because they are fast, accurate, non-sampling, non-destructive and have applications in food processing, among others [4]. The dielectric properties of materials are already used today for the optimisation of extraction processes (adjustment of solvent concentration, pH, extraction time, etc.) [5], but research on continuous monitoring of the process based on dielectric parameters is still scarce. Based on these considerations, the focus of my current research is to monitor the microwave and ultrasound intensified extraction processes of different by-products of plant origin based on the dielectric behaviour of the extracted extracts.

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2. MATERIALS AND METHODS

For the extraction processes, we used three different plant by-products as feedstock, taking into account sustainability aspects: peelings from peeling beetroot and carrots, and the residual pulp after pressing raspberries for pulping. The residues of root vegetables were chopped to a final particle size of 3-5 mm prior to extraction, and 5% aqueous suspensions were prepared from all the raw materials included in the study. The extraction processes were intensified by microwave treatment at 2.45 GHz (Labotron 500) at 2 different power levels (250 W and 500 W) and by ultrasonic extraction at 200 W (Hielscher UP200S, 24 kHz). In order to compare the monitoring of extraction operations based on different principles, the principle of energy equivalence was applied. The times of the treatments with the intensification operation were chosen so that the energy transferred to the material was 30, 45 and 60 kJ. Thus, we monitored the different extraction processes by reaching these energy levels.

Pectin and total polyphenol concentrations were determined in the obtained extracts on a dry matter basis. Pectin was determined by spectrophotometric method using m-hydroxydiphenyl reagent, total polyphenolic content (TPC) was determined using Folin-Ciocalteu reagent. In parallel, the interaction between the components in the aqueous phase and the electromagnetic field was investigated using a laboratory dielectric measurement system. Using an open-ended coaxial dielectric sensor (DAK 3.5, SPEAG GmBh) connected to a vector network analyser (ZVL-3 VNA, Rhode&Schwarz GmBh), we determined the dielectric constant (ε') values of the extracts in the frequency range between 300 MHz and 2400 MHz.

3. RESULTS AND DISCUSSION

Based on our previous research and the available literature, it can be concluded that in the frequency range of 300-2400 MHz the dielectric behaviour is mainly determined by ionic conduction and dipole rotation, however, considering that the general frequency-dependent trends of dielectric properties in multicomponent heterogeneous systems are mostly not verifiable, only certain discrete frequency bands can be reliably used for monitoring physical, chemical, biological processes. In the monitoring of extraction processes, the frequency-dependent spectrum of the dielectric constant of the extract showed a local maximum at 800 MHz, independent of the type of treatment, the amount of energy applied and the feedstock (Figures 1-3). It can be concluded that the target components under investigation, polyphenols and pectin, have a significant effect on the dielectric behaviour in this frequency range, and therefore I used the data measured in the 700-900 MHz frequency range to compare the dielectric changes.

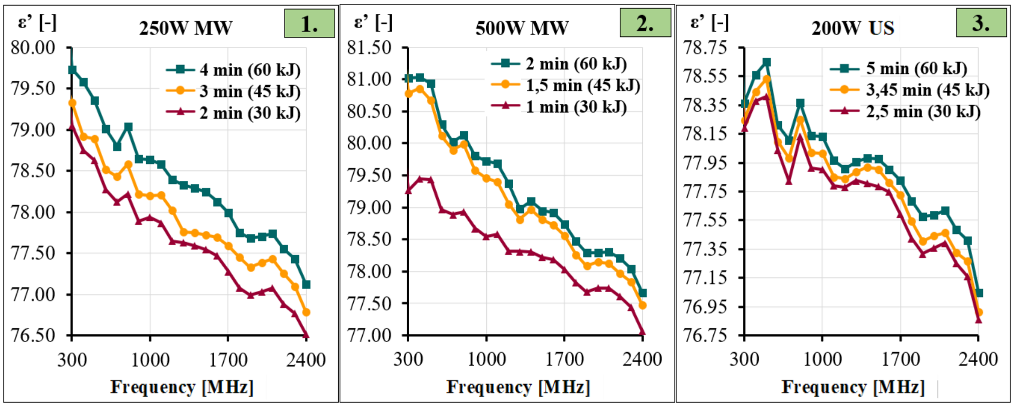

Figure 1-3. *Dielectric spectra of beet extracts obtained by different intensifying methods*

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With the progress of the microwave and ultrasound intensified extraction process of beetroot, the extraction indexes of the two tested components varied with an increasing trend, and we found that the polyphenol content of the extract exceeded the pectin concentration by 1.5-2 times during the whole extraction process. During the monitoring of the microwave extraction at 250 W power, there is a strong positive correlation between the variation of the dielectric constants measured at the inflection point of the dielectric spectrum (800 MHz) and its discrete frequency interval (700-900 MHz) (Figure 1) and the increase in the yield concentration of the tested components (Figure 4).

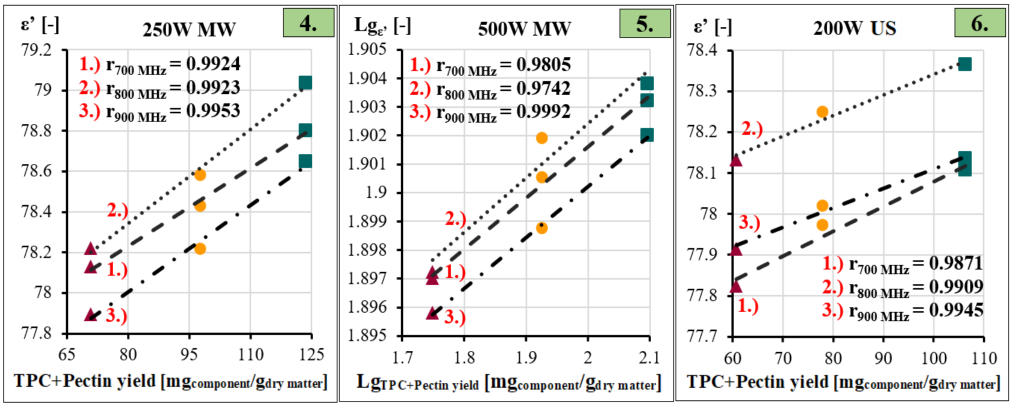

Figure 4-6. *Correlation analysis of beet extraction monitoring*

The increased (500 W) microwave power, presumably due to the different temperature rise tendencies, the relationship between the dielectric constant and the yield indices of the extract was approximated by a second-order polynomial fit. Therefore, for a proper regression and correlation analysis, the values were plotted using a logarithmic transformation, linearized, and then, based on the values of the point-fitted linear correlation coefficient, it was concluded that there was a close relationship between the variables (Figure 5). The frequency-dependent spectrum of the dielectric constant of the extract obtained after ultrasonic treatment followed a similar trend to the characteristic variation observed for microwave extraction, but due to the different disintegration effect, the local maximum value of ε' was recorded not only at 800 MHz but also at 500 MHz (Figure 3). The relationship between the dielectric constant values measured in the 700-900 MHz frequency interval and the variation of the yield indices during the ultrasonic extraction process also showed a close linear correlation (Figure 6).

