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SCANNING SYSTEM FOR OBSTETRIC ULTRASOUNDS IN RURAL COMMUNITIES

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ABSTRACT

This project aimed to address the issue of limited access to obstetric ultrasound examinations in low- and middle-income countries (LMIC) by reducing or eliminating the necessary training to perform such operations. Sponsored by Professor Benjamin Castaneda from the University of Rochester department of biomedical engineering, the project team worked to develop a low-cost mechanical device which interfaces between the operator and a Butterfly iQ, the portable ultrasound probe of choice. The primarily 3D-printed device features mechanical indicators which inform operators of the correctness of their force application and probe perpendicularity during the operation. All CAD and simulation for this project were performed using Siemens NX, and physical tests were conducted on a maternity mannequin to approximate a pregnant woman's abdominal geometry. Late into the course of the project, the design philosophy pivoted due to unpromising test results, rendering some of the initial requirements and specifications less, if not inapplicable. Nevertheless, the team communicated closely with the sponsor to ensure that expectations were met amidst constantly changing conditions.

PROBLEM DEFINITION

Prenatal complications are prevalent in low- and middle- income countries (LMICs) since healthcare personnel capable of detecting conditions early by performing ultrasound examinations are rare. Despite existing training initiatives in these areas, retention of these personnel is challenging due to a high rate of rotation in rural communities, as once they are educated on the technology and procedure, they are likely to leave for more developed areas with more competitive roles and enhanced healthcare infrastructure. Transportation back to these rural areas also poses a significant roadblock for visiting healthcare personnel who wish to perform examinations in these communities. The goal of this project is to address the problem by removing the need for training to perform ultrasound examinations. Current processes for delivering point-of care ultrasound (POCUS) in these areas require trained personnel to travel extensively to patients' homes. By constructing a device which mechanically enforces adherence to the obstetrics Volume Sweep Imaging (VSI) ultrasound protocol, pregnant women can seek ultrasounds from local physicians and healthcare providers who will be enabled to perform these examinations without specialized training.

REQUIREMENTS, SPECIFICATIONS, DELIVERABLES

Table 1: Deliverables

	Deliverable
1	Prototype device that can be tested
2	Technical report with testing data
3	Theory of operation manual for device
4	Website to summarize project work
5	Poster for design day
6	Device maintenance manual for technical engineer

Table 2: Requirements

	Requirement
1	The device must be electronically compatible internationally
2	The device must be easily transportable via plane, boat, and bus
3	Manual must provide all necessary information for operation, without specialist assistance
4	The device must be able to be disassembled and reassembled, if applicable
5	The device must be designed in such a way that it considers the patient during scanning
6	The device must not interfere with ultrasound functionality
7	The device must be designed in such a way that it considers the operator during scanning
8	The device must be designed to accommodate the 95th percentile of patients
9	The device must hold the ultrasound probe such that the probe is always in full and normal contact with the patient's abdomen
10	The gel must not interfere with the function of the device
11	The device must be compatible with different sizes of ultrasound probes

Table 3: Specifications

Specification	# Value	Units	Description	Method of evaluation (brief description)
1	22	lbf	Total weight cannot surpass international airline travel restrictions	Measure final product on a scale
2	22x14x9	inch	Total system's size when disassembled must fit within a carry-on bag based on airline travel restriction	Measure product with a tape measure
3	1.00E+02	Wh	Maximum power contained in each Lipo battery used to run the system, if applicable, must be less than 100Wh to comply with airline travel restrictions	Verify with the battery's specification data
4	18	min	The system maintains a constant scanning time of 18+/-5 min	Record the time each scan takes with a timer
5	30	N	The maximum force the system applies across a cross-sectional area of 3.08 in^2 (probe area) is 30 N.	Verify with a force sensor
6	25	Wh	Each scan must use no more than 25 Wh.	Perform scans on multiple patients

CONCEPTS

Table 4: Pugh Matrix

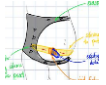
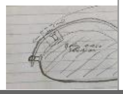
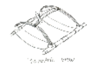
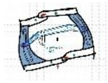
	Design 1 (Baseline) 	Design 2 	Design 3 	Design 4 
Portability	0	-	-	-
Intuitiveness	0	+	-	-
Patient Conformity	0	-	+	-
Material availability	0	+	+	+
Prototype readiness	0	+	+	-
Manufacturability	0	+	+	+
Total	0	2	2	-2

