SCANNING SYSTEM FOR OBSTETRIC ULTRASOUNDS IN RURAL COMMUNITIES

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Problem Statement

Prenatal complications are prevalent in low- and middle- income countries (LMICs) since healthcare personnel capable of performing an ultrasound are rare. Retention of these personnel is challenging due to a high rotation in rural areas, as once they are educated on the technology and procedure, they are more likely to leave for a larger community with more competitive roles and increased healthcare infrastructure. Transportation to rural areas poses a significant roadblock for visiting healthcare personnel.

Requirements and Specifications

Requirements:

- Device must be easily transportable via plane, boat, and bus
- Device must have little to no human input
- Manual must provide all necessary information for operation, without specialist assistance
- Device must be able to be disassembled and reassembled, if applicable
- Device must consider the safety and comfort of the patients and operators during scanning
- Device must not interfere with ultrasound functionality
- Device must be able to accommodate the 95th percentile of patients
- The probe, when mounted in the device, must remain in normal contact with the patient's abdomen
- Gel must not interfere with the function of the device
- Device must be compatible with different sized of ultrasound probes

Specifications:

- Total weight of device cannot surpass 22 lbf for international airline travel restrictions
- Total size of device must fit within carry-on bag and comply with international airline travel restriction (22"x14"x9")
- Maximum force the probe with a contact area of 3.08 in^2 applies is 6.7 lbf
- Constant scanning time of 18 +/-5 min

Concept Development

Initial Design Philosophy:
Create a device that properly performs the ultrasound operation mechanically.

Key design targets:

- Portability
- Standalone functionality
- Multi-axis motion capability
- Force application
- Adaptability to patient geometry

Design features:

- Constant force spring system
- 3D-printed probe mount
- Parallel pulley and rail system
- Elastic harness

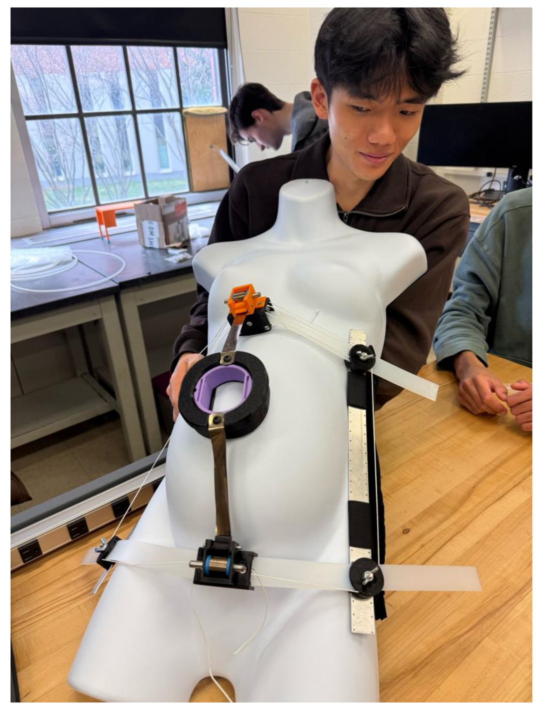


Figure 1: Testing the Frame Design on the Mannequin

Concept Description

Final Design Philosophy:
Create a device that helps new users to perform the ultrasound protocol with visual indicators

Key design targets:

- Portability
- Standalone functionality
- Force application
- Normal contact of the probe on the scanning area

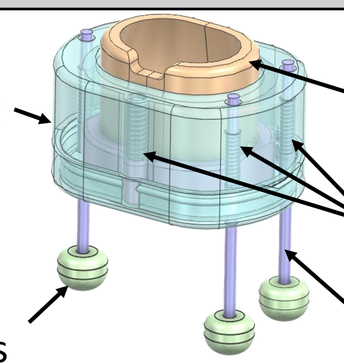


Figure 2: Final CAD Assembly

Figure 3: Final prototype of device

Design features:

- No longer working on trajectory guidance (Replace with drawing guidelines on patients)
- Spring-loaded force indicator:
- Inner sleeves with kinematic mounting to accommodate many probe sizes
- Color bars correlating displacement to force
- Spring-loaded perpendicularity mechanism:
- 3 points of contact to ensure perpendicularity on local scanning area
- Matching colors on top of the legs to maintain normal contact

Analysis

During the design phase, a question of whether two perpendicularity indicator legs were sufficient, or if a third leg was necessary. A curvature analysis was performed to quantify the loss in angular resolution by approximating perpendicularity with two legs. The analysis showed the resulting angular deviation at maximum curvature was 14°, which exceeds the angular tolerance and led to a third leg being included. Since the design requires the push rods to move smoothly in the probe holder to indicate perpendicularity, a tolerance analysis was also done to determine the necessary tolerances for each piece during manufacturing. The fit used was an FN5 fit, otherwise known as a force drive fit.

