ECE 445 Fall 2025 Project Proposal

Suction Sense - Pitch Project

Group Members: Hugh Palin, Suleymaan Ahmad, Jeremy Lee

Introduction:

1. Problem

Currently, suction systems in hospital operating rooms are left running unnecessarily for nearly 35% of their total runtime, including periods such as overnight when no surgeries are taking place. This results in wasted energy, wear overtime on expensive vacuum equipment, and higher maintenance demands. Without any system to detect or alert staff when suction is left on, hospitals face unnecessary electricity consumption and shortened equipment lifespan. This creates a huge inefficiency that scales across entire healthcare systems.

The financial and environmental impact of this waste is significant. Leaving suction on overnight alone contributes to approximately 8 billion kilograms of CO_2 emissions globally every year. This efficiency can cause hospitals to incur significant additional costs including: replacement vacuum systems that range from $100,000 to $750,000, filters that cost $2,500 to $10,000, and annual oil changes that add another $8,000. On top of that, hospitals spend an estimated $30,835 each year just on electricity for their vacuum systems. Together, these demonstrate the urgent need for a solution that minimizes unnecessary suction runtime, reduces costs, and lessens environmental impact.

2. Solution

To tackle this problem, we propose a combined hardware and software solution designed to monitor and reduce unnecessary suction usage in operating rooms. At a high level, the system consists of two parts: pressure sensors installed on vacuum systems in each operating room and a software interface that collects real-time suction data and compares it with the operating room schedule.

To implement this system, we will design a custom PCB that integrates a microcontroller and supporting components to capture suction pressure data and transmit it over Wi-Fi. A flow sensor coupled with a BMS will accomplish this. A Raspberry Pi module will receive and store the incoming data, serving as the central hub for processing. This module will also host the software component, which connects to the hospital's internal network, via Epic, to access operating room schedules. By cross-referencing suction activity with scheduled procedures, the software can automatically identify where there is unnecessary suction use. A user interface displayed on a raspberry pi touch screen will then present this information in a visual format, displaying the status of each operating room and highlighting rooms with unnecessary suction in red. The display will be placed in a central location, ensuring that medical staff can easily monitor system status and respond promptly.