In carrot extracts, the extraction of the tested components showed low absolute concentrations ($c_{max\ (pectin)} <$ 33mg/g_{dm}, $c_{max\ (polyphenol)} <$ 13mg/g_{dm}) and, similar to beet extraction, increased with increasing energy input, while the pectin content exceeded the polyphenol content. As the extraction progressed, there were no significant differences between the extraction indices and therefore no significant differences in the dielectric behaviour of the extracts obtained with different energy concentrations were observed at frequencies above 1100 MHz. The monitoring of microwave treatment at 250 W power and ultrasonic extraction showed that the correlation coefficient between the dielectric constant measured in the frequency range 700-900 MHz and the variation of the extraction indexes of the target components was high (r=0.95-0.99), i.e. the correlation is close and the relationship between the variables can be approximated linearly. For the 500 W microwave treatment, the relationship between the parameters varied according to a second-order function due to the different temperature rise profile.

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In all the raspberry pulp extractions studied, even at low energy concentrations, a significant amount of pectin was dissolved in the aqueous phase, in terms of dielectric properties, which probably masked the effect of other components (including polyphenols) on the dielectric behaviour. Furthermore, the pectin, due to its gelling effect, increased the viscosity of the raspberry extracts, thus changing the physical structure of the raw material to such an extent that the characteristic molecular mechanisms could not be validated in the frequency range I have investigated.

4. CONCLUSIONS

Based on the results of my research so far, I have concluded that dielectric parameters measured in the 700-900 MHz frequency band can be used to monitor the extraction process, regardless of the type of intensification operation. The variation of the dielectric constant showed a close correlation with the total polyphenol and pectin extraction indexes of beet and carrot extracts, thus concluding that the dielectric measurement method is potentially suitable for monitoring the extraction process. However, the specificities of the different raw materials of different origins included in the study have highlighted that the presence of components affecting the physical structure (e.g. pectin in the extraction of raspberries) and the difference in the concentrations of the extracts below the limit of detection may be limiting factors for the applicability of the method. This suggests that further experiments over a wider frequency range and other measurement set-ups are needed to clearly establish the relationship between the parameters under investigation and to develop reliable monitoring methods based on dielectric parameters, including for industrial practice.

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COMPARATIVE ANALYSIS OF MEAT PRODUCTS MADE FROM VARIOUS CHICKEN MEAT RAW MATERIAL

[1]*Tamás Kulcsár,* [1]*Bálint Erdei,* [1]*Eszter Trenyik,* [1]*József Mihalkó,* [1]*Balázs P. Szabó*

[1]Department of Food Engineering, Faculty of Engineering, University of Szeged, Moszkvai Blvd. 5-7., 6725, Szeged, Hungary
e-mail: mihalko@mk.u-szeged.hu

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ABSTRACT

Animal food, especially meat, has played an important role in the history of mankind. Different meats can be used in the production of meat products. In addition to lean meats, mechanically deboned meat (MDM) and mechanically separated meat (MSM) can also be used in meat products. However, the latter does not qualify as meat due to damage to the muscular structure due to the high pressure applied during the separation, therefore cannot be included in the meat content of products. The aim of our research work was to compare the characteristics of Bologna sausages made from chicken fillet, chicken MDM and poultry MSM. After evaluating our measurements (cooking loss, colour measurement, instrumental chemical composition measuring, stock measurement, determination of water activity, pH measurement, and sensory evaluation), we concluded that in the case of production with MSM, we produced a lower quality product using the same amount of meat raw material, which can be improved by using more additives (e.g. carminic acid, tetrasodium-pyrophosphate).

Keywords: meat, mechanically deboned meat, mechanically separated meat, Bologna sausage, comparative analysis

1. INTRODUCTION

Meat is the processed and certified skeletal muscle of mammals and poultry for human consumption [1]. According to [2], meat is the edible parts of the following animals, including blood: pigs, cattle, calves, poultry (e.g., chickens, hens, ducks, geese, turkeys), other warm-blooded animals (sheep, rabbits, goats, horses, etc.), wild animals (wild boar, deer, cervids, wild rabbits, etc.) and ratites (ostriches).
In addition to lean meat, meat removed from bones can also be used in meat products, according to the provisions of the [3]:

- Mechanically deboned meat (MDM), the production operation is limited to the mechanical removal of the bone from the boned meat and is not intended for the further extraction of meat from the bone remaining after boning.
- Mechanically separated meat (MSM) is a product obtained after boning from fresh, fleshy bones or poultry which have been removed by mechanical means in such a way as to damage or modify the muscular structure. This does not qualify as meat.

The basis of the method was developed in Japan in the early 1940s for remove and separating fish meat ([4]; [5]; [6]). According to [2], MSM cannot be made from poultry skins, neck skin and heads. Bone-in meat packaged for up to 3 days at 2°C can be used as raw material. The regulation stipulates a shelf life of 3 months when stored at -18°C. It is important that MSM can only be used in heat-treated products. MSM does not qualify as meat due to its unfavourable chemical (high fat and calcium content) and functional (poor water binding) properties. The composition and name of the product must also include 'mechanically separated meat (MSM)'. Previously, this was also classified as meat, but – due to its unfavourable properties – its use in meat products was maximized by 10% [3]. Of course, it can also be used in larger quantities to produce a product, but in this case the product cannot be called e.g., bologna sausage.
Ref. [3] also stipulates that:

- "if the raw material (primary ingredient) used to produce the meat product or prepared meat contains more than 200 mg/kg of calcium, it must be considered mechanically separated meat;

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- if the calcium content of the meat product or prepared meat is more than 350 mg/kg, the product certainly contains mechanically separated meat. The limit value is to be understood without the calcium content in other calcium-containing ingredients other than the meat in the product and the mechanically separated meat."

2. MATERIALS AND METHODS

2.1. Materials

Chicken breast fillet, chicken breast mechanically deboned meat (MDM) and poultry mechanically separated meat (MSM) were obtained from Hungerit Ltd. (Szentes, Hungary) (Fig. 1).

Figure 1. Raw materials (fillet meat, MDM, MSM). MDM: mechanically deboned meat, MSM: mechanically separated meat

In addition, we also used water, pork fat, sodium nitrite salting mixture, and tetrasodium-pyrophosphate (Soluprat) to produce the samples. The recipe can be found in Table 1. 1 mix was 400 g.

Table 1. Recipe of the prepared products

Raw materials	Amount [%]
Meat/MDM/MSM	60
Pork fat	20
Water	17.5
Sodium nitrite salt mixture	2.0
Soluprat	0.5

The manufacturing process can be seen in Fig. 2. The finished products were placed in cans and heat-treated in this way (in a water bath at 75 °C for 65 minutes). We used this procedure instead of the natural casings filling, because due to the small amount of the experimental products, a significant amount of technological loss should have been expected.

