Project Proposal

An Automated Approach to External Ventricular Drains

University of Illinois Urbana-Champaign

ECE445 - Spring 2025

Team 66

TA: Jason Jung

Professor: Yang Zhao

Ralph Nathan (ralphn2)

David Kapelyan (davidik2)

Isiah Lashley (ilashl2)

1. Introduction

1.1. Problem

External Ventricular Drains (EVDs) are used to drain cerebrospinal fluid (CSF) and alleviate pressure in the brain. However, if not performed correctly, this procedure can cause severe complications, including death. To ensure the proper amount of CSF is drained, the pressure transducers on the EVD must be accurately zeroed. However, patients frequently move during sleep or daily activities, such as showering, which can lead to incorrect pressure readings and improper CSF drainage.

According to Dr. Suguna Pappu, MD, PhD, numerous cases have been reported where approximately 40 ccs of CSF were drained instead of the intended 10 ccs due to zeroing errors. This miscalculation can result in significant harm or even death.

Dr. Suguna Pappu advocated for the development of a new approach to EVDs—one that eliminates the need for manual zeroing and ensures stable pressure readings even when the patient is in motion. She emphasized the importance of a system that can automatically drain CSF above a set pressure level and stop drainage once a ceiling pressure is reached to prevent improper fluid removal. Additionally, she highlighted the need for an automated mechanism to limit CSF flow to a maximum of 10 ccs per hour to prevent excessive drainage.

1.2. Solution

We plan to utilize a Texas Instruments **CC2340R** microcontroller to process input from a pressure transducer connected to the catheter through which cerebrospinal fluid (CSF) is drained from the brain. Our design will incorporate a pipe tee in series with a two-way solenoid valve. The catheter extending from the skull will be connected to the tee, which will also be fitted with a pressure sensor. This sensor will be linked to the microcontroller, which will control whether the solenoid valve remains open or closed. Measuring pressure digitally, rather than using a manometer, will eliminate set-point shifts caused by patient movement. Additionally, there will be no need to manually set a “zero” point, as this can be calibrated in software.

To provide a manual bypass/override, we will integrate a three-way shutoff valve in series with the pressure measurement tee, allowing the entire system to be bypassed if necessary.

The pressure sensors will output a voltage signal ranging from **0–5V**, which exceeds the voltage rating of the ADC pins on the microcontroller. To resolve this issue, we will attenuate the signal by 30% using a resistor divider and a low-offset op-amp to buffer the attenuated signal. Using a **low-offset (zero-drift) amplifier** will ensure the op-amp does not compromise the accuracy of pressure measurements.

The flow rate sensor communicates with the microcontroller via the **I2C** protocol and operates at **3.5V**.

Digital signal processing (**DSP**) will be performed by the microcontroller, including noise filtering, adaptive thresholding for real-time pressure management, and data logging of pressure readings. The system will regulate CSF flow to a drain collection bag via a push-connected solenoid valve.

The microcontroller will communicate with a display or bedside monitor via **Bluetooth**, presenting pressure data through a graphical user interface (**GUI**). This interface will include real-time pressure graphs, an alarm system for abnormal pressure readings, and data logs for physician review.

