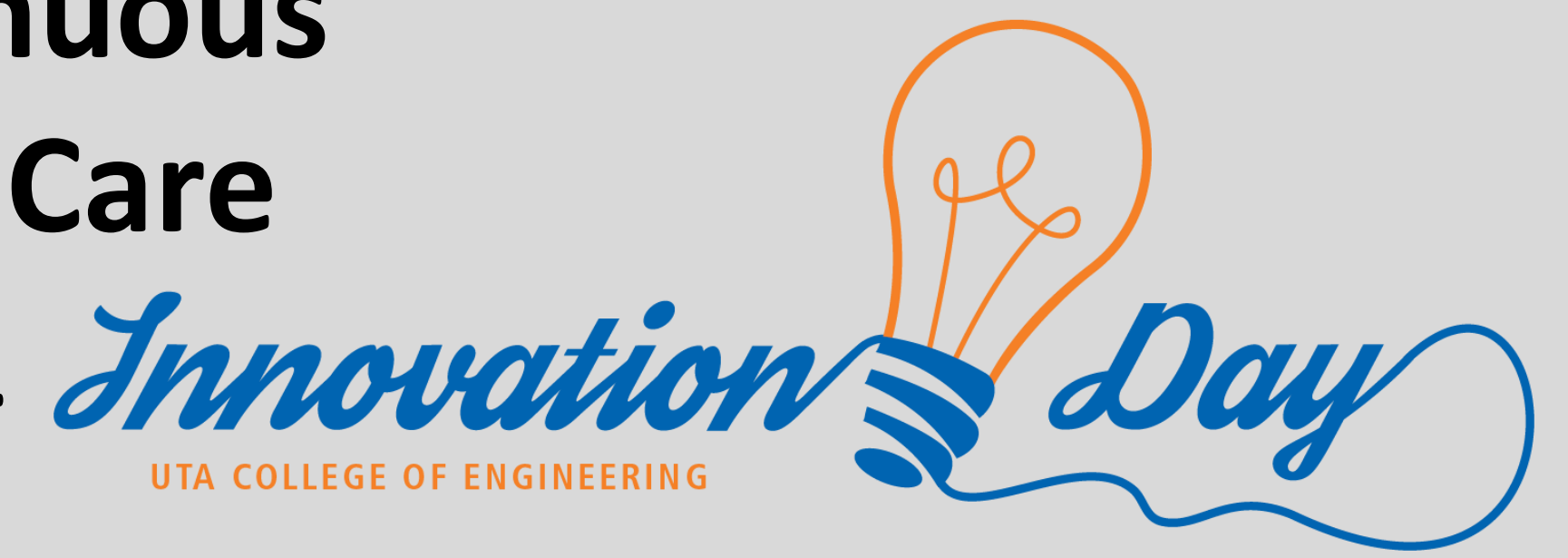


A Precision Time-of-Flight (ToF) Monitoring System for Continuous Prevention of Endotracheal Tube Dislodgement in Neonatal Care

