The Innovatest
Mobile Force Verification Kit

Group No. 02

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Statement of Originality

We hereby declare that this report and its contents were written, created and designed by the members of Group Project WS25/26 Group 02 as listed below. All sources of information utilised in the making of this report are referenced in Section 7. Bibliography. Any special tools used in the making of this report are referenced in the footnotes in the section in which they have been used.

Kleve, 28.10.25

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Executive Summary

Every so often, the hardness testing machines must be calibrated, the frequent the better as they are primary contributors to the accuracy of the machine and hence the quality of the final product. Unfortunately, due to the unportable design of the currently existing calibration equipment this is done only a limited number of times. However, what if there was a way to make this easier, a way the entire calibration kit could fit inside a small cabin luggage and be caried even in airplanes.

This is exactly the problem this project is aiming to solve, building a portable calibration kit which can be transported around and used easily for calibration of the many Innovatest machines across the globe. By making a machine able to detect a load cell automatically, read data and process it with even a visual representation of data, the effort of the calibration tester can be vastly reduced and make this process more efficient, and hence giving a possibility of increasing the frequency.

Naturally to keep the product practical, there are certain features the product must incorporate, for example it must have a battery to last at least a single day of use, which is at a minimum 8 hours. Furthermore, keeping portability in mind, the product size will be limited to a small handheld suitcase under 8kgs. Moreover, the product should be well protected to be operated in the rough environments in industries, which means an ingress protection rating of IP67. Another important feature is the ability to export data, which can be done through the USB A port with a USB-Stick.

Keeping in mind the evolving tech and how now most people are used to a touch screen, the product should remain intuitive and follow familiar Human Machine Interaction format of the touch screen devices today. While to keep it safe to use in these environments, a resistive touch screen will be used, to allow for operation with gloves.

For all functions and components being added, appropriate risk assessment strategies will be taken with mitigation strategies decided upon, to reduce the risks associated with the product.

By the end of this project (13th January 2026), a prototype will be designed which can go into production and there will be a software flowchart which can be converted to code for firmware for the product. These final two steps are beyond the scope of this project, but the steps leading up to it will be covered.

Keywords:

Portable

Rechargeable

Ingress Protected

Calibration

Signal Processing

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Milestone 1

1. Project Plan

1.1. Project Constraints

1.1.1. Project Scope

The overall scope of this project is the design of the Innovatest Mobile Force Verification Kit and relevant product documents. To achieve this, the following deliverables must be produced:

1. Concept Design
    1.1. Project Plan
    1.2. Market Analysis
    1.3. Overall Product Concept
    1.4. Functional Structure
    1.5. Human Machine Interface
    1.6. D-FMEA
    1.7. Concept Design Close-out
2. Product Design
    2.1. Complete 3D Model
    2.2. Measurement Chain
    2.3. Circuit Diagram
    2.4. Technology Selection for "Make" Parts
    2.5. Requirements Manual for "Buy" Parts
    2.6. Product Design Close-out
3. Project Documentation
    3.1. Technical Drawings for Main Assembly
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    3.3. Bill of Material
    3.4. Production Planning
    3.5. Cost Calculation
    3.6. Specification Sheet
    3.7. User Manual
    3.8. Interactive Brochure
    3.9. Project Documentation Close-out
4. Project Close-out

It should be noted that some important aspects for the success of the Innovatest Mobile Force Verification Kit are outside of the scope of this project such as:

- Competitive Pricing Strategy
- Product Launch Schedule
- Development of Functioning Prototype

1.1.2. Project Schedule

The project will adhere to a schedule consisting of 3 milestones that coincide with the main deliverables of the project. These milestones are as follows:

1. Concept Design: 2025-10-28
2. Product Design: 2025-12-02
3. Project Documentation: 2026-01-13

1.1.3. Project Resources

The project team is comprised of five engineering students and responsibilities were distributed based on their degree program and experience as shown in Table 1.

Table 1: Responsibility Distribution Table

Name	Mat No.	Responsibilities	Degree Program
Abhinav Kothari	33349	• HMI • System Logic • Specification Sheet • Project Management (Process Verification and Coordination)	Mechatronics Systems
Ahmad Zeaiter	33946	• Concept Design • Mechanical Design • Technical Drawings • Graphic Design of Brochure	Mechanical
Justin Chin Cheong	34140	• Project Management (Planning and Framework setup) • System Design and Integration • Signal Processing	Mechatronics Systems
Okan Can Meral	31684	• Market and Industry Analysis • Financial Analysis • User Manual • Sourcing	Industrial
Wasim Ahmed Mohammed Al Abashi	31090	• D-FMEA • Electrical Design • Manufacturing Technology Selection • Production Planning	Electrical

1.2. Responsibility Assignment Matrix

To distribute the work with greater precision, a responsibility assignment matrix was created to illustrate the responsibilities of all team members.

Key: X - responsible, + - support, * - approval

Table 2: Responsibility Assignment Matrix for Each Deliverable

ID	Deliverable	Wasim	Okan	Justin	Abhinav	Ahmad
1.1	Project Plan	+ *	+ *	X	+ *	+ *
1.2	Market Analysis		X	*		
1.3	Overall Product Concept	+ *		+	+	X
1.4	Functional Structure			X	*	
1.5	HMI				X	*
1.6	D-FMEA	X	*	+	+	+
1.7	Concept Design Close-out	X	X	X	X	X
2.1	Complete 3D Model	+ *				X
2.2	Measurement Chain	+		X	*	
2.3	Circuit Diagram	X		+ *	+	
2.4	Technology Selection for “Make” Parts	X	*	+		
2.5	Requirements Manual for “Buy” Parts		X	*		+
2.6	Product Design Close-out	X	X	X	X	X
3.1	Technical Drawings for Main Assembly	+ *			+	X
3.2	Program Flow Chart			+	X	*
3.3	Bill of Materials	+		X	*	+
3.4	Production Planning	X	*	*	+	
3.5	Cost Calculation		X	*		
3.6	Specification Sheet	+		*	X	+
3.7	User Manual		X	+	+	*

3.8	Interactive Brochure	*	*	+	+	X
3.9	Project Documentation Close-out	X	X	X	X	X
4.0	Project Close-out	X	X	X	X	X

1.3. Work Breakdown Structure

A complete work breakdown structure can be found in 8.1 Appendix A detailing each work package and its contributors, schedule, dependencies and type.

1.4. Gantt Chart

The following pages show the Gantt chart[1] for the project, highlighting each work package along with its resources, schedule, and dependencies. The Gantt chart is split across the three milestones. A complete Gantt chart with all three milestones at once can be found on Sciebo[2].

Key:

AK	Abhinav Kothari
AZ	Ahmad Zeaiter
JC	Justin Julius Chin Cheong
OC	Okan Can Meral
W	Wasim Ahmed Mohammed Al Abashi
	Milestone

[1] The Gantt chart was created using trial version of the Gantt Pro Software https://app.ganttpro.com/

[2] The link to the file on Sciebo is https://hochschule-rhein-waal.sciebo.de/f/197025147

