UNIVERSITY of SOUTH FLORIDA
College of Engineering
Department of Electrical Engineering

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Non-Invasive Liquid Volume Detection in Flexible Containers

FINAL REPORT

Team:

- EE: Gabriela Ferrer Negrete, Mohamed Gadalla, Enzo Telles Brentzel, Xzavier McKenzie
- BME: Alex Proctor, Mark Thivierge

Advisors:

- EE: Dr. Ashwin Parthasarathy
- BME: Dr. Souheil Zekri

Jabil Industry Contacts:
Nathaniel Richards & Mark Sussman

Table of Contents

Table of Contents

Table of Contents

Appendices

EXECUTIVE SUMMARY

1.1 Project Overview

Monitoring the volume of fluids in flexible containers continuously with great accuracy is an important and complex challenge in healthcare for IV bags, oil and gas for fuel bladders, and in food production, such as for MRE during filling and packaging phase. This project addresses the challenge of monitoring fluid levels in non-rigid containers, which is vital to A non-invasive solution that improves long-term accuracy could automate the process to save time, resources, and for healthcare professionals, ensure timely interventions especially in intensive situations. Jabil would be interested in this topic as it aligns with their focus on developing advanced healthcare technologies, improving operational efficiency, and enhancing patient outcomes through innovative solutions. Among the current technologies used are ultrasonic sensors (flow meters), flow rate pumps (infusion pumps), and IR/optics sensors.

The volume measuring system provides a cost-effective, scalable, and innovative solution for multiple applications. Automating fluid measurement enhances safety by reducing human error, improving efficiency, and enabling real-time monitoring. Fluid monitoring in flexible containers using technologies like LiDAR, AI, pressure sensors, and temperature sensors have versatile applications across industries. LiDAR enables precise, non-contact fluid level detection even in opaque containers, while AI analyzes sensor data to predict usage patterns and trigger timely maintenance or refills. Pressure and temperature sensors further enhance control by tracking volume changes and environmental stability, ensuring fluid quality and preventing contamination in applications like fuel storage, industrial chemicals, and food processing. It is important to mention that the usage of the temperature sensor is dependent on how different the temperature of the fluid itself from the temperature of the outside environment; moreover, it becomes less accurate with time as the temperature tends to equilibrium.

1.2 Purpose and Scope of this System Requirements Document

Purpose

This SRD outlines the technical and functional requirements for the capstone project focused on developing a non-invasive, automated volume measurement system for flexible containers, specifically IV bags. This document serves as a guide for the project team to design, test, and implement the system while ensuring alignment with sponsor's expectations and project objectives. It is intended for team members, project advisors, and sponsors involved in the design, development, and evaluation phases of the project.

In Scope This document addresses the following requirements related to the Automated Volume Measurement System for Flexible Containers project:

- Evaluation and selection of sensor technologies for volume measurement.
- Development of algorithms to process sensor data and calculate the container's volume.
- Design and prototyping of a device to house sensors and integrate with IV bag administration systems.
- Testing and validation of the system using rigid regularly and irregularly shaped bodies and IV bags of various sizes.

Out of Scope

- The following items address requirements related to the project that are out of scope:
- The measurement of flexible containers outside healthcare applications (e.g. hand sanitizer bags, urinary drainage bags).
- The testing and validation of the system with non-Newtonian fluids, such as blood or colloidal solutions.
- Aesthetic design considerations or optimization of the device's physical appearance.
- Integration of the device into advanced healthcare monitoring systems or future phases of development.

1.3 Definitions, Acronyms, and Abbreviations

- AI: Artificial Intelligence
- CAGR: Compound Annual Growth Rate
- IoT: Internet of Things
- IoMT: Internet of Medical Things
- IR: Infrared
- IV: Intravenous
- LiDAR: Light Detection and Ranging

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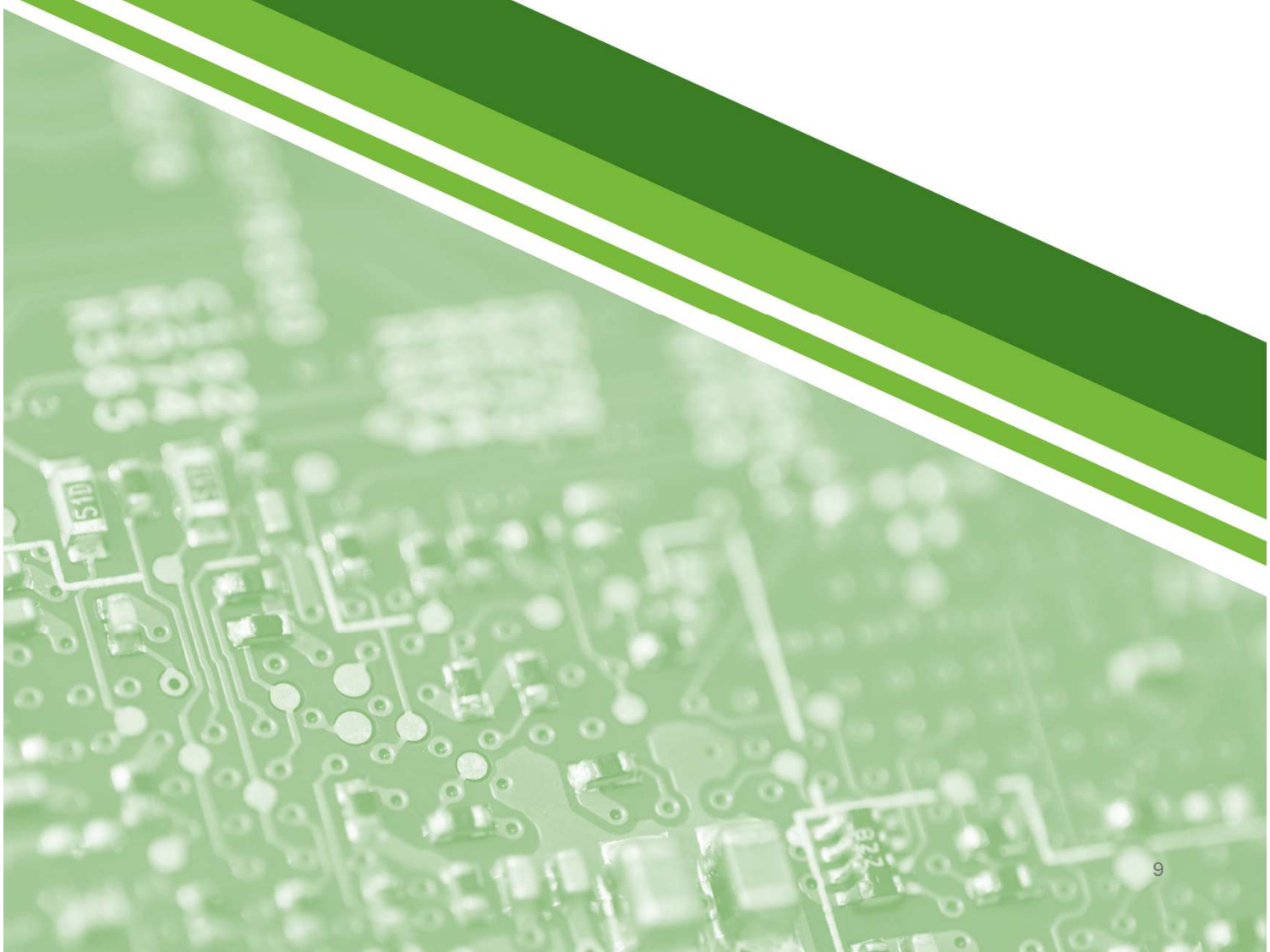
2. PRODUCT DESCRIPTION