Table 4 summarizes the team's evaluation of the four initial designs. Concept 1uses an adjustable harness-type strap to secure the device to the patient and leave the stomach area open for scanning. The ultrasound probe rides along an elastic rail spanning the scanning area and attached at either end to the top, bottom, and sides of the frame to ensure the accuracy of the sweep trajectory without expert knowledge. Design 2 is a variation of design 1 and uses an elevated rail above the patient's stomach to avoid interaction with the gel on the patient. The ultrasound probe sits in a carriage on rollers that allows for constant perpendicularity. The elevated rail is interchangeable so that the user can choose from a range of varied sizes depending on patient geometry. Similar to the first two designs, concept 3 is a patient-mounted device with two telescoping poles sitting along the sides of the patient to change the locations of the top and bottom semi-rigid rails in the shape of an arch. An elastic middle rail is attached to the top and bottom rails with clamps and can be moved horizontally with the probe fixture clamped in one location to allow for horizontal sweeps. For the vertical sweeps, the middle rail can be clamped on the top and bottom rails so the probe fixture can be moved vertically along the rail. Lastly, design 4 is also mounted on the patient. On the side panels, there is a slider mechanism acting as a mounting point for the scanning frame to move vertically across the patient's abdomen to switch scanning positions. The scanning rail is secured to the slider using screw fixture and is a four-bar mechanism. Since the rail is not curved but rather a trapezoid, a joint must be implemented within the fixture to allow the probe to rotate within a certain range to always ensure normal contact with the abdomen.

During the design selection stage, design 1 was used as the baseline to compare the other designs. Each concept was evaluated based on six properties: portability, intuitiveness, patient conformity, material availability, prototype readiness, and manufacturability. Portability refers to how easily the design can be transported from one location to another in one piece or disassembled, corresponding to requirements 2 and 5. Intuitiveness relates to requirements 3 and 4 and how easy the device is to use with little to no specialist training and little to no human input. Patient conformity is needed for requirement 9 to accommodate the 95th percentile of patients. The last few properties evaluate the designs on the difficulty of moving forward. For material availability, the materials needed for each concept were considered in terms of cost, shipping availability, and time limitations. Prototype readiness evaluates if any functionalities for each design still needed to be worked out. Finally, manufacturability refers to the CAD complexity, machinery and tool choices, and material-specific requirements of each concept.

Although design 2 and design 3 were tied in the Pugh matrix, the team decided to move forward with the main functionality components of design 3 being built into the framework of design 1. The top and bottom rails of design 3 were built into the fabric above and below the stomach of design 1. The probe fixture used a detent mechanism to allow for changing the orientation based on the sweep. The rails contained a pulley system to allow for consistent traversal of the middle rail along the top and bottom rails for the horizontal sweeps. Vertical bars were added to the sides of the fabric to outline the stomach and help prevent the top and bottom rails from being pulled inward with probe movement.

After initial testing demonstrated the difficulty of pulling the middle rail with the pulley system using the probe and mount, the team decided to pivot treating the design as a training device. The frame and rail system were removed, and the mounting fixture was changed to be a standalone device, as shown in Figure 1. The user holds and applies a force on the outer hollow piece. It is attached to a second piece inside using a spring. The inner piece sits on a small ledge on the bottom of the piece encasing the probe. As the outer piece moves down, it transmits a greater force on the probe and stomach. There is a color scale that indicates to the user if they are providing a force in the acceptable range for the scan. The three rods around the sides indicate to the user if they are keeping the probe perpendicular to the stomach. They are also attached to the inside of the outer piece using springs.

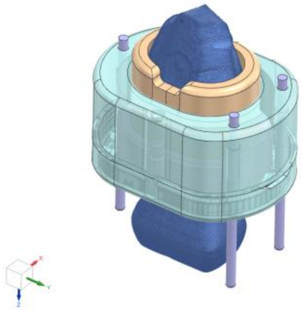


Figure 1: CAD Assembly of Final Design

MECHANICAL ANALYSIS

TOLERANCE ANALYSIS

As seen in Figure 1, there are 3 rods that slide up and down in the probe mount assembly. These rods are made of steel and there is a small aluminum collar that is press fit onto these rods so that they can function as intended. The outer diameter of the steel rod is 0.185 inches, and the inner diameter of the aluminum collar is 0.182 inches. For this press fit to be successful, both the shaft and the collar must be manufactured to certain tolerances. The inference between the shaft and pin is as follows:

$$\delta = D_{shaft} - D_{pin} \quad (1)$$

$$\delta = 0.185 - 0.182 = 0.003\, inches$$

This fit is characterized as an FN5 fit otherwise known as a force drive fit. This is the strongest kind of press fit and is used in applications where high frictional strength between parts is required. The interference calculated above is found to be greater than what is necessary for this fit. According to ANSI B4.1, to ensure a FN5 fit the following tolerances must be adhered to during manufacturing:

Table 5: 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

This tolerancing will ensure a maximum interference of 0.0017 inches and a minimum interference of 0.0005 inches, which is the recommended amount for a FN5 fit. This is smaller than the interference used in the prototype that was made.