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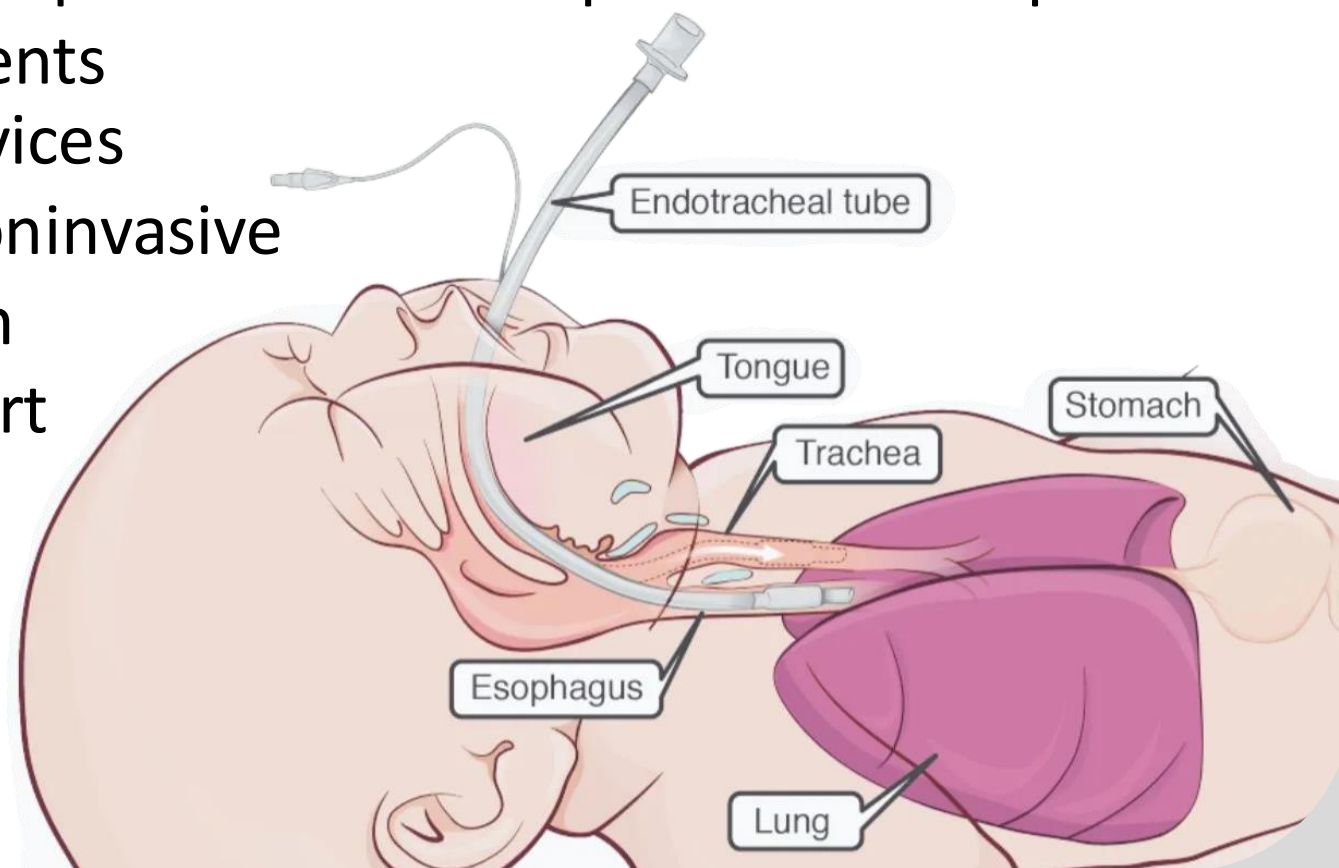
Background

Endotracheal tubes (ETT) are critical for neonates requiring mechanical ventilation however ETT displacement can be dangerous and sometimes fatal. Extubation may cause hypoxia or dislodgement to the esophagus.

Current methods of prevention are as follows:

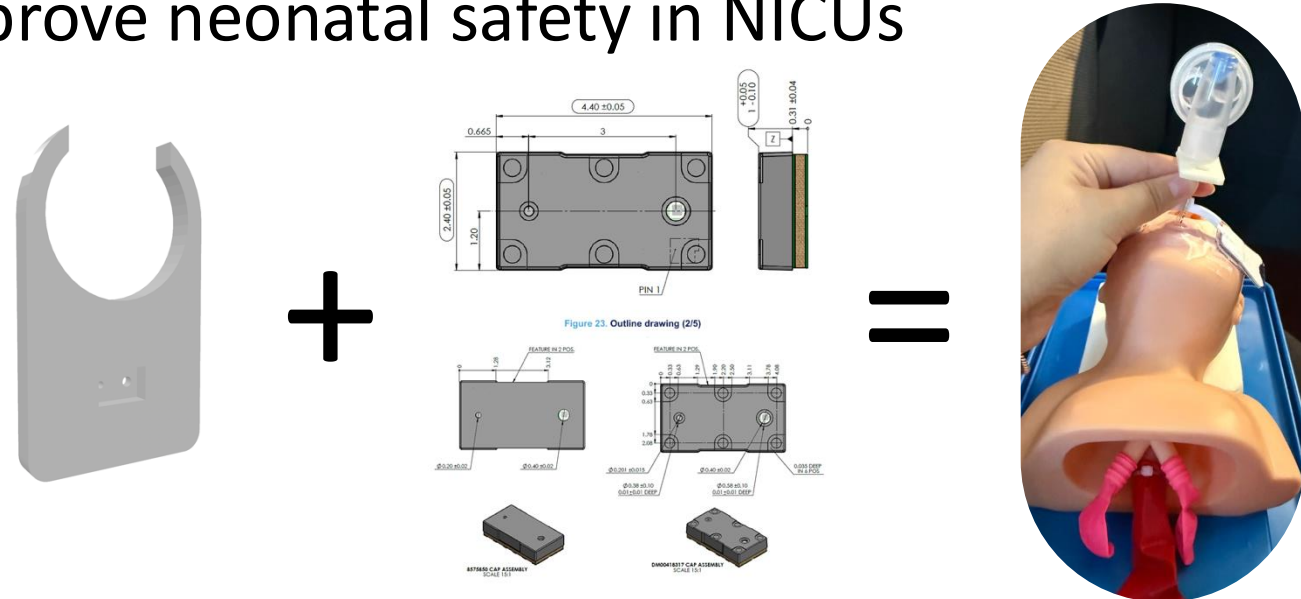
- Frequent X-rays: risks infants to DNA damage
- Sedation: prohibits from important developmental movements

Current devices focus on noninvasive stabilization without alert systems for supporting staff.



Hypothesis

Our Time-of-Flight sensor system will be able to detect within ± 1 mm of ETT displacement, provide real-time feedback and alert professionals within 3 seconds of dislodgement. Our device will reduce complications and improve neonatal safety in NICUs



Methods

Embedded systems development:

Software development:

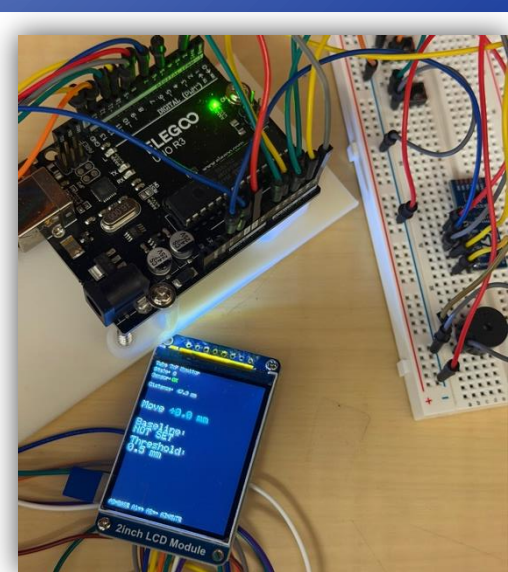
- A custom code using Arduino IDE.
- Capture a baseline distance value as a reference point and detect displacement from that point. Programmed to set a threshold, activate an alarm if displacement moves beyond the preset.

Hardware Interfacing:

- A VL53L4ED Time-of-flight sensor integrated with an Arduino microcontroller.
- A Waveshare 2-inch LCD screen was connected to provide visual feedback on real-time data.
- An integrated buzzer, triggered by the microcontroller when the displacement exceeds the threshold.

Housing Fabrication:

- SolidWorks was used to create both the adaptor and the housing.
- Printed in ABS with a PolyPrinter 229