2.1 Product Context

The Non-Invasive Liquid Volume Measurement Sensor System is designed to operate as a standalone product while also offering compatibility with other systems in healthcare, industrial, and food production sectors. More specifically, it will be used to continuously monitor the fluid level in a flexible container in the context of Sepsis treatment. IV bags are the focus of this system implementation. It is self-contained, with all critical components: sensors, a control unit, and a graphical user interface (GUI). The system's independence ensures that it can function effectively without requiring additional devices, although it can significantly enhance its utility by interfacing with other systems such as electronic medical records (EMR), industrial SCADA systems, or IoT platforms.

The system can integrate into hospital monitoring systems, where it feeds real-time IV fluid level data into EMR or electronic health record (EHR) platforms. This system enables nurses and healthcare professionals to monitor fluid levels remotely from nurse station dashboards or mobile devices. By providing alerts and status updates, the system ensures timely interventions, which is especially critical in intensive care scenarios like treating sepsis. Similarly, in industrial settings, the system interfaces with SCADA systems which allows real-time monitoring of fuel bladders or chemical containers.

The system architecture comprises two primary components: the sensor(s) and the control unit. In this division, the sensor, which may include LiDAR for non-contact volume detection, IR optics, or pressure and temperature sensors, collects data from the target object, a flexible container such as an IV bag, a fuel bladder, or a food-grade container, which is then sent to the control unit for processing and interpretation. Furthermore, the control unit analyzes and calculates, using the information from the sensor(s), the volume of the liquid inside the object. The control unit is equipped with a user-friendly GUI that displays the results and provides control settings for operators. The GUI can be accessed locally or remotely via wireless connectivity so that users can monitor fluid levels from any location.

This system's modular design ensures versatility and adaptability across different industries. In healthcare, it reduces human error and improves patient safety by automating fluid-level monitoring. By combining innovative technologies like LiDAR, SLS, AI, and IoT with robust interfaces for external systems, the Non-Invasive Liquid Volume Measurement Sensor System addresses the critical need for accurate and automated fluid monitoring in flexible containers.

2.2 Assumptions

- The dimensions of the device need to be large enough to be able to scan the entire IV bag and give the LiDAR/SLS/stereo camera enough distance to detect the surface of the bag.
- The device must have a hollow internal area for the electrical components to reside and connect through.
- The device must interface with the IV administration set (e.g., the extension hooks which the IV bag is connected to, or the IV pole) so movement of the IV bag is conferred to the device as well, reducing errors caused by motion.
- It is assumed that users, such as healthcare professionals, are familiar with the operation of the system. Adequate training or instructional materials must be provided to ensure smooth operation. User errors due to lack of expertise could necessitate design changes to improve usability.
- The device can and is permitted to be attached to or placed near the IV administration set. This assumption ensures that regulatory compliance and healthcare operational requirements are met. Changes in healthcare protocols or restrictions on such attachments could impact the system's design and implementation.
- The flexible container's size and capacity will be within a defined and standardized range. This ensures the system can reliably calculate volumes across a range of typical container dimensions.
- The flexible container's deformation characteristics under varying liquid volumes will be accounted for in the measurement system design. Accurate volume calculation assumes predictable and measurable changes in container shape.
- The container's transparency, if relevant to the measurement method, will remain consistent and free of significant obstructions. This ensures that optical sensors, if used, can accurately capture surface data for volume calculations.
- It is assumed that the necessary technologies, such as LiDAR, SLS, stereo cameras, and wireless connectivity modules, are available and compatible with the design. Delays or shortages in acquiring these components could impact the timeline or require alternate solutions.
- The project assumes that there is a sufficient schedule to design, prototype, test, and iterate the system. Any changes to the timeline may require adjustments in the scope or prioritization of features.

2.3 Constraints

- The device must operate externally to the IV bag without puncturing it or being situated inside the bag (e.g., along the bag's inner lining). It is critical to avoid altering the properties of the IV fluid or drug to prevent any potential adverse effects for the patient.

- The project timeline requires completion of the design, prototyping, and testing phases within the allocated academic schedule. Any delays may impact the ability to refine or iterate the design.

- The device must operate efficiently, relying on limited onboard power. It should sustain continuous monitoring for up to 24 hours without frequent battery replacement or charging.

- To maintain stability on the IV pole, the device will weigh no more than 1.5 lb, as the average IV pole weighs 20–45 lb and a full 1,000 mL IV bag adds 2.25 lb [4, 5].

- Healthcare providers must be able to set up and begin using the device within a reasonable amount of time.

3. REQUIREMENTS

- **Accuracy:** The system will aim for a baseline accuracy of 5% error for 1,000 mL IV bags, as this is the most used size [1], matching existing infusion pump standards [2, 3] with room for refinement.
- **Continuous monitoring:** The device should be able to provide real-time calculations of the IV bag volume as the bag is hooked to the patient via the IV administration set.
- **Lightweight: I**t must be light enough to avoid issues with center of gravity. The target weight is 2.5 lbs.
- **Portable:** The device must be compact and portable, with dimensions smaller than those of a standard 1,000 mL IV bag (3 x 4 x 13 in^3 [5]). To ensure easy storage, the device should fit within a box measuring 12 x 12 x 6 in^3.
- **Quick to deploy:** Healthcare providers must be able to set up and begin using the device within 3 minutes, ensuring quick deployment in urgent situations such as sepsis treatment [6].
- **Remote monitoring:** Providers should have access to IV fluid volume data through a separate device or application so that they can monitor the IV fluid replenishment outcomes of their sepsis patients while focusing on other parts of the sepsis treatment plan.

3.1 Following areas should be considered for Functional Requirements

3.1.1 User Interface Requirements

- The system must include a user interface that displays real-time volume of the IV bag being monitored.
- It should be intuitive and easy to navigate, allowing healthcare professionals to access critical information quickly and efficiently.
- The main screen should display the current volume (in mL) with visual representation, alerts for low volume and system status, and an option to view historical data or trends over a set period.
- The system must allow users to adjust settings, such as enabling/disabling real-time data collection and setting alert thresholds for volume.
- The system must support remote access via wireless communication, enabling healthcare professionals to monitor multiple IV bags from a central station or mobile device.