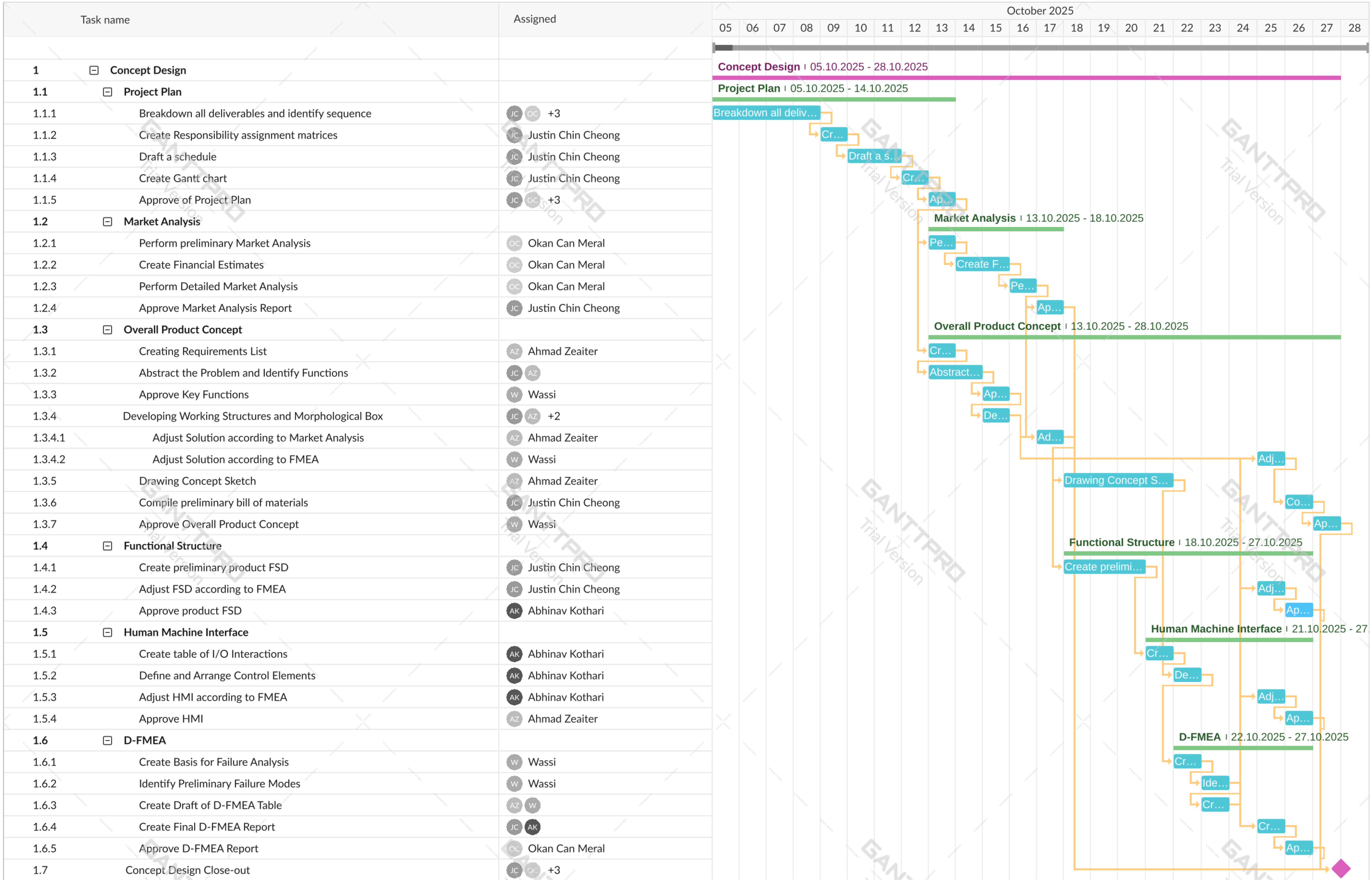


Figure 1: Gantt Chart for Milestone 1

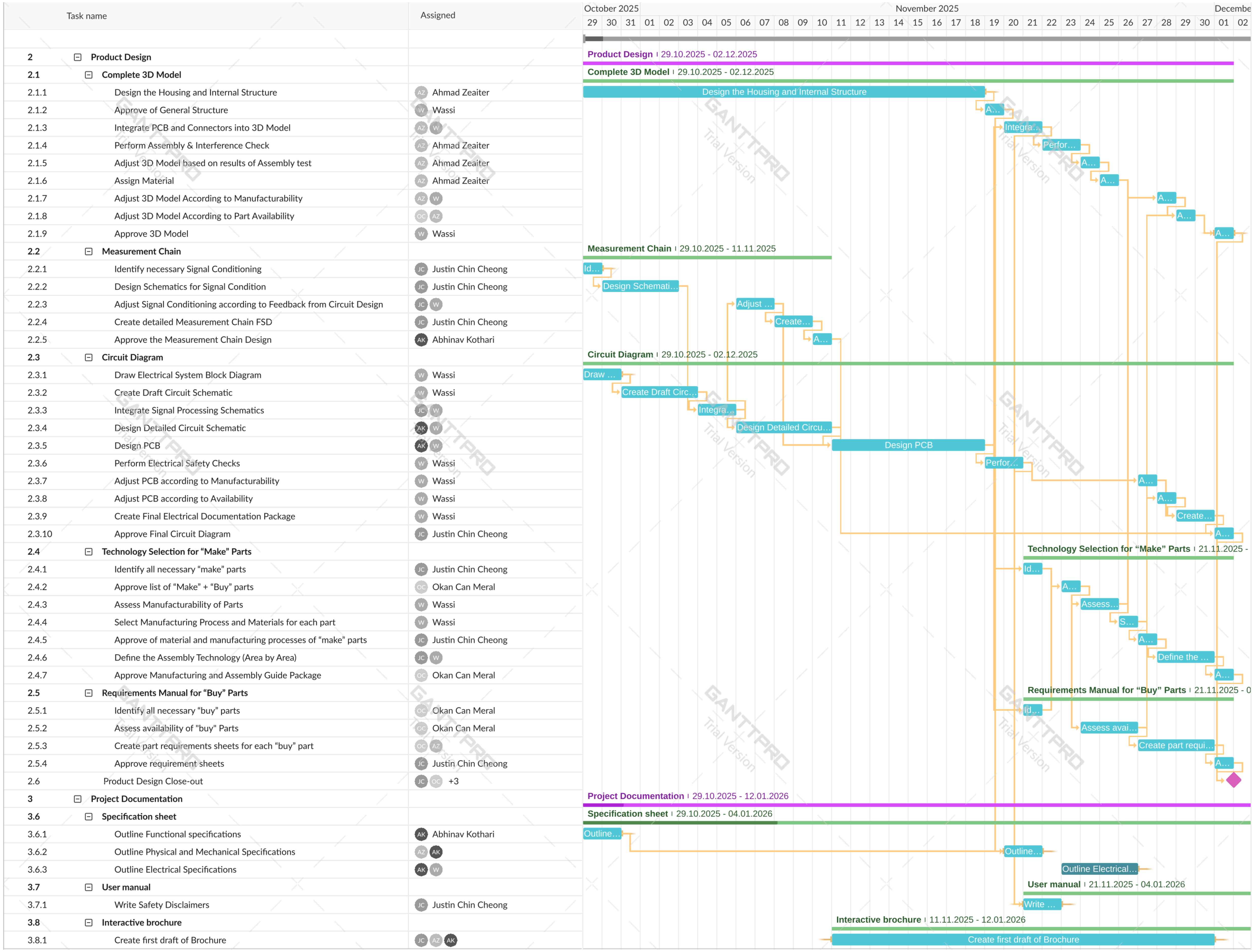


Figure 2: Gantt Chart for Milestone 2

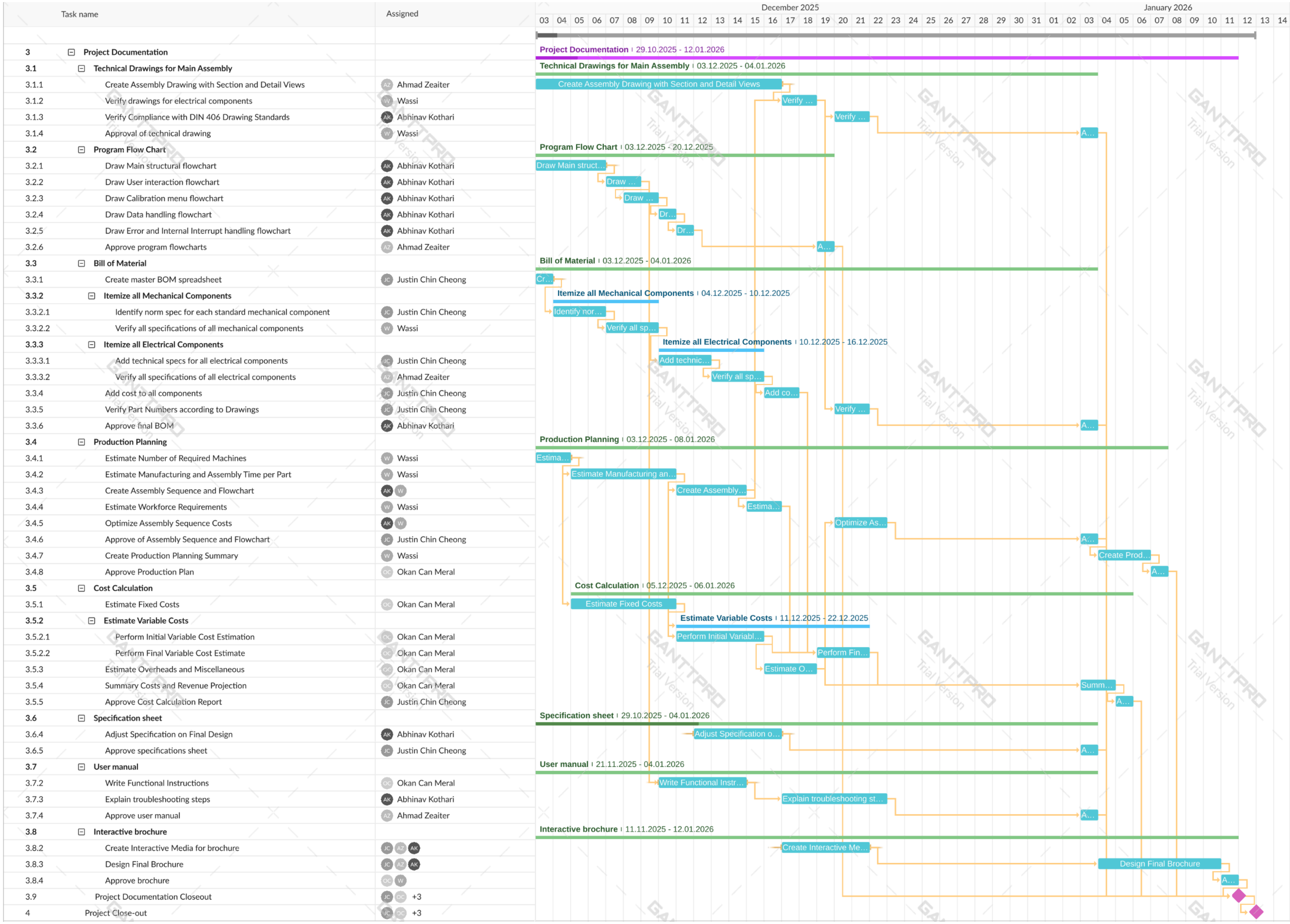


Figure 3: Gantt Chart for Milestone 3

2. Market Analysis

2.1. Industry Context

2.1.1. Market Overview

This analysis aims to determine the Innovatest Mobile Force Verification Kit's market potential, competitors, potential users, and emerging trends in force measurement and calibration systems. The basic marketing strategy and product placement will also be determined by the results.

Hardness testers and other mechanical measurement equipment are extremely pervasive in major sectors such as manufacturing, aerospace, automotive, and materials science. The global hardness testing market itself was valued at USD 274 million in 2025 according to Intel Market Research (2025) and by 2032, it is projected to reach USD 353 million. As the market grows, so does the need for precise calibration and verification equipment. Thus, there is a growing market for portable, reliable, and accurate verification kits that companies can use to evaluate and calibrate their equipment in the field. This is the exact market the Innovatest Mobile Force Verification Kit seeks to fill.

2.1.2. Competitor Analysis

The range of solutions for a mobile force verification kit currently on the market is quite sparse. However, there exists some products that can be used for force verification and calibration and could potentially be competition for the Innovatest Mobile Force Verification Unit. These products and their companies are outlined in Table 3: Comparison of Competitors in The Mobile Force Verification Kit Market.

Table 3: Comparison of Competitors in The Mobile Force Verification Kit Market

Competitor	Price Range [€]	Product Description	Region
Morehouse Instrument Company	6000 - 8000	A 5-in-1 force verification system is kit that includes a load cell, minicomputer with custom software for processing and a load cell cable stored inside of a custom pelican case.	USA
Sun-Tec Corporation	150 - 600	A set of standard hardness samples of known hardness which can be tested against the hardness tester's reading.	USA
Tovey Engineering Innovation	10000 - 60000	A portable calibration system comprised of load cells, dead weights, a laptop computer, and	USA

		load cell simulator. It can be in the form of a pushcart or carry case.	
Interfaceforce	20000 - 35000	An inspection kit with a force transducer, testing machine and measuring device which connects to a Windows computer.	Germany

Table 3: Comparison of Competitors in The Mobile Force Verification Kit Market shows that the other solutions on the market are portable, reliable and precise. However, there are some clear shortcomings. The Sun-Tec Hardness Samples requires incredibly careful handling and can only verify an extremely specific hardnesses per sample. On the other hand, the Morehouse, Tovey Engineering, and Interfaceforce products are sets of several different components that must be connected. The Interfaceforce even requires an additional computer for processing.

The Innovatest Mobile Force Verification Kit aims to overcome such faults by providing a verification system that is compact and completely integrated into the carrying case. This means all functionality is achieved with a single unit and not a series of components. By connecting to load cells of different ranges and precisions also allows the kit to verify the entire force range of the hardness testers with ease.

2.1.3. Market Drivers

The drivers of the Force Verification market are heavily tied to those of the Hardness Tester market. As precision hardness testers become more widespread, the need for accurate and convenient verification increases.

The main driver of these markets is the recent increase in quality assurance and control procedures in compliance with international standards. To ensure higher safety factors and durability hardness testers will be used more regularly and thus must be checked and monitored consistently. This is most prevalent in sectors such as manufacturing, aerospace, automotive, and material sciences.

Another driver in the market is the growth of the portable hardness tester market. It is projected to have a compound annual growth rate (CAGR) of 5.5% between 2023 and 2033. This coincides with demand for on-site testing which then requires on-site calibration and verification which the Innovatest Mobile Force Verification Kit will capitalise on.

2.1.4. Market Size

2.1.4.1. Total Addressable Market (TAM)

According to the Intel Market Research (IMR, 2025) report, the global hardness testing machine market is valued at USD 274 million in 2025 and is expected to reach approximately USD 353 million by 2032, with a CAGR of 3.8%. This growth will mainly occur in the automotive, aerospace, and heavy industry sectors, primarily due to the rising need for quality control and material verification. The ongoing automation and digitalization across industries are also significantly increasing the demand for hardness testing systems. This transformation greatly enhances the importance of both stationary laboratory equipment and portable testing devices.

The Future Market Insights (2024) report estimates the global market value at around USD 351 million for 2025, while Intel Market Research (2025) reports USD 274 million for the same year, indicating a consistent growth trend across the market.

2.1.4.2. Serviceable Available Market (SAM)

For the Innovatest Mobile Force Verification Kit, the initial commercialization area is Europe. The region's large number of industrial testing laboratories, quality control facilities, and advanced production sectors such as automotive and aerospace create a strong foundation for calibration systems.

According to Intel Market Research (2025), Europe accounts for about 30% of the global market, which corresponds to a market value between USD 100 M and 120 M as of 2025. This market includes stationary laboratory devices, as well as portable verification equipment and on-site calibration services.