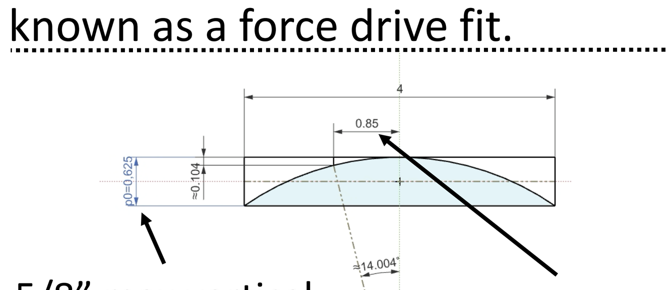


Figure 4: Curvature Analysis Results

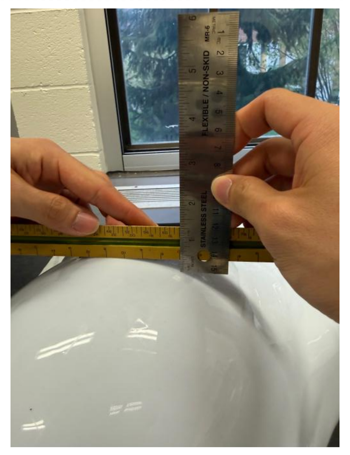


Figure 5: Example Curvature Measurement

Table 1: Tolerance Requirements for Push Rods

Component	Nominal Diameter	Tolerance (in)	Limits (in)
Hole (Sleeve)	0.1820	+0.0007/ +0.0000	0.1820-0.1825
Shaft (Rod)	0.1820	+0.0017/ +0.0012	0.1832-0.1837

Additionally, the design contains two snap fits to allow for removal of the probe and encasement pieces. These pieces slide into the inner piece of the probe holder that moves with the springs. The two hemispheres on opposite sides of the encasement pieces will lock into place above the inner piece after applying a small displacement. A structural finite element analysis was done to verify the stress on the inner piece is acceptable.

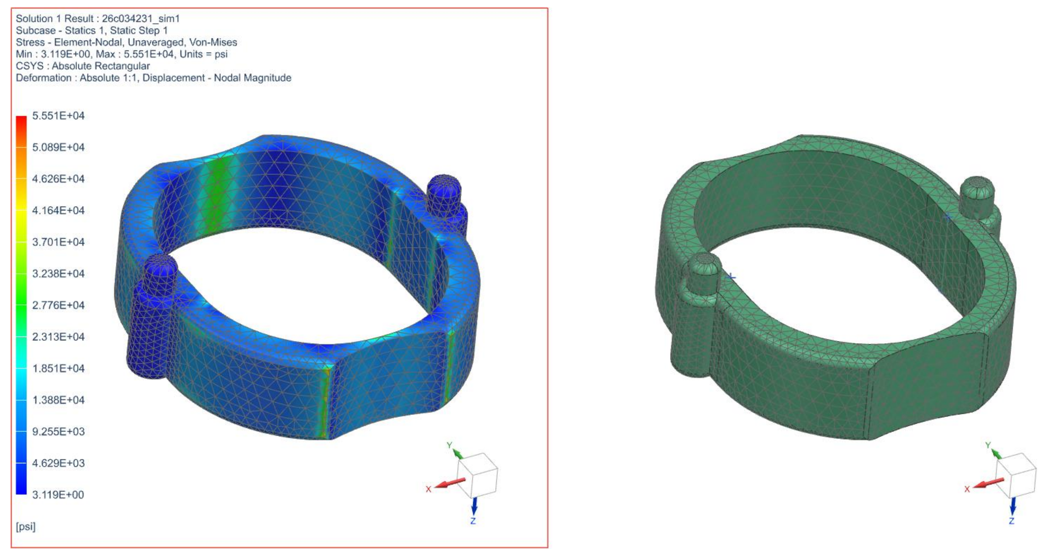


Figure 6: Structural Analysis of Snap Fits

Manufacturing

The main manufacturing method used for this prototype was 3D printing to allow for rapid prototyping between iterations. In the initial design, the team divided each subsystem for CAD modeling and printing among individuals: the probe mounting fixture with the detent mechanism, the constant force spring fixture, and the carriage, pulley, and frame system. After switching designs, the team again mostly 3D printed the individual parts. The perpendicularity rods were machined from stock.

