Riga Technical University

Faculty of Civil and Mechanical Engineering

**Institute of Mechanical and Biomedical Engineering**

The project is in accordance with the task

and can be submitted for defense

Head of Study Program

Dr. Habil. Phys. Jurijs Dehtjars

Signature……………………..

20...g. „....“..................

**Shehan Maduranga Jayawickrama**

The student of the study program “Medical Engineering and Physics”

**ENGINEER PROJECT**

# Multi-parameter desktop device for meat freshness and quality assessment

Approved by the Head of the Department of International Relations and Foreign Students:

24/05/2025, Nr. D256034AZ

Shehan Maduranga Jayawickrama

(Student’s name, family name)

Supervisor of the student: Prof. Aleksejs Tatarinovs Dr.sc.ing., leading researcher.

Standards control: Mrs. Nicole Burtovaja., MSc, R&D Head of Mechanical Design Department, VIZULO.

Consultant: Mr. Hermanis Sorokins, MSc, RTU MTAF BINI Researcher.

Rīga, 2025.

## Declaration of authorship

I, the undersigning, hereby declare that the Engineer Project entitled “Multi-parameter desktop device for meat freshness and quality assessment” is, to the best of my knowledge and belief, original and the result of my investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university. Formulations and ideas taken from other sources are cited as such. This work has not been published.

Name: Shehan Maduranga Jayawickrama

Date:…………………..

RIGA TECHNICAL UNIVERSITY

Faculty of Civil and Mechanical Engineering

**INSTITUTE OF MECHANICAL AND BIOMEDICAL ENGINEERING**

Medical engineering and medical physics program student

***Shehan Maduranga Jayawickrama***

(Student's first name, family name)

## THE REQUIREMENTS FOR THE ENGINEERING PROJECT

1. Project theme:

***Multi-parameter desktop device for meat freshness and quality assessment.***

2. Project submission deadline: **2025. g. May (Week 16)**

3. Basic project data: (data used at the start of the project: restrictions, conditions, etc., if applicable, key technical parameters necessary for consumers).

***Compact & Portable Design: 350mm (L) × 250mm (W) × 240mm (H) ± 100mm.***

***Temperature-Controlled Environment: Maintains 15°C to 23°C (±0.2°C accuracy***

***The speed of ultrasound varies between fresh meat, ~ 1550 m/s to 1600 m/s, and in fat, ~1450 m/s.***

***WHC – 56% - 72% water by weight, device measures the range 55% -75% using ultrasound.***

***Elasticity Testing: Linear actuator applies 50N–200N force, 8–32 mm/s speed, 30mm stroke.***

***pH Measurement: Glass electrode pH sensor (range 5.5 – 6, accuracy ±0.01 pH.***

***Colour Analysis: RGB camera with ΔE < 2 accuracy, using D65 (6500K) LED lighting with 500–1000 lux intensity.***

4. The content of the project report:

| **The chapters of the project** | Volume, p. | % |
|---|---|---|
| Table of contents | | 0 |
| Introduction | ≅1 | 1 |
| Purpose, tasks, and novelty of the project | ≅1 | 1 |
| Literature review on possible ways to develop the multi-parameter desktop device for meat freshness and quality assessment. | ~7-15 | 7-15 |
| Assignment of the multi-parameter desktop device for meat freshness and quality assessment, analogues, and prototypes. | 1-3 | 1-3 |
| Technical assignment for the development of a multi-parameter desktop device for meat freshness and quality assessment. | ~3 | 3 |
| A reasonable variant of the multi-parameter desktop device for meat freshness and quality assessment. | ~5 | 5 |
| Engineering calculations for the multi-parameter desktop device for meat freshness and quality assessment. | ~5 | 5 |
| Technological calculations for the production of part of the multi-parameter desktop device for meat freshness and quality assessment. | ~5 | 5 |
| Technical description of the multi-parameter desktop device for meat freshness and quality assessment. | ~5 | 5 |
| Economic calculations of the multi-parameter desktop device for meat freshness and quality assessment. | ~1-4 | 1-4 |
| Specific hazards and specific requirements for the safe use of the multi-parameter desktop device for meat freshness and quality assessment in accordance with the requirements of labor protection, civil defense, and environmental protection. | ~5 | 5 |
| Conclusions according to the purpose of the multi-parameter desktop device for meat freshness and quality assessment, and recommendations on the use of the project results. | ~1-2 | 1-2 |

| | | |
|---|---|---|
| References | ~5 | 5 |
| Total | ≥50 | 50 |

**Drawings and diagrams**

*For the machine project*

| Title of sections of the graphic part | Volume in A1 format(approximately). | % |
|---|---|---|
| Comparison of variants of multi-parameter desktop device for meat freshness and quality assessment | ~1 | 7 |
| Functional Schemes of multi-parameter desktop device for meat freshness and quality assessment. | ~0.5 | 3.5 |
| General view of multi-parameter desktop device for meat freshness and quality assessment | ~0.5 | 3.5 |
| Assembly drawing of multi-parameter desktop device for meat freshness and quality assessment. | ~1 | 7 |
| Part drawings of multi-parameter desktop device for meat freshness and quality assessment. | ~1 | 7 |
| Technological process for production of single part of the multi-parameter desktop device for meat freshness and quality assessment. | ~1 | 7 |
| Work place equipment layout of the multi-parameter desktop device for meat freshness and quality assessment. | ~1 | 7 |
| Total | **≥7** | 50 |

The task has been issued 2025/02/10

The supervisor of the student: Prof. Aleksejs Tatarinovs Dr.sc.ing., leading researcher

(First name, family name, signature)

The task has been accepted by the student 2025/02/10

Shehan Maduranga Jayawickrama

( student's signature)

The tester of the standards: MSc. Nicole Burtovaja (First name, family name, signature, date)

The tester of technologies: MSc. Nicole Burtovaja (First name, family name, signature, date)

The consultants: MSc. Hermanis Sorokins

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***The task was initiated by the Enterprise***

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***Approved by the Head of Study Program*** ***Dr. habil. phys. Jurijs Dehtjars***

(First name, family name, signature, date)

***Approved by the faculty Dean order 202... g. " "………order Nr. ………………***

# ANNOTATION

The engineering project "Multi-parameter desktop device for meat freshness and quality assessment" aims to develop a multi-parameter, compact desktop device for assessing meat quality and freshness by integrating non-destructive measurement techniques. The device will evaluate the key indicators of meat freshness and quality, such as water holding capacity (WHC), fat content, elasticity, pH, and color, while comparing existing methods to identify overlaps and eliminate inefficient measurement techniques.

The textual part of the project consists of 68 pages with 26 figures and 7 tables. The graphical part of the project consists of 7 technical drawings.

# ANOTACIJA

Inženiertehniskais projekts “Daudzparametru galda ierīce gaļas svaiguma un kvalitātes novērtēšanai” ir vērsts uz daudzparametru, kompaktas galda ierīces izstrādi gaļas kvalitātes un svaiguma novērtēšanai, integrējot nesagraujošās mērīšanas metodes. Ierīce novērtēs galvenos gaļas svaiguma un kvalitātes rādītājus, piemēram, ūdens ietilpību (WHC), tauku saturu, elastību, pH līmeni un krāsu, vienlaikus salīdzinot esošās metodes, lai identificētu pārklāšanos un novērstu neefektīvas mērīšanas metodes.

Projekta tekstuālā daļa sastāv no 68 lappusēm ar 26 attēliem un 7 tabulām. Projekta grafiskā daļa sastāv no 7 tehniskajiem rasējumiem.

## Table of Contents

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# 1 INTRODUCTION

Ensuring meat freshness is crucial for satisfying customer expectations and industry standards since it has a significant impact on purchasing decisions. Meat is one of the most valued livestock products since it is one of the main primary protein sources for human consumption. Meat is a good source of energy in addition to being an essential source of vitamins, minerals, and amino acids. Meat's quantitatively most crucial component is water, and it makes up about 75% of its weight. Meat that is rich in proteins and high in content of essential amino acids and polyunsaturated fatty acids is considered to have excellent nutritional quality.

The meat freshness and quality parameters were evaluated by properties such as water holding capacity (WHC), fat content and distribution, elasticity, pH levels, and color stability. The water-holding capacity (WHC) of fresh meat determines visual acceptability, which influences consumers' willingness to buy meat products. Additionally, WHC determines the amount of water loss that occurs during transport, storage, processing, and cooking. The fat content and quality of raw meat are also factors in the quality of processed meat. Also, fat deposition is an important aspect of meat quality. Fat accumulates after relative muscle growth decreases and continues to increase while bone growth decreases. Meat's sensory properties, such as elasticity, texture, viscosity, and toughness, are directly connected to its physical properties. Elasticity is the key indicator of meat texture. The evaluation of sensory properties provides a more comprehensive and precise way to detect the quality of meat. pH is a physicochemical, non-destructive method widely used to evaluate the meat freshness and its quality. The meat's color on retail display significantly impacts consumer purchasing decisions. Customers associate the color of the meat with an indicator of its freshness and quality. Customers expect bright red meat to be fresher and of high quality; pale, discolored, or darker meat is perceived by consumers to be nearing spoilage or poor quality.

To determine the freshness and quality parameter such as, WHC, fat content, elasticity, pH levels and color stability, each having its specific measuring technique, and with the measurement results of some techniques providing overlapping information. Integrating multiple techniques into a single system will allow direct comparison of different methods, ensuring that only the most efficient, non-destructive, and informative techniques are retained while discarding redundant or cumbersome approaches. Meat research laboratories, food quality control departments, and industrial meat processing units will benefit from this device because of its non-destructive, accurate, and rapid assessment.

# 2 AIM, TASKS, AND NOVELTY OF THE PROJECT

The project aims to develop a compact, multi-parameter desktop device for assessing meat freshness and quality by integrating non-distractive measurement methods. The device will evaluate key indicators such as water holding capacity (WHC), fat content, elasticity, pH, and color while comparing existing techniques to identify overlaps and eliminate inefficient techniques. The device will simplify the assessment of meat quality, improving accuracy, efficiency, and consistency for both research and industrial applications. The technical parameters of the desktop device for meat freshness and quality assessment to be developed will be:

- Compact & Portable Design: 350mm (L) × 250mm (W) × 240mm (H) ± 100mm.
- Temperature-Controlled Environment: Maintains 15°C to 23°C (±0.2°C accuracy)
- The speed of ultrasound varies between fresh meat, ~ 1550 m/s to 1600 m/s.In fat, ~1450 m/s.
- WHC – 56% - 72% water by weight, device measures the range 55% -75% using ultrasound.
- Elasticity Testing: Linear actuator applies 50N–200N force, 8–32 mm/s speed, 30mm stroke.
- pH Measurement: Glass electrode pH sensor (range 5.5 – 6, accuracy ±0.01 pH).
- Color Analysis: RGB camera with ΔE < 2 accuracy, using D65 (6500K) LED lighting with 500–1000 lux intensity.

To achieve the aim of the project, some tasks were strategically planned for the device's development. The tasks include:

i. Conduct a literature review on possible ways to develop a multi-parameter desktop device for meat freshness and quality assessment.
ii. Analyze the project task of developing a multi-parameter desktop device for meat freshness and quality assessment.
iii. Develop the specification to design a multi-parameter desktop device for meat freshness and quality assessment.
iv. Comparison of design options for a multi-parameter desktop device for meat freshness and quality assessment.
v. Deliver engineering calculations to justify the multi-parameter desktop device for meat freshness and quality assessment.
vi. Develop the technology to manufacture a part of a multi-parameter desktop device for meat freshness and quality assessment, and provide appropriate technological calculations.
vii. To develop the workplace layout plan of the multi-parameter desktop device for meat freshness and quality assessment.
viii. Describe the developed desktop system multi-parameter desktop device for meat freshness and quality assessment.
ix. Deliver the economic calculations for the manufacturing of the multi-parameter desktop device for meat freshness and quality assessment.
x. Analyze possible specific hazards when operating the multi-parameter desktop device for meat freshness and quality assessment, and develop specific requirements for the

safe use in accordance with the requirements of: - Occupational safety measures - civil defense and environmental protection.

xi. Develop and describe the graphic part of the multi-parameter desktop device for meat freshness and quality assessment.
- comparison of variants (A1)
- functional scheme (A1)
- general view (A1)
- assembly drawing (A1)
- drawings of parts (A1)
- technological drawing (A1)
- Workplace layout drawing (A1)

xii. Provide conclusions and recommendations related to the multi-parameter desktop device for meat freshness and quality assessment.

As for the novelty of the project, for the first time, develop a compact, multi-parameter desktop device for assessing meat freshness and quality by integrating non-destructive measurement techniques. It will evaluate key indicators such as elasticity, fat content, WHC, pH, and color while comparing existing methods to identify overlaps and eliminate inefficient techniques.

# 3 LITERATURE REVIEW ON POSSIBLE WAYS TO DEVELOP THE MULTI-PARAMETER DESKTOP DEVICE FOR MEAT FRESHNESS AND QUALITY ASSESSMENT.

Ensuring meat freshness is crucial for satisfying customer expectations and industry standards since it has a significant impact on purchasing decisions. This chapter covers the structure and composition of meat, as well as the physical and biochemical factors that influence post-mortem changes in meat. It also discusses the factors influencing meat freshness and the use of ultrasound technology for meat quality assessment, along with its advantages and limitations.

## 3.1 Composition and structure of meat

Meat is one of the most valued livestock products since it is one of the main primary protein sources for human consumption[1]. If the joint is examined through the naked eye, certain structural features of meat, such as connective tissue, muscle fibers, and tendons that connect the muscle to the bone, are visible[1].Meat is a good source of energy in addition to being an essential source of vitamins, minerals, and amino acids[1].Red meat is an excellent source of micronutrients, including bioavailable iron, zinc, selenium, and vitamins D, A, and B[1]. Additionally, it has been proven that plant sources cannot replace meat's protein and vitamins (A and B12) in meat[1].

Joint meat examined without using a microscope or magnification shows common features of the meat structure, such as muscle fibers, connective tissue, and tendons that attach the muscle to its bone[1]. Fibrous connective tissue, which is continuous with the tendon, surrounds the muscle fibers in a bundle[1]. Endomysium is the tissue that connects individual muscle fibers[2]. The sheath surrounding muscle fiber bundles is called the perimysium, and the connective tissue around an entire muscle is known as the epimysium[1]. Individual muscles have their specific connective tissue infrastructure; locomotion muscles have more outstanding collagen content than postural muscles, and the way they work affects how collagen is distributed within the muscle[1].

Meat's quantitatively most crucial component is water, and it makes up about 75% of its weight[1]. Also, it has an essential influence on color, texture, and surface appearance[1]. While the protein content of muscle is continuously maintained, the water content of the muscle varies inversely with the fat content[1]. Protein is the building block of the muscular tissue, and it is the most valuable component in the meat[1]. Protein is a complex molecule composed of simple organic molecules known as amino acids[1]. There are 20 amino acids known to be necessary for human growth and metabolism[1]. Since eight of these amino acids are unable to be synthesized in our body, they are described as essential, indicating that they must be contained in our diets[1]. The remaining amino acids are unnecessary ones[1]. Beef proteins consist of amino acids like cystine, leucine, isoleucine, lysine, methionine, tryptophan, valine, arginine, phenylalanine, threonine, and histidine; the last two of these are necessary for infants[1]. The fat portion of meat includes some fat-soluble substances, including some vitamins[1]. There are three types of fat, including subcutaneous fat, which can be found in the skin and fatty tissue; intramuscular fat, which is found within the muscles; and intermuscular fat[1].

## 3.2 Importance of meat freshness and quality assessment.

Quality is generally categorized by four terms: security (hygienic quality), healthiness (nutritional quality), satisfaction (organoleptic quality), and serviceability (utilization, processing capacity, and prices)[3]. Satisfaction is determined by the perception of consumers[3]. Along with color, texture, and juiciness, flavors are associated with the flavors the product releases in the mouth after consumption[3]. Satisfaction is also driven by technological qualities that indicate how easily the product may proceed[3]. They are mostly linked with a decrease in technological yield due to a reduction in water-holding capacity during cold storage(exudations) and cooking, or because of damage that happens after slicing[3]. Better technological qualities are correlated with low losses[3]. The food's nutritional value depends primarily on carbohydrates and proteins that make up the food[3].