Results

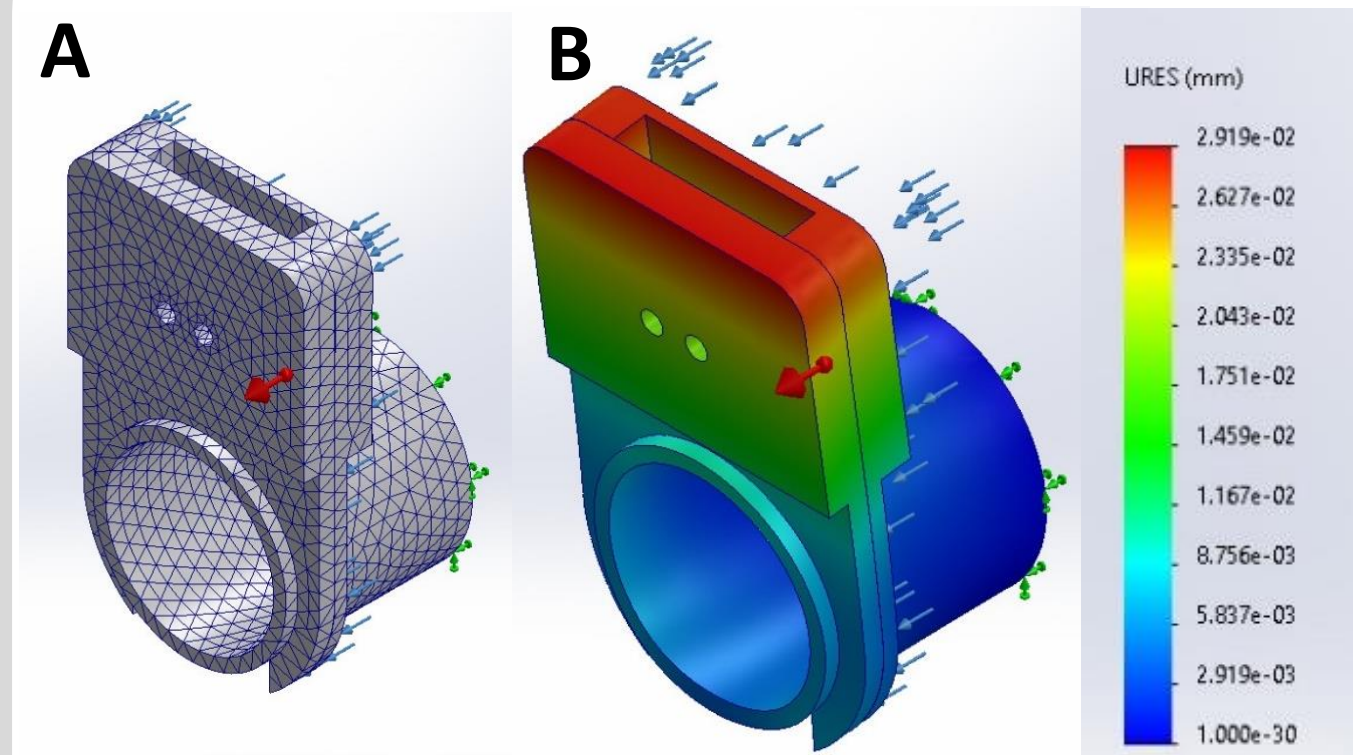


Figure 1. (A) Computational Mesh Model: structural discretization of adaptor. (B) Static Displacement Map: displays the gravitational load on the ETT with the maximum displacement being 2.919×10^{-2} mm.

Computational Testing

A study was performed in SolidWorks Simulation to show the effects of putting the weight of the device on the end of the endotracheal tube. Results: Maximum displacement was 2.919×10^{-2} mm, a negligible effect on the tubing. Study specifications:

- An external force of gravity was used to simulate the orientation of the device on the ETT. A 2-gram load was applied to simulate the weight of added component.
- One end was fixed to represent the side attached to the ventilator.