1.3. Visual Aid

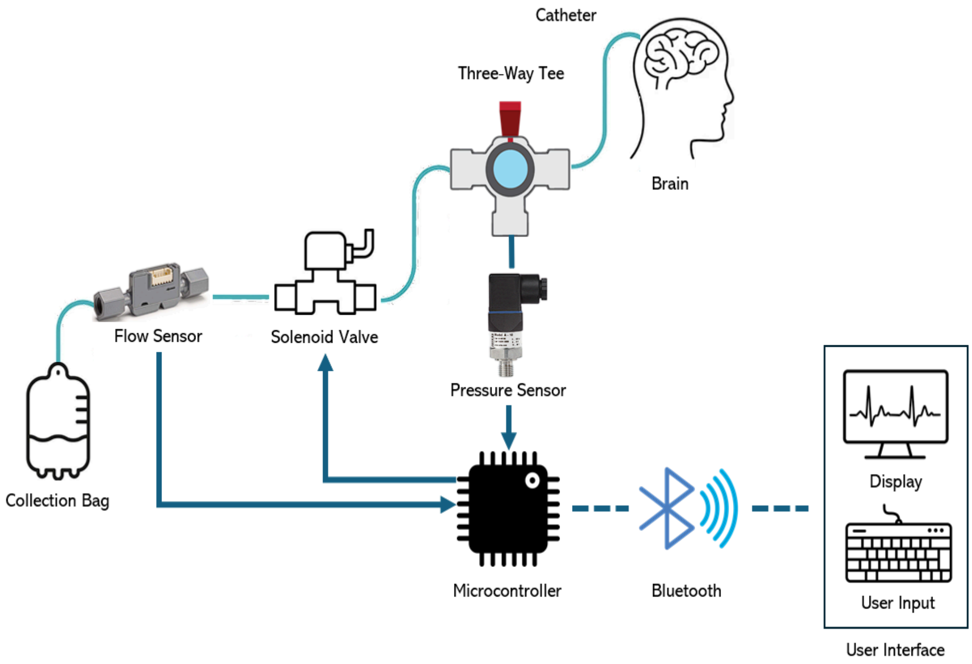

Figure 1: Visual Aid of the automated EVD system

1.4. High-Level Requirements List

1. Automated Flow Regulation: The system must automatically regulate cerebrospinal fluid (CSF) drainage using a solenoid valve. It must open the valve when the pressure, as read by a pressure sensor, exceeds a user-set threshold and close the valve when the pressure reaches the set maximum level. Additionally, the system must limit the flow rate to 10 ccs per hour, using a flow rate sensor to monitor and adjust drainage accordingly.
2. Graphical User Interface (GUI): The system must include a GUI capable of:
    a. Setting desired pressure level (floor and ceiling)
    b. Displaying real-time pressure data
    c. Providing time-resolved data for logging purposes

3. Bluetooth Communication: The microcontroller must support Bluetooth communication with a display monitor, providing near real-time data with a maximum delay of 10-30 seconds (as approved by Dr. Pappu).