Meat that is rich in proteins and high in content of essential amino acids and polyunsaturated fatty acids is considered to have excellent nutritional quality[3]. Hygienic qualities reflect the capacity of the product to be safely consumed[3]. These are primarily related to the product's bacterial load and the presence of chemical residues from pesticides and herbicides, and other additional contaminants from the environment in the product[3]. Among the mentioned qualities, critical points about the quality of the beef for consumers are primarily tenderness, color, and healthiness[3]. The main reason why consumers don't repurchase beef is because of its variability in tenderness[3]. A firm, cohesive fish with an excellent water-holding capacity is the best quality in fish[3]. These characteristics of meat and fish flesh are influenced by many vivo and postmortem factors such as species, genotypes, nutritional and slaughtering conditions, environmental factors, and post-mortem processing[3]. These factors also influence the structure and composition of skeletal muscle; their effect on meat quality could essentially show the direct connection between intermuscular biological properties and meat quality traits[3].

### 3.2.1 Factors affecting meat freshness and quality.

The formation of ice crystals during freezing damages the ultrastructure and concentrates the solutes in the meat. This leads to alterations in the biochemical reactions that occur at the cellular level and affect the meat's freshness and physical quality parameters[4]. The meat freshness and quality parameters evaluated by properties such as water holding capacity (WHC), fat content and distribution, elasticity, pH levels, and the color stability[4].

### 3.2.2 Water holding capacity (WHC)

The water-holding capacity (WHC) of fresh meat determines visual acceptability, which influences consumers' willingness to buy meat products[5]. Additionally, WHC determines the amount of water loss that occurs during transport, storage, processing, and cooking[5]. Meat juiciness, which is in part influenced by WHC, is also an important characteristic and contributes to eating quality and plays a role in texture[5]. Muscle comprises about 75% water at rigor, and the taste, tenderness, color, and juiciness of meat are all closely related to the amount of water added to the meat and its hydration after processing or cooking [5]. Low cook yields and often dry (lack of juiciness) meat are the consequences of poor WHC; hence, these can also be used to measure the WHC indirectly[5]. Poor WHC results in high drip and purge loss from meat and meat products, which can lead to considerable weight loss from carcasses and cuts and may have an impact on the yield and quality of processed meats[5]. Water is also significant because of its role in molding muscle structure and the consequent impact on quality[5]. As water is lost from the muscle structure during heating and cooking, the proteins become less pliable and more rigid[5]. However, some proteins, such as collagen and sarcoplasmic, will gelatinize and retain water when longer heating times are used[5].

According to its chemical composition, muscle contains about 75% water, and the other components are protein (20%), lipids (5%, but can fluctuate and influence water content), carbohydrate (1%), and vitamins and minerals (1%, often left as ash)[5]. There is a direct relationship between water and fat content, such that as the fat percentage rises, the water percentage decreases[5]. Furthermore, most of the water is associated with myofibrils because they make up about 85% of the volume of the muscle cell[5]. Proteins tightly bind around 1% of the water in meat, which is classed as “bound” water[5]. This water has decreased mobility and is resistant to freezing and heating[5]. The amount of bound water shows relatively little change in postmortem muscle, although the bound water undergoes continual exchange with the surrounding water molecules[5]. Another type of water in meat is termed “entrapped” or “immobilized” water, and the water is retained by steric effects or by attraction to the bound water[5]. The water does not easily escape the structure, but it can be removed by drying, lost during the rigor process, and by modification in the physical protein structure, such as through protein degradation or denaturation[5]. This fraction comprises about 85% of the total water[5]. The amount of water that can flow unimpeded from the structure when the conditions allow this to occur, independent of the charged groups, is known as “free” water[5]. It exists in the sarcoplasmic fluid and is retained by capillary forces within (extra myofibrillar) and between (intermyofibrillar) myofibrils[5]. It has been discovered that predominantly, WHC variation is with the water content of the extra myofibrillar fraction, and the loss of intermyofibrillar water through shrinkage[5]. When myofibrils and cells contact during the rigor process, the extra myofibrillar water and a small fraction of the intermyofibrillar water are simply mobilized; however, this water does not flow freely in prerigor or high ultimate pH meat[5].

| | Water (%) | |
|---|---|---|
| | Muscle | Meat |
| Protein-bound water | 1 | 1 |
| Intramyofibrillar | 80 | 75 |
| Extramyofibrillar | 15 | 10 |
| Extracellular water | 5 | 15 |

Fig 3.1 Water distribution in the muscles of live animals and meat[5]

Figure 3.1 illustrates the changes in water content within the compartments during the conversion of muscle to meat. Protein-bound water is lost from the intramyofibrillar and extramyofibrillar compartments, subsequently appearing in the extracellular space, where it is free from the meat as drip loss[5].

### 3.2.3 Fat content and deposition.

The fat content and quality of raw meat are also factors in the quality of processed meat[6]. Also, the fat deposition is an important aspect of meat quality[7]. As the animal matures, fat accumulates and is deposited in various fat depots[7]. Fat accumulates after relative muscle growth decreases and continues to increase while bone growth decreases[7]. The location and the growth rate have a significant impact on the time during which fatty tissues grow[7]. A sigmoidal curve indicates how an animal's weight changes over time and is often used to characterize an animal's growth[7]. Fat deposition occurs later after muscle and bone growth has slowed, changing the body's composition, too[7]. The accumulation of fat occurs when the energy consumed exceeds the requirements of the animal[7]. As an animal reaches mature size, less energy will be required for bone and muscle growth, and that energy will be stored as fat[7]. Some of the variables, such as species, genetics, breed, sex, and environmental factors, can affect the fat development at different points of an animal's life[7].

Fat depositions occur in specific depots that are common among all mammals[7]. These depots are in the abdominal cavity, intermuscular (between muscles), subcutaneously, and intramuscularly (within muscles)[7]. The internal fat is particularly around the internal organs, and is the first to deposit, followed by intermuscular fat, subcutaneous fat, and intramuscular fat[7]. The proportion of each fat depot changes according to the species, age of the animal, and energy intake[7]. For example, compared to sheep and cattle, pigs have less abdominal fat and more subcutaneous fat, accounting for approximately 70% of their total body fat[7]. In mature grass-finished beef steers, approximately 15%, 23%, and 14% comprise subcutaneous fat, intermuscular fat, and intramuscular fat, respectively[7]. Internal fat had an intermediate rate of fat deposition, and the faster subcutaneous fat deposition than intermuscular fat can be seen in cattle[7]. However, pigs deposited internal fat more quickly, followed by subcutaneous fat, with the slowest rate of fat deposition occurring between muscles[7]. Additionally, sheep had a similar rate of fat deposition of subcutaneous fat and internal fat, with intermuscular fat deposited at a slower rate[7].

Fat is made up of triglycerides[7]. The triglyceride is made up of three fatty acids and a glycerol backbone[7]. The triglycerides' fatty acids change by carbon chain length and the number of saturated or unsaturated bonds within the carbon chain[7]. Predominantly palmitic, stearic, oleic, palmitoleic, linoleic, and arachidonic are the main types of fatty acids found in meat[7]. The firmness of the fat is affected by the fatty acid composition of adipose tissue[7]. Longer-chain fatty acids have higher melting points, while those with more unsaturated bonds have lower melting points [7]. Between 25°C and 50°C, composite fatty acids melt, and saturated fats melt at higher temperatures, and polyunsaturated fats (PUFAs) melt at lower temperatures[7].

### 3.2.4 Elasticity and texture

Meat's sensory properties, such as elasticity, texture, viscosity, and toughness, are directly connected to its physical properties[8]. Elasticity is the key indicator of meat texture[8]. Food rheology, as a discipline that examines the deformation and flow when subjected to force, can effectively describe these physical properties of meat[8]. The evaluation of sensory properties provides a more comprehensive and precise way to detect the quality of meat[8]. In meat systems, rheological characteristics have a direct impact on product tenderness, chewiness, and dynamic changes in mouthfeel through important indicators such as elasticity and viscoelastic parameters[8]. The rheological characteristics of meat are the result of the combined effects of muscle composition, structure, and processing conditions[8]. They can provide a scientific foundation for meat processing and quality control, helping companies optimize production procedures and create new products to enhance market competitiveness and improve customer eating experience[8]. Furthermore, the development of the assessment of sensory properties plays a significant role in food safety regulation[8]. It can be used to monitor quality changes in meat throughout processing and storage, ensuring consumer health[8].

The changes in connective tissue within muscle can significantly impact the sensory properties of meat[8]. Structural changes directly influence the texture and tenderness of the meat in connective tissue[8]. The mechanical properties of meat, such as elasticity and texture, are also influenced by the type and the orientation of muscle fibers, the degree of protein cross-linking, and the amount of fat in the muscle[8]. For instance, the higher intermuscular fat content, the better tenderness and juiciness of the meat[8]. Processing methods, including thermal and non-thermal treatments, can significantly alter the rheological properties of meat[8]. Thermal processing causes protein denaturation and texture changes, while non-thermal processing methods, such as high-pressure processing, can preserve the sensory properties of meat with higher energy efficiency[8]. There is a significant correlation between water holding capacity and shear mechanical qualities in meat; meat with a higher water holding capacity shows higher elasticity in rheological tests and lower viscosity[8]. Additionally, the rheological properties of meat, such as elasticity and viscosity, change with the increasing heating time and temperature[8]. These changes not only impact the processing properties of meat but also directly affect the mouthfeel and consumer experience of meat[8].

### 3.2.5 pH levels

pH is a physicochemical, non-destructive method widely used to evaluate the meat freshness and its quality[9]. The most recent non-destructive in situ analysis for meat freshness monitoring used an optical pH sensor; however, it's challenging to assess the freshness without monitoring the entire testing period because the absolute pH values do not necessarily increase or decrease monotonically during the testing period[9].

| Meat Type | Chilling Storage at 2 °C | | | |
|---|---|---|---|---|
| | Day 0 | Day 3 | Day 6 | Day 10 |
| Pork leg (5 muscles) | $6.70 \pm 0.02^{c5}$ | $5.89 \pm 0.02^{a2}$ | $6.26 \pm 0.03^{b3}$ | $6.32 \pm 0.01^{b3}$ |
| Lamb leg (7 muscles) | $5.90 \pm 0.01^{b2}$ | $6.05 \pm 0.01^{c3}$ | $5.77 \pm 0.01^{a2}$ | $6.01 \pm 0.03^{c1}$ |
| Turkey leg (4 muscles) | $6.54 \pm 0.01^{a4}$ | $6.89 \pm 0.01^{b5}$ | $6.63 \pm 0.02^{a4}$ | $7.34 \pm 0.01^{c5}$ |
| Chicken breast (1 muscle) | $6.39 \pm 0.26^{b3}$ | $6.30 \pm 0.02^{a, b4}$ | $6.26 \pm 0.01^{a3}$ | $6.67 \pm 0.00^{c4}$ |
| Beef leg (4 muscles) | $5.71 \pm 0.01^{a1}$ | $5.71 \pm 0.10^{a1}$ | $5.52 \pm 0.02^{a1}$ | $6.20 \pm 0.01^{b2}$ |

Fig 3.2 pH values of the fresh different meat types during chilled storage at 2 °C[10].

Figure 3.2 shows the pH values of the fresh pork, turkey, chicken, lamb, and beef during chilled storage at 2℃. Pork had a significantly higher starting pH (6.70), followed by beef, turkey, chicken, and lamb[10]. This variance could be a result of postmortem metabolism differences between species[10]. Both intrinsic (species, animal age, type of muscle, position of the muscle, concentration of glycogen, etc.) and extrinsic factors, such as pre-slaughter stress, slaughter conditions, post-slaughter handling, and temperature, can influence the extent of post-mortem glycolysis, and consequently the final pH[10].

When compared to the reported levels, the initial pH levels for fresh beef and lamb meats were considerably normal[10]. According to the resolution of the rigor, these initial values were related to the kind of cut for each species and its quality[10]. Except for pork, all meat types during storage increased their pH, and at the end of the storage, they were between 6.01 and 7.34[10]. The production of nitrogenized basic compounds, mainly aminic, which are the main results of microbial spoiling and are dependent on the type of packaging, was associated with to increase[10]. However, some other studies revealed lower pH values, particularly for chicken, turkey, and pork[10].

Changes in pH values on the surface of beef and fish samples are also useful for monitoring the freshness of the food samples[9]. The accumulation of lactic acid after post-mortem glycolysis helps to decrease in pH[9]. After this early stage, pH increases as volatile basic amines are produced from the spoilage of food[9]. Therefore, to analyze the time points of food spoilage, measured pH of food samples was measured as a freshness indicator[9].

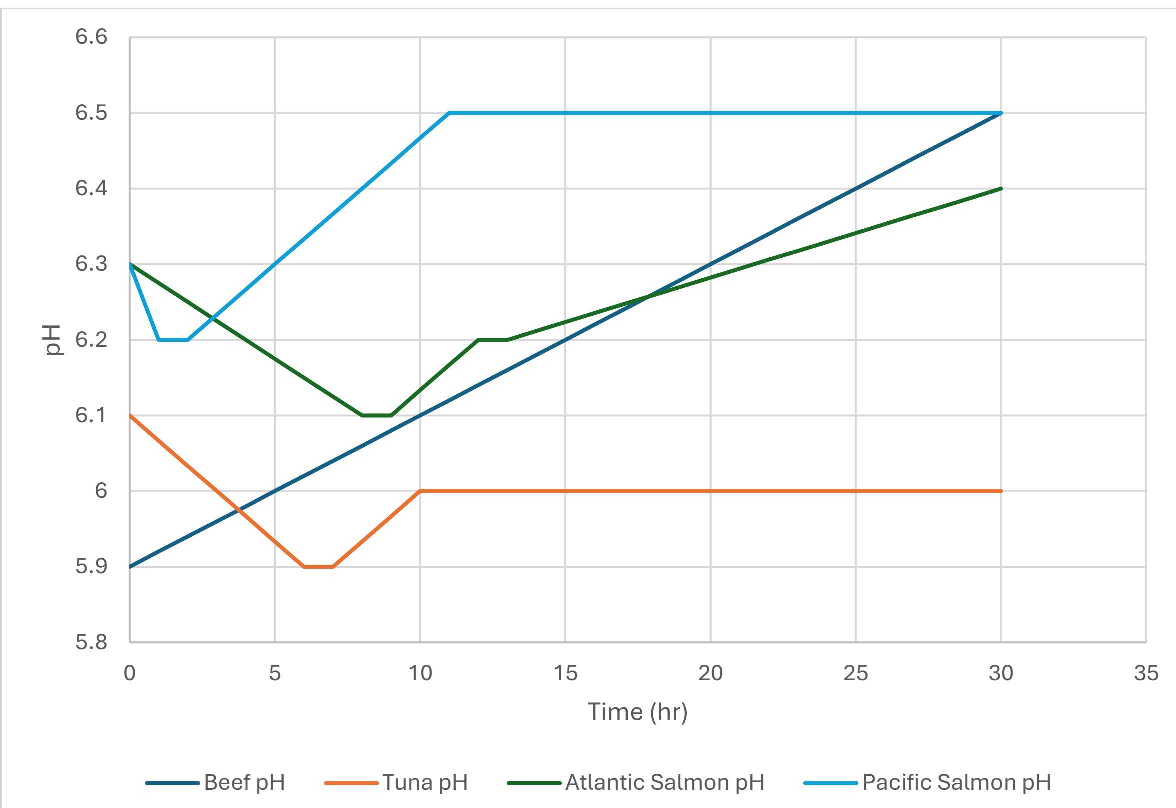


Fig 3.3 Time series of pH values for food samples to determine freshness [9].

Figure 3.3 shows the time series of pH values for food samples for determining the freshness, and each time slot, the data point is for the mean of 60 measurements (3 samples × 20 measurements), and the bar shows the standard deviation of them[9]. Fresh beef has a pH range between 5.7 and 6.0; if the pH is higher than 6.2, it refers to dark, firm, and dry (DFT) meat, making it susceptible to the growth of microorganisms[9]. As shown in Figure 3.3, the pH of beef samples increased from 5.9 to 6.5 during the 30-hour test period[9]. When the pH of the beef was lower than 6.0 during the two hours, we could identify it as being in the fresh state[9]. After a 23-hour incubation, the pH increased above 6.2, and the beef was spoiled[9]. In fresh tuna, pH is between 5.2 and 6.1, while pH is between 6.1 and 6.3 in fresh salmon[9]. Unlike beef, fish is frozen immediately after it's caught, which is why we noticed pH drops in most of the fish samples during initial measurements[9]. In tuna, pH dropped from 6.1 to 5.9 during the initial 7-hour measurements[9]. After that, the pH value increased to 6.0 for 4 hours and remained at pH 6.0 until the end of the measurement period[9].