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Figure 2. The manufacturing process of the samples

Fig. 3. shows the finished products.

Figure 3. The finished samples (from fillet meat, MDM, MSM). MDM: mechanically deboned meat, MSM: mechanically separated meat

2.2. Methods

During of our research work, we used different measuring methods:
- Cooking loss measurement,
- Colour measurement,
- Chemical composition measurement,
- Instrumental stock measurement,
- Water activity measurement,
- pH value measurement,
- Sensory evaluation.

Cooking loss was measured by simple mass loss calculation. The mass of the meat paste was measured during filling it in a can, and then after heat treatment, the mass of the product was measured. From these, the cooking loss value was calculated as a percentage.

During our work, instrumental **colour measurement** was performed in 5 different points on the surface of the products with MINOLTA CR-300 CROMAMETER (Osaka, Japan). The obtained colour coordinates (L*, a*, b*) were used to determine the colour stimulus difference (ΔE*), which was determined by the formula of [6]:

$$\Delta E^{*} = \sqrt{\left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)} \tag{1}$$

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We performed **chemical composition measurement** on examined products, we measured fat, moisture, protein content with FOSS FoodScan 2 (Hillerød, Denmark). Based on the force-displacement curves of the individual samples, the value of the spring constant was calculated between 3 mm and 6 mm, based on [8].
We performed **instrumental stock measurement** with LLOYD 1000 Texture Machine (Bognor Regis, UK) type metering device with three repeats, the force-displacement curve was made from the results.
The Novasina LAB MASTER-aw equipment (Lachen, Switzerland) was used to **measure the water activity** of the samples. The tempering unit built into the instrument ensures a constant temperature (25 °C), so the water activity of the samples was determined under the same conditions.
The **pH value** of the samples was measured with a Testo 206 (Titisee-Neustadt, Germany) device (on 3 repeats).
The **sensory evaluation** of the samples was carried out by a total of 10 people, who were students and lecturers. Sensory evaluation was done using a descriptive method and overall impression scoring. In the descriptive method, the examined properties were the colour, smell, taste, and texture of the products. For the overall impression, the reviewers could score the samples between 1 and 10 points (a higher score is considered more popular).
The **statistical analysis** was performed with the IBM (Armonk, New York, USA) Statistics 27 software. The significance level was 5% ($P < 0.05$)). ANOVA was used for statistical analysis of variance. In the case of a significant ANOVA test result ($P < 0.05$), we determined which groups differed significantly with the Tukey HSD post hoc test. The Microsoft (Redmond, Washington, USA) 365 Excel program was used for graphic representation.

3. RESULTS AND DISCUSSION

3.1. Cooking loss

It can be clearly observed that, based on the percentage of the cooking loss, there was no significant difference between the samples made from the fillet and the MDM (0.49% and 0.53%), since we experienced almost the same cooking loss for these two. In the case of the MSM-based product, the higher value is caused by the raw material, nearly twice as much loss value was observed (0.95%). However, it should be noted that the cooking loss was reduced by tetrasodium pyrophosphate, without which we would certainly have noticed a higher cooking loss.

1.2. Colour measurement

Fig. 4 shows that the lightness (L*) of the products is between 70 and 72, the red colour intensity (a*) is between 3 and 6, and the yellow colour intensity (b*) is between 9 and 13. A significant difference can be seen within some of these intervals. In terms of lightness, there is no significant difference between the samples. In the case of red and yellow colour intensity, the sample made of MSM took on a significantly higher value, i.e. it became redder and yellower compared to the other two samples. Using these values, the colour stimulus difference was calculated between 2-2 samples. The largest colour stimulus difference value (3.19) was between products made from fillet and MSM, i.e. it is a well noticeable difference. There was a visible difference between the sample made from MDM and the other two samples (values of 1.55 and 1.81).

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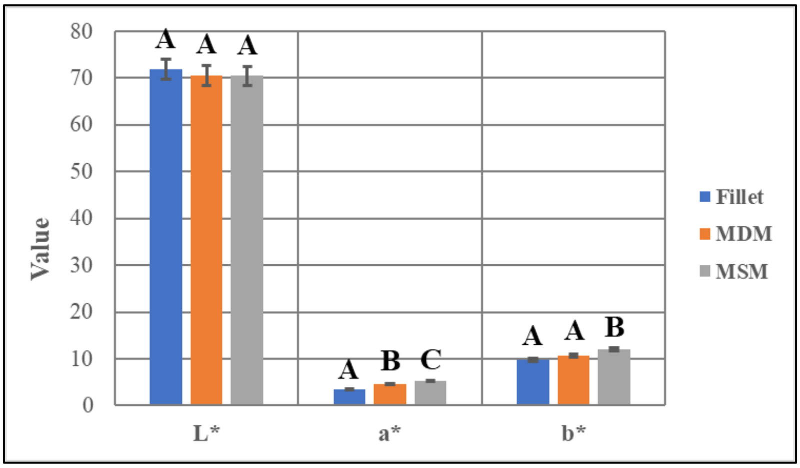

Figure 4. Colour coordinates of the samples. L*: lightness value, a*: red color intensity, b*: yellow color intensity, MDM: mechanically deboned meat, MSM: mechanically separated meat. Capital letters above the bars show significant difference (P < 0.05).

1.3. Chemical composition measurement

As we can see in Fig. 5, there is a significant difference between the fat content of the samples. The product made from fillet had the lowest fat content (20.90%), this value was not much higher for the product made from MDM (21.12%). The sample with the highest fat content was the MSM-based meat product (24.64%). There is also a significant difference between the moisture content values of the samples, however, the fillet-based product had the highest value (61.33%). This was followed by the sample made from MDM (61.20%) and MSM (58.69%). In other words, it can be seen from the trend that there is an inverse proportion between moisture content and fat content. There is also a significant difference between the results of the protein content of the samples. The Bologna sausage made from fillet contains the most protein (14.27%), followed by the MDM- (14.23%) and the MSM-based sample (13.76%). In other words, the trend of the protein content follows the trend observed for the moisture content (an inverse proportionality can be discovered with the fat content).

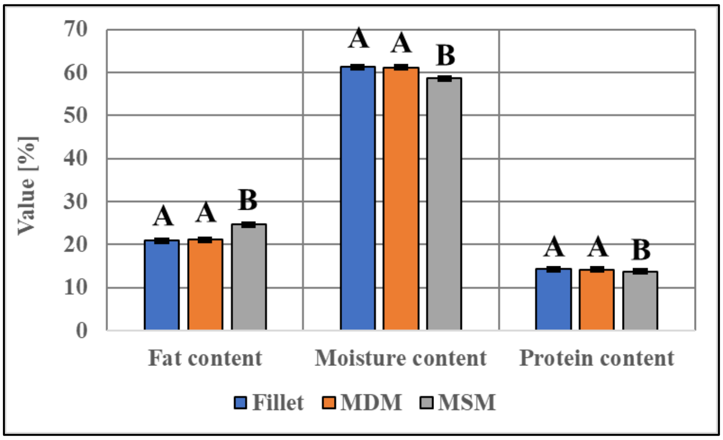

Figure 5. Chemical composition of the samples. MDM: mechanically deboned meat, MSM: mechanically separated meat. Capital letters above the bars show significant difference (P < 0.05).