3. Visual Aid

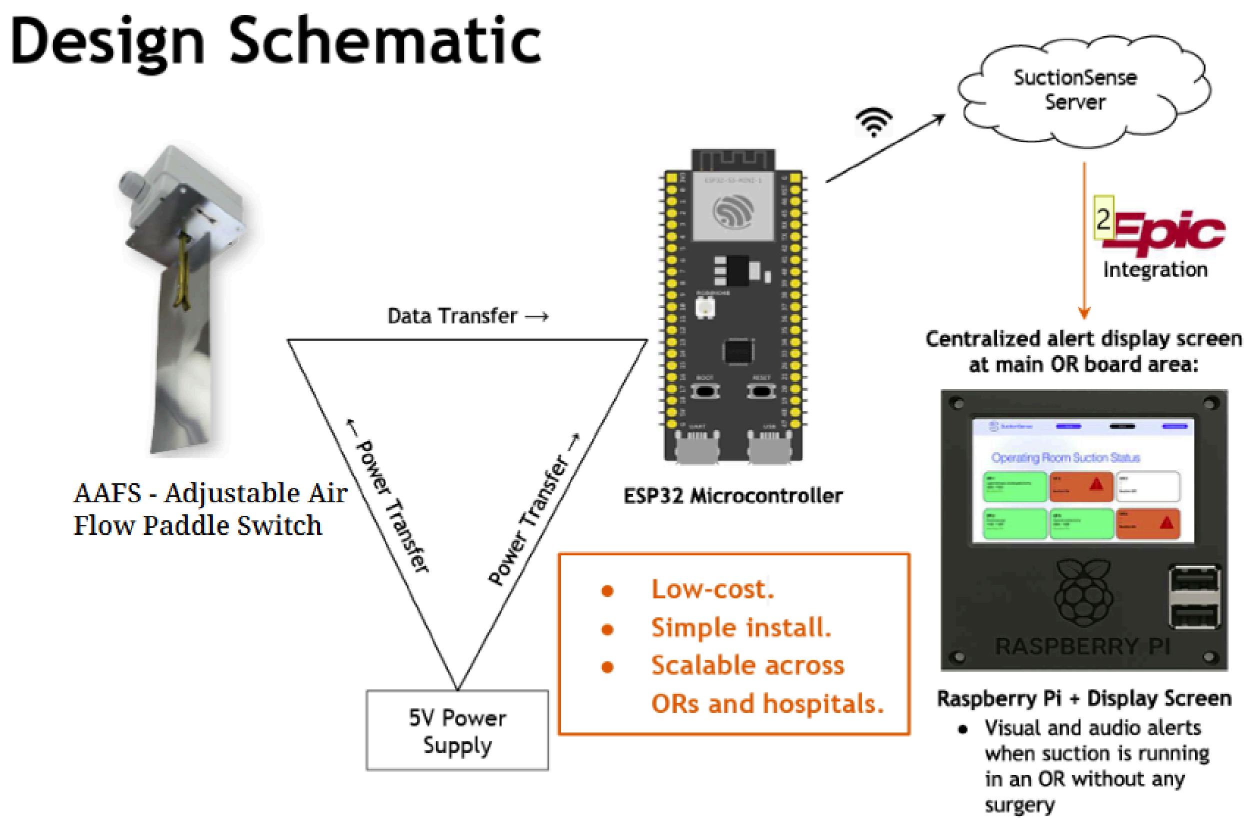


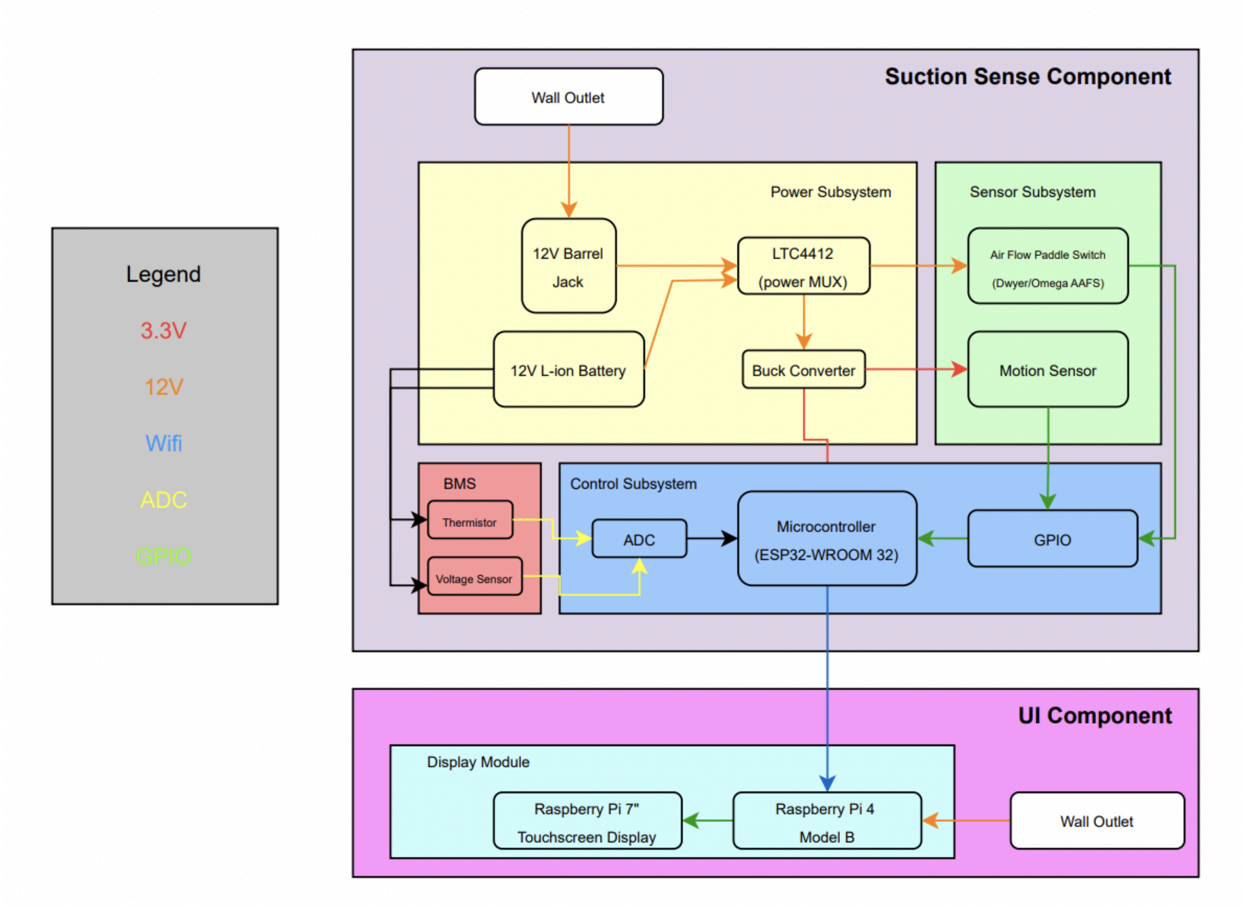
Figure 1 Addendum: This figure is from the Suction Sense class presentation [2]. Note we have moved to using a flow sensor, not a pressure transducer.