During the first 9 hours of the experiment, pH decreased from 6.3 to 6.1 in Atlantic salmon[9]. Then, the pH value gradually increased for 4 hours until it reached pH 6.2[9]. The pH slowly increased and plateaued at 6.4[9]. It can also be noticed that pH decreases during the first 2 hours of the experiment because Pacific salmon spoils faster than Atlantic salmon[9]. After that, the pH increased quickly for 10 hours until it reached 6.5 and stayed the same for 18 hours[9]. Fish are defined as "fresh" during the initial 2 hours when the pH starts decreasing and "spoiled" after 12 to 13 hours when the pH value plateaus at pH 6.4-6.5 for salmon and pH 6.0 for tuna, respectively[9].

### 3.2.6 Color stability

The meat's color on retail display significantly impacts consumer purchasing decisions[11]. Customers associate the color of the meat with an indicator of its freshness and quality[11]. Customers expect bright red meat to be fresher and of high quality; pale, discolored, or darker meat is perceived by consumers to be nearing spoilage or poor quality[11]. Meat gets its appealing bright red color from exposure to oxygen by converting deoxy myoglobin into the red pigment known as oxymyoglobin[11]. As a result of oxidative metabolism and the subsequent generation of free radical byproducts, myoglobin oxidizes into the brown pigment metmyoglobin when the meat surface is exposed to oxygen regularly[11].

Gel electrophoresis has been used to determine myoglobin in exudate, which helps to clarify why the color stability changes during freezing and thawing[12]. During freezing, frozen storage, and thawing, the globin moiety of the myoglobin molecule becomes denatured[12]. The denaturation increases myoglobin's susceptibility to autoxidation and subsequent loss of optimal color presentation[12].Many authors have confirmed this theory by comparing the degree of bloom and the ability of the meat to resist oxidation to metmyoglobin during refrigerated storage post-freeze/thaw[12]. Livingston and Brown (1981) proposed the presence of an enzyme system known as metmyoglobin-reducing activity (MRA), which can convert metmyoglobin back to myoglobin[12]. According to this theory, the enzyme in fresh muscle is very active, and the metmyoglobin forms rapidly reduced to deoxy myoglobin, and is oxygenated back to oxymyoglobin, thereby retaining the bloomed color[12]. But when the meat ages or is frozen, the MRA's activity decreases, and metmyoglobin begins to accumulate on the meat's surface rapidly[12]. Additionally, MRA and co-factors, such as NADH, may be “lost” from the post-mortem sarcoplasmic environment by leaching as exudate during thawing or due to oxidation or use by processes unrelated to MRA, all of which will contribute to accelerated oxidation and loss of bloom[12].

## 3.3 Existing methods for meat quality and freshness assessment.

This section discusses the current methods of evaluating the quality and freshness of meat, which can be used for developing the multiparameter desktop device. Special attention is paid to ultrasound-based analysis for determining the fat content and water holding capacity (WHC) of meat, as well as the methods for testing elasticity, pH, and color to evaluate the overall quality and freshness of meat.

### 3.3.1 Ultrasound-based assessment of water holding capacity (WHC) in meat.

One of the main qualitative parameters of fresh meat is water holding capacity, because it affects consumer acceptance and the product's final weight[13]. Cooking, drip loss, or evaporation can cause water loss[13]. About 75% water, 20% protein, variable amounts of lipids and carbohydrates, and small amounts of soluble organic compounds can be found in mammalian skeletal muscles[13]. The water holding capacity of meat is determined by using the ultrasound velocity; the high-water holding capacity is found the fresh meat, and the typical ultrasound velocity is between 1550 m/s and 1600 m/s[14]. A 1500 m/s – 1550 m/s ultrasound velocity is considered a low water holding capacity of meat[14]. The ultrasound velocity is temperature-dependent, and during the experiment, temperature fluctuations can affect the results[14]. Using this approach can get the general idea about the meat's water-holding capacity.

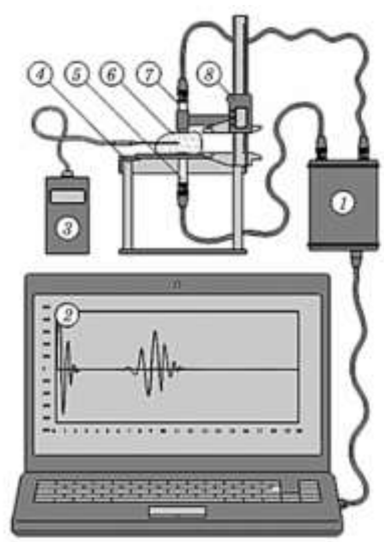


Fig 3.4 Experimental stands for measuring the ultrasound velocities of different meat types[15]

1- OPBOX 2.0, 2- PC, 3-electronic thermometer, 4-platform, 5-fixed acoustic transducer, 6-sample, 7-moveable acoustic transducer, 8-electric caliper.

Figure 3.4 shows the experimental setup for measuring the ultrasound velocities of different meat types. Sound velocity was calculated by the differential method, which means using two samples of the same material with different thicknesses based on Equation 1[15].

$$c = \frac{d_2 - d_1}{\tau_2 - \tau_1} \tag{1}$$

Where: $d_1$ and $d_2$ are the thicknesses of thick and thin samples; $\tau_1$ and $\tau_2$ are time of flight.

Equation 2 was used to determine the attenuation coefficient[15].

$$\alpha = \frac{1}{d_1 - d_2} \ln \frac{A_1}{A_2} \tag{2}$$

Where: $d_1$ and $d_2$ are the thicknesses of thick and thin samples; $A_1$ and $A_2$ are attenuation coefficients.

| Muscle | Sound velocity $c$ [m/s]* | | Attenuation coefficient $\alpha$ [1/m]* | |
|---|---|---|---|---|
| | $t = 5 \pm 1°C$ | $t = 20 \pm 1°C$ | $t = 5 \pm 1°C$ | $t = 20 \pm 1°C$ |
| Turkey breast (*m. pectoralis major*) | 1550.7 (5.4)$^A$ | 1582.7 (6.3)$^A$ | 21.3 (10.4)$^A$ | 22.2 (10.1)$^A$ |
| Turkey thigh (*m. extensor iliotibialis*) | 1536.6 (8.6)$^B$ | 1578.5 (5.7)$^A$ | 23.2 (11.7)$^{A,B}$ | 18.9 (7.7)$^A$ |
| Pork loin (*m. longissimus dorsi*) | 1558.7 (8.5)$^C$ | 1596.9 (4.7)$^B$ | 30.6 (13.0)$^B$ | 22.0 (9.4)$^A$ |
| Pork ham (*m. biceps femoris*) | 1559.7 (5.5)$^C$ | 1592.7 (5.9)$^B$ | 28.1 (13.4)$^{A,B}$ | 22.4 (12.1)$^A$ |

Fig 3.5 Mean values of sound velocity and the attenuation coefficients in different muscle samples[15].

Figure 3.5 shows the mean values of sound velocity and attenuation coefficients of turkey breast, turkey thigh, pork loin, and pork ham. According to the results, significant differences were observed between pork and turkey muscles[15].

### 3.3.2 Ultrasound-based assessment of fat content in meat.

Fat provides essential nutrients for our body; however, consuming it excessively can lead to health complications such as heart disease, high blood pressure, and obesity[16]. One of the main fat sources is meat, either chicken, beef, or fish[16]. The researchers developed to measure the fat content in meat fillet using an ultrasound A–Mode scan[16]. After that, the results of the fat measurements from this ultrasound method were compared to the results of fat measurement using a proven method to find the accuracy of this non-invasive method[16]. Association of Official Analytical Chemists (AOAC) recommended the Soxhlet method as the standard method for fat measurements, and it is also used to validate the ultrasound velocity results[16]. Chicken, meat, and fish fillets were the samples used in this investigation[16]. The experimental results of the study demonstrated that the relationship between the measured ultrasound velocity travelled in the sample and the fat content[16].

For this study, two 2.25 MHz single-element transducers are used to transmit and receive the ultrasonic pulse, and a Panametric 500PR pulser receiver to produce them[16]. For this research, 12 samples from two different suppliers are used[16]. The fat content of the meat fillet was determined at room temperature[16].

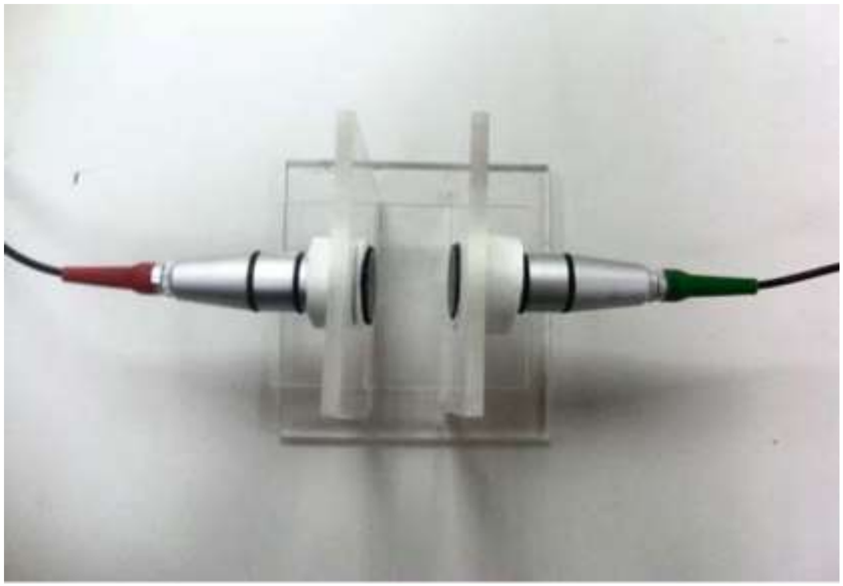

Fig 3.6 Fat measurement rig[16].

Figure 3.6 shows the fat measurement rig for velocity measurement that was used in the experiment[16]. The rig is used to position the sample between the ultrasound transmitter and receiver[16]. Ultrasound Echoscope GAMPT-scan is used to produce an ultrasound pulse[16]. A 2 MHz ultrasound transmitter transmits the ultrasound wave, and the 4 MHz receiver receives the transmitted ultrasound signal[16]. Before the measurement begins, ultrasound gel is applied to the sample to increase the sound conductivity[16]. A computer was used to log the acquired data[16].

Theoretically, the density of the medium affects the ultrasound pulse velocity[16]. The time of flight of the ultrasonic pulse is recorded to determine the ultrasound velocity in the samples[16]. Equation 3 is used to measure the velocity[16]. The ultrasound velocity for each sample was measured 5 times, at 5 different sites, and was then averaged[16].

$$Ultrasound\ velocity, ms^{-1} = \frac{Fillet\ Thickness, m}{Time - of - flight, s} \qquad (3)$$

The fat in all the samples was then extracted and measured using the Soxhlet method to examine the precision at the ultrasound velocity measurement method[16]. Fat percentage is calculated by using equation 4[16].

$$\%\ of\ Fat\ in\ sample = \frac{weight\ of\ the\ fat\ in\ sample\ (g)}{weight\ of\ sample\ (g)} \times 100 \qquad (4)$$

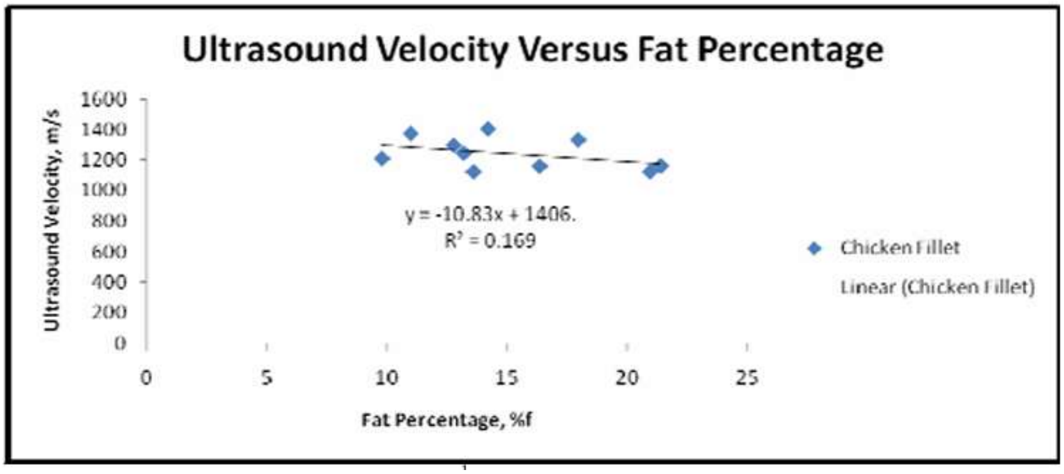


Fig 3.7 Ultrasound velocity versus fat percentage for chicken fillet[16]

Figure 3.7 shows the ultrasound velocity versus fat percentage for chicken fillet[16]. The graph shows a trend of decreasing ultrasound velocity with increasing fat content[16].

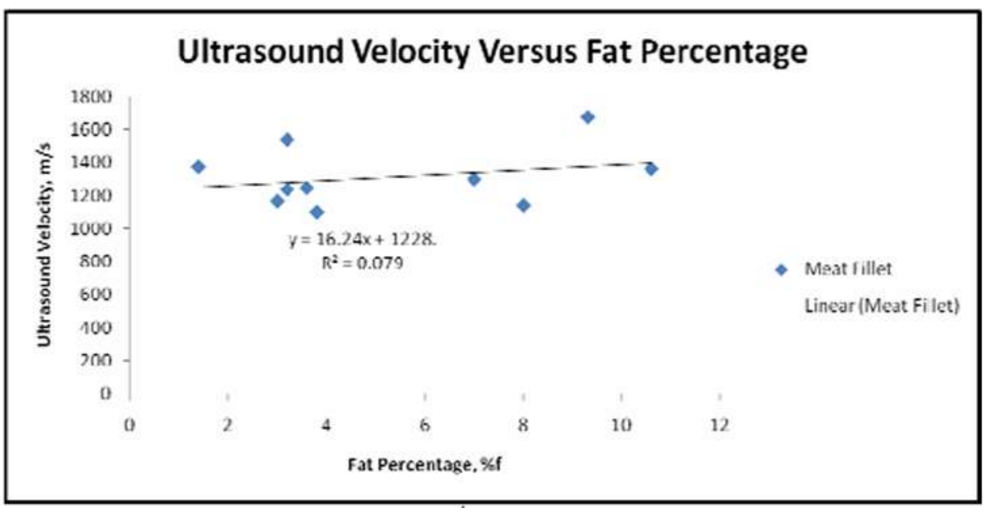


Fig 3.8 Ultrasound velocity versus fat percentage for Beef fillet[16]

Figure 3.8 shows the ultrasound velocity versus fat percentage for beef fillet[16]. This graph also shows an increase in ultrasound velocity with an increase in fat content[16].

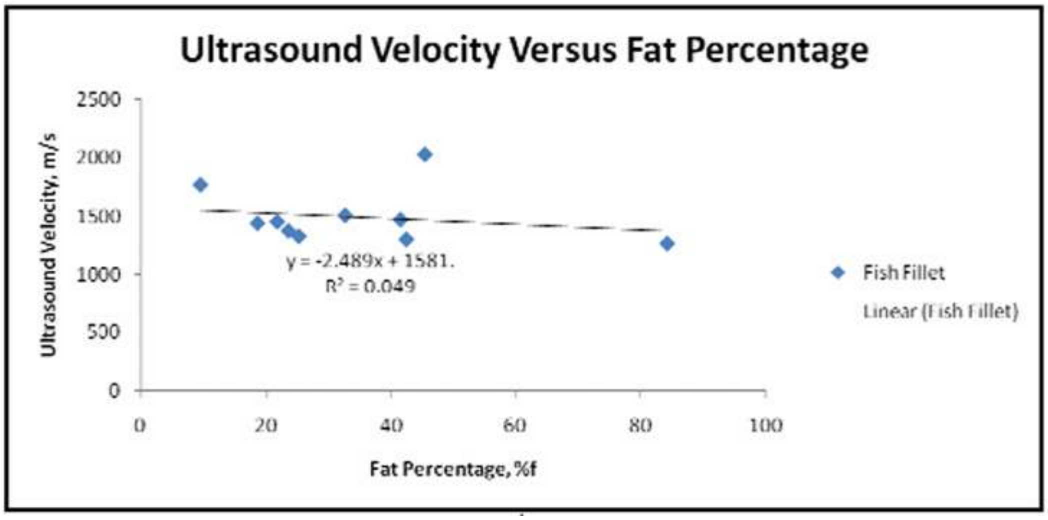

Fig 3.9 ultrasound velocity versus fat percentage for fish fillet[16].

Figure 3.9 shows the ultrasound velocity versus fat percentage for fish fillet[16]. The graph shows a trend of increasing ultrasound velocity with increasing fat content[16]. Results from the experiment can be said to be slightly inaccurate due to several number of measurement errors made during the experiment[16]. However, there is a trend of decreasing ultrasound velocity with increasing fat content of the sample[16].