MarketsandMarkets (2025) highlights that Germany, the Netherlands, Switzerland, and the Scandinavian countries are the regions where hardness testing activities are most concentrated within Europe.

2.1.4.3. Serviceable Obtainable Market (SOM)

When calculating the SOM, one of the most important factors is to fully understand the company's capacity and capabilities. In Europe, the Innovatest Mobile Force Verification Kit focuses on the portable, field-type calibration systems segment. Due to their ability to save time and increase mobility in quality control processes, there is a growing demand for these solutions.

Sharma (n.d.) states that the global market for such devices is valued at approximately USD 350 million, and it is expected to reach USD 580 million by 2032. This calculation is based on target countries such as Germany, the Netherlands, Switzerland, and the Scandinavian region.

Capturing even 1% of this market would mean about 100–200 units sold during the launch period of 6 months. This demonstrates that the Innovatest Mobile Force Verification Kit effectively addresses the high-quality standards and on-site verification needs of the European market.

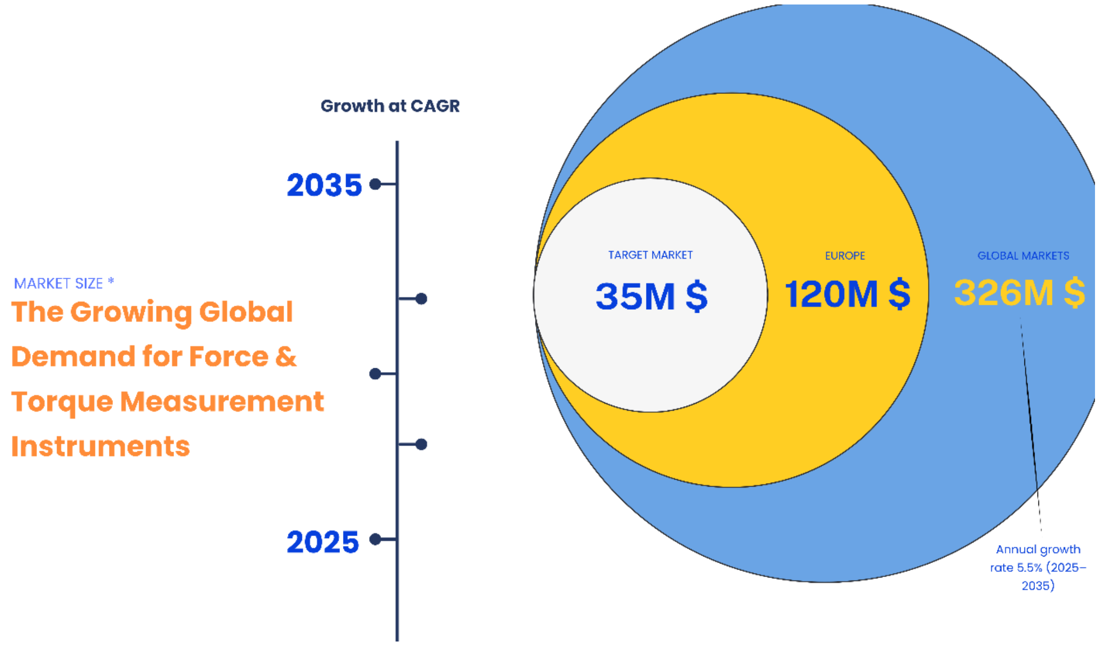


Figure 4: Market Size Chat

2.2. Target Buyer Analysis

2.2.1. Overview

The Innovatest Mobile Force Verification Kit is an intended to be sold in a business to business (B2B) capacity. It is especially designed for organizations and institutions engaged in quality assurance, metrology, and mechanical testing.

The product addresses a critical gap between laboratory-based calibration systems and practical field verification tools, offering laboratory-level precision in a compact, mobile design.

2.2.2. Primary Target Buyer

The primary target buyers for the Innovatest Mobile Force Verification Kit are institutions and companies that have already purchased Innovatest Hardness Testers and/or other products. This would include:

- Industrial Quality Assurance Departments
- Research and Development Institutions

2.2.2.1. Industrial Quality Assurance (QA) & Metrology Departments

These departments of larger industrial companies (e.g., automotive, aerospace, and precision manufacturing) require a convenient and reliable way to perform routine checks and internal calibrations.

Some of the key needs met by the product include:

- Compact and rugged design that can be used in the field in harsh conditions
- Reducing external calibration by enabling in-house functional checks
- Compatibility with multiple Innovatest load cell models
- Integrated data logging for USB export
- Intuitive graphical user interface

2.2.2.2. Research & Development (R&D) and Academic Institutions

Technical universities and research centres need force verification tools to inspect the machines they use to investigate materials, develop prototypes, and train engineers.

They are primarily interested in the research and learning opportunities. Similarly to the QA departments they are required to do checks of their hardness testers. Besides the needs highlighted in 2.2.2.1, the ease of use of the product can make it an excellent educational tool.

2.2.3. Secondary Target Buyer

2.2.3.1. Machine Manufacturers & OEM Partners

There is also potential to sell to other manufacturers of hardness testers for preliminary testing after assembly. This provides and quick and easy alternative to lab testing and can reveal issues before more complicated testing methods are used.

2.2.3.2. Geographical Focus

The initial commercialization phase focuses on Europe, where force calibration activities and standards are well established.

Some key markets include:

- Germany, Netherlands, Switzerland, Scandinavia - High industrial density and quality infrastructure
- France, Belgium, UK - Strong aerospace and research institutions
- Eastern Europe - Emerging demand from cost-sensitive manufacturers

Following successful European deployment, expansion will target North America and Asia-Pacific, driven by industrial modernization and increasing quality regulation.

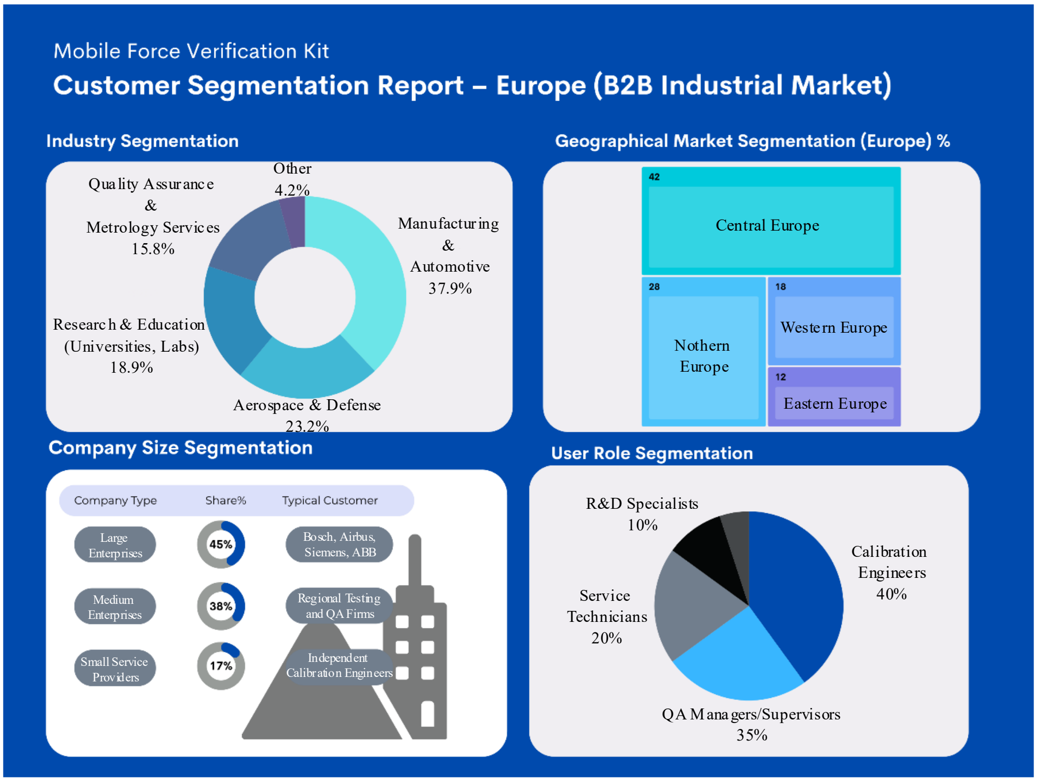


Figure 5: Customer Segmentation Report

2.3. Basic Marketing Approach (4P Analysis)

2.3.1. Product

The Innovatest Mobile Force Verification Kit is a compact, portable, and precise measurement device designed to verify the applied forces of hardness testers in both laboratory and field environments.

Developed for Innovatest Europe BV, the product integrates existing Innovatest load cells with a portable digital control unit capable of automatically identifying up to six different load cells, all together covering a force range from 10 gf to 3,000 kgf. Allowing engineers to perform on-site calibration and verification across a wide spectrum of hardness testing machines.

The verification kit is housed in an IP-67 rated Pelican 1500 case, ensuring full protection against dust, water, and shock. The case has a modular interior separating the electronics from a dedicated load cell storage compartment. This modular design simplifies assembly, maintenance, and future upgrades.

With 8-10 hours of battery life, USB-C charging, and a graphical user interface that supports data logging, USB export, and calibration functions, the device ensures efficient and user-friendly operation.

The primary needs that the product aims to meet is portability and ease of use for field engineers. Being encased in rugged and compact carrying case makes it easier to travel with and having everything contained and integrated into the case allows engineers to quickly setup and start measurements.

Figure 6: Product Preview Image

2.3.2. Price

Typical products in this market, as seen from Section 2.1.2, range from €6,000-€60,000, The Innovatest Mobile Force Verification Kit, aims to be produced at a maximum cost price of €4,000. So even after a profit margin of 50%, makes it €6,000, keeping it very competitively priced.

The competitive price comes without compromise on precision and reliability, while also being highly portable.

During the introduction and growth stage, a combination of value-based pricing and cost-plus pricing strategy may be implemented to quickly establish a market presence while ensuring no loss is borne by the company itself.

<u>Example:</u>

Innovatest could look at the competitors from Section 2.1.2 and set the pricing based on what the value the product bares in mind of the customer compared to the already existing customers. This can be done through primary research of the customers perception of the product as well. Special prices can also be offered to already existing customers, to encourage them to stay in the Innovatest ecosystem.

Providing services on top of the product, such as extended warranties, training sessions, can also increase the value of the product in the customers mind, leading to a higher price which the company can charge and justify.

This pricing model combination ensures both market entry and sustainable revenue, as no losses will be borne by the company.

Moreover, as the product life cycle goes forward towards decline stage, prices can be reduced to keep the product relevant and competitive.

2.3.3. Place (Distribution)

Distribution will primarily follow a B2B model, focusing on direct sales to industrial clients, calibration service providers, and research institutions.
Initial market entry will target Europe, particularly Germany, the Netherlands,

Switzerland, and Scandinavia, due to their established industrial and testing infrastructure.

Distribution channels include:

- Direct sales through Innovatest's existing dealer network.
- Online sales platform for product demonstration, quotation, and customer support.
- Participation in industrial trade fairs such as *Control Expo Germany* and *Sensor+Test Nürnberg*.
- Partnerships with calibration service providers and testing laboratories for joint demonstrations and pilot installations.

As market demand grows, Innovatest may expand into North American and Asia-Pacific markets through authorized distributors.

2.3.4. Promotion

Promotion activities will aim to position The Innovatest Mobile Force Verification Kit as a professional, reliable, and portable solution for force verification while maintaining high precision and accuracy.