Testing of ToF sensor

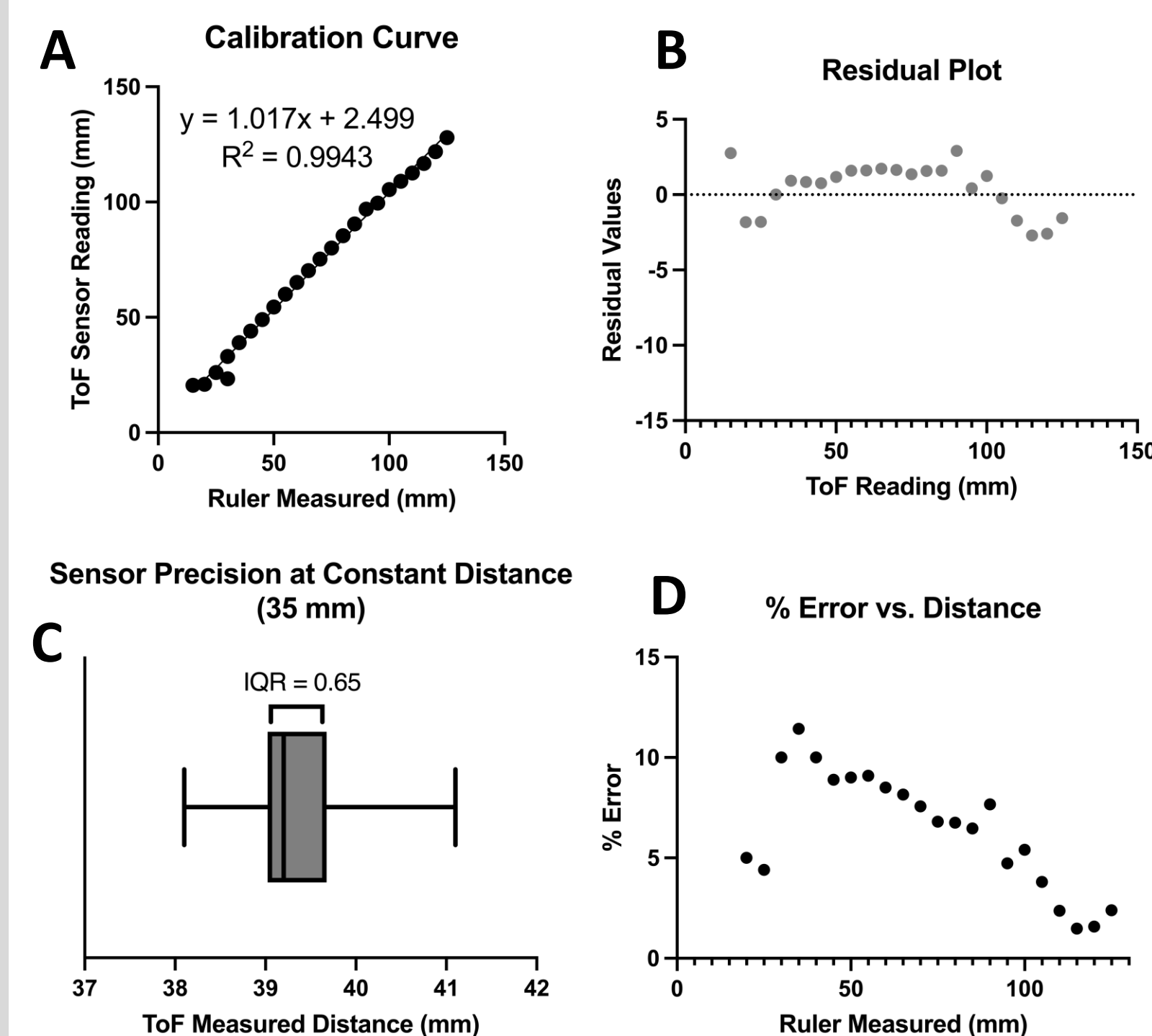


Figure 2. (A) Calibration curve indicates high linearity and predictability across the 20-125 mm range. (B) Residual plot shows the reliability of the calibration model with minor variance at extreme measurements. (C) Static precision analysis shows the high precision and low signal noise essential for the low displacement. (D) Measurement of percentage error as a function of distance, accuracy improves as distance increases with majority of the % error being under 10%.

