Low-cost Anesthesia Automation Device

Aadi Shah, Dylan Kong, Rikhilsai Duvvuri, Nishant Saravanan, Ryan Daoudi

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Research Question: How might we expand access to healthcare in rural or low-income areas by developing an affordable and efficient automated anesthesia administration system that aids anesthesiologists and improves patient care during surgery?

Abstract/Intro

The general purpose of this study is to develop an automated anesthesia dispensing system that is precise and safe during medical procedures. This system is supposed to minimize human error, allow for changing dose sizes based on patient-specific parameters, and streamline workflow in operating rooms. The specific goals of the study include designing a system that accurately measures and dispenses anesthesia based on real-time patient data and assessing its impact on patients, doctors, and clinics. The hypothesis is that implementing this system will lead to improved dosing accuracy and increased efficiency in surgeries. A mixed-methods approach will be used for this study. We will use a design-based research method for developing the solution over time based on the results of trials. These iterations will allow us to adjust calculations and our equipment to help refine the overall system. The significance of this proposed study is its potential to enhance patient safety and operational efficiency in prolonged surgeries. By focusing on challenges related to manual anesthesia administration, the automated system could reduce the burden for doctors, leading to more productivity and efficiency. This study could eventually lead to more advanced, automated solutions in healthcare, promoting better patient outcomes and supporting clinicians.

Importance and Background

Importance:
In rural areas around the world, there are a severe lack of anesthesiologist providers (Cohen et al.). 55.1% of these countries do not have surgeons, and 88.2% do not have access to anesthesiologists (Cohen et al.). Anesthesiology is a complicated field with many nuances that need to be considered for various surgical interventions. The issue regarding the lack of anesthesiologists within these areas is also multifaceted. From barriers that arise from low socioeconomic status to a general lack of attraction regarding employment in rural areas, it is clear that there is no "one-size-fits-all" solution to this provider shortage (Menezes & Zahalka, 2024). Currently, incentive programs known as "Pass-Through" programs help motivate anesthesiologists to temporarily work in these areas by offering monetary rewards (American Society of Anesthesiologists). However, these solutions are temporary and cannot be steadily relied upon as they are simply unable to make up for the sheer shortage of anesthesiologists in these areas. Moreover, these solutions cannot be extrapolated to rural countries as many of these countries are missing these programs altogether, further fueling the current shortage crisis.

Background:
Currently, prototypes/concepts about anesthesia automation have been put forth. However, there is a standardization surrounding these devices and questions regarding reliability. It is clear, however, that the healthcare field is moving toward the possibility of tele-anesthesia and closed-loop anesthesia in the future (Hemmerling). Therefore, our study aims to get ahead of this cutting-edge research and provide meaningful insights to the medical community

As indicated by our research, the impact of our product is intended to support anesthesiologists by relieving them of extra burdens that can reduce their efficiency during surgeries. Anesthesiologists often do more than just administer anesthesia and often have other responsibilities that require their attention. By automating anesthesia administration, it reduces human error by lessening the number of tasks. As indicated by the National Library of Medicine, "AI devices can automatically record vital signs, medication dosages, and other crucial data, enabling the anesthesiologist to concentrate on patient care" (Singhal et. al). The paper highlights that automating anesthesia can allow anesthesiologists to concentrate on more important tasks, reducing human error in patients.

Our product will mainly impact anesthesiologists and patients. Automating anesthesia will relieve any work burdens by handling sedation procedures which allows for them to concentrate on more complex and important tasks. It also makes surgeries and procedures more efficient. By automating anesthesia, it also increases precision and consistency with anesthesia delivery.