The marketing department shall highlight:

- IP67 Rating: for incredible durability even in industrial environments
- All day battery life: 8 hours' worth of uninterrupted usage
- Automatic load cell identification: hassle free cell detection and naming
- HMI: Intuitive UI design and easy to use touch screen display
- Ergonomic + Stylish shape: Pelican case provides ergonomic handles for carrying while maintaining a sleek look
- Portability: The small size and nominal weight design makes it easy to travel with

Much more benefits can also be highlighted in marketing.

Planned promotional strategies may include:

- Technical presentations and webinars for calibration engineers and quality managers.
- E-Newsletters to existing Innovatest customers
- LinkedIn campaigns targeting industrial testing professionals.
- Collaborations with universities and research labs for academic demonstrations.
- After growth rate case studies and customer testimonials can be used to showcase field performance.
- Trade show exhibitions and product brochures emphasizing features and ROI.

During the maturity stage, Innovatest can strengthen its brand visibility through certifications and global reseller partnerships, ensuring long-term market presence and trust.

3. Overall Product Concept

3.1. Requirements List

3.1.1. Functional Requirements

- System can recognize at least six Innovatest load cell models automatically.
- Each load cell is displayed with an intuitive name that can be modified by user.
- System uses a universal port compatible with all supported load cells.
- Device can measure forces from 10gf – 3,000 kgf.
- Measurement results displayed numerically (in gf, kgf, N, kN) and graphically in real-time.
- User can configure numerical formats on digital display.
- Interface includes standard functions such as Tare, Zero, and Peak & Hold.
- Device supports data logging and export via USB, manually triggered by the user.
- System can delete old data with confirmation when storage is full.
- System includes 1 channel for the load measurement signals and 1 channel for cell recognition.
- System can perform basic calibration of load cells using 1 to 5 data points per cell.
- Sampling rate is adjustable.

3.1.2. User Interface (UI) & Display Requirements

- Display is a 10-inch touchscreen.
- UI is intuitive and responsive, suitable for field operation.
- Display can show real-time force curves.
- Display includes status indicators for battery, connection, and data logging.

3.1.3. Mechanical Requirements

- Compact, ruggedized housing integrated into a portable protective case.
- Minimum IP65 protection rating with shock absorbing padding.
- Protective compartments for load cells.
- Minimum operating temperature range: 0-60°C.
- Minimum humidity tolerance: 10-90% non-condensing.

- Weight: ~5-6 kg.
- Aesthetically refined and ergonomic form factor.

3.1.4. Electrical Requirements

- Rechargeable power source with a battery life of 8-10 hours.
- Battery voltage range 3.2 V − 4.2 V.
- 3.3 V regulator for microcontroller.
- 5V/10V boost converter for selectable load cell excitation.
- 24-bit ADC for precision measurement.
- Input sensitivity: 4mV/V.
- Low pass and noise filtering on input signals.
- Non-volatile internal storage for measured data.
- USB-A port for data export.
- USB-C port for charging.

3.1.5. Software Requirements

- Integrated signal to force conversion algorithm.
- Sufficient sampling rate to prevent aliasing.
- Software supports real-time graph plotting of force measurements.
- Calibration data and user preferences are stored persistently.
- Basic troubleshooting instructions/functions.

3.1.6. Reliability & Lifecycle Requirements

- Expected service life: 8 years.
- System designed for field robustness and electrical protection.
- Firmware supports future software updates.

3.1.7. Economic Requirements

- Target production cost: $\leq$ 4000 EUR per unit.

3.2. Abstraction to Identify the Essential Problems

Table 4: Abstraction of essential problems

Requirements	Functional Abstraction	Generalized Problem	Essential Problem Definition
Measurement range: 10 gf – 3000kgf	Ability to detect and quantify force signals of varying magnitudes	Transform electrical signal from load cell into a force measurement	Accurately measure mechanical forces across a wide range
Recognize 6 Innovatest load cell models	Interface compatible with multiple sensor types	Establish adaptable communication between sensor and processor	Enable automatic identification and integration of various load cells
Numeric and graphical output on display	Visualise real-time data and user parameters	Translate measurement data into interpretable information	Present measurement data clearly
Calibration using 1 to 5 points per cell	Adjust system response to known reference loads	Ensure traceable and repeatable force measurements	Maintain measurement accuracy through user calibration
Data logging, USB export, deletion function	Store, manage, and transfer data	Maintain organized, retrievable measurement records	Provide reliable data handling
Minimum IP65, shock protected, and portable housing	Protect internal components from environment	Maintain functionality under field conditions	Ensure durability and usability in rough environments
Programmable sample rate, low-pass, and noise filtering	Adapt signal to different measurement needs	Minimize signal distortion and noise	Deliver accurate and stable readings across different measurement conditions
Cost ≤ 5000 EUR	Economically feasible design	Optimize material manufacturing, and components cost	Achieve a balance between performance, manufacturability, and cost

The crux of the problem: to develop a portable and robust system capable of accurately acquiring, processing, and presenting force measurements from multiple load cell types under different field conditions.

3.3. Working Structure

3.3.1. Morphological Box

Table 5: Morphological Box for Selection of Solutions

Function	Sub-function	Option 1	Option 2	Option 3
Sensor Interface	**Load Cell Interface**	5-pin header Connector	M12 5-pin connector	MIL-Circular Connector
	Load Cell Identification	Resistor-based recognition in connector	1-wire ID chip embedded in connector	Software-based AI Detection
	Load Cell Excitation Voltage	Fixed 5V output	Selectable 5V/10V output	Software-adjustable voltage
Signal Processing	**Analog Signal Conversion**	Delta-Sigma 24-bit ADC	24-bit SAR ADC	Integrated bridge front-end ICs
	Signal Conditioning	Passive low-pass filter	Instrumentation Amplifier	Programmable gain amplifier (PGA)
	Processing Unit	Micro-controller	Micro-processor	ASIC
User Interface	**Data Display**	TFT LCD	OLED	IPS TFT LCD
	HMI	Analogue Buttons	Capacitive Touch Screen	Resistive Touch Screen
	Data Logging Export	USB flash drive storage	MicroSD card slot	Wireless data transfer via Wi-Fi
Structure	**Power Source**	Rechargeable Li-ion Battery	Rechargeable NiMH Battery	Replaceable Li-ion Battery
	Housing Size and Form	Tablet-style Hand-held	Compact, rugged brief case size	Laptop-Style and Size
	Housing Protection Class	IP65	IP66	IP67

3.3.2. Solution Evaluation

Table 6: Solution Evaluation Table

Solution	Reasoning
M12 5 pin connector	• Standard connector with IP67-IP68 rating • Locking mechanism • Support five pins, 4 for signal transmission and 1 for load cell recognition • Compact footprint [3]
Resistor based recognition	• Reasonable • Can do many variations of load cells
Selectable 5V/10V output	• Allows for flexibility • Can increase sensitivity or reduce power consumption
Delta-Sigma 24-bit ADC	• Good speed • High accuracy
Passive low pass filter and instrumentation amplifier	• Blocks high noise • More reliable
Microcontroller	• Less heat dissipation • Flexible enough, compared to ASIC
TFT LCD	• Less power consumption • No burn-in
Resistive touch screen	• Less power consumption • More durable in harsh environments[4] • Can be used with gloves
USB Flash Drive Storage	• More common than Micro USB • Faster than most Wi-Fi networks
Rechargeable Li-ion batteries	• Higher energy density • Lighter weight • More charge-discharge cycles[5]
Compact rugged brief case size	• Can carry load cells as well • Easy to carry
IP67	• Can withstand harsh environments

[3] (Dlesauvage, 2023)

[4] (TouchWo, 2025)

[5] (EcoFlow, n.d.)

3.4. Preliminary Bill of Materials

Table 7: Preliminary Bill of Materials

Component	Description	Quantity	Approx. Total Cost [EUR]
Electrical			
Microcontroller (MCU)	Main control unit and processor	1	4
Printed Circuit Board (PCB)	Circuit board upon which all electrical components are mounted and connected via	1	10
Load Cell Connector	Wire that connects the load cell to the verification kit	1	40
Load Cell Interface Port	Port for the load cell connector to interface with verification kit	1	5
Noise and Low-pass Filter	Module that eliminates noise from load cell signal	1	2
Amplifier	Module that amplifies load cell signal for better reading	1	4
Analog to Digital Converter (ADC) Module	Module that converts load cell signal into digital signal that the microcontroller can process	1	10
Cell Excitation Regulator	Power regulator to regulate the excitation voltage of the load cells	1	8
Touchscreen Display	Screen that displays graphical output and allows user input	1	100
Latching Push Button	Reliable button for controlling power to the Kit	2	40
LED light	Light to indicate warnings such as low battery or measurement ongoing	1	0.1
Internal Memory Module	Module that stores measured data within the verification kit	1	3
USB-A Port	Connector for standard USB stick for exporting measured data	1	1
Power Regulator	General power regulator to provide regulated power to components on the PCB	1	4
USB-C Port	Connector for charging cable	1	2
Battery Charging Circuit	Module to regulate incoming power to safely charge battery	1	5

Battery	Storage of electrical energy which provides power to entire verification kit	1	20
Misc	Passives, Wires, Insulation, Pin headers	n./a.	15
Mechanical			
Protective Carrying Case	Housing for the verification kit that provides IP67 level protection of the exterior	1	200
Foam	Soft foam that provides padding for internal electronics	1	50
1-Panel Frame	Frame that outlines the HMI of the kit secures it to the protective case and seals it for IP67	1	30
Internal Aluminium Frame	Aluminium frame inside which electronics and battery are secured and then placed into the protective case	1	150
Misc	Screws, Fasteners, O-rings, Mounting brackets	n./a.	50
Estimated Total of control unit			753.1
Load cells	The instruments that send signals to the kit when force is applied	6	2.884
Estimated Total of full Verification Kit			3,637.1