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3.4. Instrumental stock measurement

The results obtained from the average of the measurement data were plotted on a force-displacement curve (Fig. 6). It can be read from the curve that the product made from the fillet proved to be the hardest (the hardness corresponding to the maximum penetration value was 19.92 N). This was closely followed by the sample made from MDM (18.92 N). The meat product made from MSM was the softest (12.02 N). The value of the spring constant also was calculated. The product made from fillet (1.92 N/mm) and MDM (1.7 N/mm) has the highest spring constant value, the sample made from MSM had the lowest value (1.1 N/mm).

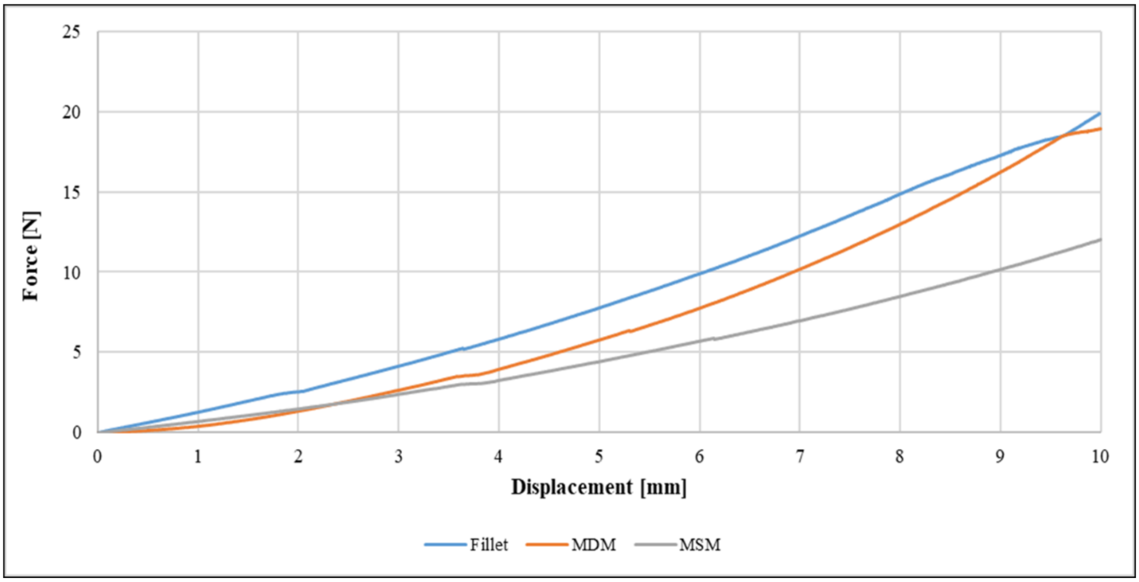

Figure 6. Force-displacement curve of the samples. MDM: mechanically deboned meat, MSM: mechanically separated meat

3.5. Water activity

From the water activity values of the samples, it can be concluded that there is a significant difference between the products made from MSM and the other samples. The fillet and MDM-based products had the lowest water activity (0.954), meaning that these samples contain less free water. The sample made from MSM had the highest value (0.963).

3.6. pH value

There was no significant difference between the pH values of the products made from meat raw materials, as the pH values of the samples were as follows: the MSM-based one was 6.42, the MDM-based one was 6.44 and the fillet-based one was 6.46.

3.7. Sensory evaluation

No excessive difference can be noticed between products made from chicken fillet and MDM. In both cases, the colour of the product was characteristic of cooked, marinated meat (pink). In addition, the smell and taste of the product made from fillet and MDM was typical of cooked meat, with so many additions that the taste of the MDM-based sample was weaker in intensity. In addition, the stock of products made

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from fillet and MDM was compact and could be sliced well. However, the meat product made from MSM fell short of the other two raw materials in all aspects. Because the colour of the product was pale, with a yellowish tint, a slight foreign character was noticeable in its smell and taste, the latter also had a slightly rancid, stale taste. In addition, the product became too hard and not cohesive. These differences also appeared in the numbers given during the overall impression, since the product made from fillet became the most popular (7.5), followed by the sample made from MDM (6.9), and the meat product made from MSM was far behind (4.3).

4. CONCLUSIONS

After evaluating our measurements (cooking loss, colour measurement, instrumental chemical composition measuring, stock measurement, determination of water activity, pH measurement, and sensory evaluation), we concluded that in the case of production with MSM, we produced a lower quality product using the same amount of meat raw material, which can be improved by using more additives (e.g. carminic acid, tetrasodium-pyrophosphate).

ACKNOWLEDGEMENT

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DEVELOPMENT OF AN IOT BASED 3D PRINTED MOBILE ROBOT PLATFORM FOR TRAINING OF MECHATRONICS ENGINEERING STUDENTS

[1] ***János Simon***, [2]***László Gogolák***

[1] Department of Mechatronics and Automation, Faculty of Engineering, University of Szeged, Moszkvai krt.9. 6725 Szeged, Hungary,

[2] Department of Mechatronics and Automation, Faculty of Engineering, University of Szeged, Moszkvai krt.9. 6725 Szeged, Hungary,

e-mail: simon@mk.u-szeged.hu

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ABSTRACT

The advent of the Internet of Things (IoT) has opened up new opportunities in education, particularly in the field of mobile robotics. Mobile robotics is a fast-growing field, and with the increasing demand for skilled robotics engineers, it is essential to provide students with hands-on experience in designing and developing robots. In this regard, an IoT-based 3D printed mobile robot platform has been developed for students training. STEM (Science, Technology, Engineering, and Mathematics) education has been gaining attention as a means to improve science and engineering education. STEM education aims to foster critical thinking, problem-solving skills, creativity, and innovation among students. It involves an educational policy that aims to develop the next generation of skilled professionals by integrating the fields of Science, Technology, Engineering and Mathematics. The goal of this approach is to provide students in mechatronics, who are assigned to the robotics lab during their studies, an up to date knowledge and experience in research and development activities. Thus, this paper aims to provide education that focuses on the acquisition and application of engineering knowledge, including control engineering, mechanical engineering, electrical and electronic engineering, information engineering, among others, with the main focus on mobile robot research.