### 3.3.3 Waner-Blatzer Shear Force (WBSF) / Texture profile analysis (TPA) for meat mechanical assessment.

The texture of the meat is the most significant quality that consumers appreciate[17]. Mechanical studies prefer to study the hardness and elasticity of meat[17]. Additional textural characteristics, including tenderness, firmness, and springiness, also play essential roles in the overall meat quality[17]. A key parameter of chicken meat freshness is elasticity, which is mainly influenced by muscle structure, such as the characteristics of connective tissues, and physicochemical characteristics, such as the contents of moisture, liquid-neutral lipids, and myofibrillar proteins[17].

The methods used for texture assessment can be separated into three categories: sensory, instrumental, and indirect methods[18]. Instrumental methods of texture assessment are commonly applied in mechanical analysis, measuring food resistance, as the food's opposing force is greater than gravity[18]. The sample is frequently ruined during the process because the applied power is beyond the strength of the tested sample[18].Therefore, the texture-measuring mechanical test is typically destructive[18].The Warner–Bratzler Shear Force (WBSF) test and texture profile analysis are classic instrumental methods for the estimation of meat mechanical properties such as texture and tenderness[18].

- Warner – Bratzler Shear Force (WBSF)

This test measures the compression to shear (cut off) a sample of meat (MPa) and the maximum force (N) as a function of knife movement (mm)[18]. The measurement shows the hardness (toughness) of the meat[18]. In the WBSF method, various analysis devices with heads or blades are attached[18]. These include machines such as texture analyzers[18]. Either a unique machine or some other automatic device with the WBSF blade mount performs WBSF[18]. In the examination, a blade slices through the meat samples so that shearing is perpendicular to the muscle fiber's longitudinal position[18]. Also observed the effect of the changing angle of the cutting edges of the blade and concluded that the shear force increases if the blade's angle increases from 30° to about 70°[18]. On the other hand, increasing the angle over this point does not increase the shear force[18].

The meat samples must be consistently around the same diameter for the WBSF test[18]. Specifically, beef samples and other animals' large muscles, in general, are recommended to be cut cylindrically with an internal diameter of either 0.5 or inch (1.27 or 2.54 cm)[18]. On the other hand, smaller muscles are put into the blade's triangular hole without cutting[18]. Afterward, the sample is cut into two pieces, and the newly obtained surface cross-section is included as a correction in the WBSF calculation[18]. The cross-sectional area can be measured by pressing the surface on a piece of filter paper, marking the line around it, and then using a planimeter to measure the area[18].

- Texture profile analysis (TPA)

The texture profile analysis method and instrument are referred to as the "Texturo-meter" to measure TPA parameters[19]. In this test, the sample is compressed twice, and TPA parameters are obtained by analyzing the force-time curves[19]. The leading indicators of TPA analysis can be divided into two categories: primary and secondary[18]. The TPA test imitates the chewing process like that in the human mouth, and its performance speed is equivalent to that of the human jaw[18]. Some previous studies presented variations in sample length (L) from 10 to 20 mm, diameter (D) from 13 to 73mm, and D/L ratio from 1.4[18]. Furthermore, the compression ratio ranged from 50 to 85%, and the compression speed ranged from 5 to 200 mm/min[18]. Hardness, cohesiveness, and gumminess decreased as D/L decreased, and springiness and chewiness increased[18]. Increasing the compression rate helps to reduce the springiness, cohesiveness, gumminess, and chewiness[18]. At the same deformation rate, a shorter sample is deformed at a higher strain rate and, consequently, should exhibit higher stress than a longer sample under the same strain[18]. Therefore, only when the tests are conducted using standard procedures are TPA parameters comparable[18].

### 3.3.4 pH sensor for meat freshness detection

Studies in the literature show that the most important factor affecting the quality of meat is pH[20]. The ultimate pH range for high-quality meat is between 5.4 and 5.6[20]. In general, a slaughtered animal has a pH value of 7.1[20]. A pH sensor can detect a specimen's pH value based on the concentration of hydrogen (H) ions, which is commonly between 1 and 10 × - 14 gram equivalents per liter[20]. The higher the hydrogen, the higher the substance's acidity[20]. Speaking, the pH value of a neutral solution is 7.0[20]. Acidic solutions have a pH value below 7.0, and solutions with above 7 pH considered basic (alkaline)[20].

The meat freshness detector is an embedded program that helps in determining the freshness based on pH levels using readily available pH sensors in the market[20]. This system is made up of an Arduino microcontroller, a pH sensor, a set of light-emitting diodes (LEDs), and switches[20].

The microcontroller is the core component, and it receives input from the pH sensors and transmits the signal to a dedicated LED to show the output[20]. The microcontroller is programmed by Arduino programming[20]. The pH sensor has been chosen for this application, and its range of indicator forms from 0.00 to 14.0[20].

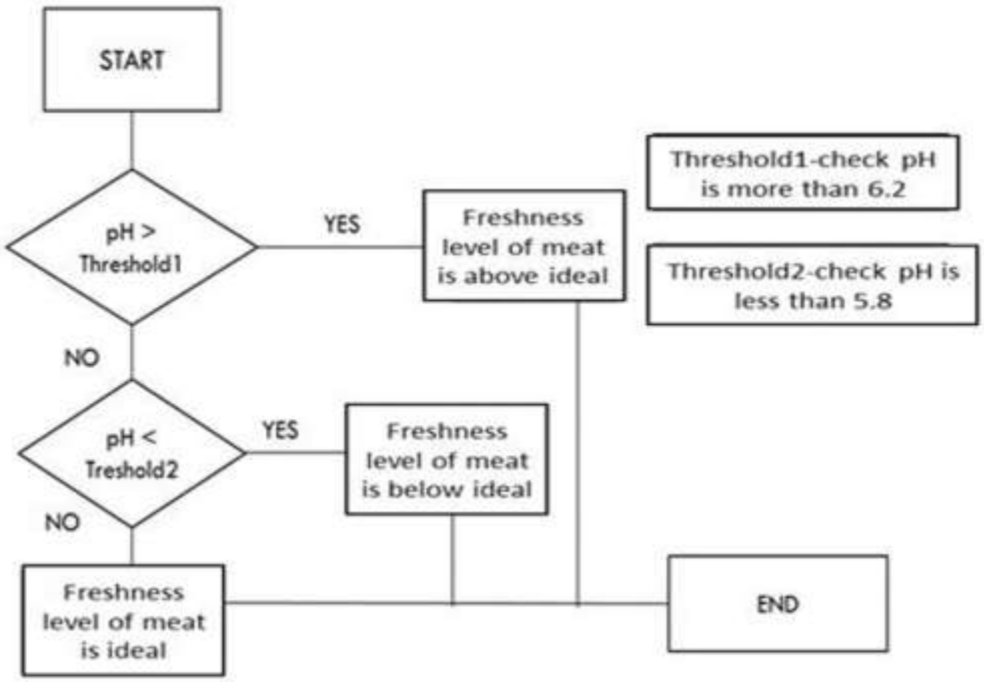


Fig 3.10 Flowchart of how the meat freshness detection system works[20].

Figure 3.10 shows the flowchart of the meat freshness detection system. According to the literature studies done, meat's ultimate pH range is between 5.4 and +/- (5.7)[20]. Because of that need to set two thresholds here, that is, 5.8 and 6.2[20]. If the readings indicate that it is less than 5.7, then it's acidic, which is regarded as not ideal or not fresh[20]. However, if the reading is more than 6.2, then it is regarded as ideal or really fresh, and if the reading is between 5.7 and 6.2, it is regarded as that meat is ideal and fresh[20]. Distilled water is used to ensure the sensor operates properly, and the sensor result is set at 7[20]. Furthermore, pH sensor calibration is done using various buffer solutions[20]. Finally, the pH sensor probe is directly inserted into the meat sample and gets the readings on the LCD screen[20].

### 3.3.5 Computer vision system for color stability assessment of meat.

Color is a subjective psycho physical attribute as it exists only in the observer's eyes and brain[21]. The computer vision system (CVS) method is possible to estimate the meat sample's overall color and its heterogeneity[21]. Using this method, it's possible to analyze the entire surface of the foods, defects, and their characteristics[21]. The main objective of digital color management is to preserve as much as possible the chromatic fidelity of an image when it's displayed as a digital image on a monitor or printer on different peripherals[21].

Fig 3.11 Computer vision system. The camera and the lightning system are inside the black wooden box[21].

Figure 3.11 shows the computer vision system. For image acquisition, a CANON EOS 450D digital camera with a 12.2 Megapixel CMOS sensor[21]. The camera was positioned vertically, 30 cm away from the sample[21]. The camera setting was the following: shutter speed 1/6 s, manual operation mode, aperture Av F/11.0, ISO velocity 100, flash off, focal distance 30 mm, lens: EF-S18-55 MM f 3.5-5,6 IS[21]. Four fluorescent lamps (Philips Master Graphica TLD 965) were used for the lighting, with a color temperature of 6500 K and a color rendering index (Ra) of nearly 98%[21]. Each lamp is covered with a light diffuser[21]. To achieve a uniform light intensity on the sample, the lamp is located above the sample at an angle of 45̊[21]. To minimize background light, the camera was placed inside the box, and the internal walls were covered with black opaque cloth to reduce background light[21]. The color checker was photographed using the implemented CVS to get input device RGB signals within the theoretical range of 0 – 255[21]. The camera can be connected to the NEC MultiSync PC equipped with an LCD monitor with a standard RGB[21].


Fig 3.12 Image color analysis using Adobe Photoshop CS3 software[21].

Figure 3.12 shows the picture of image analysis using Adobe Photoshop CS3 software. The L*, a*, and b* values were determined on the digital image of the sample visualized on the monitor by placing the cursor at the center of the area to be assessed and by clicking on it[21]. For research purposes, a RAW format file (non-compressed) is preferable compared to the compressed file (JPEG)[21]. Mainly, RAW photos were used to measure the RGB L*, a*, and b* values[21].

# 4 ASSIGNMENT OF THE MULTI-PARAMETER DESKTOP DEVICE FOR MEAT FRESHNESS AND QUALITY ASSESSMENT, ANALOGUES, AND PROTOTYPES.

Stage 1: Identification of the problem.

The first stage in analyzing the project task is identifying the related problem. This project involves developing a multi-parameter desktop device for meat freshness and quality assessment.

Ensuring meat freshness and quality is essential for achieving industry standards and consumer expectations, influencing their purchasing decisions. Results of different processing conditions appear to undergo structural and compositional changes, including storage temperature, handling, and packaging are the key challenges in the meat industry. Water holding capacity (WHC), fat content, elasticity, pH, and color stability are the key indicators that can be used to evaluate the freshness and quality of meat.

The visual appearance of fresh meat is determined by its WHC, which influences consumers' willingness to buy the product. WHC is known as the ability of meat to retain water during preparation, storage, and cooking. Fresh meat WHC usually has 56%-72% water by weight. WHC can be quantified using various methods, including drip loss, pressing techniques, and centrifugation. However, these techniques put pressure on meat, which could damage the structure of the muscle. For that reason, ultrasound is a quick, precise, and non-destructive method for evaluating the WHC of meat. Because of its higher water content, fresh meat usually has a sound velocity range from 1550 m/s to 1600 m/s, and the ultrasound attenuation is between 1.5 – 3.0 dB/cm/MHz.

The fat content and distribution of meat greatly impact its tenderness, juiciness, and flavor, making them major considerations when making a purchase. Ultrasound velocity decreases as fat content increases, proving that fat and lean tissues have different sound speeds. Fat tissues have a lower speed of sound (~1450 m/s) compared to the lean tissues (~1580 m/s). Also, fat tissues show a higher attenuation coefficient than lean tissues; however, for all layers, attenuation was not affected by a thickness ranging from $1.6 \pm 0.7$ to $2.7 \pm 1.5$ dB MHz (-1) cm.

Elasticity is one of the main factors for determining the texture and structural integrity of meat. The Texture Analyzer (TA) / Universal Testing Machine (UTM) is a commonly used method for determining the meat elastic modulus. How well meat retains its texture and shape over time can be determined by using elastic modulus. Meat with a higher elastic modulus indicates firmer, less tender and meat with a lower elastic modulus indicates softer muscle fibers, making it more pleasant and easier to chew. Consumers frequently prefer tender meat; aging, marination, and cooking are some of the factors that affect the elasticity of meat.

pH is another crucial factor for determining the freshness, shelf life, and microbial growth of meat. Because of microbial activity, pH rises, and typically, the fresh meat has a pH range between 5.5 – 5.8. When the pH increases above 6.0, it's an indicator of more conducive to the spoilage, growth of bacteria or the beginning of spoilage signs.

Color is the characteristic that meat consumers look at first to judge meat freshness and its quality. ClE L*, a*, b* color space is the industrial standard method for meat color evaluation. Pale or brown meat indicates spoilage, and bright red meat is considered fresh. Temperature, oxygen exposure, and pH variations can affect the meat color over time.

So, the problem is that the above-mentioned methods show that various factors can be used to determine the meat freshness and its quality, each having its specific measuring technique, and with the measurement results of some techniques providing overlapping information. Thus, it becomes evident that some methods can be prioritized over others when selecting the minimal set of measurement modalities.

Stage 2: Finding the practical solution to the problem

Integrating multiple techniques into a single system will allow direct comparison of different methods, ensuring that only the most efficient, non-destructive, and informative techniques are retained while discarding redundant or cumbersome approaches. This will lead to improved standardization and measuring repeatability. This proposed device will measure key parameters, including water holding capacity (WHC), elasticity, fat content, pH, and color. By combining these key methods into a single desktop unit, the device will streamline the meat quality evaluation process, eliminating the need for multiple instruments and reducing inconsistencies caused by overlapping assessments.

- All the techniques for assessing the quality and freshness of meat will be combined into a small, enclosed unit that is around 350 mm long, 250 mm wide, and 240 mm high. These parameters were chosen to ensure that the device is user-friendly, hand transportable, and has enough space to integrate all required testing setups.
- The specimen weight: 100g ≤, specimen size: 60 x 40 x 40 mm. This standardized size guarantees compatibility with the device chamber.
- Ultrasound technology was selected for the water holding capacity (WHC) and fat content measurements because of its precise, non-destructive, and fast technology. Fresh meat WHC is about 56%-72 %, and this can be measured in real-time sound velocity 1550 – 1600 m/s) and attenuation (1.5-3.0 dB/cm/MHz). The difference between ultrasound velocities on fat tissues (~1440 m/s) and lean tissues (~1580 m/s) provides accurate results for fat content measurements.
- Fresh meat has a pH between 5.5 and 5.6; glass-type pH sensor is ideal for measuring this pH range.
- For mechanical testing 50N-200N, speeds ranging from 8 mm/s to 32 mm/s and 30mm stroke linear actuator can apply forces.
- RGB camera (The Canon EOS 5D Mark IV) used to capture meat color changes precisely. Also, this same camera is used to measure the deformation of meat during mechanical testing.
- Environmental lightning variations can affect the color measurement results. Using a consistent light source, D65 light source (6500K, daylight) can prevent outside light interference.
- All meat properties (WHC, fat content, elasticity, pH, color) are temperature dependent. Therefore, an integrated temperature controller will maintain the temperature range between 15 °C and 23 °C to ensure accurate readings at room temperature.

# 5 TECHNICAL ASSIGNMENT FOR THE DEVELOPMENT OF A MULTI-PARAMETER DESKTOP DEVICE FOR MEAT FRESHNESS AND QUALITY ASSESSMENT.

The problems and challenges of designing the multi-parameter desktop device for meat freshness and quality assessment, and the practical solutions were already discussed in the previous chapter; the technical approaches and engineering solutions will be discussed in this chapter.

Sub-chapters will discuss the appropriate design solutions for the parts according to the parameters in the previous chapter.

## 5.1 Ultrasound measurement setup.

According to the parameters mentioned in the previous chapter, an ultrasound measurement setup should be set up to measure the water holding capacity (WHC) and fat content of meat. This configuration comprises an ultrasound transducer and receiver. Both the transducer and the receiver must be movable to contact the meat sample to ensure the accuracy of the measurements. The air medium between the transducer, sample, and receiver will negatively impact the accuracy of the results by changing the ultrasound velocity and attenuation. The transducer and receiver connect to the actuators for precise movement and contact during the testing with the meat sample; both transducer and receiver are automated.

## 5.2 pH measurements

The pH measurement setup consists of two glass electrode pH sensors. Both sensors are connected to the two actuators, this configuration helps to contact the pH sensors with the meat sample to get the pH readings.