3.5. Concept Design Sketch

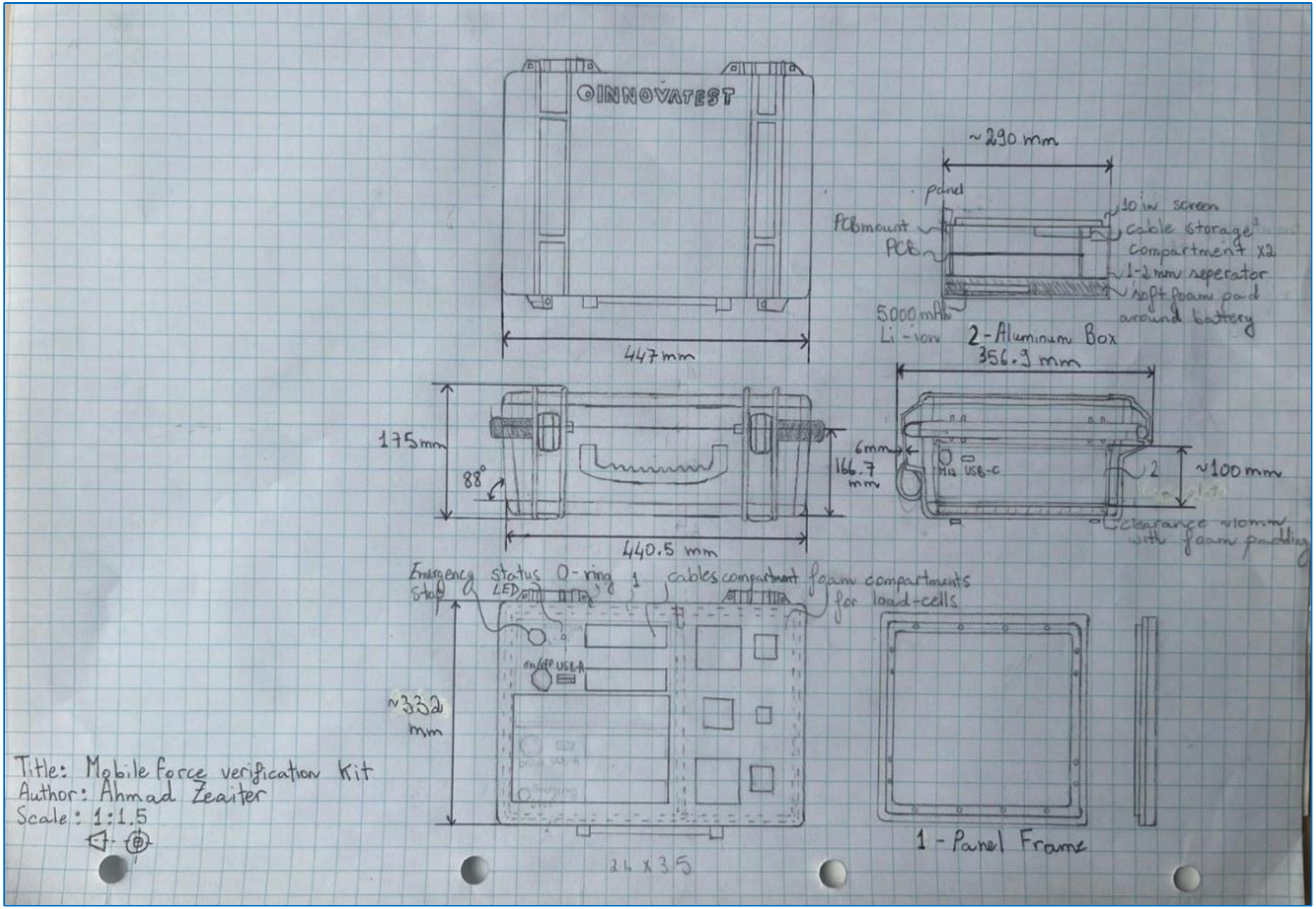


Figure 7: Freehand Sketch according to ISO 129 using First Angle Projection

3.6. Overall Product Concept Description

The Innovatest Mobile Force Verification Kit is designed to be a compact, and rugged system stored inside a Pelican 1500 protective case. The case provides IP67 level protection, is portable and robust for field operations. The interior is modularly with two separate sections one for load cell storage and another containing the verification kit.

3.6.1. Structure

The electronics panel is mounted in a metal frame with O-ring sealing. The frame is supported by the case ribs and reinforced with two L-brackets on the suspended side. Foam compartments store load cells securely on the opposite side. Inside the aluminium electronics box, the PCB is mounted above Li-ion battery. Foam padding and a separator plate provide shock absorption and thermal isolation. The box sits slightly above the case bottom with foam padding under it to further protect components.

3.6.2. Power

A rechargeable 5000 mAh Li-ion battery will run the system for 8-10 hours. See 8.2 Appendix B for the battery life estimation calculations. Cutouts in the case for USB-C port is used to charge the battery to full health in approximately 1-2 hours.

3.6.3. Sensor Interface

The kit connects to Innovatest load cells via an M12 5-pin connector. The load cell model is automatically recognized via a specific resistor placed inside of the connector cable. The system can provide excitation voltage of 5V or 10V depending on the load cell model.

3.6.4. Signal Processing

Signals from the load cells are filtered by the passive low-pass filter and then amplified by the instrumentation amplifier. These two together reduce noise and amplify before conversion using a dedicated 24-bit ADC. The microcontroller handles real-time processing of the signal into force measurements.

3.6.5. User Interface

A 10-inch TFT touchscreen displays numerical and graphical measurements in real time. Standard functions like Tare, Zero, and Peak & Hold are built in. Data logging is supported via USB-A. A LED indicates the status of the kit and an emergency shut off button is included. Cable and accessory storage are integrated around the touchscreen.

3.6.6. Cell Detection Concept

The 5-pin M12 connector allows for identification of individual load cells while simultaneously carrying the power and signal lines for the load cell.

There are 4 cables from the load cells which must be connected for successfully reading of the required data. This includes the V_{CC}, GND, + Signal and – Signal, as shown in the figure below.

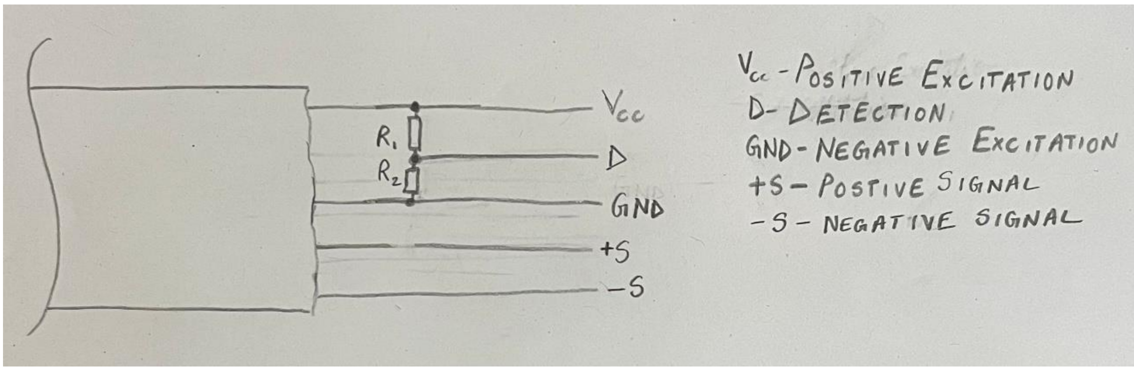


Figure 8: Load cell identification concept

For the identification of the load cell, a voltage divider can be placed between the V_{CC} and GND, and a 5th cable can be connected to read the voltage and hence identify each load cell. When first identified, it will give it an intuitive name, based on the existing data, however the user will be given the possibility to rename it, and when the same resistance is identified in future use, that name will be displayed from the saved storage.

$$D = \frac{R_1}{R_1 + R_2} \times V_{CC}$$

Through the formula above the D can be calculated for each load cell, so this can be saved and used to compare for load cell voltages measured in the future, allowing us to easily identify load cell if the value matches within a tolerance.

Whenever a new load cell, other than predefined one is connected and added, a random name will be given and the voltage value will be saved, this same load cell can then be identified by using the saved value.

This mechanism will be placed entirely withing the M12 connector.

4. Functional Structure

4.1. Key Functions

As determined in Section 3.2, the key function of the Innovatest Mobile Force Verification Kit is acquiring, processing, and displaying force data from connected sensors. Achieving this overall function requires the following system functionalities:

- Startup: User powers on system and battery supplies power.
- User Control: User can select commands to start measurement or export measured data.
- Interface Sensor: Load cell is recognised and then interface is ready to receive raw measurement signal when force is exerted on the load cell and user initiates measurement.
- Process Sensor Signal: Internal components filter, amplify and convert signal into force measurement readings.
- Display Force Curve: Screen displays force measurements in real-time, plotting a curve.
- Log and Export Data: Data is stored internally and exported to USB when prompted by the user.
- Alert Status and Battery Level: LED alerts user of measuring status or low battery level.
- Shutdown: User switches off kit after measurement is complete, and data is exported.
- Emergency Shutdown: User can kill power to kit in case of an emergency.

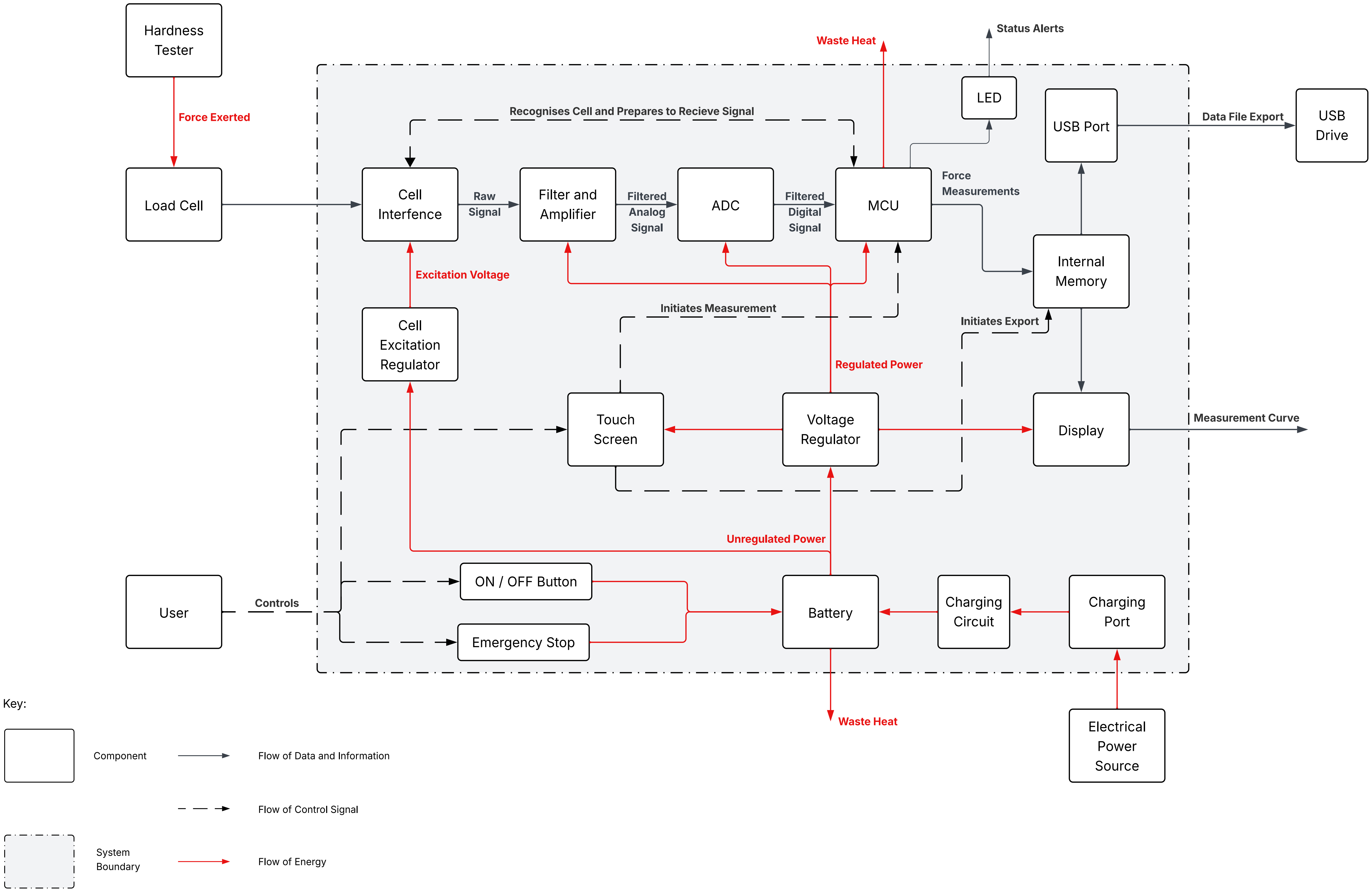
4.2. System Boundaries and Interactions

To create a structure of the system functionalities, the exact boundary of the system and its interactions with the environment must be outlined.

- System Boundary:
    - Internal electrical components that make up the filter, amplifier, ADC, microcontroller, and internal memory
    - HMI including the touchscreen, push buttons, LED, and USB A port
    - Power management system including the battery, charging circuit and USB C port
    - Interior of the carrying case housing
    - The interface port for the load cell
- External Environment:
    - User

    - Load cell
    - Hardness tester
    - USB drive
    - Source of electrical power
- Interactions:
    - User inputs commands
    - Load cell signals are sent for processing
    - Display shows measurement curve to the user
    - LED alerts the user of the system status
    - Measured data is exported to USB drive
    - External power source charges internal battery

4.3. Functional Structure Diagram (FSD)



5. Human Machine Interface

5.1. Human Machine Interface Overview

The Human Machine Interface section is a crucial part of the design process, as it converts the conceptual design of the product and functional structure into a tangible method of interaction for the end user. This must be done keeping three things in mind: clarity, simplicity, and safety.