3.1.2 Performance

- The system must ensure real-time measurements.
- It must maintain a measurement accuracy of ±5% for IV bags ranging from 250 mL to 1,000 mL.

3.1.3 Capacity

- The system must be capable of monitoring one container at a time.
- The system must store measurement data locally for later analysis, ensuring that data can be accessed after the session ends.

3.1.4 Availability

- The system should remain operational during continuous monitoring sessions, maintaining availability throughout typical medical procedures.
- It must include fallback mechanisms to recover quickly from system faults.

3.1.5 Latency

- Data transmission and display updates must occur with minimal delay to support real-time monitoring.
- The system must enable healthcare professionals to make timely decisions based on the most current fluid-level data and alerts.

3.1.6 Manageability/Maintainability

- Provide replaceable components for easy replacement and maintenance.
- Include automated diagnostic tools to identify faults and suggest corrective actions.

3.1.7 Monitoring

- The system must include automated monitoring to detect volume changes in real time.
- Alerts should be triggered when measurements exceed predefined thresholds.
- Users should be able to view monitoring data to analyze historical records.

3.1.8 Maintenance

- The system must be designed with replaceable components to simplify repairs and replacements.
- A maintenance guide must be provided, including instructions for common tasks, such as replacing sensors, cleaning components, and upgrading the software.
- All hardware components should be designed for ease of access to minimize downtime during repairs or upgrades.

3.1.9 Systems Interfaces

- The system will have the capability to output the sensor data directly to a PC.
- Each sensor relays the matrix point cloud directly to the Raspberry Pi 5, where it creates a 3D line vector for each degree of rotation. The data will be transmitted and saved to a software where a mesh will be made from each line vector of the scanned object.
- The software will be able to interpret the line vectors and plot them into a 3D mesh.

3.2 System Requirements Matrix

Req#	Function	Requirement	Comments	Date Rewd	SME /Faculty Reviewed / Approved
1	EE	The system must achieve a baseline accuracy of 5% error for a 1,000 mL IV bag.		11/28/24	
2	EE	The system should provide real-time volume calculations of the IV bag.		11/28/24	
3	ME	The device must weigh no more than 2.5 lbs to avoid stability issues on IV poles.	Ensures compatibility with standard clinical setups.	11/28/24	
4	ME	The device should be compact and fit within a 12 x 12 x 6 in^3 box for easy storage and transport.	Smaller than a standard 1,000 mL IV bag to ensure portability.	11/28/24	
5	Design	The device must be deployable within 3 minutes, including setup and activation.	Crucial for urgent scenarios like sepsis treatment.	11/28/24	
6	EE	The system must support wireless monitoring of IV fluid data via a separate device or application.		11/28/24	
7	Software	The user interface must display real-time volume and alerts and allow for data adjustments and troubleshooting.		11/28/24	
8	Software	The system will use a database of common IV fluids to calculate volume based on predefined molecular characteristics.		11/28/24	

4. SYSTEM DESIGN

4.1 Overview

PURPOSE

The system aims to track the volume of a liquid in a vacuum-sealed IV bag to assist health professionals with fluid monitoring in sepsis treatment. The tracking must be continuous, and the device should not interrupt the workflow of a medical environment. In addition, the device should measure the liquid volume non-invasively.

GOALS

- ✓ The system must measure the volume of a liquid in a flexible container
- ✓ The system must assist health-care professionals in constant volumen monitoring
- ✓ The system should be capable of monitoring the liquid volume non-invasively
- ✓ The system must not interrupt workflow

SYSTEM SUMMARY

The system consists of two time-of-flight (ToF) sensors that create a 3D map of the IV bag. The 3D map is used to calculate the volume of the bag using the RP1 I/O controller. ROS2 nodes are used to calculate this volume and then transmit the estimation to a user interface via wi-fi. The ToF sensors are controlled using stepper motors placed in a 3D printed chassis. The system obtains feedback of the stepper motor position using switches and a 3D-printed throne for the sensors.

4.2 Architecture

The system block diagram can be found in figure 4.2.1. Figure 4.2.2 shows the ROS2-based software architecture of the system.

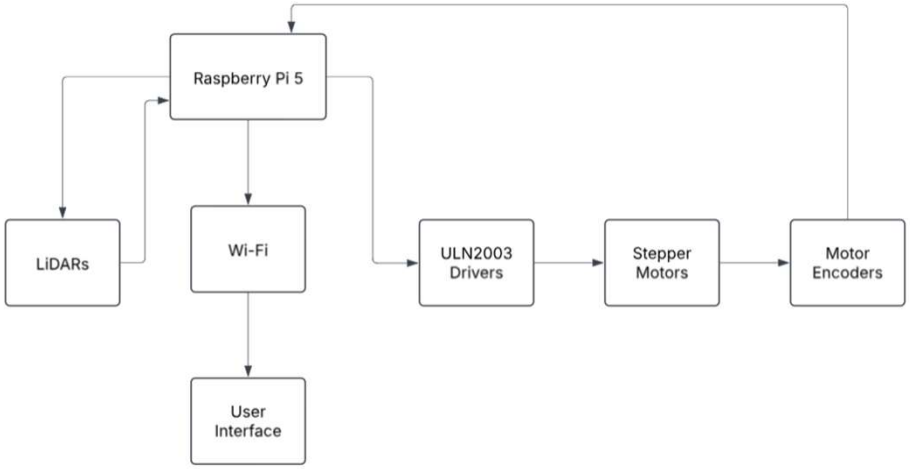


Figure 4.2.1. System Block Diagram

The robot operating system (ROS2) utilizes nodes to act as Publisher and subscriber under a topic. The architecture has one node for each LiDAR sensor, a node that calculates the volumen and controls the stepper motors, and the Server node for communication with the user Interface.