## 5.3 The Mechanical Testing Setup

To find the elastic modulus of meat, we must apply a force to the meat specimen; according to the guidelines, the mechanical testing setup should also be suitable for portable standards. The mechanical testing setup, which consists of an actuator attached to the plate with a surface area similar to the meat specimen, provides uniform force distribution. The entire force applicator component is mounted firmly into the setup and maintains alignment during force application.

## 5.4 RGB camera measurements

Meat color changes are measured using the RGB camera. The standard method for quantitatively measuring color, the CIE L*, a*, b* color space, is used to determine the captured images and color variations. This method ensures the accurate and objective assessment of color changes, allowing for precise evaluations of the meat's condition. Also, this same camera is used to find the deformation of the meat specimen during mechanical testing.

All the application setups are integrated into a portable box, fulfilling the requirement of the multi-parameter desktop device for meat freshness and quality assesment.

# 6 A REASONABLE VARIANT OF THE MULTI-PARAMETER DESKTOP DEVICE FOR MEAT FRESHNESS AND QUALITY ASSESSMENT.

During the design of the device for the multi-parameter desktop device for meat freshness and quality assesment, various functional and practical designs for the ultrasound measurements and mechanical testing methods were checked out. A comparison of the ultrasound methods and mechanical testing methods was conducted to determine the most cost-effective solution. This chapter will discuss each version of ultrasound methods and mechanical testing methods.

## 6.1 Version 01

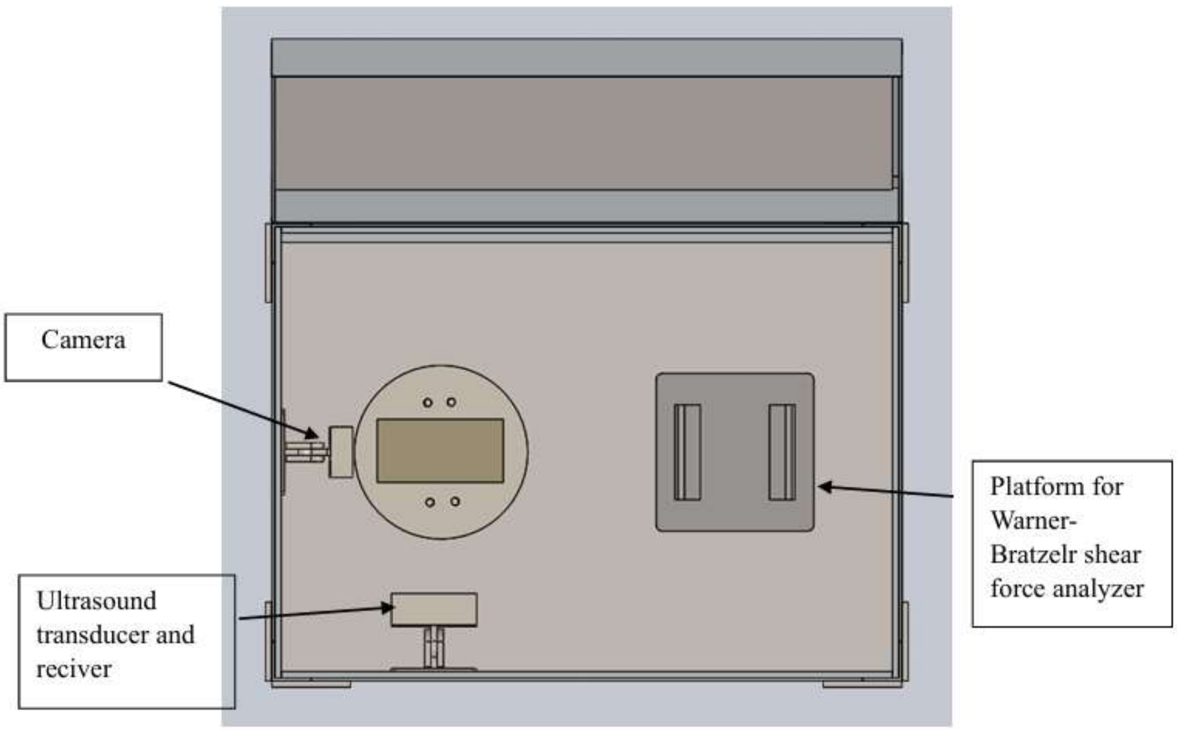


Fig 6.1 Version 01 of the multi-parameter desktop device

According to version 01, the ultrasound transducer and receiver are combined into a single device. This device can emit ultrasound waves and capture the reflected waves. The changes in the detected ultrasound waves can be analyzed to assess the meat's condition. However, in this arrangement, the ultrasound device is set at a significant distance from the meat sample. The medium of air between the device and the meat sample can affect the accuracy of the results because air can affect the ultrasound velocity and attenuation, which can lead to inaccurate measurements.

To get accurate deformation and applied force measurements during the mechanical testing, I initially considered setting up the Warner-Bratzelr shear force analyzer on the left side of the platform in Figure 6.1. Even though the device is highly accurate for these measurements, several challenges make it inappropriate for my application. Specifically, it applies force using a hydraulic pressure pump, further complicating the system. This makes the device less practical as a portable device and increases its size and weight.

## 6.2 Version 02

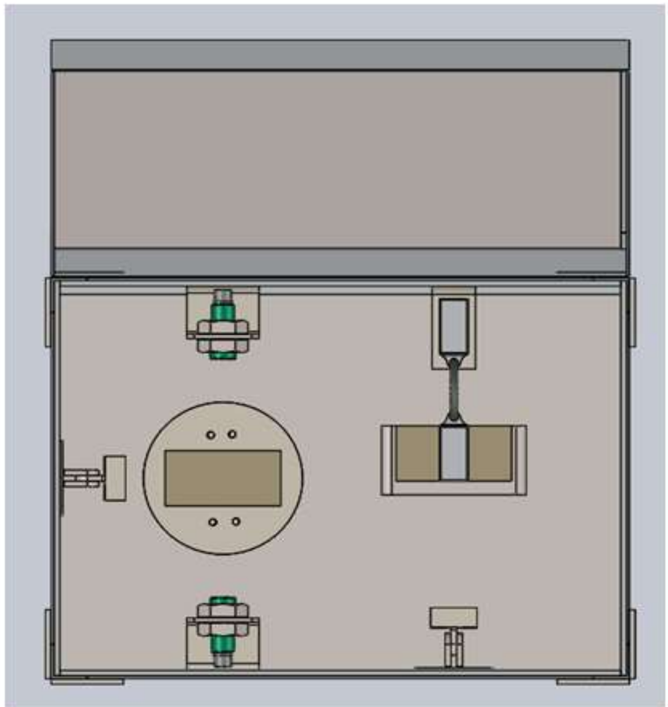

Fig 6.2 Version 02 of the multi-parameter desktop device

In the configuration of version 02, both the ultrasound transducer and receiver are fixed to the designed box, and the ultrasound receiver is positioned directly across from the transducer to accurately measure the structural properties of meat.

The emitted ultrasound signal travels through the meat specimen, and the receiver detects variations in the signal that are impacted by the internal structure of the meat. These changes offer valuable data regarding the condition of the meat; however, there is air between the transducer and the meat specimen, as well as between the meat specimen and the receiver. The air medium affects the ultrasound velocity, and attenuation leads to unreliable results.

The Version 2 mechanical testing setup is simple. The mechanical testing measures need to be done manually. The meat sample is securely placed on a platform for stability during the test.

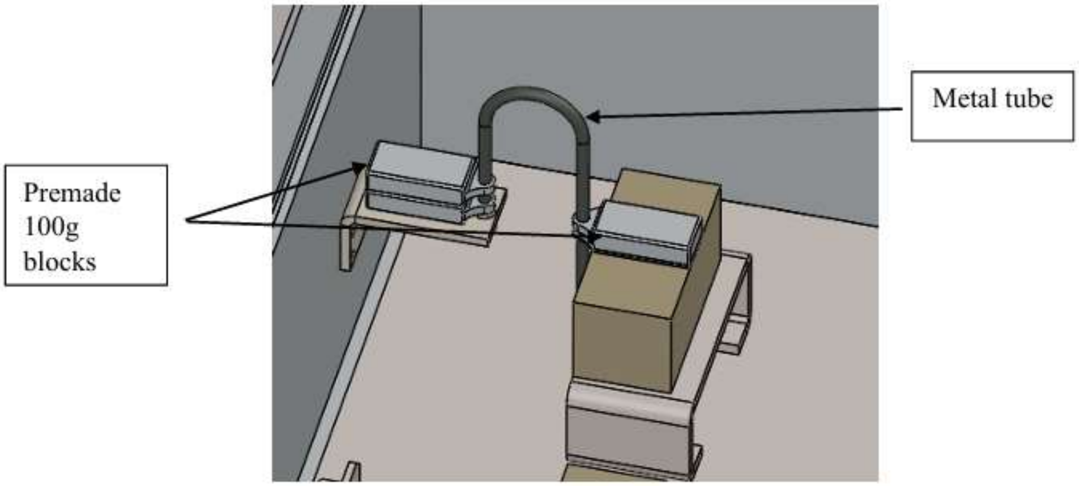


Fig 6.3 Version 02 mechanical testing setup

The force applicator plate is connected to the fixed tube and can move along the tube. When the meat sample is placed on the platform, the plate can be moved to contact the sample surface. We can apply force using three pre-made 100g (1N) metal blocks. For instance, if two blocks are placed on a plate, the applied force is 2N, and so on. The setup consists of 3 blocks, and the force range is 1N-3N. The camera is placed in front of the force applicator to capture images of the meat sample before and after applying the force. Using the initial and final values from the taken images helps to find the deformation of the meat specimen. However, the plate does not cover the entire area of the meat surface, which results in incorrect deformation calculation.

## 6.3 Version 03

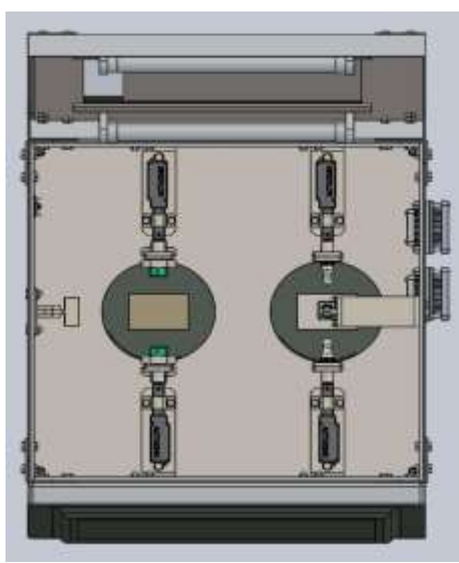

Fig 6.4 Version 03 of the multi-parameter desktop device

Version 3 is fully automated. In this setup, the ultrasound transducer and receiver are mounted to the actuators and can move independently. The actuators can adjust the ultrasound transducer, and the receiver can directly contact both sides of the meat specimen's surface. This direct contact reduces the effect of the air medium on ultrasound attenuation and velocity. The ultrasound pulses can directly pass through the meat specimen by removing air gaps with negligible interference.

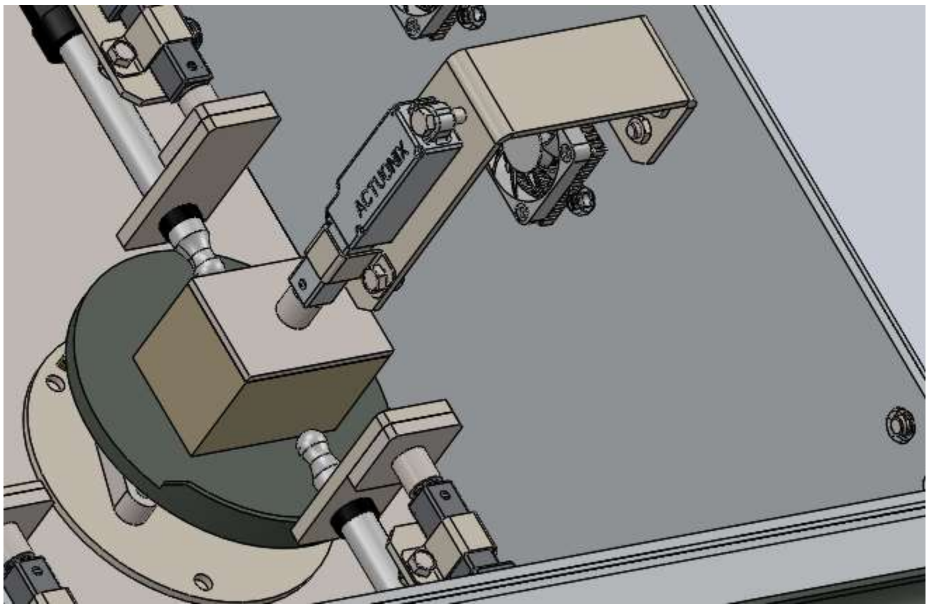


Fig 6.5 Version 3 mechanical testing setup

Figure 6.5 shows the mechanical testing setup for version 3. In this case, the actuator is the main part of the setup and is responsible for applying regulated and precise force to the meat sample. To use the force on the meat sample, the testing head(plate) moves vertically. At the lower end of the actuator, a flat plate equipped with the same area of meat spacemen applies uniform force to the meat sample. This helps to ensure the validity of the results during measurements because, if used, there is consistent pressure. The meat sample is placed on a removable platform, and the platform is attached to a load cell. This can be used to find the deformation and applied force during testing. The load cell is used to find the applied force to the meat sample. The initial weight of the meat sample, before applying the force, was measured and noted. The load cell measurement increases when force from the actuator to the meat sample is applied. The difference between the initial and increased values is used to find the applied force precisely. Like version 2, the camera is placed in front of the force applicator to capture images of the meat sample before and after applying the force. Using the initial and final values from the taken images helps to find the deformation of the meat specimen.

## 6.4 Comparison of the versions

A comparison of the three versions of the multi-parameter desktop device for meat freshness and quality assessment was used to find the best version of the device based on several important features. Different ultrasound mechanisms and the different mechanical testing setups are integrated. To impartially evaluate each mechanism’s practicality and suitability, an evaluation method was used that involved individual scores and coefficient values. The most suitable mechanism for the device was selected thanks to this systematic approach. The evaluation is as follows.

$$Total = \sum [\mu(n) \times Score\ (n)] \tag{5}$$

Where

n – Considered feature

μ – Comparison coefficient

The score values range between 0 to 3 for each mechanism of the system, and a score of 3 is awarded if the specific design performs optimally. Other versions are evaluated concerning the version with the optimal performance.

The comparison coefficient readings are given from -1 to +1. The comparison coefficient readings have the following meanings.

- -1 = Considered a feature increasing the probability of failure and reducing the manufacturing effectiveness and desired operating behavior.
- +1 = Vise versa of “ -1”.
- 0 = Considered feature has no influence.

Fig 6.6 comparison of the design versions.

| Feature | μ | Version 1 | Version 2 | Version 3 |
|---|---|---|---|---|
| Measurement accuracy | 1.0 | 1 | 1 | 3 |
| Air effect for ultrasound measurements | 0.8 | 1 | 1 | 3 |
| Force application setup | 1.0 | 1 | 2 | 3 |
| Deformation measurement accuracy | 0.9 | 1 | 2 | 3 |
| Portability | 0.5 | 1 | 2 | 2 |
| Complexity of manufacturing | -0.7 | 2 | 2 | 1 |
| Image analysis | 0.5 | 1 | 2 | 2 |
| Manufacturing cost | -1.0 | 1 | 2 | 1 |
| Total | | 3.1 | 8.8 | 13.1 |

The above table evaluates the three versions of the multi-parameter desktop devices. From the table, it can be concluded that version 3 is the best version for assessing meat freshness and quality.

# 7 ENGINEERING CALCULATIONS FOR THE MULTI-PARAMETER DESKTOP DEVICE FOR MEAT FRESHNESS AND QUALITY ASSESSMENT.

This chapter is dedicated to choosing the actuator to apply the force for mechanical testing and finding the required power for the mechanical testing setup integrated into the multi-parameter desktop device. Applying compressive force to the meat specimen (60mm × 40 mm × 40mm) determines the deformation for elastic modulus calculations. The reference shows that fresh meat has a 20 – 80 kPa elastic modulus. When applying the force, the meat should not be damaged, and the force must be sufficiently strong for the meat to deform.

- Calculation pressure applied from the actuator.

The actuator applies the force to the top face (60mm × 40mm),

$$A = 60\ mm\ \times 40\ mm = 2400\ mm^2 = 2.4\ \times 10^{-3}\ mm^2$$

Max pressure,

$$P = \frac{F}{A} \tag{6}$$

$$P = \frac{200N}{2.4\ \times 10^{-3}} = 83.3\ kPa$$

Where,

F - Force applied by the actuator.