4. High-level requirements

- The system must be able to handle input from at least 8 operating rooms simultaneously without data loss or low performance
- The user interface must refresh visual indicators (e.g., red highlighting, OR status) within 10 seconds of identifying unnecessary suction usage
- The hardware sensors and transmission module must support continuous operation for 24 hours without data transmission failures.

Design:

1. Block Diagram



2. Subsystem Overview

Subsystem 1 Sensor & Peripherals:

Our first subsystem is responsible for measuring the pressure of the vacuum which will be used to monitor real-time suction. It works by converting vacuum flow rate into an electrical signal readable. We will be using the AAFS ADJ Air Flow Paddle Switch for its compatibility with medical suction ranges, compact design for easy integration, and reliability in continuous-use environments. The sensor's analog output provides a simple and accurate way to track suction status with minimal additional circuitry. The output of our flow rate sensor will then be stepped down to a safe operating voltage and imputed into our MCU. Another sensor we will be including is an Adafruit MINI PIR MOT motion sensor to monitor if anyone is in the room during OR operation. This is necessary in case we do not gain access to Operating Room data due to HIPAA or data compliance issues, so we can still determine if an operation is being conducted

Subsystem 2 Power Supply System:

Our second subsystem is responsible for providing the operating voltages required by the components on our board, including the sensor and MCU, which runs on a 3.3 V supply. Since minimizing power consumption from the hospital is a primary goal, we designed a dual power supply system to balance efficiency and reliability. The system will normally be powered by a battery, but when the battery management system (BMS) signals low charge or other conditions, the power source will seamlessly switch to a wall plug to maintain continuous operation. We will be able to achieve this functionality through using a powerpath controller (LTC4412), which will essentially provide output to the load(our system) consistently while making sure to use the battery when possible to reduce strain on the overall power consumption from the hospital wall outlet. Regardless, the output of the LTC4412 will then be ran through a buck converter (TPS629210) so that we can safely power our mcu (3.3v). When the battery is no longer charged or we are running on wall power an LED will light up to indicate to the user.

Subsystem 3 MCU and WiFi:

Our third subsystem provides system control and wireless connectivity. For this we will use the ESP32-WROOM-32, which combines a powerful microcontroller with built-in WiFi capability. The ESP32 was selected for its small form factor, low cost, and robust performance, making it well-suited for deployment in hospital environments where multiple devices may be installed. Its integrated WiFi enables direct communication with the Raspberry Pi and hospital networks without the need for a separate BLE shield, simplifying the overall design.

Subsystem 4 Battery Management System:

Our battery management system (BMS) will control the power module by monitoring voltage and temperature. Voltage will be measured through a sensor connected to a voltage divider, while temperature will be monitored using a thermistor (ERT-J0EG103FA). These measurements will be processed in our firmware, where calculations will determine when the battery is no longer operable. At that point, the BMS will send a signal to the LTC4412, which will switch the main power source from the battery to the wall plug.

Subsystem 5 Raspberry Pi, LCD Display, and Software Application:

The Raspberry Pi 4 Model B paired with the Raspberry Pi 7″ Touchscreen Display will serve as the central monitoring and alert system. The Raspberry Pi was chosen for its quad-core processing power, I/O support, and strong software ecosystem, which will allow us to easily integrate with the Epic scheduling system. The 7″ touchscreen will allow the module to be mounted in the hallway, providing an interface that allows staff to quickly view operating room suction status, with clear color-coded indicators and alerts. This combination also enables both visual and audio notifications when suction is unnecessarily left on, ensuring staff can respond promptly.

The application will run on the Raspberry Pi and serve as the central hub for data processing and visualization. It will collect suction pressure readings from the ESP32 via its WiFi transceiver and compare this data against the hospital's operating room schedule retrieved through the Epic system. If integration with the Epic system is not available, the operating room schedules will be entered manually. A color-coded interface on the Raspberry Pi touchscreen will clearly show which operating rooms are in use, whether suction is active, and show where suction has been unnecessarily left on.

3. Subsystem Requirements

Subsystem 1 Requirements:

- The flow rate sensor must return the correct state of flow with 99% accuracy.
- The VAC flow sensor output must be conditioned and stepped down to ≤ 3.3 V.
- The flow rate sensor requires a 12 V supply, so we will supply it with a stable 12 V rail while conditioning its output for the MCU.
- The motion sensor shall be supplied with 5 V and will present a 3.0 V output signal compatible with the MCU input.