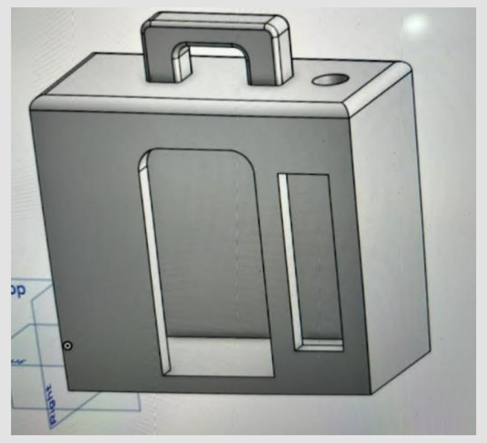
Materials

- Arduino MEGA
- Stepper Based Peristaltic Pump
- Silicon Tubing
- Pulse Oximeter (MAX 30102)
- Blood Pressure Sensor
- 12V Power Adapter
- Buck Convertor
- LCD Arduino Display
- CO_2 Sensor

Methodology and Process Steps

<u>Design Based Research</u>

1. **Problem Identification:** There is a global shortage of anesthesiologists, particularly in rural areas, and accurate measures of real-time data.
2. **Conceptual Design:** Developed using CAD in SolidWorks

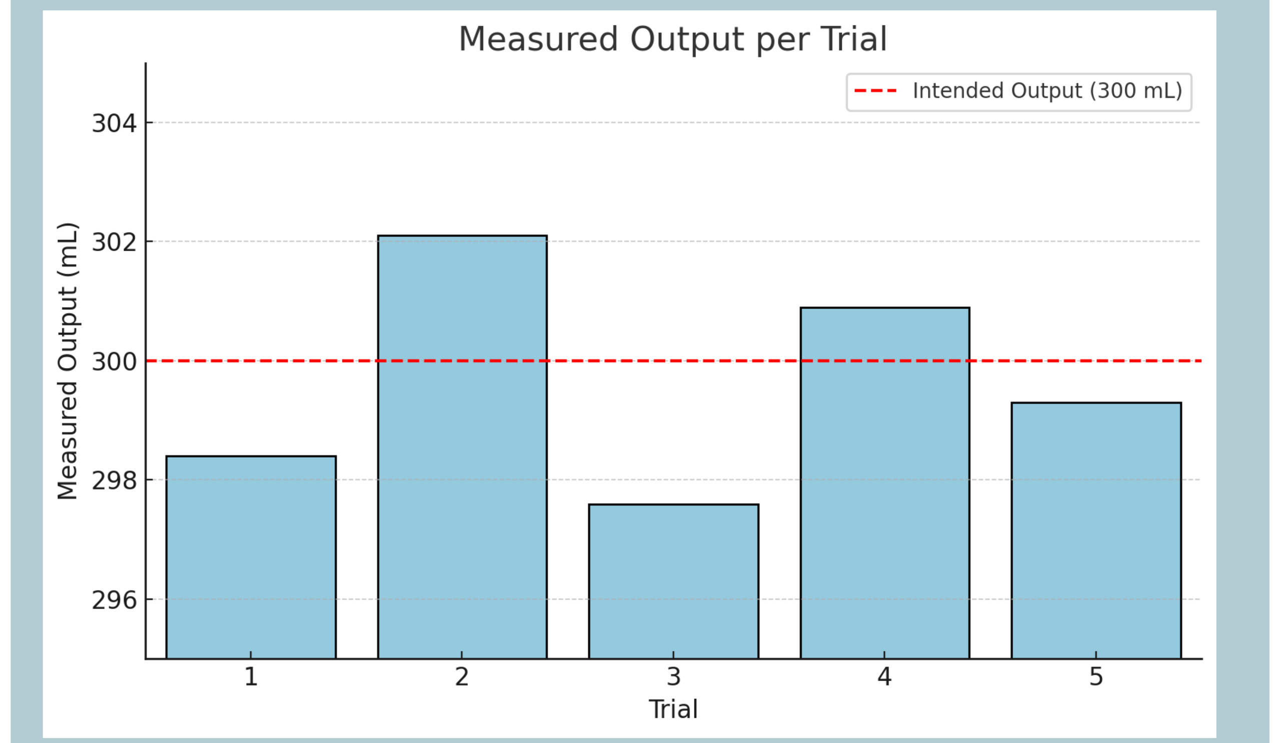


3. **Prototype Development: (Currently Being Built)**
   1. Use buck converter to step down 12V to 5V for Arduino but connect the peristaltic pump to 12V
   2. Connect the sensors to the Arduino (Pulse Oximeter, Blood Pressure Sensor, CO_2 Sensor, LCD Display)
   3. Connect the peristaltic pump to the Arduino and attach the silicon tubing
   4. Install the necessary libraries for sensors, verify the sensor accuracy, and then code the program
4. **Iterative Testing:**
   a. Run 5 trials and calculate the standard of the mean (SEM), then multiply it by 2
      i. $SEM = \sqrt{\left(\frac{\sum_i^N (x_i - \bar{x})^2}{N(N-1)}\right)}$
   b. Perform the Wilcoxon Signed-Rank Test
      i. Calculate the difference between paired observations
      ii. Rank by absolute differences then attach the original signs to the ranks
      iii. Sum the ranks of the positive or negative differences then compare the test statistic to values from the Wilcoxon signed-rank table to get p-value
   c. 95% probability from 2SEM test and a that p-value is less than 0.05 from the Wilcoxon test both indicate success.

Criteria for Success

1. Accuracy of Anesthesia Disposal
   1a. The actual disposed volume must be within ±2% of the intended disposal volume.
2. Consistency Across Trials
   2a. The standard deviation (SD) of repeated trials (≥10 runs per volume) should be less than 1% of the mean output.
3. Statistical Validation
   3a. 2SEM (95% confidence interval) must include zero(no significant bias)
   4a. Paired t-test (or Wilcoxon signed-rank test) must yield $p > 0.05$, indicating no statistically significant difference between intended and actual output
4. Machine Response to Variable Inputs
   4a. The machine should maintain ±2% accuracy across its operation range.

Results



Trial #	Intended Output	Actual Output	Deviation	Perent Error (%)
1	300mL	298.4mL	-1.6	0.53%
2	300mL	302.1mL	2.1	0.70%
3	300mL	297.6mL	-2.4	0.80%
4	300mL	300.9mL	0.9	0.30%
5	300mL	299.3mL	-0.7	0.23%

Mean Measured Output: 299.6mL
SEM: 0.82mL
2SEM (>95%): 1.64mL
P-value: 0.678
Standard Deviation: 1.83 mL

Wilcoxon Signed Rank Test:
Test Statistic: 6.0
P-Value: 0.8125

Data Results:

Accuracy: Within ±2.5 mL (or <1% error), which meets the stated success criteria of being within 1% deviation of the intended output.