A – Cross-sectional area.

The fresh meat has a 20 – 80 kPa elastic modulus, and the 83.3 kPa is within permissible limits and provides enough stress to measure the deformation of meat without damaging the sample.

Texture profile analysis, TA. XT plus Texture analyzer, research on pork/beef elasticity shows that the typical compression speeds are respectively 1-10mm/s, 5-20mm/s, and 10-20 mm/s. Mostly 5mm/s to 25 mm/s are used for elasticity testing, and high-speed apps sometimes use up to 30 mm/s.

Force and deformation are used to calculate the elastic modulus,

$$E = \frac{Stress}{Stain} = \frac{F/A}{\Delta L/L} \tag{7}$$

Where ,

L - Original length of the meat specimen

ΔL – Change in length.

- Maximum compression analysis according to 30 mm stroke,

If the sample height is 40mm and the actuator stroke is 30mm,

$$Max\ compression = \frac{30}{40} = 0.75 = 75\%$$

This means the actuator can compress the meat sample up to 75% compared to its initial height. Meat quality assessment compression tests generally show 20% to 80% deformation of the sample's original height.

Fig 7.1 Desired compression and required stroke for 40mm height meat samples.

| Desired compression | Actuator Stoke |
|---|---|
| 20% | 8 mm |
| 50% | 20 mm |
| 75% | 30 mm |
| 80% | 32 mm |

Finally, conclude that the selected force 50 – 200N, stroke 30mm, and the speed 8 – 32mm actuator is suitable for the elastic modulus assessment in the developed desktop device.

- Calculating the actuator power requirement

$$Power\ (Watts) = Force\ (N)\ \times Speed\ (ms^{-1}) \tag{8}$$

Max speed = 32mm/s = 0.032 m/s

$$Required\ mechanical\ \ power = 200\ N\ \times 0.032\ ms^{-1} = 6.4\ W$$

Due to the friction loss and motor efficiency (≈ 30%-50 %), power can be adjusted up to 21.3W.

$$Electrical\ power\ requirement = \frac{P_{mechanical}}{\eta} \tag{9}$$

η – efficiency (Mechanical power – electrical power)

$$P_{electrical} = \frac{6.4}{0.3} \approx 21.3W$$

12V/4A (48W) power supply is strong enough to power the actuator at maximum load.

# 8 TECHNOLOGICAL CALCULATION FOR THE PRODUCTION OF A PART OF THE MULTI-PARAMETER DESKTOP DEVICE FOR MEAT FRESHNESS AND QUALITY ASSESSMENT.

The device for multi-parameter desktop device for meat freshness and quality assessment consists of many parts, and different manufacturing technologies are used to manufacture its parts. Most of the solid assembly parts in the device are manufactured by laser cutting technology.

Laser cutting is a thermal-based, non-contact technology capable of precisely and accurately cutting complex contours on materials. It involves heating, melting, and evaporating material in a small, well-defined area, and it is possible to cut almost all materials. The word LASER stands for Light Amplification by Stimulated Emission of Radiation. Demand for laser cutting processes is growing in industrial industries such as aerospace, automobiles, shipbuilding, and nuclear industries because of the ability of the laser to cut materials with attractive processing speed, high productivity, and the ability to cut materials with complex geometries.

This non-contact technology does not require expensive or replaceable tools. It doesn't result in any force that can harm the workpiece, so it can be substituted for mechanical cutting processes. Different lasers are available, such as solid, liquid, and gaseous. Solid-state lasers like Nd: YAG and gaseous CO2 lasers are commonly used for cutting because of their high power and suitable material-cutting properties.

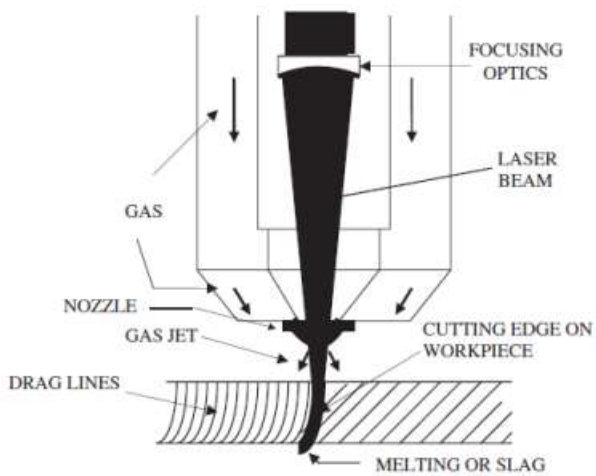


Fig 8.1 Schematic diagram of laser beam cutting.

Figure 8.1 shows the schematic diagram of laser beam cutting. When a high-power density beam concentrates in a spot, it melts and evaporates material in a fraction of a second. A coaxial assist gas jet removes the evaporated molten material from the affected zone.

Therefore, this chapter describes the technological process and calculations needed to manufacture the actuator mount for the experimental complex's ultrasound testing. The following figure shows a picture of the part.

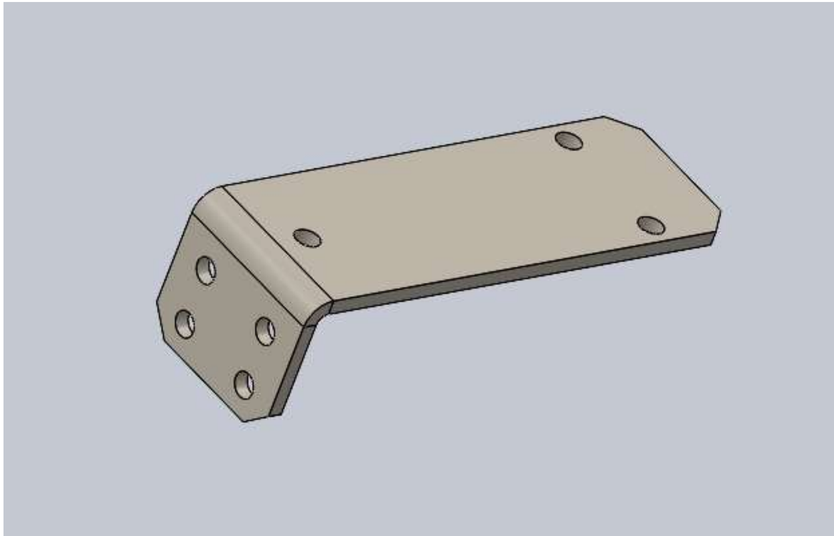

Fig 8.2 The actuator mount of the ultrasound testing setup.

The steps of the technological process of the part are described below. This part will be manufactured using stainless steel 316.

- Design and material selection
- Laser cutting
- Deburring
- Bending
- Quality checking

Some technological calculations were necessary to calculate the values of the necessary parameters, to ensure the correct and efficient manufacturing of the chosen

**i. Bend allowance**

When designing a sheet metal part using CAD and exporting its flat pattern for laser cutting, the bend allowance is an important parameter. It should be added to the part to account for material that will stretch and compress during the bending process[22].

**ii. Laser-cutting speed**

The appropriate cutting speed of the laser cutting machine should be selected by considering the material to be cut, the material thickness, and the required laser power for high-quality cutting[22].

**iii. Maximum bending force**

An important parameter in sheet metal part bending is the maximum bending force value, which determines the force capacity that is necessary to bend the sheet into the desired shape[23].

## 8.1 Calculations for bend allowance

Fig. 8.3 shows the terminology used in sheet metal bending, including bend angle, bend radius, k-factor, and sheet metal thickness. These factors are important in determining the bend allowance, which is determined using Eq 10.

$$BA = \pi \left(R_i + kT\right)\alpha_b/180° \tag{10}$$

Where,

$BA$ = Bend allowance

$R_i$ = Bend radius

$K_b$ = k – factor

$T$ = Sheet metal thickness

$\alpha_b$ = Bend angle in degrees

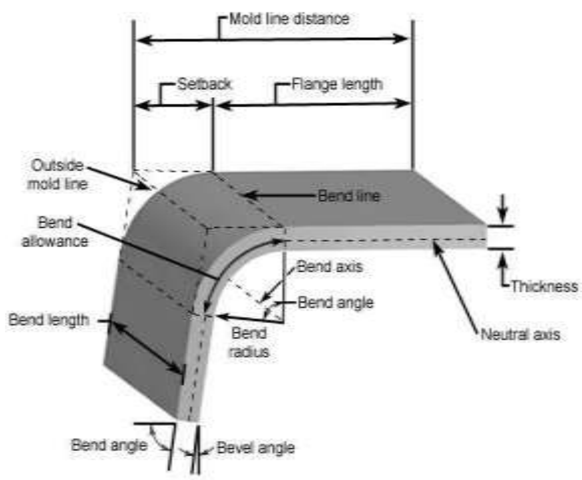


Fig 8.3 Bending terminology [23]

The ratio between the material thickness "$T$" and the neutral axis "$t_1$" used to find the k-factor value. The k-factor value in Eq. 10 shows the section of the material that is not compressed or extended. The mechanical properties of the material, sheet thickness, dimensions of the punch tool, and dimensions of the die width influence the k-factor, which always varies from zero to one.

Previous studies found that the respective k-factor value required for the bending allowance determination to produce the actuator mount made of 3mm thick stainless steel 316 was 0.4[24]. The bend allowance value can be calculated as follows.

The bend radius value is "R=1.5 mm" and all the bend angles for producing the part were "$\alpha_b$= 90°".

$$R_i = 1.5\ mm$$

$$K_b = 0.4$$

$$\alpha_b = 90°$$

$$T = 3\text{mm}$$

$$BA = \pi\ (1.5mm + 0.4\ \times 3mm)90°/180°$$

$$BA = 4.24\ \text{mm}$$

Therefore, to make 90° bend to produce the actuator mount part of the device; bend allowances of 4.23mm are needed at each bend.

## 8.2 Calculations of laser cutting speed

According to the previous study, the theoretical value for the laser cutting speed by fiber laser cutting can be determined by Equation 11.

$$v_c = \frac{P_L}{T.2r_0.\rho.\Delta h_m} \tag{11}$$

Where

$v_c$ – Theoretical value for laser cutting speed

$P_L$ – Laser power

$T$ – Sheet metal thickness

$r_0$ – Laser beam radius

$\rho$ – Density of the material to be cut

$\Delta h_m$ – Necessary increase in the specific enthalpy to cause melting of the material to be cut

The calculation can be performed as follows.

Recommended laser power ($P_L$) to cut 3mm thickness stainless steel 316 sheet 1500W[22].

$T$ = 3mm

Recommended laser beam radius ( $r_0$ ) to cut 3mm thick stainless steel 316 sheet = 0.05mm.

$\rho$ = 7.93 ×$10^{-3}$ Kg/$m^3$

$\Delta h_m$ = 935 $KJ/Kg$

$$v_c = \frac{1500W}{(3mm).(2 \times 0.05mm).(7.93 \times 10^{-3}Kg/m^3).(935KJ/Kg)}$$

$$v_c = 2.2ms^{-1}$$

But the cutting speed, in a real-world scenario, must be lower than the theoretically calculated speed value because the laser power ($P_L$) It is only partially absorbed by cutting the material, and some of the absorbed parts are lost in the cutting process due to heat conduction into surrounding materials.

### 8.3 Calculation of maximum bending force

The maximum bending force can be calculated using Eq.12 to determine the necessary tonnage values for the press brake to bend the sheet metal part into the required shape.

$$F_b = \frac{L_b T^2(\sigma_m)}{W_D} \tag{12}$$

Where

$F_b$ - Maximum bending force

$L_b$ - Length of the sheet metal

$T$ – Sheet metal thickness

$\sigma_m$ – Boundary tensile stress of the material

$W_D$ – Die opening width

The maximum bending force can be calculated using the sheet metal's longest and shortest bending lengths. These two values can be used to determine the desired tonnage values for all bends. The calculation can be carried out as follows.

$L_b$ - 125.5mm

$T$ – 3mm

$\sigma_m$ - 620$N/mm^2$

$W_D$ – 16mm

$$F_b = \frac{125.5mm \times (3mm)^2 \times 620N/mm^2}{16mm}$$

$$F_b \ = 43.77 \text{ KN}$$

In this part, only one bend needs to be done, so the maximum bending force that can be used is 43.77KN.

# 9 TECHNICAL DESCRIPTION OF THE DEVELOPED DEVICE.

The problems and challenges of designing the device for multi-parameter desktop device for meat freshness and quality assessment, and the practical solutions were already discussed in the previous chapter; the technical approaches and engineering solutions will be discussed in this chapter.

This chapter will discuss the appropriate design solution for the parts according to the parameters described in the previous chapter. Figures 9.1 below show the complete design solution of the multi-parameter desktop device.

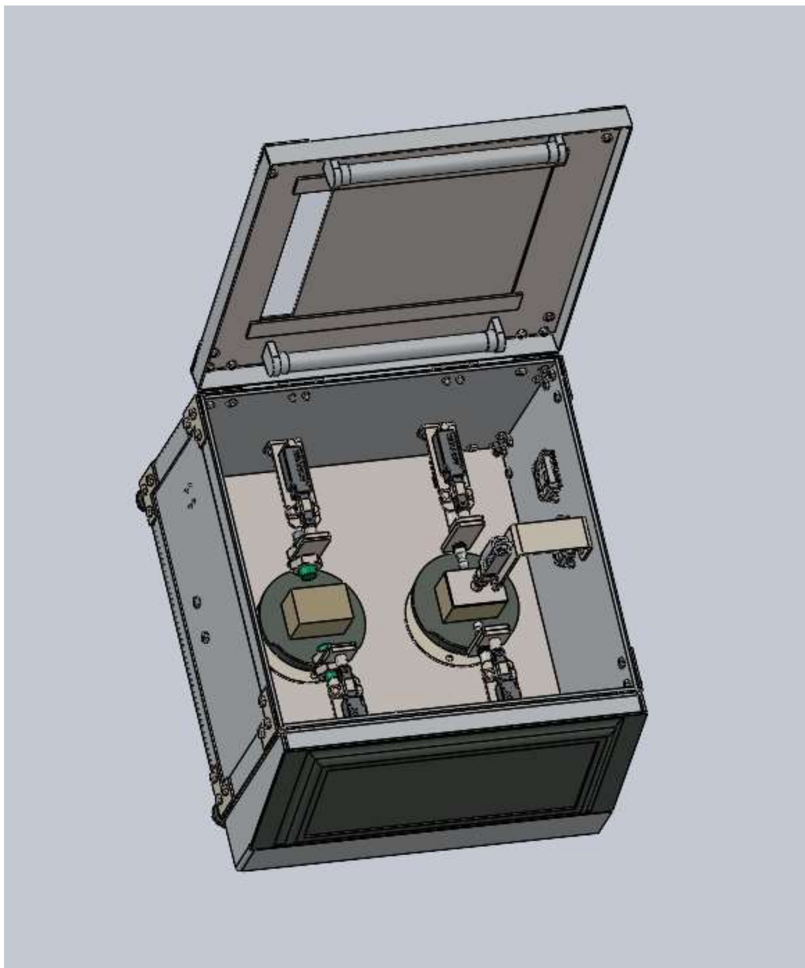

Fig 9.1 Design of the multi-parameter desktop device for meat freshness and quality assessment.

The ultrasound receiver is positioned directly across from the transducer to measure the structural properties of meat accurately. During testing, the transducer and receiver are securely mounted to the actuators to maintain precise alignment and direct contact with the meat sample. This configuration is crucial because the air between the transducer, receiver, and the meat sample can disrupt the transmission of ultrasound waves and result in inaccurate velocity and attenuation readings. The method ensures reliable coupling between the ultrasound component and the meat sample by removing air gaps, which is essential for accurate data. The actuators are essential in this setup because they allow precise and automatic transducer and receiver positioning. Regardless of the sample size or shape, this ensures the constant angles and distance between the components because even slight variations in positioning might impact the accuracy of the ultrasound result. Maintaining this consistency is essential for reproducible results. The actuator-based mounting solution not only improves the reliability of the measurements but also simplifies the experimental procedure by enabling the easy adjustment of various testing conditions.