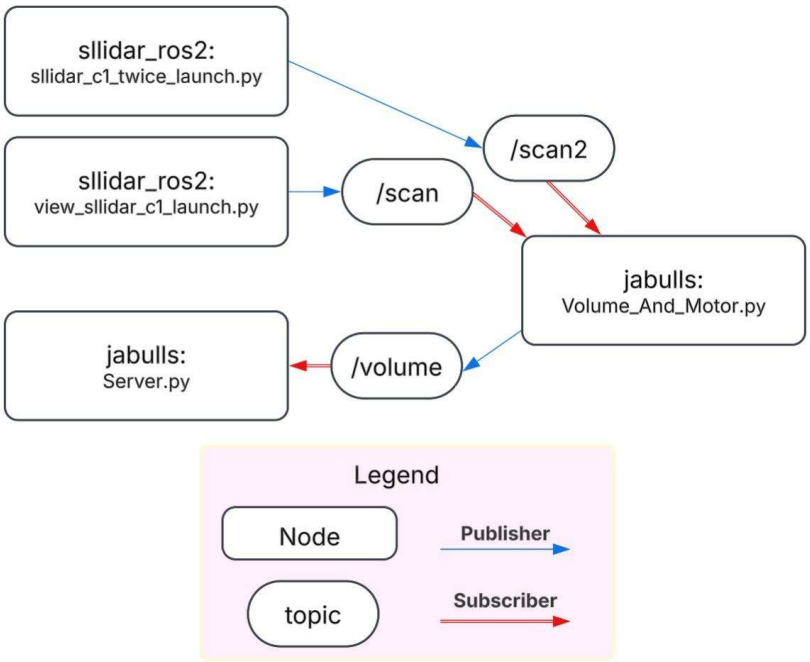


Figure 4.2.2. Software architecture

4.3 Key Components

RPLIDAR C1

The LiDAR scanner has a sampling frequency of 5kHz and 360-degree full-range laser scanning. It provides reflectivity data which is useful when it comes to IV bag scanning since they are commonly translucent. This LiDAR scanner is cost-effective and is usually used for small robots. Lastly, the scanner reaches Class 1 Laser Safety Standard which is safe to human eyes, ensuring safety among patients and health professionals that are around the sensor.

RASPBERRY PI 5

The Raspberry Pi 5 uses the RP1 I/O controller. It has 8GB of RAM and the Broadcom BCM2712 quad-core Arm Cortex A76 processor at 2.4GHz. The Raspberry Pi 5 was chosen because of this and its compatibility with ROS2, which is the software embedded in the LiDAR scanner. In addition, it allows for Bluetooth and wi-fi connectivity, which is useful to connect to peripherals and transmit the volume calculation wirelessly. Moreover, the USB ports are useful to connect the LiDAR and ensure proper communication between both components.

MOTOR ENCODER

The motor encoder consists of two switches that will be placed on either side of the LiDAR sensor. The LiDAR will be placed on a 3D-printed chassis that will move with the stepper motor. The chassis will press one of the two switches whenever the stepper motor rotates 90°. Like this, the system will be able to get feedback on the position of the LiDAR and switch direction

STEPPER MOTOR AND DRIVER

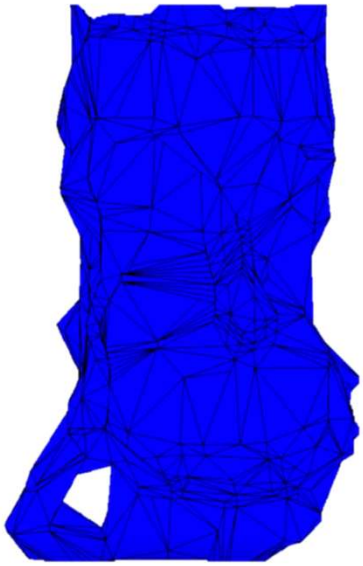
The ULN2003 driver and 28BYJ-48 stepper motor is a common cost-effective pair used in numerous applications, including camera motion. Because of this, it is easy to find documentation on how to use these components and ensure reliability on them. Moreover, they fit the specifications required for the non-invasive volume measurement device: torque of at least 0.0216Nm to be able to rotate the LiDAR, compatibility with Raspberry Pi 5, and similar power usage as the Pi.

4.4 Technologies

ROS2 AND PYTHON

The RPLiDAR C1 supports ROS2 to integrate the data in the design. Robot Operating System 2 (ROS2) is an open-source set of libraries and algorithms used in different applications. ROS2 nodes are programmed using python. The nodes act as publishers and subscribers under different topics for the system to run. This falls under the Data Distribution Service (DDS) protocol used by ROS2.

TIME OF FLIGHT AND 3D-MAPPING



The LiDAR obtains datapoints using Time-of-Flight principle, in which a device measures the amount of time a laser takes to reflect back in order to measure the distance. A depth map, which represents the three-dimensional shape of the target object, is created from the data from the motor encoders and the LiDARs. Since they are two scanners, these datasets are aligned together using Kabsch Algorithm. Then, a subset is defined to differentiate the target object and the background environment via hierarchical clustering. Lastly, by the 3D map is made continuous using polynomial regression. Then, the volume is calculated assuming convex hull geometry.

WI-FI AND CLIENT-SERVER ARCHITECTURE

The user interface communicates with the system via Wi-fi using client-server architecture. The user interface receives from the server (Raspberry Pi 5) the last estimated volume every time it measures a new scan.

4.5 Bill of Materials

Component name	Qty.	Cost (p. u.)
Slamtec C1 ToF LiDAR Scanner	2	$69.00
28BYJ-48 Stepper motor and ULN2003 Driver board	2	$7.99
SPDT Snap Action Switch	2	$1.35
IV Bag	1	$12.25
Cables/ Connector pack	1	$6.98
Aluminum (12x12x1/8)	4	$13.99
USB-B	1	$2.55
Electronics kit	1	$15.77
Raspberry Pi 5	1	$80.00
Total		$330.19

5. USER SCENARIOS

5. USER SCENARIOS/USE CASES

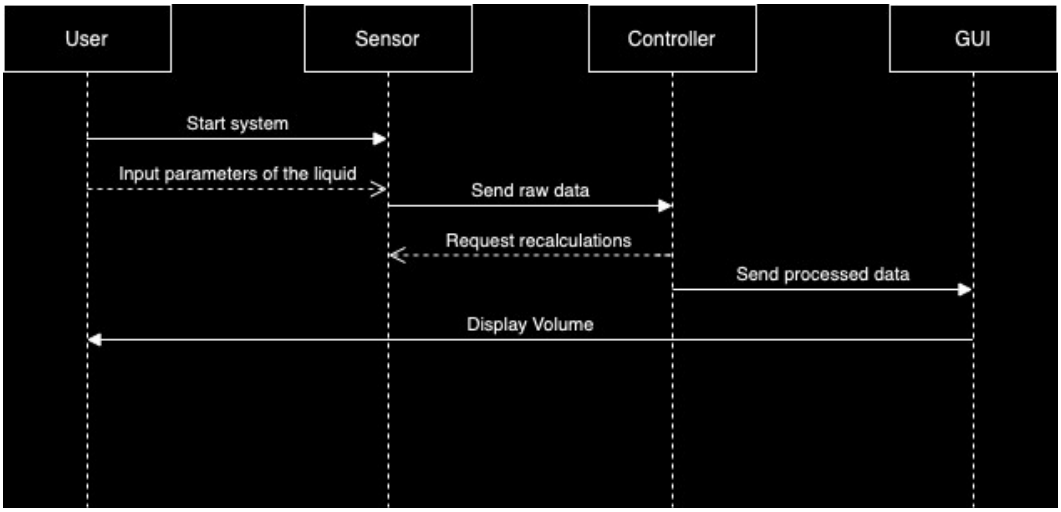
- In emergency situations moving a patient to different departments and locations can be vital to their survival. During this timeframe, there's no affordable solution for monitoring intravenous infusion other than by sight. A product that can monitor volume and volume changes of fluid in an IV bag remotely with minimal motion artifacts. would improve the workflow and reduce stress for nurses and physicians. LiDAR technology will be used to provide a solution to this problem. The goal will be to use LiDAR to calculate changes in volume over time.