The objective behind developing a good Human Machine Interface system is a satisfied customer, as it is the primary interaction an end user has with a system and is the basis of their opinion about the product. A good HMI system could lead to a user being able to do the same tasks successfully in a much more time efficient manner and have more focus towards the task rather than getting the system to work.

To make this a successful system, the product must fulfil all the functional requirements and functions mentioned in the sections above which specifically include managing the display operation, facilitating basic calibration of the cell, and handling data logging and export functionality. This also must be done while keeping in mind ergonomics and safety aspects of products.

5.2. Inputs and Outputs

Based on the functions discussed in Section 4, here is a list of all the inputs and outputs interactions between the system and the user.[6]

Table 8: Input/Output Interactions of Product with User

Interaction	Purpose	Input/Output	Character
Power on/off	To turn on/off the system	Input	Digital control signal
Battery/Power level	Display battery percentage	Output	Text
Critical Battery/Power alert	Alert user if battery too low, or in case of power fault	Output	Text / LED
Battery charging indicator	Indicate if battery is charging or full	Output	Text / LED
Menu navigation	Move between the different functions of the device	Input	Digital control signal
System status indicator	Alert user if system busy for interaction	Output	Text / LED

[6] Some I/O interaction ideas taken from ChatGPT

Load cell detection	Inform user if load cell detected or not	Output	Text
Load cell disconnection	If load cell is disconnected alert the user	Output	Text / LED
Load cell naming	Allow user to name individual load cell	Input	Digital control signal / Text
Start calibration	To get system ready for calibration/reading data	Input	Digital control signal
Calibration begins	Let users know calibration process is starting	Output	Text
Calibration status	Let user know if calibration was completed successfully or not	Output	Text
Start/Stop logging	Start/Stop recording data	Input	Digital control signal
Force signal onto load cell	Receive raw analogue signal from load cell, converted via 24-bit ADC for processing	Input	Analog variable
Store processed data	Confirms data is stored to the user	Output	Text
Display current data	Process and show data visually currently being read	Output	Text / Graph
Emergency cancel calibration	Cancel calibration at any point	Input	Tactile button (External interrupt)
Tare command	Set current force reading to zero	Input	Digital control signal
Storage full alert	Inform user if internal storage is full on device	Output	Text
Old data deletion confirmation	Ask users if older data can be deleted	Input	Digital control signal
USB Drive plugged in confirmation	Confirm a device being connected	Output	Text
Data export trigger	Get data in state to export onto a USB drive	Input	Digital control signal
Data export confirmation	Let user know if data was exported successfully	Output	Text
Error detection	Let user know in case of error with troubleshooting steps	Output	Text

Error reset	User clears error message	Input	Digital control signal
Data display format change	Allow users to customize data display format	Input	Digital control signal / Text / Numeric
Data display unit change	Allow user to change the unit of displaying	Input	Digital control signal / Text / Numeric
Current unit display	Display the currently used unit (N, kgf etc.)	Output	Text
USB Ejection trigger	End all tasks using USB drive	Input	Digital control signal
USB Ejection confirmation	Ensure no tasks are using USB drive	Output	Text
Peak and hold value function trigger	Record measurements and keeping only the highest measured value	Input	Digital control signal
Emergency peak and hold value function stop	Stop peak and hold value	Input	Tactile button (External interrupt)
Peak and hold value display	Show the maximum force value captured by the peak and hold function	Output	Text
Interaction	Purpose	Input/Output	Character

5.3. Control Elements

Table 9: Selection of control elements

Control Element	Function	Type	Further consideration
ON/OFF button	Power on/off the device	Tactile button	
Emergency Stop button	Button to cancel an operation in case of emergency	Tactile button	This button should be harder to press
Touch screen display	Show data, help user navigate, take inputs	LCD Resistive Touch screen	Should be usable with gloves
LED Status Indicator	Indicate in case of critical alert	RGB LED	Should not extrude out of the device for durability reasons

LED Charging indicator	Indicate if battery is charging or full	RGB LED	Should not extrude out of the device for durability reasons
USB A Port	Data export	USB Type A 2.0 female port	
USB C port	Power supply	USB C Female port	
Load cell connector port	To connect any Innovatest load cell	5-pin M12 Circular Connector	Should not disconnect too easily

5.4. Safety Aspects

5.4.1. Data Safety

For such devices data is crucial and losing it can mean hours of work to be repeated. So, for data safety these things are to be considered and followed:

- USB Ejection Protocol: prevent data corruption when USB Drive is removed.
- Battery/Power alert: alert user in case of low/unstable power
- Automatic data backup: periodically save data to minimize problems in case of unexpected interruptions.

5.4.2. Operational Safety

This aspect of safety is necessary to be looked at to ensure user interaction with system is only under safe and valid conditions.

- System status indicator: inform user when system is busy/unsafe for interaction.
- Lockout for critical operations: reduce/remove interactions with system in case of certain critical operations such as file transfers.
- Emergency cancellation: allow user to abort both calibration and peak and hold function in case required, for instance in case of the screen hanging.

5.4.3. Hardware and Environmental Safety

These measures must be taken to protect the load cells and the hardware itself from damage/misuse.

- Overload protection: alert user as well as stop taking readings in case force exceeds load cell’s safe range.

- Port disconnection detection: alert user and stop process in case the load cell port is disconnected or unexpected readings are read.
- Temperature warning: alert user in case device is nearing or out of its recommended temperature range for readings.

5.4.4. User Safety

Measures must be taken to protect the user within the environment as well, these include:

- Permit use with gloves: resistive touch screen has been chosen to permit use of screen with gloves, which will be required in the environment these devices are used in.
- Emergency cancel/stop button: a tactile button to cancel any process immediately in case of emergency such as evacuation of the working area. An external button permits user to cancel process even if screen freezes.

5.5. Control Elements Arrangement

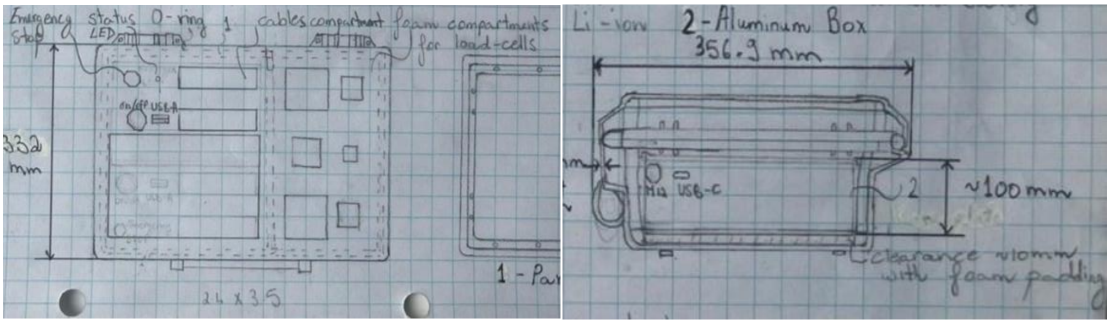


Figure 10:Arrangement of control elements (extracted from Freehand Sketch in Section 3.5)

The device has been made keeping the convenience and ergonomics of the user in mind. The power button has been placed right above the screen for easy access and has the led for telling the status of the battery on it for easy visibility. The emergency button has been placed away from all other used devices, to prevent accidental presses, but close enough for pressing in case of an emergency. The status indicator has been placed beside it to see if the device is busy or not. Keeping the similar function I/O together makes the design more intuitive for the user.

The screen has been kept closer to the opening of the case, for easy access for the user. Even in case of a USB-stick plugged into the device, it will not interrupt the user or make it uncomfortable because it is above the screen.

The charging port and M12 connector for load cells have been kept outside, so that no cables are sticking out from the inside of the case which could have also been damaged in case of the case being closed. Charging port being available while case is closed also makes it easier to charge.

5.6. User Interface Design Description

Upon start up, the user will be met with a login screen to access the device only with valid credentials. All buttons will be big and clearly visible with high contrast.

Upon logging in, the main menu will be shown, allowing the user to go between different functions: calibration, settings, peak and hold value, data read/export, etc. At the top left of the screen, there will be permanently placed navigation buttons for back-and-forth navigation between the menus. The placement is also keeping in mind the familiarity of users with today's software. On the top right there will be a battery percentage indicator also permanently visible again for similar reasons.

Upon going into calibration menu, the user will be asked to connect the load cell, if not already connected. Upon connection the UI will also let the user know which load cell has been connected. After confirmation from user for starting calibration, if load cell connected, the system will start the calibration process. While calibration takes place, the readings will be shown while also plotting a graph of force vs time, with units visible as well. After calibration, the data will be saved with a name by default, according to time, with an option to be modified by user.

The settings menu will allow the user to change units, adjust brightness, reset/restart device, and some other settings. Furthermore, peak-hold function will allow user to see the maximum value being displayed with its units.

Lastly, the data menu will allow user to access older saved recordings, as well an option to export the data to the USB-stick, considering one is connected and detected. Upon pressing the power button, the UI will ask user for confirmation for shutdown and close all processes before powering off.

5.7. Ergonomics Aspects Considered

For a device to be used for hours at a stretch, its ergonomics must be considered. The device is designed keeping in mind that the user will travel with it and therefore an inbuilt handle has been provided. The handle of pelican cases is also ergonomically shaped (Mostafawi Group, 2024). The latches are made to be secure and easy to close for a secure closure of the case. The foam inside the case also prevents movement of equipment inside, which would hamper the weight distribution while carrying and affect the comfort of carrying the case.

Placing related items together, makes the experience better for the user, for example the power button right next to the main screen, as well as the USB-A port used to extract data from the device.

The system's user interface will also be designed keeping ergonomics in mind. For easy understanding of data being read, analogue values will be read whilst also plotting a graph to visualize the data. The UI will also not be violating any stereotypes of traditional and already familiar user interface designs. This, for instance, includes placing the navigation icons on top left, and graphs being growing from left to right on x-axis and bottom to top on y-axis (European Commission, 2010).

6. Design-Failure Mode and Effect Analysis (D-FMEA)

6.1. D-FMEA Rating Scheme

FMEA is a formalised analytical method for the systematic identification of possible failures and the estimation of the related risks (Pahl, Beitz, Feldhusen & Grote, 2007). It helps quantitatively illustrate the potential failures of the product.

Three Factors must be considered:

- Severity (S) – An estimation of the effects of the failure on the customer
- Occurrence (O) – An estimation of the probability of occurrence
- Detection (D) – An estimation of the probability that the failure can be detected before delivery.

With these factors, the Risk Probability Number (RPN) can be calculated as:

$$RPN = S \cdot O \cdot D$$[7]

Any RPN greater than 125 is considered critical and requires action.