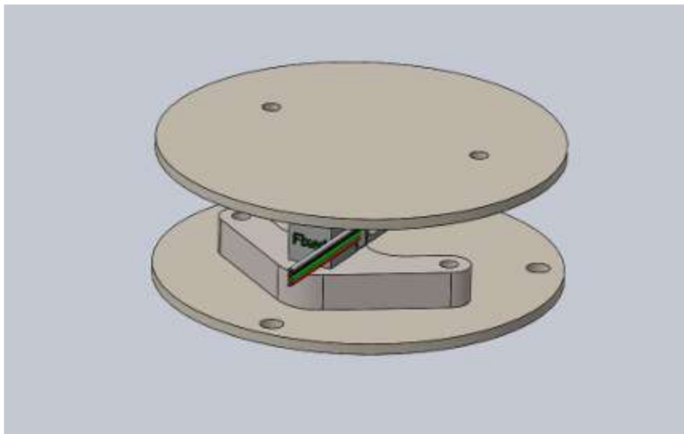

Fig 9.2 The load cell arrangement

Figure 9.2 shows the load cell arrangement. It is positioned between the ultrasound transducer and receiver to accurately measure the sample's weight during testing. A circular platform is placed on the load cell to securely hold the meat sample.

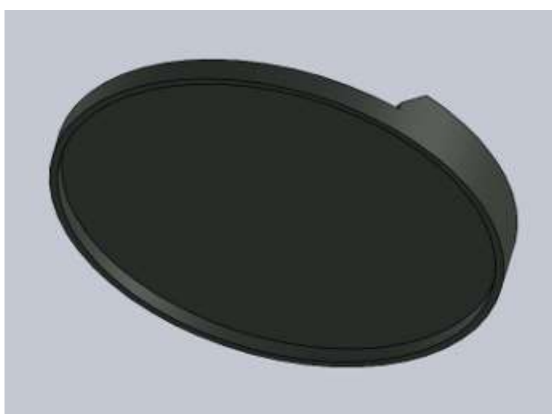

Fig 9.3 Meat placing plate

Figure 9.3 shows the circular platform on which the meat sample is placed. To ensure accurate and precise measurements, the load cell is automated to display only the weight of the meat sample, excluding the platform’s weight. The circular platform’s removable design gives flexibility in the testing procedure. The meat sample can be readily positioned on the platform and fastened during the experimentation to provide stability. The load cell maintains the accurate alignment and coupling required for ultrasound testing while ensuring precise weight readings once the sample is fixed. Integrating the load cell with the platform enhances its functionality and allows simultaneous weight measurement and ultrasound analysis.

The RGB camera was placed on the side of the ultrasound setup. This camera monitors the meat's color changes and the meat specimen when force is applied. This camera captures a high-resolution picture of the meat in its initial undeformed state. Once the force is applied to the meat, another image is captured, directly comparing the initial and final states.

The steady white light source is fixed inside the device lid to ensure uniform and consistent illumination of the meat specimen during the color measurement process.

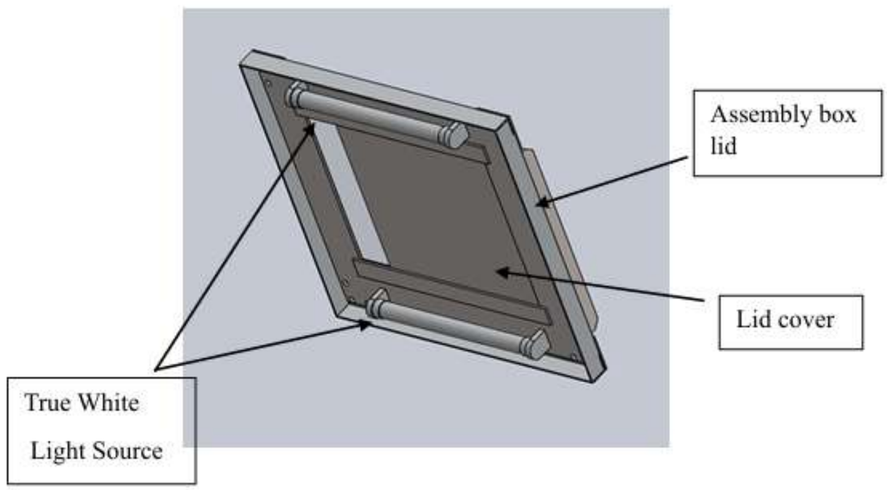


Fig 9.4  Assembly box lid

Figure 9.4 shows the true white light source installed on the assembly box lid. When analyzing color changes of meat, it's essential to use stable white light to ensure that the captured images precisely represent the actual color changes in the meat. The lights must be switched on before the camera captures the images to measure color changes. The lid and lid cover must be closed to avoid interference from external environmental light sources, which can affect the results of the captured images from the camera.

Figure 9.5 shows the force applicator used to apply force to meat specimens for mechanical testing.

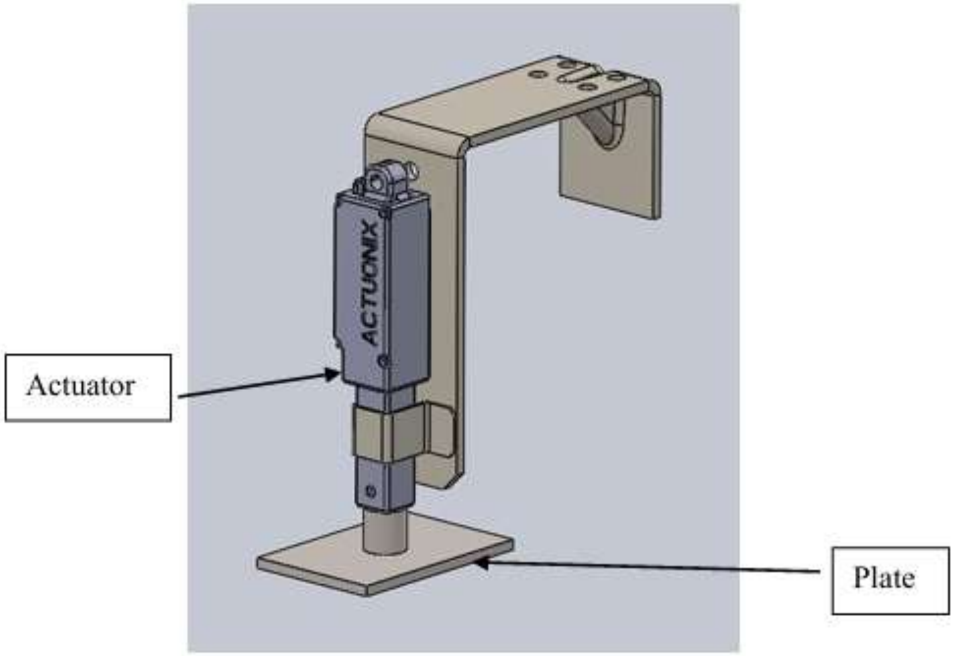


Fig 9.5 Force applicator

One key component of the device is the force applicator, which is designed to apply force to the meat specimen during testing. It consists of an actuator attached to the plate with a surface area similar to the meat specimen, providing a uniform force distribution. The entire force applicator component is mounted firmly into the setup and maintains alignment during the force application.

The second load cell is installed below the force applicator to measure the force applied to the sample. It ensures the actual weight of the meat specimen before applying the force. The load cell's measurement increases when the force is applied through the actuator because meat is subject to the additional force. The applied force can be measured precisely by subtracting the specimen's initial weight from the total measurement. Depending on the experimental requirements, the force applicator provides a different force range between 50N and 200N. The meat specimen and the meat holding plate are positioned on the second load cell after the color and ultrasound measurements are performed. This setup enables accurate force application and accurate measurements to ensure deformation. Once the process is done, the system provides all the important information required to calculate the elastic modulus of the meat specimen. This includes the meat sample's initial dimensions, deformation, applied force, and cross-sectional area.

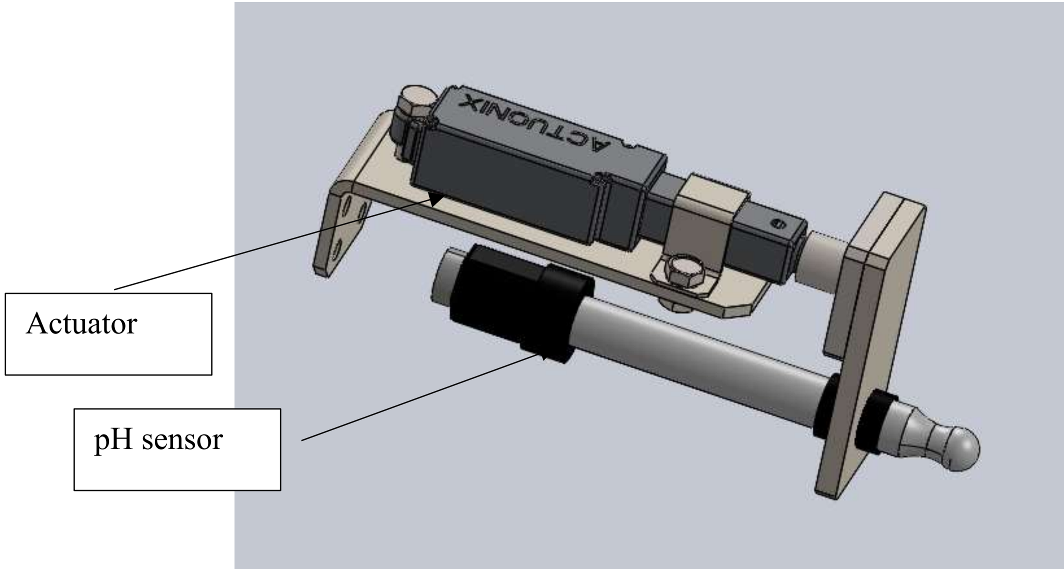

Fig 9.6 pH sensor setup

Figure 9.6 shows the arrangement of the pH sensor with the actuator. The pH sensors are integrated between the second load cell of the device. The setup consists of two Atlas scientific pH sensors, which are a type of glass electrode pH sensor. The advantage of using two sensors, pH can be measured by two different surfaces of the meat sample, and then the average pH value is obtained; this average value improves the accuracy of the results. Fresh meat typically pH range between 5.5 -5.8, and the selected pH sensor offers ± 0.01 pH accuracy and a 0 – 14 measurement pH range.

As discussed in the previous chapter, all the meat parameters are temperature dependent. Maintaining a constant temperature during the testing process is essential for the accuracy of the results. Therefore, the temperature should be maintained between 18℃ and 23℃ with a narrow range to ensure reproducible results.

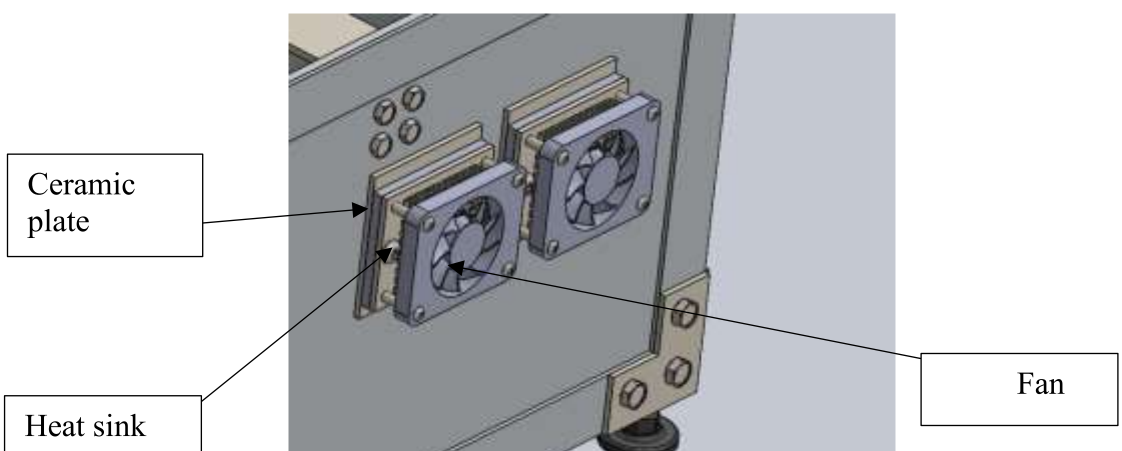

Fig 9.7 Temperature control unit

Figure 9.7 shows the temperature control unit for maintaining the temperature between 18℃ and 23℃. The unit consists of two Peltier thermoelectric modules. It was made up of p-type and n-type semiconductor materials interconnected by two ceramic plates. In this setup, heat is absorbed from one side, and it's transferred to the other side, which consists of a heat sink and fan. This helps to reduce the temperature inside the device. And another module connected with the reverse polarity, which is used to transfer heat into the device. The fan can increase the air flow over the heatsink and maintain a consistent temperature inside the device. The temperature sensor can detect the temperature inside the device, and if the temperature is below the required level, activate the heating Peltier to increase the temperature, and if the temperature is high compared to the required level cooling Peltier helps to drop the temperature.

This project aims to develop a multi-parameter desktop device for meat freshness and quality assessment. All the required components and apparatus are integrated within a single box to ensure accessibility of use, portability.

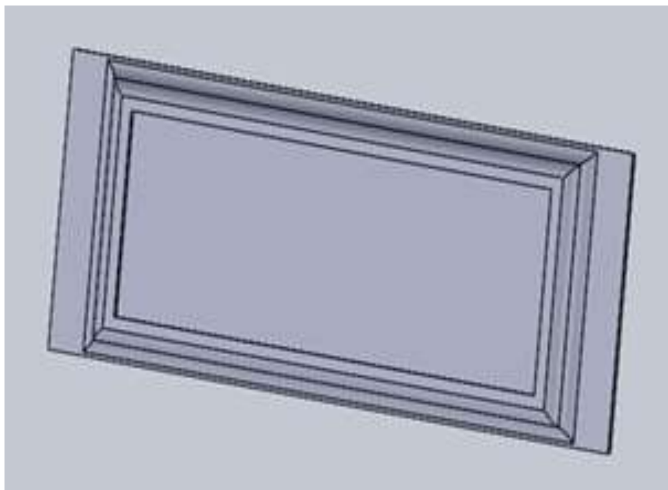

Fig 9.8 Human Machine Interface (HMI)

Figure 9.8 shows the Human Machine Interface (HMI) connected to the device, which creates an interactive platform between the device and the user. In this device, the HMI provides a user-friendly interface for controlling and monitoring during the process. Device operation control, such as controlling and positioning the ultrasound transducer and receiver, force applications, RGB camera measurements, switching on or off the light source, and data display, such as applied force, weight measurements, and ultrasound signal data, can be displayed on the HMI screen. Also, the HMI screen shows potential errors and malfunctions during the experiments and gives alerts, which are very useful for the accuracy of the results. A USB port makes it easy to connect to a computer for data transfer. To increase its practicality, the device has a hinged lid that can be closed securely after the measurements are complete. This protects the internal parts and makes it easier to transport by hand. Due to its lightweight, compact design, this device is suitable for field applications and laboratories, ensuring easy mobility.

# 10 ECONOMIC CALCULATIONS.

The economic calculations, which include expenses for the production parts, purchase part costs, labor costs, etc., will play an essential role in the manufacturing process of a particular model. Because of that, it's important to find economic calculations to figure out the total cost of manufacturing the device.

Determining each component's purchasing and production costs is essential to organizing and planning the project's economics. The sum of each part's production costs, labor, materials, and electricity determines the total cost of custom-made parts. The prices are listed, and different vendors from different countries are compared, and the lowest prices are chosen. The labor cost for assembling the parts for manufacturing devices is also considered.

The costs and expenses for all the parts listed in the following tables are as of April 2025.

The following table shows the total cost calculation for the main parts of the device.

Fig 10.1 Total cost calculation for the main parts of the device

| Part No. | Description | Qty | Item cost (EUR) | Total cost (EUR) |
|---|---|---|---|---|
| IP.005.01.001 | Actuator Mount | 4 | 5.99 | 23.96 |
| IP.005.01.002 | Back and front side plate | 2 | 13.64 | 27.28 |
| IP.005.01.003 | Force applicator actuator mount | 1 | 3.89 | 3.89 |
| IP.005.01.004 | Left side plate | 1 | 13.64 | 13.64 |
| IP.005.01.005 | Lid cover | 1 | 22.00 | 22.00 |
| IP.005.01.006 | Peltier thermoelectric A.plate | 2 | 21.42 | 42.84 |
| IP.005.01.007 | Right side plate | 1 | 13.64 | 13.64 |
| | pH bracket | 2 | 5.99 | 11.98 |
| | 400 mm L bar | 2 | 7.42 | 14.84 |
| | 240 mm side L bar | 4 | 7.32 | 29.28 |
| | Upper 240 mm plate | 2 | 2.20 | 4.40 |
| | Upper 240 mm plate 2 | 2 | 2.20 | 4.40 |
| | Bottom plate | 1 | 11.21 | 11.21 |
| | Meat holding plate | 2 | 2.44 | 4.88 |
| | Camera (Raspberry Pi) | 2 | 65.00 | 130.00 |
| | Load cell bracket part lower | 2 | 3.95 | 7.90 |
| | Load cell bracket part upper | 2 | 3.95 | 7.90 |
| | Digital temperature sensor (DS18B20) | 1 | 3.88 | 3.88 |
| | Ultrasoundsensors (UBE1000-18M40-SE2) | 2 | 203.67 | 407.34 |
| | pH electrode | 2 | 46.08 | 92.16 |
| | (L16-P Miniature Linear) Actuators | 5 | 78.00 | 390.00 |

| | | | | |
|---|---|---|---|---|
| | Fan 40x40x7mm | 4 | 9.09 | 36.36 |
| | 40x40x11mm heatsink | 2 | 5.69 | 11.38 |
| | HMI | 1 | 29.08 | 29.08 |
| | HMI holder | 1 | 8.88 | 8.88 |
| | LED Batten Light 6500K | 2 | 7.67 | 15.34 |
| | | | | |
| | Total | | | 1378.26 |

Table 10.2 shows the total cost calculation for assembly components and the fasteners.