Interpretation of 2SEM: The p-value is much greater than 0.05, indicating no statistically significant difference between the intended output (300mL) and the measured outputs. The machine is performing accurately within acceptable variability.
Interpretation of Wilcoxon Signed-Rank Test: The Wilcoxon test also shows **no significant difference** between the paired outputs and the target.
Interpretation of Standard Deviation: The standard deviation of the measured outputs is approximately 1.83 mL. This indicates that output volumes vary only slightly around the mean, demonstrating high precision in device performance.

Conclusion

The research we found helped us decide what materials and technological components to use, and the CAD model we made has given us an idea of what the future product may look like. At this point in the project, we have nearly finished the development of our automated anesthesia dispensing system, with only the pulse oximeter left. This is just the first iteration of the product, so future prototypes may end up looking very different when we have fully finished testing and refined it. However, our current selection of sensors, pumps, pipes, and Arduino will help make sure that the system will be capable of accurately measuring and dispensing anesthesia based on the values we give it. Our iterative, design-based research approach will allow us to continuously refine the prototype and improve dosing precision and system efficiency. With this stage of our project finished, the next phase will focus on <u>finalizing the initial prototype, testing it, then refining.</u>

Next Steps

Once the automated anesthesia machine meets all testable success criteria, demonstrating accurate (±2% error), precise (SD < 1%), and statistically validated performance, the next steps would involve refinement and preparations for real-world implementation. First, any minor deviations observed during testing would be addressed through either recalibrating the hardware or making software adjustments. Next, long-term reliability testing would be conducted to assess performance under continuous use, simulating clinical conditions. We would also add safety and fail-safe protocols (e.g., alarm systems for overdosing, power failure backups), which would also be rigorously tested. If results remain good, the machine would proceed to trials in a controlled medical environment (e.g., animal studies or simulated surgeries) to evaluate usability and integration with existing workflows. Finally, collaboration with regulatory bodies would begin to design clinical trials and pursue certification for human use. Throughout this process, feedback from anesthesiologists and biomedical engineers would drive more improvements to ensure the machine meets standards before commercialization.

Acknowledgements

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