The rating schemes for these factors and the calculated Risk Number are as follows:

Table 10: Rating Scheme for Severity (S)

Rating	Effect on Customers
1	Effects hardly noticeable
2-3	Failures not important (little trouble to the user)
4-6	Reasonably serious failure (difficult to use)
7-8	Serious failure (annoying for the user)
9-10	Failure with large negative effects (almost unusable)

Table 11: Rating Scheme for Occurrence (O)

Rating	Probability of Occurrence
1	Very low
2-3	Medium low
4-6	Medium (occasional)
7-8	Medium high
9-10	High likelihood (almost inevitable)

[7] (Juran, 2024)

Table 12: Rating Scheme for Detection (D) Probability

Rating	**Probability of Detection**
1	High (obvious)
2-5	Medium high
6-8	Medium (detectable in quality control)
9	Medium low
10	Low (almost undetectable)

6.2. D-FMEA Table

Table 13: Design Failure Mode and Effect Analysis of the Product

Component	Function	Failure Mode	Potential Effect	Potential Cause	S	O	D	RPN	Recommended Actions
Load Cell Interface	Connect sensor to electronics	No function	Device reads zero, cannot measure	Broken wiring, open bridge	10	2	4	80	Check wiring, add diagnostics
		Underfunction	Low readings, poor precision	Connector corrosion, broken wires	6	4	5	120	Check wiring, scheduled calibration and maintenance
		Overfunction	Overstated readings	Shorted bridge, wrong polarity	9	3	5	135	Add diagnostics, plausibility checks
		Intermittent	Glitches or dropouts	Loose crimp, connector mismatch	6	6	7	252	Securing connectors, strain relief
Load Cell Excitation Regulator	Supply regulated voltage to sensor	Underfunction	Gain error, low readings	Regulator drift, battery sag	8	4	5	160	Use high precision regulator, monitor Vcc
		Overfunction	Pegged output, sensor damage	Transient surge	9	2	5	90	TVS diodes, input protection
		Intermittent	Temporary gain shifts	Loose connector	7	3	6	126	Monitor Vcc, secure connectors
		Malfunction	Sensor damaged, erratic readings	Voltage spike or regulator failure	9	2	5	90	Surge protection
Signal Conditioning Chain	Filter & compensate signal	Underfunction	Biased readings	Missing compensation	8	4	5	160	Add temperature sensor, compensation
		Overfunction	Slow response	Low cutoff	6	4	4	96	Tuning filters
		Malfunction	Permanent biased readings	Faulty filter components	8	3	4	96	Add diagnostics checks
ADC	Convert analog to digital	Underfunction	Small loads unreadable	Wrong gain	7	4	5	140	Precise calibration
		Overfunction	Maxed readings	Amplifer saturation	8	3	5	120	Clamping diodes
		Malfunction	Readings always incorrect or pegged	ADC/amplifier damage	9	2	5	90	Clamping diodes and current limiting resistors
Microcontroller	Process & manage data	No function	Device unresponsive	Memory corruption	9	3	4	108	Watchdog, regression tests
		Underfunction	Non-linear readings	Wrong coefficients	7	4	5	140	Validate algorithm, calibration
		Intermittent	Missed samples	RTOS issue	7	3	4	84	Priority config, watchdog
		Malfunction	Device unresponsive, no measurement	Firmware crash or hang	10	3	5	150	Watchdog, firmware rollback
Display	Show measurement	No function	No visible readings	Display driver failure	9	3	4	108	Driver check, display replacement
		Underfunction	Truncated readings	UI bug	5	4	4	80	Check formatting, raw view
		Overfunction	Displayed values incorrect	Unit mapping bug	8	3	5	120	End-to-end checks

		Intermittent	Blank/flickering display	Race condition	6	5	5	150	Decouple refresh
Buttons	User interaction tactile buttons	No function	Buttons stuck in pressed state	Broken spring	9	5	1	45	Use good quality springs
		Underfunction	Buttons require excessive force	Button contacts damaged	4	4	4	64	Increase buffer rating
		Overfunction	Repeated operation for single press	Contact bouncing	5	6	6	180	Implement software debouncing
		Intermittent	Ocassionaly presses unregistered	Contact contamination	5	6	5	150	Ensure a clean enviroment near button soldering
Touch Screen	User interaction with screen	No function	Unresponsive touch screen	Touch controller failure	9	4	3	108	Test screen functionality, replace controller if required
		Underfunction	Harder press for click registering	Spacer dots are too large / too few	5	6	5	150	Ensure precision application of spacer dots
		Overfunction	Multiple touches for same touch	Contact bouncing	6	4	4	96	Increase debounce time
		Intermittent	Ocassional touches unregistered	Prescence of conductive debris	6	7	4	168	Ensure a clean enviroment near panel assembly
		Malfunction	Ghost interactions	Layers stick together due to adhesive failure	9	5	4	180	Ensure a clean enviroment near panel assembly
Internal Memory and USB Port	Record & export data	Overfunction	Data overwritten	Too frequent logs	6	3	6	108	Limit data rate, alarms
		Intermittent	Partial file transfer	Voltage fluctuation disrupts write process	6	6	6	216	Brown-out detector
		Malfunction	Cannot retrieve data	Flash memory corruption	9	2	4	72	CRC Checks, periodic memory dumps
Battery	Provide power to device	No function	Device does not power on	Battery failure	10	2	4	80	Battery test/replacement
		Underfunction	Short operating time	Parasitic drain	9	4	5	180	Monitor battery drain
		Overfunction	Battery damage	Faulty charger	10	2	4	80	Certified IC, thermal cutout
		Intermittent	Unexpected resets	Loose connector	9	4	4	144	Secure connectors, brown-out
		Malfunction	Battery swelling or fire	Overcharge or short	10	2	2	40	Overcharge alerts
Housing Fasteners	Provide mechanical structure	Overfunction	Overstressing the housing	Fasteners too tight	5	3	4	60	Determine precise fastening torque for material
		Intermittent	Occasional misalignment	Loose fasteners	6	4	6	144	Retention clips, torque specification
Housing Protection	Protect electronics	No function	System stops working	Water ingress	10	1	2	20	Regular QA inspection
		Underfunction	Moisture ingress, corrosion	Gasket wear	8	2	6	96	Purchasing high durability gaskets
		Intermittent	Short, transient faults	Poor assembly	9	5	4	180	IP connectors, QA

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8. Appendices

8.1. Appendix A: Work Breakdown Structure

WBS Number	Task name	Assigned to	Start	End	Predecessor	Type
1	Concept Design		10/5/2025	10/28/2025		phase
1.1	Project Plan		10/5/2025	10/14/2025		deliverable
1.1.1	Breakdown all deliverables and identify sequence	Justin, Okan, Ahmad, Abhinav, Wasim	10/5/2025	10/9/2025		task
1.1.2	Create Responsibility assignment matrices	Justin	10/9/2025	10/10/2025	1.1.1	task
1.1.3	Draft a schedule	Justin	10/10/2025	10/12/2025	1.1.2	task
1.1.4	Create Gantt chart	Justin	10/12/2025	10/13/2025	1.1.3	task
1.1.5	Approve of Project Plan	Justin, Okan, Ahmad, Abhinav, Wasim	10/13/2025	10/14/2025	1.1.4	task
1.2	Market Analysis		10/13/2025	10/18/2025		deliverable
1.2.1	Perform preliminary Market Analysis	Okan	10/13/2025	10/14/2025	1.1.5	task
1.2.2	Create Financial Estimates	Okan	10/14/2025	10/16/2025	1.2.1	task
1.2.3	Perform Detailed Market Analysis	Okan	10/16/2025	10/17/2025	1.2.2	task
1.2.4	Approve Market Analysis Report	Justin	10/17/2025	10/18/2025	1.2.3	task
1.3	Overall Product Concept		10/13/2025	10/28/2025		deliverable
1.3.1	Creating Requirements List	Ahmad	10/13/2025	10/14/2025	1.1.5	task
1.3.2	Abstract the Problem and Identify Functions	Justin, Ahmad	10/13/2025	10/15/2025	1.3.1	task
1.3.3	Approve Key Functions	Wasim	10/15/2025	10/16/2025	1.3.2	task

1.3.4	Developing Working Structures and Morphological Box	Justin, Ahmad, Abhinav, Wasim	10/15/2025	10/16/2025	1.3.3	task
1.3.4.1	Adjust Solution according to Market Analysis	Ahmad	10/17/2025	10/18/2025	1.2.3, 1.3.4	task
1.3.4.2	Adjust Solution according to FMEA	Wasim	10/25/2025	10/26/2025	1.6.3, 1.3.4	task
1.3.5	Drawing Concept Sketch	Ahmad	10/18/2025	10/22/2025	1.3.4.1	task
1.3.6	Compile preliminary bill of materials	Justin	10/26/2025	10/27/2025	1.3.4.2	task
1.3.7	Approve Overall Product Concept	Wasim	10/27/2025	10/28/2025	1.3.6	task
1.4	Functional Structure		10/18/2025	10/27/2025		deliverable
1.4.1	Create preliminary product FSD	Justin	10/18/2025	10/21/2025	1.3.4.1	task
1.4.2	Adjust FSD according to FMEA	Justin	10/25/2025	10/26/2025	1.6.3	task
1.4.3	Approve product FSD	Abhinav	10/26/2025	10/27/2025	1.4.2	task
1.5	Human Machine Interface		10/21/2025	10/27/2025		deliverable
1.5.1	Create table of I/O Interactions	Abhinav	10/21/2025	10/22/2025	1.4.1	task
1.5.2	Define and Arrange Control Elements	Abhinav	10/22/2025	10/23/2025	1.5.1, 1.3.5	task
1.5.3	Adjust HMI according to FMEA	Abhinav	10/25/2025	10/26/2025	1.6.3	task
1.5.4	Approve HMI	Ahmad	10/26/2025	10/27/2025	1.5.3	task
1.6	D-FMEA		10/22/2025	10/27/2025		deliverable
1.6.1	Create Basis for Failure Analysis	Wasim	10/22/2025	10/23/2025	1.5.2	task
1.6.2	Identify Preliminary Failure Modes	Wasim	10/23/2025	10/24/2025	1.6.1	task
1.6.3	Create Draft of D-FMEA Table	Ahmad, Wasim	10/23/2025	10/24/2025	1.6.2	task
1.6.4	Create Final D-FMEA Report	Justin, Abhinav	10/25/2025	10/26/2025	1.6.3	task

1.6.5	Approve D-FMEA Report	Okan	10/26/2025	10/27/2025	1.6.4	task
1.7	Concept Design Close-out	Justin, Okan, Ahmad, Abhinav, Wasim	10/28/2025	10/28/2025	1.6.5, 1.2.4, 1.5.4, 1.4.3, 1.3.7	milestone
2	Product Design		10/29/2025	12/2/2025		phase
2.1	Complete 3D Model		10/29/2025	12/2/2025		deliverable
2.1.1	Design the Housing and Internal Structure	Ahmad	10/29/2025	11/19/2025	1.7	task
2.1.2	Approve of General Structure	Wasim	11/19/2025	11/20/2025	2.1.1	task
2.1.3	Integrate PCB and Connectors into 3D Model	Ahmad, Wasim	11/20/2025	11/22/2025	2.3.5, 2.1.2	task
2.1.4	Perform Assembly & Interference Check	Ahmad	11/22/2025	11/24/2025	2.1.3	task
2.1.5	Adjust 3D Model based on results of Assembly test	Ahmad	11/24/2025	11/25/2025	2.1.4	task
2.1.6	Assign Material	Ahmad	11/25/2025	11/26/2025	2.1.5	task
2.1.7	Adjust 3D Model According to Manufacturability	Ahmad, Wasim	11/28/2025	11/27/2025	2.1.6, 2.4.3	task
2.1.8	Adjust 3D Model According to Part Availability	Okan, Ahmad	11/29/2025	11/28/2025	2.1.7, 2.5.2	task
2.1.9	Approve 3D Model	Wasim	12/1/2025	12/2/2025	2.1.8	task
2.2	Measurement Chain		10/29/2025	11/11/2025		deliverable
2.2.1	Identify necessary Signal Conditioning	Justin	10/29/2025	10/30/2025	1.7	task
2.2.2	Design Schematics for Signal Condition	Justin	10/30/2025	11/3/2025	2.2.1	task
2.2.3	Adjust Signal Conditioning according to Feedback from Circuit Design	Justin, Wasim	11/6/2025	11/8/2025	2.3.3	task
2.2.4	Create detailed Measurement Chain FSD	Justin	11/8/2025	11/10/2025	2.2.3	task