Figure 7: 3D Print Iterations

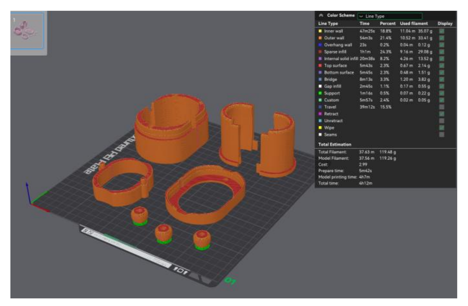
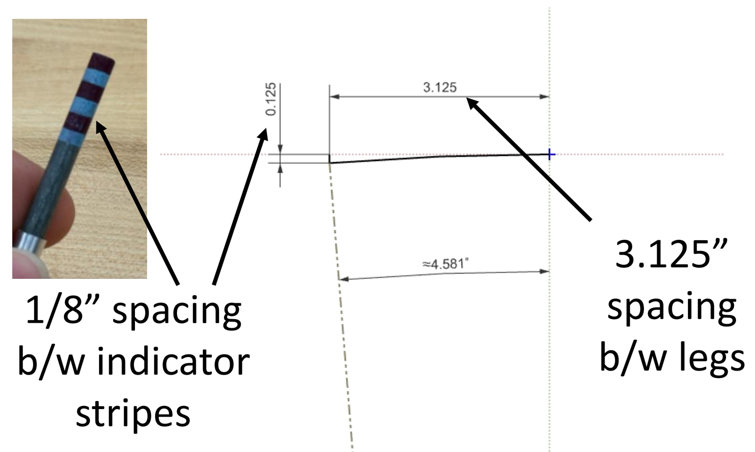


Figure 8: Screenshot of printbed in slicer

Testing



Combined spring constant = 2*1.1 = 2.2 lbf/in

$$Resolution = k(x_{green\ max} - x_{green\ min})$$

In addition to testing the device on a pregnant phantom model, the team also calculated the resolution of the perpendicularity and force indicators to determine accuracy of the device. The perpendicularity indicators are accurate within 4.5 degrees while the accuracy of the force indicators was found to be 0.275 lbf.

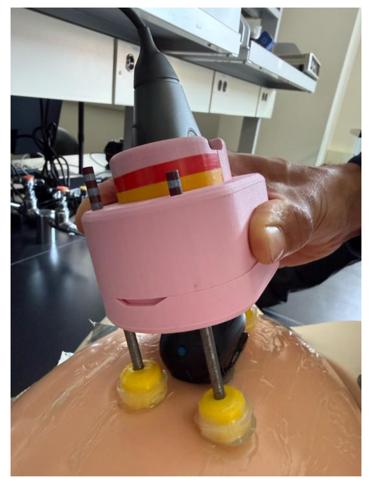


Figure 9: Probe not pressed with enough force and not at normal contact

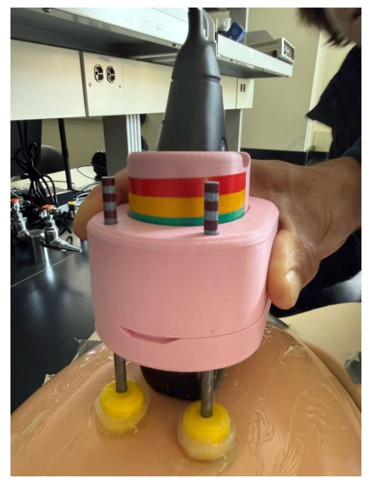


Figure 10: Probe pressed with enough force (at green color bar) and at perpendicular contact (same levels on leg indicators)

Figure 11: Testing functionality of prototype on vertical sweeps

Specification	Description	Pass/Fail
1	Total weight cannot surpass international airline travel restrictions	Passed
2	Total system's size when disassembled must fit within a carry-on bag based on airline travel restriction	Passed
3	The maximum force the system applies across a cross-sectional area of 3.08 in^2 (probe area) is 6.7 lbf.	Passed
4	The system maintains a constant scanning time of 18+/-5 min	Failed

Future Work

If given more time on the project, the team would be able to troubleshoot the frame-spring design more. Firstly, an alternative to the sharp and overpowered constant force spring could be found and used. Additionally, the team would be able to design a stiffer frame for the probe to attach to via the springs to reduce the amount of deformation. Lastly, the team could explore other ways of solving the problem using electronic sensors and robotics.

Acknowledgements

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