- Healthcare professionals and administrators have cited a growing need for continuous monitoring devices. These customers also insist that these new devices be easy to integrate into their existing workflows and intuitive for users of the devices. In addition, the devices must be cost-effective to maintain hospital and department budgets. Demand for "smart" ambulances is on the rise. These also require devices that collect and continuously monitor vital information for better care in the ambulance and the hospital. The scope of this work only looks at the devices that may be used for monitoring the volume of a fluid in a flexible container (IV bag). There are currently three methods used: direct observation, infusion pumps, and infrared monitoring. Among these three methods, the gaps identified include high upfront costs, accuracy and precision under motion, and remote and continuous monitoring.

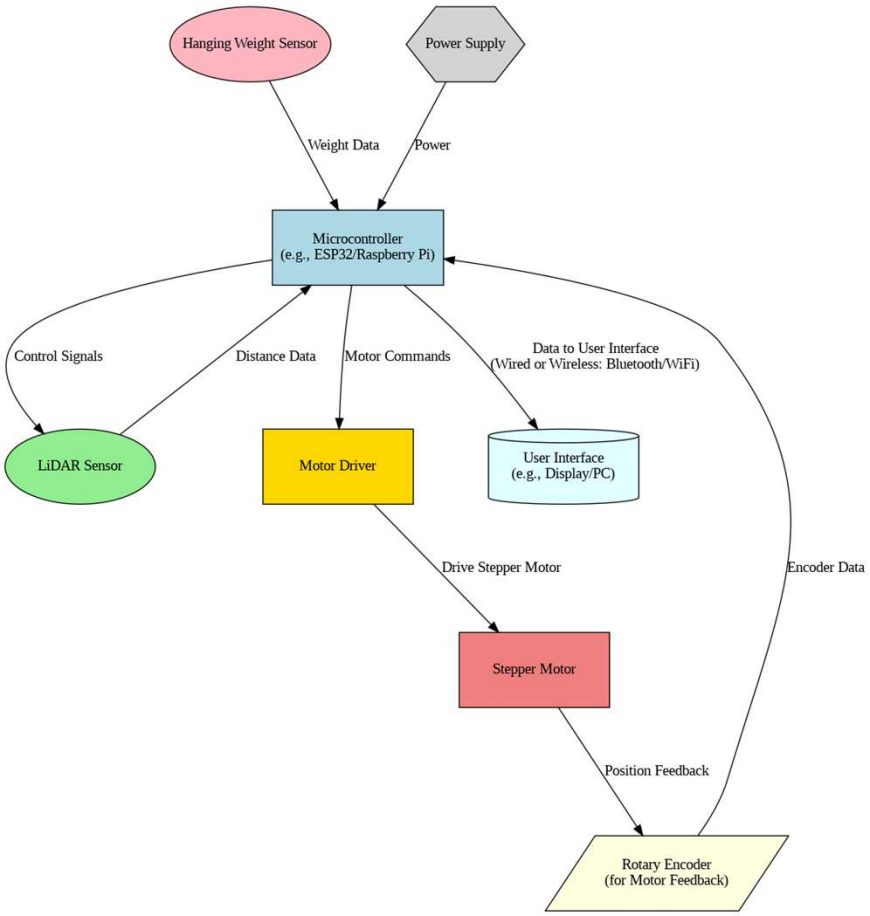
6. ANALYSIS MODELS

6. DIAGRAMS

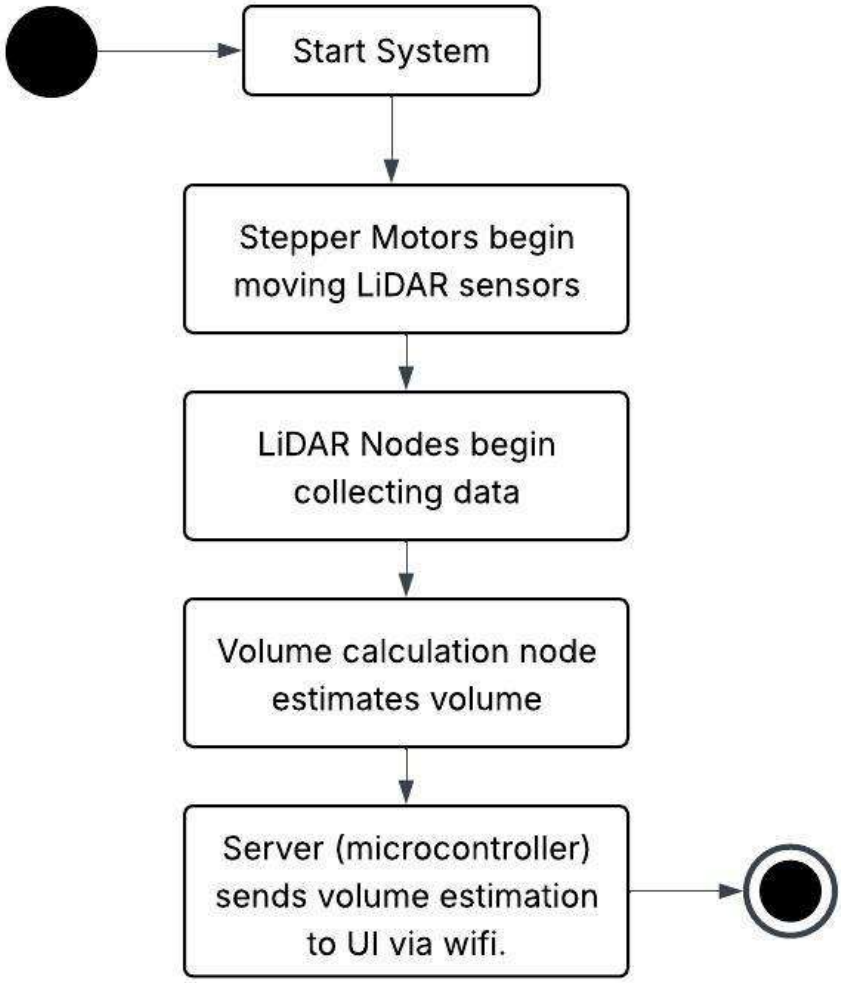
6.1 Sequence Diagram



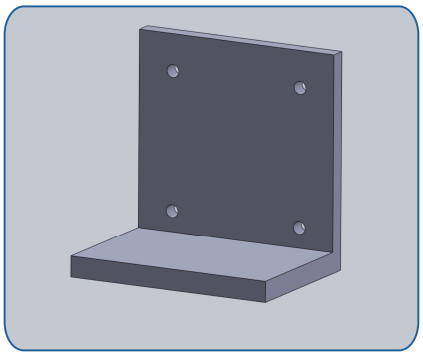
6.2 Data Flow Diagram



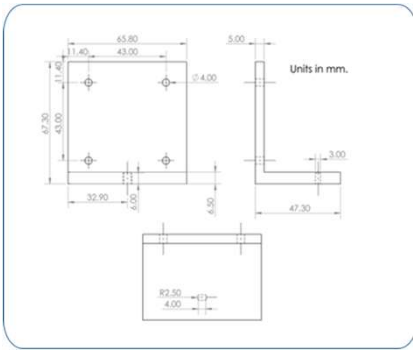
6.3. State-Transition Diagram

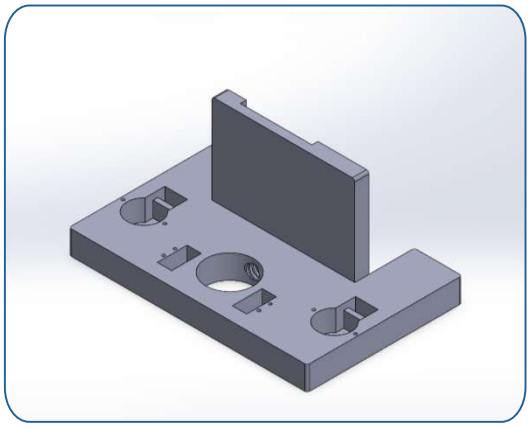