Fig 10.2 Total cost calculation for assembly fasteners

| Description | Qty | Item cost (EUR) | Total cost (EUR) |
|---|---|---|---|
| B 18.2.3.1 M – Hex cap screw, M5 × 0.8 ×20 – 20N | 5 | 0.19 | 0.95 |
| B 18.2.4.1M- Hex nut, style 1, M5 ×0.8—D-N | 4 | 0.22 | 0.88 |
| B18.2.4.5M - Hex jam nut, M20 x 2.5 --W-N | 4 | 0.45 | 1.80 |
| B18.2.3.2M - Formed hex screw, M5 x 0.8 x 8 --8WN | 10 | 0.12 | 1.20 |
| B18.2.4.5M - Hex jam nut, M5 x 0.8 --D-N | 31 | 0.01 | 0.31 |
| ISO 7380 - M3 x 12 - 12N | 16 | 0.19 | 3.04 |
| B18.2.3.2M - Formed hex screw, M6 x 1.0 x 12 - 12WN | 62 | 0.35 | 21.70 |
| B18.2.4.5M - Hex jam nut, M6 x 1 --D-N | 59 | 0.08 | 4.72 |
| B18.2.3.2M - Formed hex screw, M5 x 0.8 x 12 - 12WN | 20 | 0.22 | 4.40 |
| B18.6.7M - M2 x 0.4 x 10 Indented HFMS --10N | 4 | 0.12 | 0.48 |
| B18.2.4.1M - Hex nut, Style 1, M2 x 0.4 --D-N | 4 | 0.03 | 0.12 |
| B18.6.7M - M4 x 0.7 x 13 Indented HFMS --13N | 8 | 0.21 | 1.68 |
| B18.2.4.1M - Hex nut, Style 1, M4 x 0.7 --D-N | 8 | 0.46 | 3.68 |
| ISO - 4032 - M5 - W - N | 4 | 0.33 | 1.32 |
| ISO 7380 - M5 x 20 - 20N | 4 | 0.19 | 0.76 |
| Connectors (W-5021 Three-Hole Flat Angle Plate) | 20 | 2.43 | 48.70 |
| Rubber bush | 2 | 1.25 | 2.50 |
| Total | | | 98.54 |

Table 10.3 shows the overall labor cost estimation based on man-hours to assemble, program, and quality check the device.

Fig 10.3 Total cost estimation for labour

| Labourer | Main hours (hours) | Wage per hour (EUR/h) | Total cost (EUR) |
|---|---|---|---|
| Assembler | 5 | 5.50 | 27.50 |
| Programmer | 4 | 7.50 | 30.00 |
| Quality checker | 2 | 6.00 | 12.00 |
| Total | | | 69.50 |

The estimated costs shown in the tables above must be included in the overhead cost to calculate the total manufacturing cost of this device. Overhead costs include rent, property taxes, utilities, insurance, and salaries essential for maintaining the business operations but are not directly related to producing the device. Overhead costs usually fall under the 20% margin and should also be included in the total cost calculations.

$$TC_D = TC_M + TC_S + TC_F + TC_L \tag{14}$$

Where

$TC_D$ – The direct costs

$TC_M$ – The cost estimation for manufacturing parts

$TC_S$ – The cost estimation for standardized and ready-made parts

$TC_F$ – Total cost estimation for fasteners

$TC_L$ – Total cost estimation for labor

$$TC_D = 117.55\ EUR + 1260.71\ EUR + 98.54\ EUR + 69.50\ EUR$$
$$TC_D = 1546.30\ EUR$$

$$Overhead\ costs = (\ Total\ direct\ costs\ )\ \times 20\% \tag{15}$$

$$Overhead\ costs = \ 1546.30\ \times \frac{20}{100} = 309.26 \text{ EUR}$$

$$Overall\ production\ cost = Total\ direct\ costs + Overhead\ cost \tag{16}$$

$$\mathit{Overall\ production\ cost} = 1546.30 + 309.26 = 1855.56\ \mathit{EUR}$$

The overall production cost for producing the multi-parameter desktop device for meat freshness and quality assessment can be approximately estimated at 1855 EUR.

# 11 SPECIFIC HAZARDS AND REQUIREMENTS FOR SAFE USE.

According to the General Product Safety Directive, only safe products should be on the market. European standardization organizations developed voluntary standards that may be relevant to proving product safety. Products that comply with standards referenced in the European Union's Official Journal are presumed to be safe[25].

Therefore, it is essential to analyze the risks, hazards, potential harm to consumers and the environment, and the potential harm that would occur when a product is set to be released into the market in a particular region (in this case, the European Union).

A risk or safety assessment is a process that aims to detect, evaluate, and minimize risks and hazards that might be caused by products to the general public or the environment, as per the EU consumer product legislative framework[25].

The EU risk assessment methodology describes the key technical terms in risk assessment and management. The important terms are as follows[26]

1 **Risk**: the combination of the probability that a hazard would cause harm in each scenario and the severity of that harm.

2 **Harm**: Injury or damage to the people’s health, property damage, consumers' finances, damage to the environment, security, and other elements defined in the scope of New Approach Directives.

**3** **Hazard:** a potential source of harm. Hazard, or danger, is inherent to the product.

**4** **Probability of the occurrence of that harm:** the likelihood of the damage occurring.

**5** **Risk level:** The risk level can be defined as “serious,” “high,” “medium,” or “low.” When different risk levels in various scenarios have been identified, “the highest risk gives the risk” of the product.

The three stages of risk assessment, in accordance with the EU general risk management methodology, are risk identification, risk analysis, and risk evaluation.

## 11.1 Risk assessment methodology

### 11.1.1 Risk identification

The device described in this engineering design project is a multi-parameter desktop device for assessing meat freshness and quality. To verify that the device meets safety, environmental, and operational requirements, it must comply with a number of EU product directives and regulations.

Possible hazards related to the device include physical hazards due to electric shocks, high-frequency ultrasound waves, thermal burns during operation, and mechanical hazards due to crushing points, moving fan blades, unconventional mounting, and electrical hazards due to overheating or short circuits. Chemical hazards can occur due to cleaning agents, leakage in pH electrode, and contaminated meat samples. The environmental hazards are due to electronic waste, heat emission, and improper waste disposal.

Subjects at risk include users, maintenance personnel, and the test environment (laboratory), such as the improper disposal of biological waste, chemical waste, and e-waste. Consumers are included as an indirect risk.

### 11.1.2 Risk analysis

Physical hazards, such as electrical shocks, can happen due to internal circuit exposure, broken insulation from fans, Peltier modules, electrodes, and actuators. Thermal burns can happen due to touching the Peltier module directly because the module can become very hot or very cold. Mechanical hazards, such as crush points, cause trapped fingers in moving parts if the device is handled carelessly. The rotating blades of the fan may result in cuts or impact damage. Cleaning agents can cause chemical burns, inhalation, or skin contact risks during maintenance. Also, the pH electrode leakage may result in eye and skin irritation during the breakage or replacement, which are chemical hazards. Chemical waste, e-waste, overheating of the device, and improper disposal of meat, which are environmental hazards, can contaminate water, air, and soil.

## 11.2 Risk Evaluation

The EU Risk Assessment Directive outlines two possible approaches to describing the severity of harm. One way is to list the damage levels for each subject area separately. Another more practical approach is to use abstract terms that could apply to any subject. The likelihood of suspected harm or injury should be carefully assessed with the assistance of a board of professionals under EU general risk assessment criteria. The probability of harm can be estimated in two possible ways. One method is to multiply the chance of occurrence of each incident step or a single estimated figure for the overall probability.

This is the last step of the risk assessment methodology under the EU risk assessment directive. Here, the severity of the risk and the probability that it will occur in the scenario are combined to assess the risk level. Upon identifying the different harm scenarios for the product, “the risk” of the product corresponds to the highest risk level across all scenarios [26]. The following table shows how the risk level is determined.

Fig 11.1 Risk level determination

| Probability of Occurrence | Severity of harm | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| >50% | High risk | Serious risk | Serious risk | Serious risk |
| >1/10 | Medium risk | Serious risk | Serious risk | Serious risk |
| >1/100 | Medium risk | Serious risk | Serious risk | Serious risk |
| >1/1000 | Low risk | High risk | Serious risk | Serious risk |
| >1/10,000 | Low risk | Medium risk | High risk | Serious risk |
| >1/100,000 | Low risk | Low risk | Medium risk | High risk |
| >1/1,000,000 | Low risk | Low risk | Low risk | Medium risk |
| >1/10,000,000 | Low risk | Low risk | Low risk | Low risk |

### 11.2.1 Risk assessment of the device

The following table was created considering the possible hazards, typical harm scenarios, and the associated risk levels according to the EU risk assessment directive for the multi-parameter desktop device for meat freshness and quality assessment.

Fig 11.2 Summarization of hazards, harms, and risk level

| **Hazard group** | **Hazard** | **Harm scenario** | **Potential negative effect** | **Probability of occurrence** | **Severity and risk level** |
|---|---|---|---|---|---|
| Mechanical | Moving part (Fan blades) | During operation, fingers can be inserted into the fan. | Minor injury to the finger. | >1/100 | 2 |
| | Injury from a force applicator | Fingers or hands were trapped during the operation. | Crush injury | >1/1000 | 2 |
| | Shape | Contact between the user and the sharp edges. | Cuts and minor injuries. | >1/100 | 1 |
| Electrical | Failure of power | Short circuit while in operation | Electrical shock, potential device damage. | >1/1000 | 3 |

| | | | | | |
|---|---|---|---|---|---|
| Thermal | Burn from the hot Peltier surface | The user is touching a heated surface. | Minor burns or pain. | >1/100 | 1 |
| Biological & chemical | Exposure to cleaning agents. | Eye or skin contact with cleaning chemicals. | Rashes, allergies or eye irritation. | >1/1000 | 2 |
| | Biological contamination | Improper cleaning of the testing chamber. | Meat samples cross-contamination that affects results. | >1/100 | 2 |
| Environmental | Electronics improper disposal. | Electronic components incorrect disposal. | Serious environmental pollution. | >1/100 | 3 |
| Civil/structural | Vibration | Vibration can affect the stability of the device. | Internal component misalignment. | >1/100 | 1 |
| Operational | User error | Insufficient instruction resulting in incorrect use of the device. | Incorrect measurements | >1/100 | 2 |

## 11.3 Demands to use the equipment according to occupational, civil safety/protection, and environmental protection.

To ensure the safety of non-food products supplied in European market, Regulation 2023/988/EU states that "a 'safe product' means any product which, under normal or reasonably foreseeable conditions of use, including the how long the product used, whether it present any risks or whether it has fewest risks compatible with the product's use, considered acceptable and in line with the high level of consumers protection of the safety and health"[26].

### 11.3.1 Labor Protection

The Labor Protection Law of the Republic of Latvia [26] is taken into consideration to develop specific rules that users must follow when utilizing the 'multi-parameter desktop device for meat freshness and quality assessment. The following measures apply to the device, in addition to the general measures related to labor protection.

- Only trained and certified personnel familiar with ultrasonic sensors, temperature control systems (Peltier modules), and glass pH electrodes should operate or maintain the device.

- The device has multiple powered components, so all exposed wires need to be completely insulated. To prevent electrical risks, surge protection systems or residual current devices (RCDs) must be installed.
- Personnel must avoid direct contact between Peltier modules. There should be a thermal warning sign about thermal hazards. After the operation, parts near the thermal unit must be operated using heat-resistant gloves.

Fig 11.1 surface warning sign

- The workplace must be equipped with personal protective equipment (PPE), including gloves for handling raw meat and cleaning, and to prevent direct contact with cleaning chemicals.


Fig 11.2 Informational signs

- The device is securely set up on a stable, anti-vibration, non-slip slip, away from direct sunlight zones and flammable materials. Ensure there is enough space to flow air around the cooling fans.

### 11.3.2 Civil defense

The civil defense aims to protect the people of a state from both human and natural disasters. It makes use of emergency management principles such as emergency evacuation, prevention, mitigation, preparation, response, and recovery.

The specific measures of civil defense related to the developed device are as follows:

- The power circuit must include a fuse and a circuit breaker that suits the rated power of the heating/cooling modules, force applicator, and ultrasound, pH sensors. The lab must be installed with a Class C (electrical) fire extinguisher.
- As the device uses standard electronic parts and polymers, they are not flammable, but if they catch fire, they can emit harmful fumes. Therefore, the equipment must be operated in good ventilation environments with away from extreme heat or open flame sources.
- Special attention must be paid to prevent the liquid (raw meat) from electronic components. Spill containment trays and hydrophobic pads must be used to prevent the spread of accidental spills during experiments.
- Operators must be well-trained for emergency response processes. Safety data sheets (SDS) for all working chemicals (pH buffers, cleaning agents) must be printed and stored accessible near the device.

### 11.3.3 Environmental protection

The sustainable use of natural resources, preservation, and restoration of environmental quality are ensured by the Environmental Protection Law [27]. The main environmental risk of the multi-parameter desktop device for meat freshness and quality assessment is its electrical components. Every electrical component has a lifespan or some work cycles and should be disposed of after continued usage. But it should not be disposed of together with household waste. Instead, the “WEEE”(Waste Electrical and Electronic Equipment Directive) label must be marked, and it indicates it should not be disposed of with household waste.

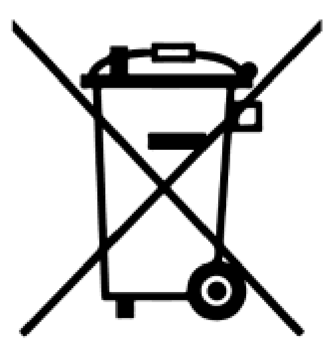

Fig 11.3 “WEEE” label

The specific measures of environmental protection related to the developed device are as follows:

- Ultrasound sensors, pH sensors, and actuators are some examples of device components that must bear the “WEEE” label and be disposed.
- Used pH buffers and cleaning fluids must be disposed of as per local or EU chemical waste guidelines.
- Biological waste (raw meat) must be added to biohazard bags and then proceed to the biological waste container.
- Materials such as aluminum parts, stainless steel parts, and reusable plastic parts should be recycled if possible.

# 12 CONCLUSIONS AND RECOMMENDATIONS.

After overcoming numerous design challenges, this design process succeeded in developing a multiparameter desktop device for meat freshness and quality assessment, and satisfies all the expected features, including,

- Compact and portable design: 350 mm (L) × 250 mm (W) × 240 mm (H) ± 100 mm
- Temperature maintains: 15℃ to 23℃ (±0.2 ℃ accuracy)
- Ultrasound velocity measurements: fresh meat (~1550 m/s to 1600 m/s), in fat (~1450 m/s).
- Water holding capacity (WHC): 56%-72% water by weight. This developed device measures between 55% and 75% using ultrasound.
- Mechanical testing: Force 50N – 200N, 8 – 32mm speed, and 30 mm stroke by linear actuator.
- pH measurement: Glass electrode pH sensors (pH range 5.5 – 6). ± 0.01 pH.
- Color analysis: RGB camera with D65 (6500K) LED lighting. (Accuracy - $\Delta E < 2$, intensity 500 – 1000 lux).

Considering all the mechanisms and features above, it can be concluded that this engineering project for developing a multi-parameter desktop device for meat freshness and quality assessment was successful. Meat research laboratories, food quality control departments, and industrial meat processing units will benefit from this device because of its non-destructive, accurate, and rapid assessment. As for recommendations, it can be recommended to:

- By evaluating multi-parameter sensor data, use AI machine learning algorithms to classify meat quality and freshness automatically.
- For the data transfer, use wireless data transmission (Wi-Fi, Bluetooth) methods for sync with mobile applications or the required database.
- Modify and calibrate the device to measure the quality and freshness of plant-based meat alternatives.
- Reduce the power usage and the size of the device to develop the handheld battery-powered version.

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