Keywords: 3D print, STEM, IoT, Multi-robot systems

1. INTRODUCTION

The rapid advancements in technology have significantly impacted the field of robotics, and as a result, there is an increasing demand for skilled robotics engineers. It is, therefore, essential to provide students with hands-on experience in designing and developing robots. STEM represents an interdisciplinary approach to education that integrates these four disciplines into a cohesive learning paradigm. STEM education aims to foster critical thinking, problem-solving skills, creativity, and innovation among students. By emphasizing real-world applications and hands-on learning experiences, STEM education prepares students for future careers in fields such as engineering, computer science and mechatronics. However, robotics education can be challenging due to the high cost of equipment and the complexity of the subject matter. To address these challenges, an IoT-based 3D printed mobile robot platform has been developed for students training. The platform is designed to be easy to use, cost-effective, and customizable, making it an ideal tool for teaching robotics to students [1]. The platform utilizes four different microcontrollers, namely, the ESP32, ESP8266, Raspberry Pi, and PIC 18x, to provide flexibility in programming and control. Each microcontroller has its unique features, and students can choose the one that best suits their needs. The use of microcontrollers provides a practical approach to teaching programming and control, making it an excellent platform for mechatronics students. The platform is 3D printed, making it easy to manufacture and assemble [2]. The design is modular, allowing students to customize the robot according to their requirements. The robot's chassis, wheels, and sensors can be easily replaced or modified, making it an excellent tool for students to experiment with different designs and configurations. The robot platform is equipped with a variety of sensors, including ultrasonic sensors, line-

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following sensors, and infrared sensors. The sensors enable the robot to detect obstacles, follow lines, and detect objects. Students can program the robot to perform various tasks, such as navigating a maze, following a line, or avoiding obstacles. The platform is also equipped with Wi-Fi and Bluetooth modules, allowing students to control the robot remotely using a smartphone or tablet. This feature enables students to experiment with wireless communication and control, providing them with essential skills in the field of IoT. The development of the IoT-based 3D printed mobile robot platform has been successful in providing students with a practical approach to learning robotics [3]. The platform's modular design, flexible microcontroller options, and variety of sensors make it an ideal tool for teaching robotics to students of all levels. The platform is cost-effective, easy to manufacture and assemble, and customizable, making it an excellent tool for schools and universities with limited resources. In conclusion, the development of an IoT-based 3D printed mobile robot platform has opened up new opportunities in robotics education as depicted in fig 1. The platform provides students with a practical approach to learning programming, control, and wireless communication. The modular design, flexible microcontroller options, and variety of sensors make it an ideal tool for teaching robotics to students of all levels [4]. With the increasing demand for skilled robotics engineers, providing students with hands-on experience in designing and developing robots is essential, and the IoT-based 3D printed mobile robot platform provides an excellent platform for achieving this goal.

2. MATERIALS AND METHODS

This section outlines the proposed tools aimed at mechatronic engineering students to reconstruct core learning elements using basic concepts based on active learning. Unlike educational robotics, the tools aim to develop students' skills and abilities to generate innovative solutions to industrial automation problems and facilitate their integration into the job market. The core of the educational strategy lies in the promotion of analytical thinking, achieved through the implementation of elements of STEM. [5]. To ensure logical development in each student guide, a purpose or objective must be presented first, followed by a question that guides the problem or issue, and information gathering from facts, data, evidence, or experiences. Inferences and conclusions can then be drawn, and assumptions and beliefs can be justified with solid evidence. Concepts such as ideas, theories, laws, principles, or hypotheses are used to make sense of the gathered information, and a point of view or perspective is taken into account.

2.1. Hardware components

The hardware requirements for the development of an IoT-based 3D printed mobile robot platform for students training would depend on the specific features and capabilities of the platform. However, there are some general hardware requirements that would be essential for building such a platform:

- Microcontroller: The platform would require a microcontroller to control the robot's movements and sensors. The ESP32, ESP8266, Raspberry Pi, and PIC 18x microcontrollers are all suitable options for this purpose.
- Sensors: The platform would require a variety of sensors to detect the robot's surroundings and enable it to perform tasks. Sensors such as ultrasonic sensors, line-following sensors, and infrared sensors are commonly used in mobile robot platforms [6].
- Motors: The platform would require motors to drive the wheels and enable the robot to move. DC motors or servo motors are commonly used for this purpose.
- Power source: The platform would require a power source to run the microcontroller, sensors, and motors. A rechargeable battery or a power supply would be suitable options.
- Wi-Fi/Bluetooth module: The platform would require a Wi-Fi or Bluetooth module to enable wireless communication and control. The Raspberry Pi 4, ESP32 and ESP8266 microcontrollers have built-in Wi-Fi and Bluetooth capabilities, while the PIC 18x microcontrollers require additional modules.

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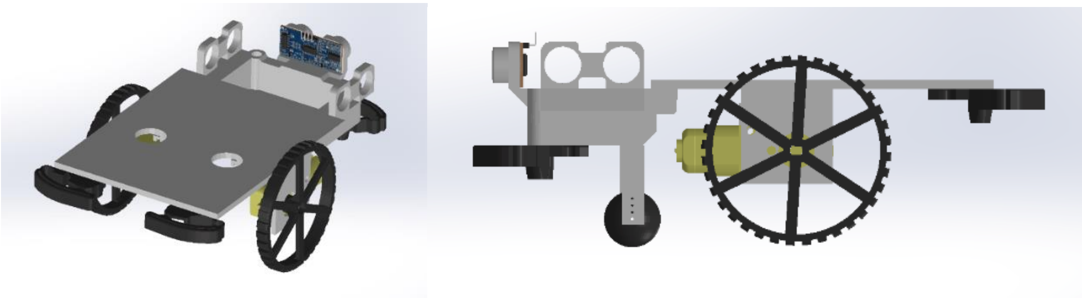

Figure 1. 3D model of the developed mobile robot platform. (Perspective view)

Overall, the hardware requirements for the development of an IoT-based 3D printed mobile robot platform for students training are relatively simple and affordable. The platform can be built using readily available components, and the use of 3D printing technology makes it easy to customize the robot's design and components.

2.2. Software components

The software environment for the development of an IoT-based 3D printed mobile robot platform for students training would depend on the microcontroller used in the platform. Each microcontroller has its own software development environment, but some general software requirements include an Integrated Development Environment (IDE) which is a software application that provides a programming environment for writing, debugging, and testing code [7]. Depending on the microcontroller used, the appropriate IDE should be selected. For example, the Arduino IDE is commonly used for programming the ESP32 and ESP8266 microcontrollers, while the Raspberry Pi can be programmed using Python or other programming languages. The firmware is the software that runs on the microcontroller and controls the robot's movements and sensors. The firmware should be programmed in the appropriate programming language for the microcontroller used, such as C or Python. Libraries are collections of pre-written code that can be used to perform specific tasks, such as controlling motors or sensors. The appropriate libraries should be selected for the microcontroller used. Simulation software can be used to simulate the robot's movements and test the firmware before uploading it to the robot. This can be useful in identifying errors and optimizing the firmware. Communication software can be used to establish wireless communication between the robot and a smartphone or tablet. The appropriate communication software should be selected depending on the microcontroller used. CAD (Computer-Aided Design) software can be used to design the robot's chassis, wheels, and other components before 3D printing them. This can be useful in customizing the robot's design and components. The software environment for the development of an IoT-based 3D printed mobile robot platform for students training should be easy to use and accessible to students of all levels. The software should be free or low-cost, and the appropriate software should be selected depending on the microcontroller used in the platform [8]. Additionally, simulation software and CAD software can be useful in optimizing the robot's design and performance.