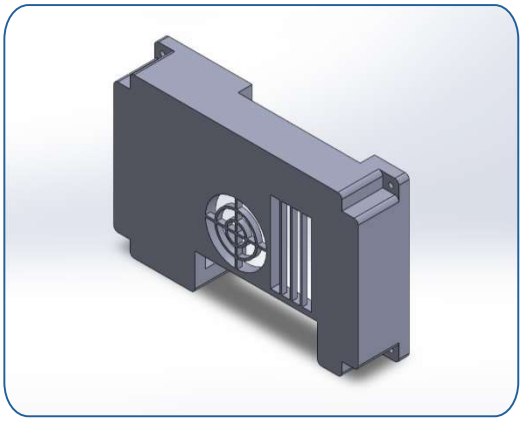
6.4.1 SIZE



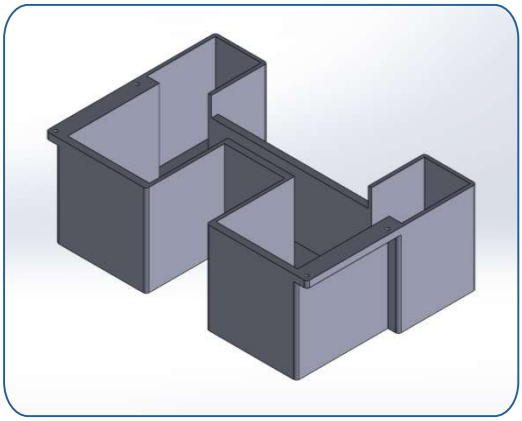
LiDAR Mount
47 x 65 x 67 mm







Electronics Box
200 x 150 x 150 mm



Dimensions: 200 x 100 x 220 mm

6.4.2 WEIGHT

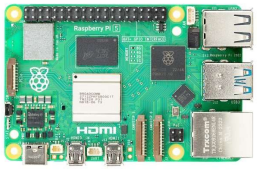
This is a modular device that has interchangable parts fastened throuh screws and friction fittings

Weight: 0.835 kg (1.84 lbs.)

6.4.3 POWER

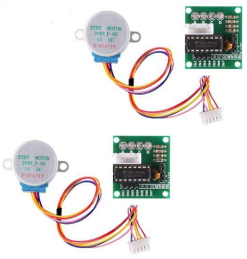
Raspberry Pi:

2.7 - 5 Watts



LiDAR:

1.15 Watts



Stepper Motors:

1.2 Watts

Total Power Consumption:
~ 7.7 - 10watts

6.5 SYSTEM PERFORMANCE

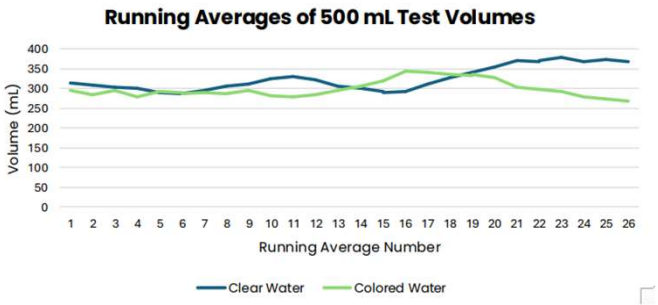
Distance Analysis

	25 cm	30 cm	35 cm
Avg Vol (mL)	670 .8	441.4	437.5
% Error	34.1	11.7	12.5
Expected Vol (mL)	500 mL		

Average IV poles hang the bag about 20 cm away from but our system performs best with 35+ cm gap

Color Analysis

Tests concluded that the opacity and color of the liquid had little to no effect on the calculated volume



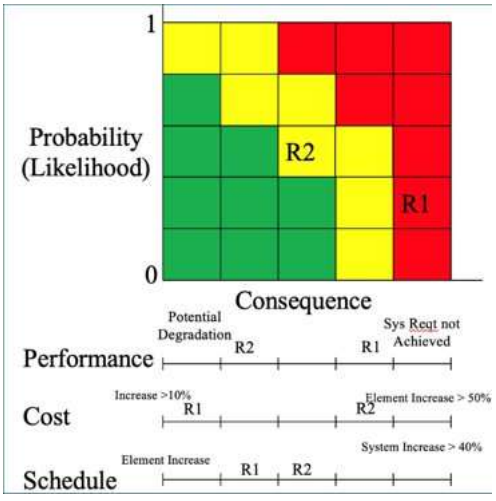
Volume Analysis

	100 mL	300 mL	500 mL
Avg Vol (mL)	119	264	465
Std Dev.	36.2	32.6	67.8
% Error	19	12	7

Utilizing a running average technique allowed for better optimization of output volume calculated