2. Design

2.1. Block Diagram

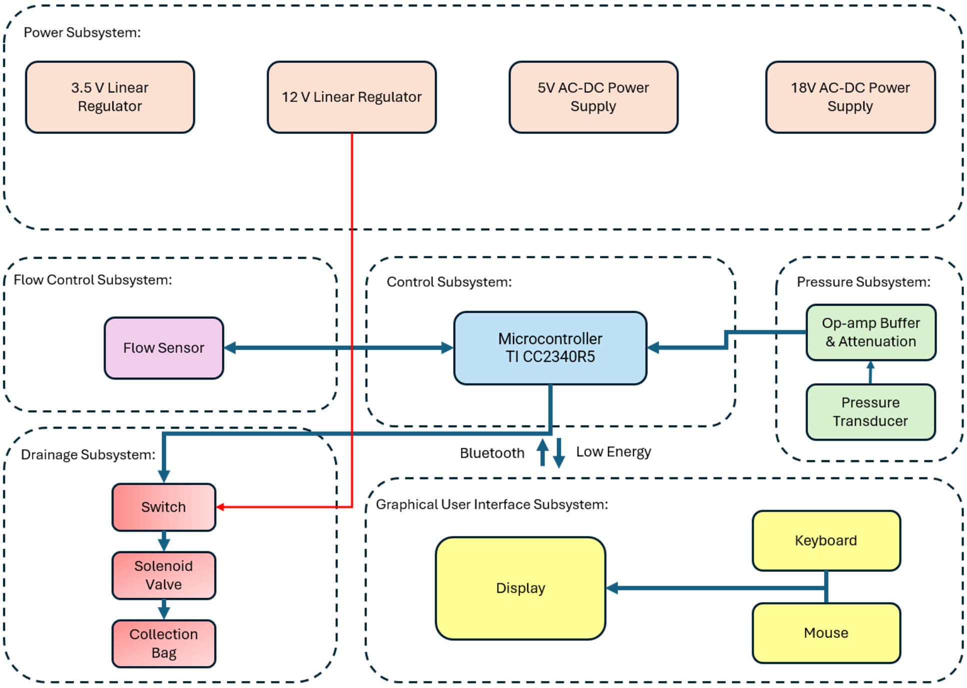

Figure 2: Block Diagram of the automated EVD system

2.2. Subsystem Overview

2.2.1. Control Subsystem (Microcontroller)

The **Microcontroller Subsystem** serves as the central processing unit, managing all sensor inputs and control outputs to ensure **automated, real-time regulation** of CSF drainage. It reads **pressure transducer** and **flow rate sensor** data, processes the information using **digital signal processing (DSP)**, and controls the **solenoid valve** accordingly. Additionally, it interfaces with the **Graphical User Interface (GUI)** via **Bluetooth** to transmit real-time pressure and flow data.

Specifically, we’ll be utilizing a Texas Instruments CC2340R52N0RGER Microcontroller which has built-in support for Bluetooth making it suitable for wireless communication. It is also equipped with an RF transceiver offering improved range and data rates compared to earlier Bluetooth versions.

The ADC has a 12-bit resolution which will be useful for accurately measuring the output signal of our pressure sensor. The CC2340R52N0RGER comes with an internal reference voltage that is typically derived from the supply voltage.

2.2.2. Power Subsystem

The **Power System Circuit** ensures a stable and reliable power supply to all subsystems, maintaining **continuous operation** of the microcontroller, sensors, solenoid valve, and Bluetooth module. Given the **medical nature** of the system, power reliability is crucial.

Specifically, we’ll be utilizing 2 linear regulator types. A 3.5V linear regulator for the flow rate sensor/microcontroller and a 12V linear regulator for the buffer op-amp, pressure sensor, and solenoid. We will also utilize 5V and 18V AC-DC supplies as they allow us to minimize power loss when using linear regulators to create our voltage rails. The difference between the input and output voltage of a linear regulator should be minimized to minimize the amount of power lost as heat.

A high-voltage rail powered by an AC-DC wall adapter will be used to power the board. A linear regulator will be utilized to decrease the voltage such that it can be used to power the microcontroller.

2.2.3. Drainage Subsystem (Solenoid Valve)

The **Solenoid Valve** controls **CSF flow regulation** based on pressure readings, ensuring automated drainage only when needed. It **opens when pressure exceeds the set threshold** and **closes when pressure normalizes** to prevent over-drainage. The solenoid valve we are using is normally closed so if the system were to suddenly

A switch will be placed between the high-voltage rail and the solenoid input. The switch will be controlled by an output signal from the microcontroller.

A solenoid is an actuator designed to control the flow of fluids or gases. It operates using a 12V DC power supply and has a power rating of 14W necessitating an input current of 500mA. The solenoid we are using is normally closed so if the power is lost and the microcontroller can no longer control the valve, it will automatically close, preventing an uncontrolled event from occurring.

2.2.4. Pressure Subsystem

The **Pressure Transducer** measures the **intracranial pressure (ICP)** within the **CSF drainage catheter**. It provides real-time data to the **microcontroller**, which determines whether drainage is required.

The PX119 pressure transducer offers a range typically from 0 to 10 psi. The transducer provides a voltage output of 0.5 to 4.5 V. It also has a high accuracy of +-0.25% ensuring reliable and precise pressure measurements. It operates with a 5 VDC supply voltage.