3. DISCUSSION

An IoT-based 3D printed mobile robot platform for students can be used for a wide variety of tasks and exercises that can help students develop their skills in robotics, programming, and electronics. Here are some examples of tasks and exercises that can be solved using such a platform:

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- Line-following: The robot can be programmed to follow a line on the ground using line-following sensors. This task can help students develop their skills in programming and sensor integration.
- Obstacle avoidance: The robot can be programmed to avoid obstacles using ultrasonic or infrared sensors. This task can help students develop their skills in programming and sensor integration.
- Remote control: The robot can be controlled remotely using a smartphone or tablet via Wi-Fi or Bluetooth. This task can help students develop their skills in wireless communication and programming.
- Autonomous navigation: The robot can be programmed to navigate a maze or follow a specific path using a combination of sensors and algorithms [9]. This task can help students develop their skills in algorithm development and programming.
- Robotic arm control: The robot can be equipped with a robotic arm that can be controlled using servos and sensors. This task can help students develop their skills in robotics and electronics.
- Object detection and recognition: The robot can be programmed to detect and recognize objects using cameras and machine learning algorithms [10]. This task can help students develop their skills in image processing and machine learning.
- Swarm robotics: Multiple robots can be programmed to work together to perform a task, such as navigating a maze or carrying objects [11]. This task can help students develop their skills in collaboration and teamwork.
- Environmental monitoring: The robot can be equipped with sensors to monitor environmental factors such as temperature, humidity, and air quality [12]. This task can help students develop their skills in sensor integration and data analysis.
- Home automation: The robot can be programmed to control home appliances such as lights and fans using Wi-Fi or Bluetooth. This task can help students develop their skills in IoT and home automation.

Using, an IoT-based 3D printed mobile robot platform can provide students with a hands-on learning experience in robotics, programming, and electronics [13]. The tasks and exercises listed above are just a few examples of what can be achieved using such a platform, and the possibilities are virtually endless. Figure 2 presents the 3D printed and assembled mobile robot platform.

Figure 2. 3D printed and assembled mobile robot platform.

The decision to incorporate a mobile robot into the curriculum is driven by the significance of this type of robot setup in the context of Industry 4.0 [14]. The main objective of utilizing this mobile robot (depicted

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in Fig. 2) is to familiarize students with the mathematical model, control inputs, sensors, and actuators, with the aim of equipping them to tackle Industry 4.0-related challenges, such as devising a new configuration to address a particular issue in the industry, for example, streamlining the packaging process of an e-commerce enterprise [15].

4. ELEMENTS OF THE SYSTEM

4.1. Central processing unit

Raspberry Pi 4, ESP32, ESP8266 microcontrollers, and PIC 18x microcontrollers can all be used as the central processing unit of an IoT-based 3D printed mobile robot platform. Each microcontroller has its own strengths and weaknesses, and the appropriate one to use would depend on the specific requirements of the robot and the tasks it needs to perform. The Raspberry Pi 4 is a powerful single-board computer that can run a full-fledged operating system such as Linux [16]. It has a quad-core ARM Cortex-A72 CPU, up to 8GB of RAM, and a wide range of connectivity options such as Wi-Fi, Bluetooth, Ethernet, and USB. The Raspberry Pi 4 is well-suited for tasks that require a lot of processing power and connectivity, such as image processing and IoT applications. The ESP32 is a low-cost, low-power microcontroller that is designed for IoT applications. It has a dual-core Tensilica LX6 CPU, up to 520KB of RAM, and built-in Wi-Fi and Bluetooth connectivity. The ESP32 is well-suited for tasks that require wireless connectivity, such as remote control and IoT applications. The ESP8266 is a low-cost, low-power microcontroller that is similar to the ESP32 but has less processing power and memory. It has a single-core Tensilica L106 CPU, up to 80KB of RAM, and built-in Wi-Fi connectivity. The ESP8266 is well-suited for simple tasks that require wireless connectivity, such as data logging and remote sensing. The PIC 18x microcontrollers are a family of 8-bit microcontrollers that are designed for low-power, low-cost applications. They have a range of processing power and memory options, and can be programmed using the C language. The PIC 18x microcontrollers are well-suited for simple tasks that require low power consumption, such as sensor reading and control [17].

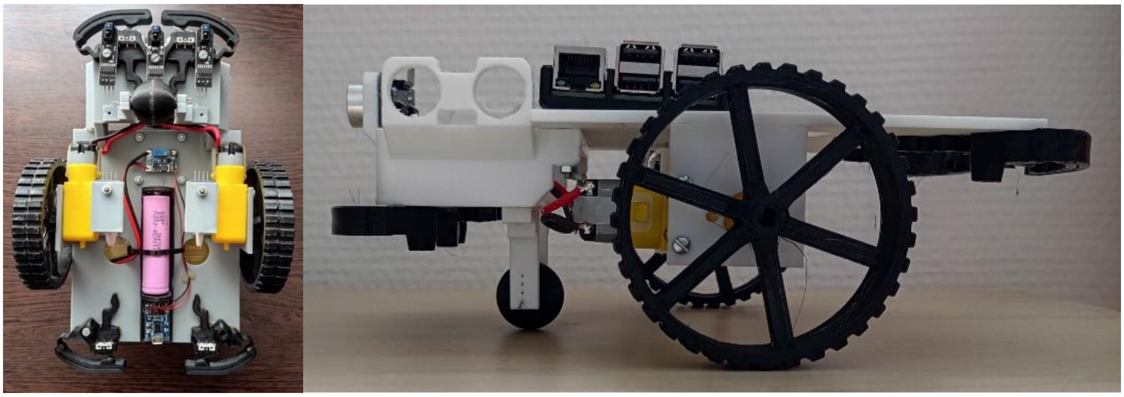

Figure 3. 3D printed and assembled mobile robot platform bottom and side view.

In many cases, Raspberry Pi 4, ESP32, ESP8266 microcontrollers, and PIC 18x microcontrollers can all be used as the central processing unit of an IoT-based 3D printed mobile robot platform. The appropriate one to use would depend on the specific requirements of the robot and the tasks it needs to perform.

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4.2. Sensors

Each sensor has its own unique capabilities and can be used for different purposes. Bumpers are simple sensors that detect physical contact with objects. They are often used to detect collisions and prevent the robot from damaging itself or its surroundings [18]. The HC-SR04 sonar sensor uses ultrasonic sound waves to measure distances. It is often used to detect obstacles and map the environment around the robot. The TCRT5000 IR sensor is a reflective sensor that detects the presence of objects by reflecting an infrared beam off them. It is often used for line following and obstacle detection. The FC-03 optical encoder module measures the rotation of a wheel or shaft. It is often used for measuring distance traveled and controlling the speed of the robot as can be seen in fig 3. The BME280 is a sensor that measures temperature, pressure, and humidity. It is often used for environmental monitoring and weather forecasting. The OV2640 camera module is a low-cost camera that can capture still images and video. It is often used for vision-based tasks such as object detection and recognition. The list of used sensors are given in table 1.