7. PROJECT RISKS

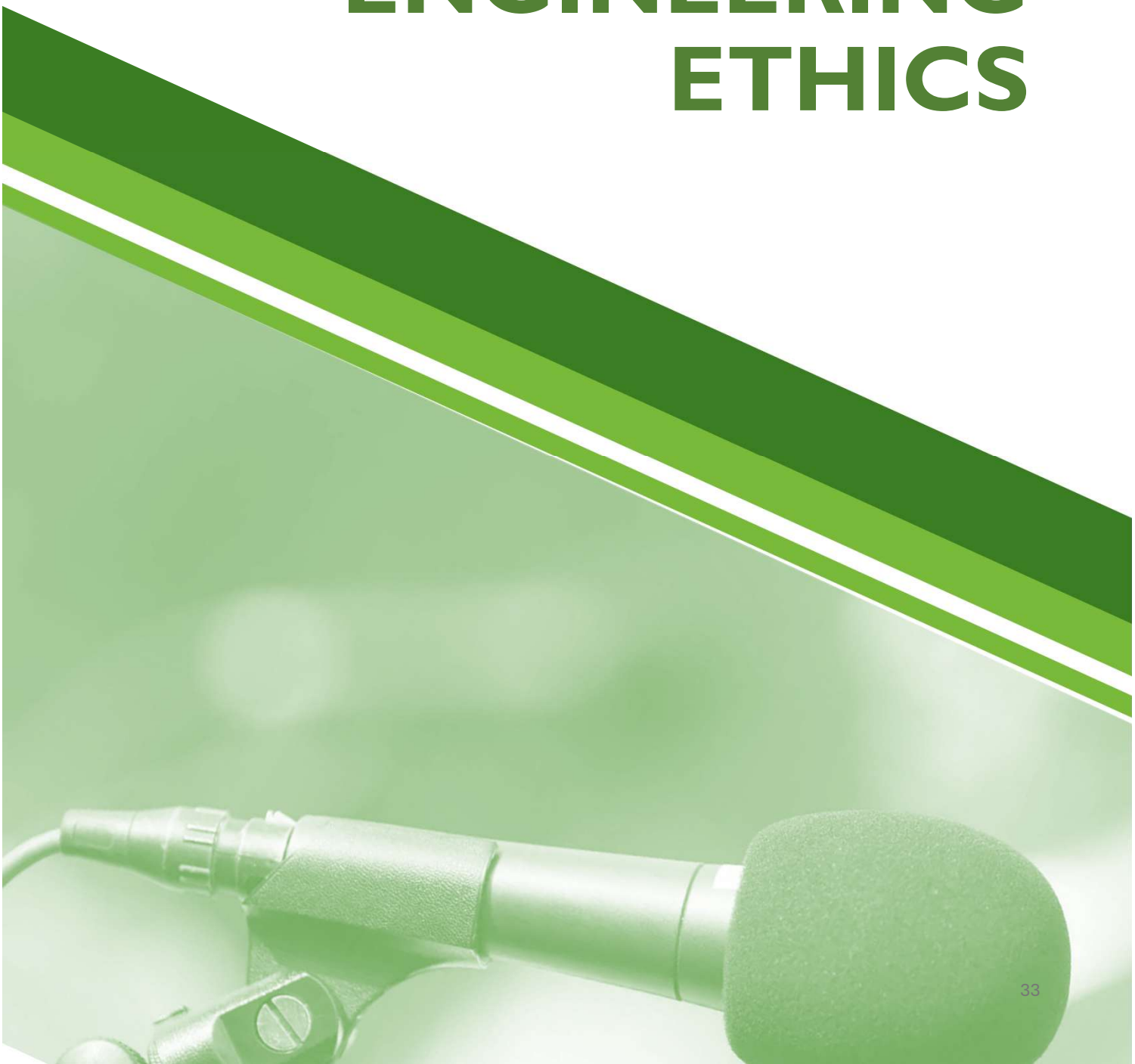
- **Component unavailability or delays:**
  - Key components might not be available on time, potentially delaying the project.
  - Mitigation Strategy: Order the most important components early and look for substitute components if necessary.
- **Accuracy below required threshold:**
  - The system may not meet the required 5% error target.
  - Mitigation Strategy: Conduct testing and refining sensor calibration algorithms. Test under real-world scenarios to ensure accuracy across different conditions.
- **System integration issues:**
  - Problems may occur in integrating sensors, the control unit, and the user interface, leading to performance issues or system failure.
  - Mitigation Strategy: Perform rigorous interface testing during development and include diagnostic tools to troubleshoot integration issues.
- **Budget issue:**
  - The project costs may exceed the expected budget due to unforeseen expenses or component availability issues.
  - Mitigation Strategy: Regularly monitor spending and prioritize cost-effective components.
- **User acceptance and usability issue:**
  - Healthcare professionals might find the device difficult to use or unreliable.
  - Mitigation Strategy: Design an intuitive interface and provide training materials.



8. STANDARDS

- The sensor will use Raspberry Pi 5, USB 3.0, and Bluetooth to be remotely controlled.
  - USB 3.0:
    - https://standards.ieee.org/standard/802_15_1-2002.html
  - Bluetooth:
    - https://standards.ieee.org/standard/802_15_1-2002.html
- In addition, it should follow the FDA's Code of Federal Regulation (CFR), regulations for medical devices, the International Organization for Standarization (ISO) regulations and the International Electromechanical Commission Standard (IEC).
- FDA Code of Federal Regulation:
  - https://www.fda.gov/medical-devices/device-advice-comprehensive-regulatory-assistance/overview-device-regulation
- ISO 13485: Medical Devices – Quality Management Systems – Requirements for Regulatory Purposes
  - https://www.iso.org/obp/ui/en/#iso:std:iso:13485:ed-3:v1:en
- IEC 60825: Safety of Laser products
  - https://webstore.iec.ch/en/publication/3587

9. ENGINEERING ETHICS



9.1 Public Health

Key Points

- ✓ Safe monitoring of medical supplies
- ✓ Fast response time in crisis situations
- ✓ Reduces human error for IV bag management

The sensor aims to provide continuous monitoring of IV fluids in hospitals, eliminating the frequent need for healthcare professionals to constantly check the fluid level and allowing them to focus on more urgent tasks. This would positively impact overall patient care and assist healthcare professionals by reducing the amount of time spent performing routine checks on fluids, increasing operational efficiency. The sensor will improve the treatment of patients with conditions that require very precise and consistent IV fluid transmittal. An example of this is Sepsis, which requires precise administration of antibiotics and fluids to the patient in order to stabilize their condition.

9.2 Global, Social, & Cultural Factors

Key Points

- ✓ Quick Accessibility
- ✓ Enhance supply chain tracking
- ✓ Cultural Rejection

The fluid monitoring device can be used anywhere around the world since it will adhere to International Standards for medical devices and laser safety, specifically the guidelines set by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), ensuring that the device is safe, reliable, and effective. The device has the potential to improve healthcare for rural areas and other medically isolated regions, where access to advanced medical technologies is limited. Because of this, language and illiteracy considerations should be taken into account for the device's design, this could include providing intuitive interfaces, multilingual supports, and visual indicators, ensuring that the device is accessible to all users. Moreover, cultural beliefs and practices might impact the usage of this device in certain regions, where there might be resistance to the usage of this device due to traditional medical practices or skepticism toward the new technology. Additionally, this device can assist on elderly and pediatric care, which is highly prioritized in some cultures. Lastly, in emergency and crisis management situations such as natural disasters or war zones, there is usually a lack of healthcare professionals to assist every patient: the sensor would assist in improving and ensuring good care for all these patients.