The pressure transducer will be connected to the pipe tee. The pressure transducer will need to be a precision pressure transducer as the standard Intracranial Pressure is approximately 16mg(0.309 PSI) which is a relatively low pressure.

2.2.5. Flow Control Subsystem

The **Flow Rate Sensor** monitors the **CSF drainage rate** to prevent **excessive flow (>10 ccs/hour)**. If the flow rate **exceeds the set threshold**, the **microcontroller will signal the solenoid valve to close**.

The Sensirion SLF3S-0600F is a low-power differential pressure sensor. It outputs data as a 16-bit number via I2C. The flow rate is equal to the output value in uL/min. Additionally, It features a pressure range of -600 Pa to +600 Pa. The sensor provides a digital output using the I2C interface. This sensor is typically powered by a 3.3 V. The SLF3S has high accuracy for its offset error, +-0.5 Pa, and full-scale error, +-3 Pa, which is essential for precise monitoring.

2.2.6. Graphical User Interface Subsystem

The **GUI** provides an **interactive display** for medical professionals to **monitor pressure, flow rate, and valve status** in real time. It also **logs data and triggers alerts** for abnormal pressure levels.

Since we are using the **Texas Instruments CC2340R52N0RGER** microcontroller, our graphical user interface (GUI) will need to communicate with it via **Bluetooth Low Energy (BLE)**. We must establish a connection for the BLE which will allow the GUI to read sensor data and send control commands. The GUI will run on a **Windows, Linux, or Mac monitor**, so we will be using **Python with PyQt, Kivy, or Bleak (for BLE connectivity)**.

2.3. Subsystem Requirements

2.3.1. Control Subsystem (Microcontroller)

1. Must have an ADC resolution of at least 12 bits to process small pressure variations accurately.
2. Must support I²C and Bluetooth communication for sensor data acquisition and real-time transmission.

3. Must process and respond to sensor data within 100 ms to ensure timely CSF regulation.

2.3.2. Power Subsystem

1. Must supply at least 25mA continuously at 5V ± 0.1V to support all components.
2. Must have low dropout voltage regulators to maintain stable operation.
3. Must include power filtering to prevent electrical noise from affecting sensor readings.
4. Must protect against overcurrent (>1A) and overvoltage (>5.5V) to prevent system damage.

2.3.3. Drainage Subsystem (Solenoid Valve)

1. Must fully open within 500 ms of receiving a HIGH signal.
2. Must fully close within 500 ms of receiving a LOW signal.
3. Must operate on 12V at min. 300mA power.
4. If power is lost, the valve must default to a closed state to prevent uncontrolled drainage.

2.3.4. Pressure Subsystem

1. Must have an accuracy of at least ±1 mmHg for precise pressure regulation.
2. Must operate within a range of 0–50 mmHg.
3. Output must be 1–5V analog signal, linearly mapped to pressure.
4. Must have low drift (<1 mmHg/month) to ensure long-term accuracy.
5. If sensor failure is detected, the system must default to closing the solenoid valve.

2.3.5. Flow Control Subsystem

1. Must measure flow rates from 0–10 ccs/hour with ±5% accuracy.
2. Must use I^2C protocol to interface with the microcontroller.
3. Must have a sampling rate of at least 1 sample/second to detect sudden flow changes.
4. If the sensor fails or provides inconsistent data, the system must default to closing the solenoid valve.

2.3.6. Graphical User Interface Subsystem

1. Must display real-time pressure and flow data with at most a 10–30-second delay.
2. Must allow users to set custom pressure thresholds for automated control.
3. Must provide visual alerts if pressure exceeds safe limits (>20 mmHg).
4. Must support Bluetooth 4.0 or higher for stable connectivity.
5. If the Bluetooth connection is lost, it must reconnect within 5 seconds or notify the user.