Table 1. Mobile robot sensor types

Type	Description
Bumpers	4x Digital switches
HC-SR04	3x Sonar sensor (min. 1)
TCRT5000	3x IR sensor
FC-03	2x Optical Encoder Module
BME280	1x Temperature, humidity sensor
OV2640	1x Camera Module

Bumpers, HC-SR04 sonar, TCRT5000 IR Sensor, FC-03 Optical Encoder Module, BME280, and OV2640 Camera Module are all useful sensors for an IoT-based 3D printed mobile robot platform. The appropriate sensors to use would depend on the specific requirements of the robot and the tasks it needs to perform.

4.3. Actuators

Two TT Micro DC geared motor with encoder is used as a main actuator of the robot platform. It is a motor with a 120:1 gearbox and an encoder disc with 20 slots and 24mm outer diameter along with encoder slit sensor module for detecting the number of counts moved by the wheel. The encoder slit sensor module is responsible for detecting these counts and relaying the information back to the control system of the robot. This information is crucial in determining the position and speed of the robot, allowing for accurate and efficient movement. With this setup, the robot platform is able to achieve smooth and precise motion, making it suitable for a variety of applications. The parameters of the motor are given in table 2.

Table 2. Actuator specifications

Parameter	Value
Gear ratio:	120:1
No-load speed @ 6V:	160 rpm
No-load speed @ 3V:	60 rpm
No-load current @ 6V:	0.17A
No-load current @ 3V:	0.14A
Max Stall current:	2.8A
Max Stall torque:	0.8kgf.cm

Rated torque:	0.2kgf.cm
Encoder operating voltage:	4.5~7.5V
Motor operating voltage:	3~7.5V (Rated voltage 6V)
Operating ambient temperature:	-10~+60°C
Weight:	50g

4.4. Power supply

The TP4056 Li-Ion battery charger module was used with a 2600mAh rechargeable Li-ion battery cell - 18650 - 3.6V battery to power the mobile robot. This module is made for charging rechargeable lithium batteries using the constant-current/constant-voltage (CC/CV) charging method. In addition to safely charging a lithium battery the module also provides necessary protection required by lithium batteries. The 2600mAh capacity of the battery provides a sufficient power supply for the mobile robot, allowing it to operate for an extended period without needing to recharge the battery frequently. The 18650 form factor is also convenient, as it is widely available and easy to replace if necessary.
An MT3608 DC/DC Boost converter was used to step up the voltage level from the battery to the required 6V. This converter is efficient and can provide a stable output voltage, which is essential for the proper operation of the robot's components. The specifications of mobile robots can vary widely depending on their intended application, so I will provide a comparison based on some common parameters:

- Size and Weight: The newly developed 3D printed mobile robot is likely to be smaller and lighter than many commercially available systems, as it is designed for student training and likely does not require heavy-duty components.
- Sensors: The newly developed robot may have a similar range of sensors to commercially available systems, such as bumpers, sonar, IR sensors, encoders, and cameras. However, the specific sensors used and their accuracy and precision may vary.
- Power Supply: The use of a 2600mAh rechargeable Li-ion battery cell and a TP4056 Li-Ion battery charger module with an MT3608 DC/DC boost converter provides a reliable and safe power supply for the robot. However, some commercially available systems may have more powerful batteries or alternative power sources such as solar panels.
- Processing Power: The use of a Raspberry Pi 4, ESP32, ESP8266, or PIC 18x microcontroller as the central processing element provides a decent amount of processing power, but it may not be as powerful as some commercially available systems. For example, some high-end robots may have dedicated processors and GPUs for advanced computation.
- Connectivity: The use of IoT technologies such as Wi-Fi and Bluetooth for connectivity is a modern and convenient feature of the newly developed robot. However, some commercially available systems may have additional connectivity options such as cellular networks or satellite communication.
- Control Interface: The newly developed robot likely has a user-friendly control interface that is designed for student training purposes. Commercially available systems may have more complex control interfaces for advanced users.

A newly developed 3D printed mobile robot may have some limitations compared to commercially available systems, particularly in terms of processing power and connectivity options. However, it is likely to be a cost-effective and user-friendly option for students and hobbyists who are interested in learning about robotics.

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5. TESTING AND RESULTS

The mobile robot physical dimensions are (LxWxH) 204x150x160mm witch servers as an excellent platform for educational purposes. The methodology is implemented with the involvement of nine mechatronics students from the University of Szeged and Óbuda University (as shown in Fig. 4 an 5) and is based on the theories of forward and inverse kinematics as well as SLAM.

Figure 4. Students working with 3D printed and assembled mobile robot platform.

After applying the educational methodology, 85% of the students confirmed that what they had learned in class was sufficient to solve the exercise. Additionally, 95% of them found the concepts, techniques, and tools used significant for their future goals. All students preferred the teaching and learning process using the developed mobile robot. The use of developed mobile robot allowed the students to have a better grasp of the theoretical concepts and their practical applications, providing them with greater confidence when interacting with a real mobile robot.

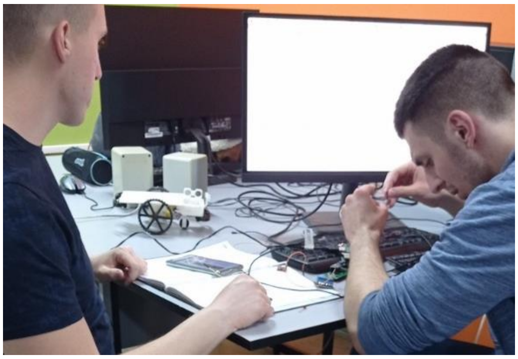

Figure 5. Students working with 3D printed and assembled mobile robot platform.

Furthermore, the process enabled them to improve their skills in designing robots, which will prove useful in their future endeavors. The Dabble Android application is utilized to remotely control a mobile robot that is based on the ESP32 microcontroller, using Bluetooth technology. Figure 6 depicts the remote controller of the mobile robot using an android phone or tablet.

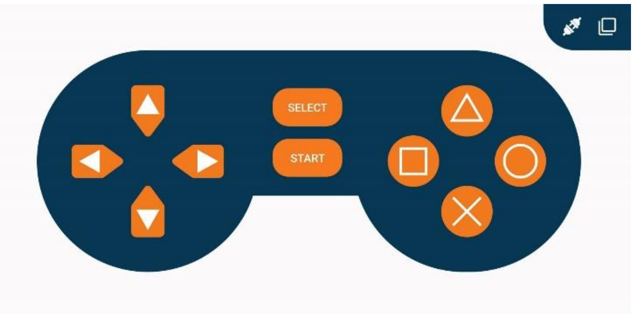

Figure 6. Using Dabble android application to control an esp32 based mobile robot via Bluetooth.