2.2.5	Approve the Measurement Chain Design	Abhinav	11/10/2025	11/11/2025	2.2.4	task
2.3	Circuit Diagram		10/29/2025	12/2/2025		deliverable
2.3.1	Draw Electrical System Block Diagram	Wasim	10/29/2025	10/31/2025	1.7	task
2.3.2	Create Draft Circuit Schematic	Wasim	10/31/2025	11/4/2025	2.3.1	task
2.3.3	Integrate Signal Processing Schematics	Justin, Wasim	11/4/2025	11/6/2025	2.3.2, 2.2.2	task
2.3.4	Design Detailed Circuit Schematic	Abhinav, Wasim	11/6/2025	11/11/2025	2.3.3	task
2.3.5	Design PCB	Abhinav, Wasim	11/11/2025	11/19/2025	2.3.4, 2.2.3	task
2.3.6	Perform Electrical Safety Checks	Wasim	11/19/2025	11/21/2025	2.3.5	task
2.3.7	Adjust PCB according to Manufacturability	Wasim	11/27/2025	11/28/2025	2.4.3, 2.3.6	task
2.3.8	Adjust PCB according to Availability	Wasim	11/28/2025	11/29/2025	2.5.2	task
2.3.9	Create Final Electrical Documentation Package	Wasim	11/29/2025	12/1/2025	2.3.7, 2.3.8	task
2.3.10	Approve Final Circuit Diagram	Justin	12/1/2025	12/2/2025	2.3.9, 2.2.5	task
2.4	Technology Selection for “Make” Parts		11/21/2025	12/2/2025		deliverable
2.4.1	Identify all necessary “make” parts	Justin	11/21/2025	11/22/2025	2.3.5, 2.1.3	task
2.4.2	Approve list of “Make” + “Buy” parts	Okan	11/23/2025	11/24/2025	2.4.1, 2.5.1	task
2.4.3	Assess Manufacturability of Parts	Wasim	11/24/2025	11/27/2025	2.4.2	task
2.4.4	Select Manufacturing Process and Materials for each part	Wasim	11/26/2025	11/27/2025	2.4.3	task
2.4.5	Approve of material and manufacturing	Justin	11/27/2025	11/28/2025	2.4.4	task

	processes of “make” parts					
2.4.6	Define the Assembly Technology (Area by Area)	Justin, Wasim	11/28/2025	12/1/2025	2.4.5	task
2.4.7	Approve Manufacturing and Assembly Guide Package	Okan	12/1/2025	12/2/2025	2.4.6	task
2.5	Requirements Manual for “Buy” Parts		11/21/2025	12/2/2025		deliverable
2.5.1	Identify all necessary “buy” parts	Okan	11/21/2025	11/22/2025	2.1.3, 2.3.5	task
2.5.2	Assess availability of "buy" Parts	Okan	11/24/2025	11/27/2025	2.4.2	task
2.5.3	Create part requirements sheets for each “buy” part	Okan, Ahmad	11/27/2025	12/1/2025	2.5.2	task
2.5.4	Approve requirement sheets	Justin	12/1/2025	12/2/2025	2.5.3	task
2.6	Product Design Close-out	Justin, Okan, Ahmad, Abhinav, Wasim	12/2/2025	12/2/2025	2.5.4, 2.4.7, 2.3.10, 2.1.9	milestone
3	Project Documentation		10/29/2025	1/12/2026		phase
3.1	Technical Drawings for Main Assembly		12/3/2025	1/4/2026		deliverable
3.1.1	Create Assembly Drawing with Section and Detail Views	Ahmad	12/3/2025	12/17/2025	2.6	task
3.1.2	Verify drawings for electrical components	Wasim	12/17/2025	12/19/2025	3.1.1, 3.4.3	task
3.1.3	Verify Compliance with DIN 406 Drawing Standards	Abhinav	12/20/2025	12/22/2025	3.1.2	task
3.1.4	Approval of technical drawing	Wasim	1/3/2026	1/4/2026	3.1.3	task
3.2	Program Flow Chart		12/3/2025	12/18/2025		deliverable
3.2.1	Draw Main structural flowchart	Abhinav	12/3/2025	12/7/2025	2.6	task

3.2.2	Draw User interaction flowchart	Abhinav	12/7/2025	12/9/2025	3.2.1	task
3.2.3	Draw Calibration menu flowchart	Abhinav	12/8/2025	12/10/2025	3.2.2	task
3.2.4	Draw Data handling flowchart	Abhinav	12/10/2025	12/11/2025	3.2.3	task
3.2.5	Draw Error and Internal Interrupt handling flowchart	Abhinav	12/11/2025	12/12/2025	3.2.4	task
3.2.6	Approve program flowcharts	Ahmad	12/19/2025	12/18/2025	3.2.5	task
3.3	Bill of Material		12/3/2025	1/4/2026		deliverable
3.3.1	Create master BOM spreadsheet	Justin	12/3/2025	12/4/2025	2.6	task
3.3.2	Itemize all Mechanical Components		12/4/2025	12/10/2025		tasks group
3.3.2.1	Identify norm spec for each standard mechanical component	Justin	12/4/2025	12/7/2025	3.3.1	task
3.3.2.2	Verify all specifications of all mechanical components	Wasim	12/7/2025	12/10/2025	3.3.2.1	task
3.3.3	Itemize all Electrical Components		12/10/2025	12/16/2025		tasks group
3.3.3.1	Add technical specs for all electrical components	Justin	12/10/2025	12/13/2025	3.3.2.2	task
3.3.3.2	Verify all specifications of all electrical components	Ahmad	12/13/2025	12/16/2025	3.3.3.1	task
3.3.4	Add cost to all components	Justin	12/16/2025	12/19/2025	3.3.3.2	task
3.3.5	Verify Part Numbers according to Drawings	Justin	12/20/2025	12/22/2025	3.1.2	task
3.3.6	Approve final BOM	Abhinav	1/3/2026	1/4/2026	3.3.5	task
3.4	Production Planning		12/3/2025	1/8/2026		deliverable
3.4.1	Estimate Number of Required Machines	Wasim	12/3/2025	12/5/2025	2.6	task

3.4.2	Estimate Manufacturing and Assembly Time per Part	Wasim	12/5/2025	12/11/2025	3.4.1	task
3.4.3	Create Assembly Sequence and Flowchart	Abhinav, Wasim	12/11/2025	12/15/2025	3.4.2	task
3.4.4	Estimate Workforce Requirements	Wasim	12/15/2025	12/17/2025	3.4.3	task
3.4.5	Optimize Assembly Sequence Costs	Abhinav, Wasim	12/20/2025	12/23/2025	3.5.3	task
3.4.6	Approve of Assembly Sequence and Flowchart	Justin	1/3/2026	1/4/2026	3.4.5	task
3.4.7	Create Production Planning Summary	Wasim	1/4/2026	1/7/2026	3.4.6	task
3.4.8	Approve Production Plan	Okan	1/7/2026	1/8/2026	3.4.7	task
3.5	Cost Calculation		12/5/2025	1/6/2026		deliverable
3.5.1	Estimate Fixed Costs	Okan	12/5/2025	12/11/2025	3.4.1	task
3.5.2	Estimate Variable Costs		12/11/2025	12/16/2025	3.5.1	tasks group
3.5.2.1	Perform Initial Variable Cost Estimation	Okan	12/11/2025	12/16/2025	3.4.2	task
3.5.2.2	Perform Final Variable Cost Estimate	Okan	12/19/2025	12/22/2025	3.5.2.1, 3.4.4, 3.3.4	task
3.5.3	Estimate Overheads and Miscellaneous	Okan	12/16/2025	12/19/2025	3.5.2.1	task
3.5.4	Summary Costs and Revenue Projection	Okan	1/3/2026	1/5/2026	3.5.2.2, 3.5.3	task
3.5.5	Approve Cost Calculation Report	Justin	1/5/2026	1/6/2026	3.5.4	task
3.6	Specification sheet		10/29/2025	1/4/2026		deliverable
3.6.1	Outline Functional specifications	Abhinav	10/29/2025	10/31/2025	1.7	task
3.6.2	Outline Physical and Mechanical Specifications	Ahmad, Abhinav	11/20/2025	11/22/2025	2.1.2, 3.6.1	task

3.6.3	Outline Electrical Specifications	Abhinav, Wasim	11/23/2025	11/27/2025		task
3.6.4	Adjust Specification on Final Design	Abhinav	12/12/2025	12/17/2025	3.6.3, 3.6.2, 2.6	task
3.6.5	Approve specifications sheet	Justin	1/3/2026	1/4/2026	3.6.4	task
3.7	User manual		11/21/2025	1/4/2026		deliverable
3.7.1	Write Safety Disclaimers	Justin	11/21/2025	11/23/2025	2.3.6	task
3.7.2	Write Functional Instructions	Okan	12/10/2025	12/15/2025	3.2.2, 3.7.1	task
3.7.3	Explain troubleshooting steps	Abhinav	12/17/2025	12/23/2025	3.7.2	task
3.7.4	Approve user manual	Ahmad	1/3/2026	1/4/2026	3.7.3	task
3.8	Interactive brochure		11/11/2025	1/12/2026		deliverable
3.8.1	Create first draft of Brochure	Justin, Ahmad, Abhinav	11/11/2025	12/1/2025	1.7	task
3.8.2	Create Interactive Media for brochure	Justin, Ahmad, Abhinav	12/17/2025	12/22/2025	3.8.1, 2.1.9	task
3.8.3	Design Final Brochure	Justin, Ahmad, Abhinav	1/4/2026	1/11/2026	3.8.2	task
3.8.4	Approve brochure	Okan, Wasim	1/11/2026	1/12/2026	3.8.3	task
3.9	Project Documentation Closeout	Justin, Okan, Ahmad, Abhinav, Wasim	1/12/2026	1/12/2026	3.1.4, 3.5.5, 3.4.8, 3.3.6, 3.6.5, 3.7.4, 3.8.4, 3.2.6	milestone
4	Project Close-out	Justin, Okan, Ahmad, Abhinav, Wasim	1/13/2026	1/13/2026	3.9	milestone

8.2. Appendix B: Preliminary Battery Life Calculations

Assumed current draw rates:

- Microcontroller: 200 mA
- Signal Conditioning Circuit: 10 mA
- ADC: 5 mA
- Display: 150 mA
- Peripherals: 5 mA
- USB: 2.5 mA (suspended) or 500 mA (data transfer)

Assumed operating times:

- USB Data Transfer: 5s
- Working Period: 8h

Additional assumptions:

- Safety Factor: 1.2
- Number of USB Transfers in a Working Period: 4

Within a single working period, the average USB data transfer current:

$$I_{USB}^{avg} = 500mA \cdot \frac{5s}{8h \cdot 3600\frac{s}{h}} \cdot 4 = 0.347\ mA$$

The total average current in a working period:

$$\begin{aligned} I^{avg} &= 200mA + 10mA + 5mA + 150mA + 5mA + 2.5mA + 0.347mA \\ &= 372.847mA \end{aligned}$$

Hence, the expected battery life:

$$T_{dur} = \frac{5000mAh}{372.847mA \cdot 1.2} = 11.175h$$