2.4. Tolerance Analysis

pressure:0.25%< and long term drift <0.3%

The primary tolerance issue that can occur within our system is the interaction between the microcontroller and our pressure transducer. In the case of our pressure measurement, the normal intracranial pressure ranges from 15-17 mmHg(0.290-0.309 PSI). As a result, we want to achieve a pressure resolution of at least 1mmHg(0.0193 PSI). The accuracy of the sensor itself and its long-term drift are negligible as they are less than 0.25% and 0.3% respectively. The resolution of the measurement can be calculated as: $(P_{max}/2^{bits})$. Assuming we have the full 12 bits of resolution that would result in a resolution of 0.0366 PSI. However, we have to assume that we will not be able to achieve the full resolution of our ADCs as there will most likely be noise which results in the effective number of bits decreasing. Assuming that we wish to have a resolution of 1mmHg(0.0193 PSI), we can afford to lose 2 bits of precision. With 10 bits of precision, a resolution of 0.0146 PSI is obtained.

The flow rate transducer can introduce error into the system as the measurement can have at worst 5% error. The repeatability of the measurement is 0.5% so the error could be corrected assuming that a fluid flow reference was available. The fact that the transducer outputs a digital signal will significantly decrease the effects of external factors on our system. Temperature changes can effect the accuracy of the transducer as it has a temperature coefficient of 0.2%/°C so there could be a significant difference if the device were to be used in an extreme environment.

3. Ethics and Safety

IEEE Code of Ethics (IEEE Code of Ethics, 2025)

Though only a prototype, our External Ventricular Drain (EVD) Automation Project involves automating the drainage of cerebrospinal fluid (CSF). Any malfunction—such as excessive or insufficient drainage—could result in severe patient harm, including brain injury or death. As such, we will adhere to the 2025 IEEE Code of Ethics.

First, our team will ensure the safety and privacy of the public, as stated in IEEE Code 1.1. We are committed to incorporating multiple safety features to prevent failure-related hazards. For example, our solenoid valve control system will include fail-safe mechanisms to prevent excessive CSF drainage in case of microcontroller failure; in other words, the solenoid will automatically close when the voltage is cut.

Additionally, an emergency manual bypass valve will be available in case of unexpected system failure, allowing medical professionals to take immediate control. Lastly, we will integrate alerts into our GUI to notify medical professionals of anomalies, such as pressure and flow readings exceeding user-determined ranges.

Regarding IEEE Code 1.5, our team is committed to seeking and accepting honest criticism of our technical work, maintaining transparency, and properly crediting contributions, especially within our course network, including our TA, Jason Jung, and supervising professor, Yang Zhao. Any references from external sources used in the project will also be documented and credited accordingly.

Lastly, since our project involves electrical and medical components, we will adhere to university laboratory safety policies and state regulations concerning electrical safety and biohazard handling. Electrical safety is a primary concern, as our system involves microcontrollers, sensors, and solenoid valves that require careful handling. We will implement proper grounding, insulation, and circuit protection to prevent short circuits, electrical shocks, or fire hazards. Additionally, all testing will be conducted in designated laboratory areas. While developing and testing our system, we will comply with ECEB Lab Safety standards for laboratory safety. Ensuring proper safety measures when working with sensitive medical devices and fluid-based systems. By following these safety protocols, we will ensure a secure and compliant environment for the successful development of our Automated Approach to External Ventricular Drains.

4. References

[1] IEEE, "IEEE Code of Ethics," ieee.org, https://www.ieee.org/about/corporate/governance/p7-8.html. Accessed 13 Feb. 2025.

[2] Bertuccio, Alessandro et al. "External Ventricular Drainage: A Practical Guide for Neuro-Anesthesiologists." *Clinics and practice* vol. 13,1 219-229. 31 Jan. 2023, doi:10.3390/clinpract13010020

[3] ECE 445 Safety Guidelines, "Safety :: ECE 445 - Senior Design Laboratory", https://courses.grainger.illinois.edu/ece445/guidelines/safety.asp.

Accessed 13 Feb. 2025