Dabble is an Android application that allows for easy control of an ESP32-based mobile robot via Bluetooth. The application provides a user-friendly interface with various controls, such as joysticks, buttons, sliders, and switches, that enable users to operate the robot remotely. By utilizing the Bluetooth technology, the user can connect to the ESP32 and control the robot from a distance of up to 10 meters. One of the main advantages of using Dabble is that it simplifies the process of controlling the robot, as it eliminates the need for complex coding and programming. The user can simply drag and drop the controls they want to use and customize them to their desired functionality. Figure 7 depicts one of the developed controller module based on the ESP32.

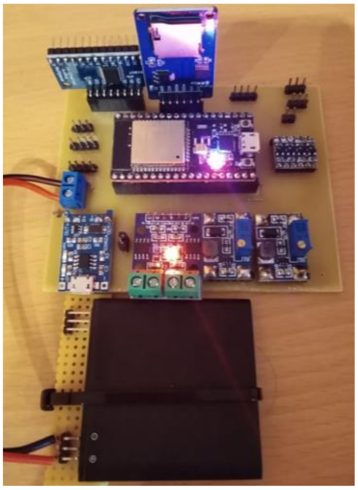

Figure 7. Developed ESP32 board for the mobile robot.

Moreover, Dabble provides a feature to log sensor data which helps the user to monitor and analyze the performance of the robot. Another advantage of using Dabble is its compatibility with different platforms and devices. It can be used with various ESP32-based robots that have Bluetooth connectivity, and can be accessed from any Android smartphone or tablet.

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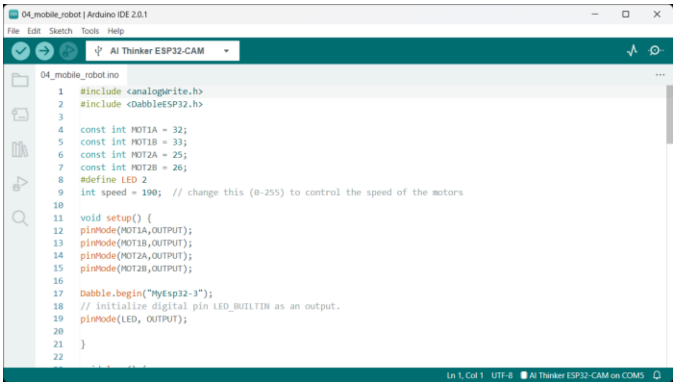

Figure 8. Arduino IDE for ESP32 board.

The Arduino IDE is an integrated development environment used for programming Arduino boards (fig 8). However, it can also be used for programming other microcontroller boards like the ESP32 and ESP8266. Swarm robotics is a field of robotics that focuses on the study of decentralized systems consisting of large numbers of relatively simple robots or agents that are able to coordinate and work together to achieve a common goal (see fig 9). The robots in a swarm are typically capable of sensing and reacting to their environment, communicating with one another, and making decisions based on local information.

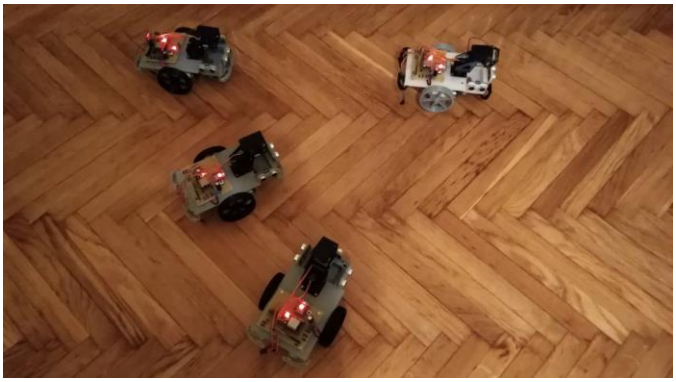

Figure 9. Swarm robotics with the developed platform.

Swarm robotics has applications in a wide range of fields, including search and rescue, environmental monitoring, agriculture, and manufacturing. Examples of swarm robotics systems include swarms of Automated Guided Vehicles (AGVs) used for surveillance and swarms of autonomous vehicles used for transportation. Swarm robotics research is focused on developing algorithms and techniques for coordinating large numbers of robots, as well as understanding the emergent behavior that can arise from interactions between individual robots in a swarm. Some of the key challenges in swarm robotics include developing effective communication and coordination mechanisms, dealing with uncertainty and partial information, and ensuring robustness and fault tolerance in the face of individual robot failures.

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4. CONCLUSIONS

In conclusion, the development of an IoT-based 3D printed mobile robot platform has opened up new opportunities in robotics education. The platform provides students with a practical approach to learning programming, control, and wireless communication. The modular design, flexible microcontroller options, and variety of sensors make it an ideal tool for teaching robotics to students of all levels. With the increasing demand for skilled robotics engineers, providing students with hands-on experience in designing and developing robots is essential, and the IoT-based 3D printed mobile robot platform provides an excellent platform for achieving this goal. Considering the interdisciplinary nature of the curriculum and the emphasis on hands-on practice, educators view the proposed mobile robot-based teaching process as highly beneficial to students, resulting in increased satisfaction levels with the course and related disciplines. The current reference course is mechatronics engineering, but the mobile robot-based approach can be adapted to incorporate various processing units, such as thermoforming and non-traditional processing, to fulfill diverse subject requirements and enrich the mechatronics engineering training experience. Educators and teachers have provided the following feedback: (I) The mechatronics engineering training system meets the demands of contemporary engineering education, thanks to the appropriate selection of equipment and facilities, and the advanced planning of training workshops. (II) Enhancing communication between the teaching staff and students is critical in promoting comprehensive training gains. (III) Improvements to the engineering training curriculum are necessary to ensure proper execution of the education plan, high-quality courseware, and an effective teaching system. The future research directions and plans are:

- Investigating the scalability of the proposed system to accommodate larger datasets and more complex tasks, with a focus on optimizing performance and efficiency.
- Exploring the integration of additional sensors and perception modules to enhance the robot's ability to interact with its environment and adapt to changing conditions.
- Conducting longitudinal studies to evaluate the long-term effectiveness and impact of the educational robotics platform on students' learning outcomes and development of computational thinking skills.
- Collaborating with educators to develop and implement curriculum enhancements that leverage the educational robotics platform to address specific learning objectives and standards.
- Exploring the potential of incorporating machine learning and artificial intelligence techniques to enable the robot to autonomously adapt its behavior and decision-making based on observed data and feedback.
- Investigating the usability and accessibility of the educational robotics platform for diverse student populations, including those with special needs or varying levels of technological proficiency.
- Exploring interdisciplinary applications of the educational robotics platform beyond STEM subjects, such as incorporating elements of arts, humanities, and social sciences to foster creativity, critical thinking, and interdisciplinary problem-solving skills.
- Collaborating with industry partners to explore real-world applications of the educational robotics platform in fields such as manufacturing, healthcare, and environmental monitoring, with a focus on addressing pressing societal challenges and advancing technological innovation.

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