9.3 Economic Factors

Key Points

- ✓ Quality Assurance
- ✓ Reduce Labor
- ✓ Market Expansion

There is a growing demand for continuous monitoring devices among medical settings: these devices must be easy to install and user friendly. This device could be integrated not only in hospitals but also in nursing homes, and in "Smart" ambulances. This last one has had a growing demand [add ref]. In addition, it could be a tool that nurse home care nurses could use as well to provide better care for their patients. The fluid monitoring sensor's design should fit these characteristics to be successful in the market. The sensor will be efficient and affordable to fill in the market gap for fluid monitoring devices in the healthcare industry. By filling this gap and ser friendly, intuitive, and easily integrate assuming the market for these devices will keep on growing, the manufacturer will benefit from the revenue of selling the fluid monitoring sensor. Moreover, it will require healthcare professionals to be trained in their usage and calibration: this sensor will not destroy nor create new jobs. Rather it will demand more skills from medical professionals. However, it is intended to be highly ued into existing medical workflows to be attractive for healthcare administrators and professionals. This means that even though some level of skill will be required to use this device, the sensor will have a simple and straightforward user interface that requires little training.

Moreover, if this technology shows a positive impact on the medical world, it may expand to other markers such as inventory management where it can be used to more efficiently scan material

9.2 Enviromental Factors

Key Points

- ✓ Minimized Waste
- ✓ Reduce Carbon Footprint
- ✓ Reallocate Resource Management

Our system is designed to foster an environmentally friendly approach, focusing on sustainability and adaptability through the implementation of repairable and multifunctional components. A key aspect of this strategy is the incorporation of biodegradable materials, such as organic light-emitting diodes (OLEDs). Unlike traditional materials, OLEDs in our system utilize compostable substrates made from natural polymers, such as cellulose or polylactic acid (PLA), which can break down into non-toxic components like water, carbon dioxide, or organic biomass when exposed to microorganisms in industrial composting conditions. This ensures that even at the end of the system's life cycle, its environmental impact is minimized.

To further enhance the sustainability of the system, its frame is primarily constructed from aluminum. This material was selected for its exceptional balance of properties, including high strength-to-weight ratio, corrosion resistance, and recyclability. Aluminum is one of the most widely recycled metals, with a recycling process that consumes 95% less energy compared to producing aluminum from raw bauxite ore, thereby significantly reducing associated greenhouse gas emissions. Additionally, the inherent durability of aluminum extends the system's operational lifespan, minimizing the frequency of replacement and reducing waste generation.

Despite these sustainable features, a challenge arises from the system's typical role as single-purpose equipment. As technology advances, the system risks becoming obsolete over time, resulting in reduced functionality and use. This obsolescence contributes to the growing issue of electronic waste (e-waste), which poses a severe threat to the environment. E-waste often contains non-biodegradable and toxic components, such as heavy metals and plastics, which can leach into soil and water, contaminating ecosystems and endangering human health.

10. SAFETY

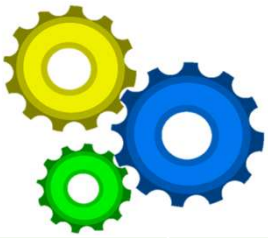
The sensor uses LiDAR technology to map a flexible container and generate a 3D model and find the volume. LiDAR works by using time of flight measurements and laser beams to determine distance between the sensor and objects nearby, allowing for accurate mapping of the object's shape. Due to this technology, the design will have to follow IEC 60825: Safety of laser products, ensuring that the human eye remains safe under all conditions while the sensor is in operation. Since the purpose of the sensor is to provide constant and real-time monitoring, the laser must operate with wavelengths between 180nm and 1mm to avoid any risk of harm to individuals nearby. In addition to this, the design will account for emergency medical settings, where rapid decision-making is vital, and therefore, should not pose a hazard for healthcare professionals, patients, and families. This means that the hardware in which the electrical parts are placed should be lightweight, stable, and easy to handle, as it should not significantly change the setting and layout of the regular hospital room. In addition, since the sensor will be used to monitor IV fluid administration, the error should be of 5% or less and should have redundancy to verify every measurement.

11. Conclusions

In this project, we successfully developed and iteratively refined a LiDAR-based, non-invasive device capable of measuring the internal liquid volume of flexible containers. Following the Stanford Biodesign process, we progressed through six prototype stages—beginning with proof-of-concept scans and culminating in a fully integrated, pre-production prototype with automated motor control, ROS2-based data handling, and regression-based volume calculation. Preliminary testing demonstrated that our device can reliably reconstruct 3D point-clouds of both clear and dyed fluids, with statistical analysis (including an unpaired t-test yielding $p=0.001$) confirming consistency between fluid types. Real-time filtering and running-average algorithms further improved measurement stability, meeting our must-have criteria for accuracy and ease of use in emergency-care scenarios.

Moving forward, we will focus on clinical benchtop validation, continuous-flow measurements, and user-interface development to facilitate seamless integration into hospital workflows. Key next steps include refining our regression models across a broader range of bag sizes and fluid viscosities, implementing Wi-Fi connectivity for real-time remote monitoring, and conducting comparative studies against predicate devices (e.g., DripAssist). From a business perspective, our cost-optimized bill of materials and 3D-printed chassis design offer a clear path to scalable manufacturing, while our IP and regulatory strategies position this technology for a Class II 510(k) clearance within 3–7 years. Ultimately, by reducing manual fluid-level checks and enabling continuous monitoring, our device has the potential to enhance patient safety, alleviate nursing workload, and improve outcomes in sepsis management and other critical-care applications .

12. WORK DIVISION



Hardware

	MooMan	Gabster	Ez E	X
CAD Design	✓			✓
Schematic		✓	✓	
Encoder	✓			✓
Research	✓	✓	✓	✓

Software

	MooMan	Gabster	Ez E	X
UI Design	✓	✓	✓	
ROS 2	✓	✓		
Testing	✓	✓	✓	✓
Volume Calculator				✓

Throughout the project each section of work was evenly between each team member. For main components of the system (i.e., CAD Design, ROS 2 implementation) we create teams of 2 to become the technical specialists on each area of the project. For the general tasks such as research and testing the team collaborated to analyze the needed information so that we can collectively brainstorm solutions and improvements that can be made on the project

13. FUTURE ENHANCEMENTS

- Performance
  - Improve volume regression formula
  - Faster Motor syncing/ scanning

- Reduce form size
  - Custom PCB
  - Custom made LiDAR
  - Integrate internal power supply
- Ease of Use
  - Customizable bag dimensions
  - Real-time visualization
- Functionality
  - Incorporate water level sensor for noncompressible containers

Appendices