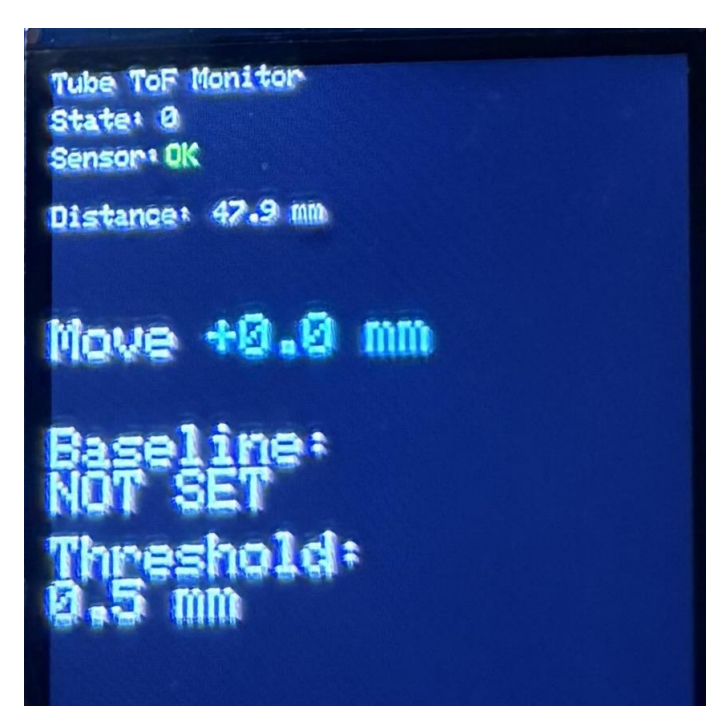
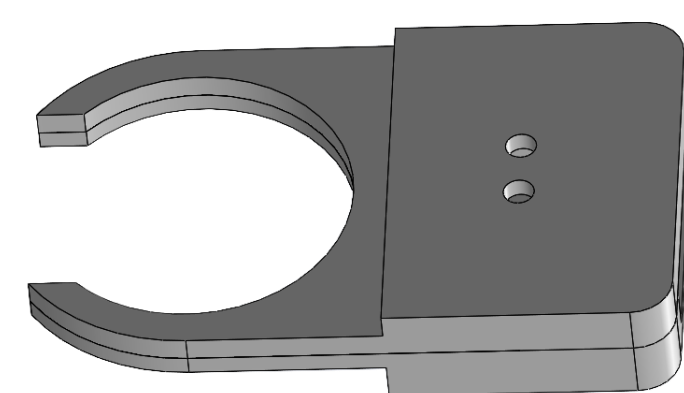


Figure 3. Current User Interface & adaptor for respiratory therapist

Table 1. Validation of Device Structural Integrity and Sensing Performance. Summary of mechanical and functional testing.