Subsystem 2 Requirements:

- All board voltages other than the 12 V input shall be generated locally with buck converters from the 12 V rail.
- The 3.3 V rail must remain within ±5% regulation to ensure stable MCU operation.
- The power subsystem must seamlessly switch to battery power via the BMS when the external 12 V supply is removed, with no loss of operation.
- The Power mosfet must be able to take the better of two inputs effectively creating an OR gate between the two power sources .
- Buck converter must be able to step down 12v to 3.3v with load current <200ma

Subsystem 3 Requirements:

- The MCU must be capable of sampling the flow rate sensor output with a correct reading within a +-1-2% margin of error.
- The MCU must transmit suction data wirelessly via WiFi to the Raspberry Pi with latency less than 1s, when the Raspberry Pi is within a reasonable distance.
- The MCU must reconnect automatically if the WiFi link to the Raspberry Pi is lost.
- The MCU firmware must be updateable via USB for maintenance and feature upgrades.

Subsystem 4 Requirements:

- The thermistor must be NTC 10 kohm to reduce power draw, but accurately provide temperature values.
- A voltage sensor should be able to accurately provide voltage level of battery with 5-10% margin of error, will make use of a voltage divider to step down voltage into range for the MCU.
- Both sensors should be able to interface without ESP32 MCU.

Subsystem 5 Requirements:

- The Raspberry Pi must display suction status updates with latency less than 1 s from when data is received from the MCU.
- The software must integrate suction data with the hospital's Epic scheduling system or example OR scheduling data.
- The system must generate both visual and audible alerts when suction is active outside scheduled operating room use.
- The Raspberry Pi must reliably log suction activity data for later review and performance monitoring, including power savings & costs.

4. Tolerance Analysis

The most critical part of any system is what powers it. Especially in this system with its intended applications in life saving environments. We believe the most susceptible part of design is the power system switch (power mux) that controls where we source the power for the entire board from. The intended purpose of this is to provide a dynamic response to when our primary power source (the 12v Lithium-ion battery) fails. The biggest issue that could arise from this is the potential transient voltage drop that would be seen across our power module as the LTC4412 switches from the battery to the power source, which could brown out our MCU.

The battery we are using is a 4000mAh 18650 lithium ion DC 12.6V this will feed into the LTC4412. When we enable the GPIO pin connected to the LTC4412 the primary FET will switch off, this will take approximately 13-22us, during this interval of switching the load will be supplied by Bulk capacitors the ESP32-wroom which operates at voltage 3.0-3.6, will brownout at voltages 2.9v-3.0v, to avoid this we will use 470uf Capacitances at the output(per data sheet recommendations) of the LTC4412 and the input of the Buck Converter(TPS629210), the TPS629210 is rated at a maximum load output of 1A, this means that during the switching time (22us worst case) we should not see an inrush current greater than this from the 470uf cap to account for our load this would cause a voltage drop across output of the buck converter. The buck converter operates at 85% efficiency (per the data sheet) so ideally input current to the MCU is 0.5A (Esp32 max load) x 3.3v(buck converter output)/(12v*0.85), which is equal to 0.15A. 0.15A < 1A. In addition, using the capacitor differential model C (dv/dt) = I we can solve for the voltage dip across the output of the buck converter since C =470uf, dt(worst) = 22us, and I = 0.15. Rearranging our equation gives us dv = I*dt / C, so dv = 27mv, which is within tolerance because 3.3v - 27mv = 3.2v will not put us in the 2.9v -3.0v range on our MCU to brownout.

Ethics and Safety:

Our project raises both ethical and safety considerations that we must address responsibly. Following the IEEE and ACM Codes of Ethics, we will avoid harm, be honest about our system's limitations, and protect privacy. The system is not meant to be a real-time controller, meaning it will not be in charge of turning off the suction. Its purpose is purely advisory, and we will make sure users understand this through clear labeling and timestamp updates on the UI. We will also minimize privacy risks by only using room numbers and schedules, not any personal health information. Because our system connects to hospital scheduling software, we will also treat the project as subject to HIPAA rules. That means we will limit access to the minimum necessary information, only displaying the operating room numbers and type operation without any individual patient information in order to maintain privacy. We will also secure our connections with either encryption or an authorization layer to ensure only authorized staff can view or interact with the data.

On the safety side, we must ensure our hardware does not interfere with existing medical gas systems, so we will design it to attach non-invasively and comply with hospital facility rules. We will also follow basic lab safety practices during development, such as using PPE while soldering and keeping prototypes separate from live medical systems until properly reviewed. By keeping these ethical and safety principles outlined by IEEE and ACM in mind, we can deliver a system that helps hospitals save energy and reduce emissions without creating new risks for patients or staff.

References

References [1] - IEEE, "IEEE Policies - Section 7-8 - IEEE Code of Ethics," [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 18-Sep-2025].
References [2] - Chao, Sharon. "Suction Sense Lecture Proposal." Carle Illinois College of Medicine, courses.grainger.illinois.edu/ece445/lectures/Fall_2025_Lectures/Lecture2/lecture_2_suction.pdf.