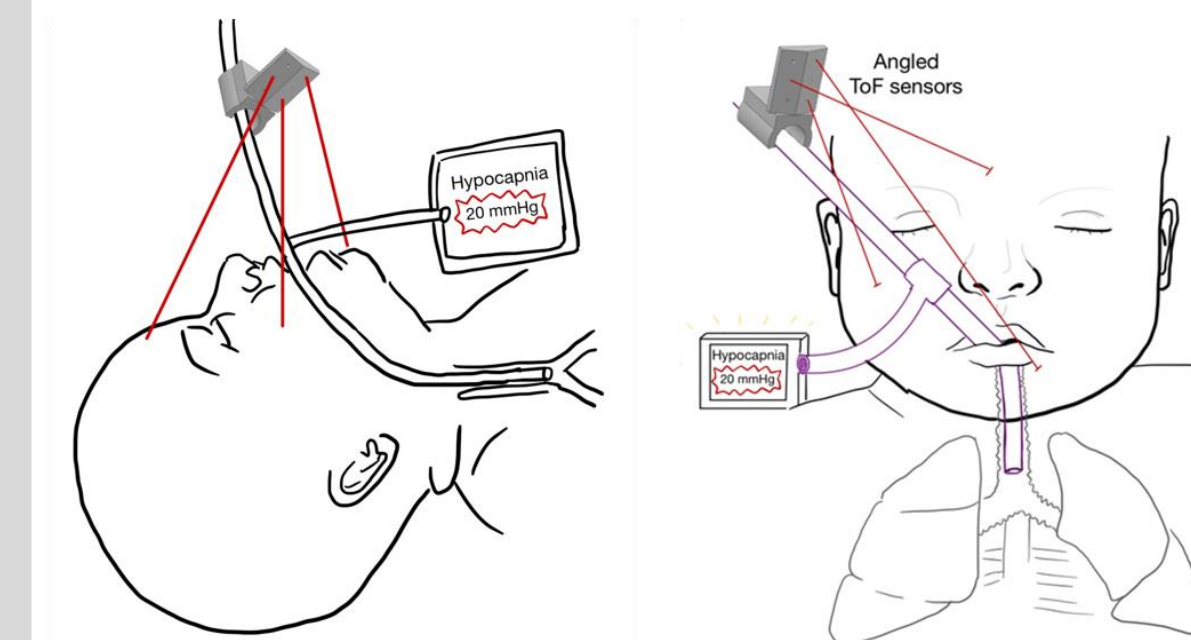
Test	Description	Results
Drop Test	Device was dropped from 1 meter and checked for damages. (n=30)	No significant damages to structural integrity
Alarm Sensitivity	Device was hovered past the threshold to determine the amount of time to alert. (n=30)	1 ± 0.05 second response time with a ± 1 mm sensitivity
False Alarm	The alarm response was converted to binary and recorded in response to the threshold being reached. (n=30)	There were 0 false alarms
Illumination Sensitivity	Device was tested at different distances ranging from 10-120 mm in the light and dark. (n=30)	There was no significant difference in the ToF sensor readings in light or dark conditions ($P > 0.05$).

Specifications and Constraints

Table 2. Design specifications and constraints

Req ID#	Function	Description	Type	Specification	Metric
FS-01	User interface	The system should be able to allow the clinician to input information and control the monitoring.	Objective	The clinician should be able use the UI to record baseline, alarm threshold, pause/start monitoring in ≤ 3 taps.	No. of taps
FS-02	Movement Detection	The system should be able to detect movement of the ETT from a baseline set by the clinician after intubation.	Objective	The system should be able to detect ± 1 mm displacement in < 3 seconds.	Displacement (mm)
FS-03	Display data	The system should be able to monitor the tube continuously and display information on a screen.	Objective	The system should show on display movement from the reference point as "0.5 mm/1 mm."	Displacement (mm)
FS-04	Mechanism and Interference	The system should be able to avoid interference with other equipment.	Constraint	Position the device in a way so its mechanism is not affected by the external tubing or neobars.	Sensor reading accuracy
FS-04	Alarm	The system should be able to sound an alarm to notify the clinician in case of an emergency.	Objective	The system should give audible alarm when tube moves beyond the predetermined threshold within ≤ 3 breaths and show color-coded alerts on the screen.	Displacement (mm)
FS-05	Alert specificity	The system should not trigger any false alarms and avoid alerts when baby is being moved.	Constraint	The system should have ≤ 1 false alarm/hr.	Rates of false alarm per hour
FS-06	Battery life	The system should be able to operate on battery.	Objective	Battery runtime of ≥ 8 hours; initial prototype battery life for at least 1 hour.	Hours
FS-07	Life cycle	The device should be for long-term use.	Objective	At least 6 months.	Months
FS-08	Calibration	The system should not require frequent recalibration.	Objective	Recalibrating once a week.	Weeks
FS-09	Leakage current	The system should exhibit safe electrical exposure.	Objective	Under faulty conditions, current must not exceed $50 \mu A$	$\mu Amperes$

Conclusion



Overall, our results have demonstrated a safe and reliable method for real-time feedback with high accuracy and precision within standards for the clinical environment. In future iterations, we hope to add multiple ToF sensors for improved monitoring from multiple angles and positions of the neonate.

Additionally, combining this sensor with other sensors such as capnography sensors for a double verification of dislodgment would improve reliability. Unfortunately, time and cost constraints prohibit us from fabricating an invasive device which would likely give a better gauge on dislodgement. We will also continue to do more testing with the user interface to design something more in line with clinical needs.

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