FATIGUE ANALYSIS

The design of the device uses a total of five springs: two for the transmission of the force and three for helping keep the probe in normal contact with the stomach. For the two springs transmitting the force on the probe, a spring fatigue analysis using a torsional Goodman failure criterion with Zimmerli data was conducted to estimate the factor of safety guarding against fatigue-failure per spring. To start, the mean coil diameter, D, was calculated to be 0.35 inches by subtracting the wire size from the outside coil diameter. Then, the spring index, C, was calculated using Eqn (2) to be 14.

$$C = \frac{D}{d} \quad (2)$$

From there, the Bergstrasser factor, K_B, was calculated using Eqn (3) to be 1.09.

$$K_B = \frac{4C+2}{4C-3} \quad (3)$$

Next, since the springs are preloaded, the preload force and maximum operational load during use were calculated using Eqn (4). The preload was found to be 0.55 lbf and the maximum force was found to be 1.1 lbf.

$$F = kx \quad (4)$$

These values were then plugged into Eqns (5) and (6) to calculate the alternating force and mean force, respectively. The alternating force was found to be 0.275 lbf while the mean force was calculated to be 0.825.

$$F_a = \frac{F_{max} - F_{min}}{2} \quad (5)$$

$$F_m = \frac{F_{max} + F_{min}}{2} \quad (6)$$

The alternating shear-stress was calculated using Eqn (7) to be 17.2 kpsi and the mean shear-stress was calculated using Eqn (8) to be 51.5 kpsi.

$$\tau_a = K_B \frac{8F_a D}{\pi d^3} \quad (7)$$

$$\tau_m = K_B \frac{8F_m D}{\pi d^3} \quad (8)$$

After calculating the shear-stresses, the ultimate tensile strength is estimated using Eqn (9) to be 343.2 kpsi. The constants A and m are taken from [2]. The springs used in this design are music wire steel, so A is 201 kpsi-in^m and m is 0.145.

$$S_{ut} = \frac{A}{d^m} \quad (9)$$

Then, the shear modulus of rupture is estimated using Eqn (10) which applies for cold drawn wire with relatively small diameters. This is found to be 229.9 kpsi

$$S_{su} = 0.67S_{ut} \tag{10}$$

Next, the endurance limit based on the Goodman criterion is calculated using Eqn (11) and the Zimmerli endurance strength components for unpeened springs. S_{sa} is taken to be 35 kpsi and S_{sm} is taken to be 55 kpsi. From these values and the calculated shear modulus of rupture, the endurance limit is found to be 46 kpsi.

$$S_{se} = \frac{S_{sa}}{1 - \frac{S_{sm}}{S_{su}}} \tag{11}$$

Finally, the Goodman fatigue criterion, which is adapted for shear, can be used to estimate the factory of safety using Eqn (12). The calculated factor of safety of each spring is 1.67.

$$n_f = \left(\frac{\tau_a}{S_{se}} + \frac{\tau_m}{S_{su}}\right)^{-1} \tag{12}$$

MATERIAL SELECTION

The primary material used in this device is 3D-printed PLA. As mentioned previously, PETG was used in previous iterations of the design where endurance was a concern, but this is no longer the case with the current design. PLA was chosen as a result of the additive manufacturing-based nature of the device's component design. As one of the most accessible and affordable 3D printing filaments, PLA was the clear choice for cost effectiveness and iteration efficiency [2]. In the future, production at scale would likely use injection molded plastics, taking advantage of the rapid throughput and low costs at scale associated with injection molding.

SPRING ANALYSIS

The assembly contains two types of springs: one used for indicating how much displacement the user is enforcing on the probe, and one used to vary the height of the three contact legs and ensure the probe is in normal contact with the scanning area. For the springs used in the three contact legs, a spring sizing analysis was conducted to verify that the chosen springs will not yield under the operation. The springs used in the prototype are made from 302 Stainless Steel, and each has the following measurements: outer diameter OD=0.219", inner diameter ID=0.187", wire diameter d=0.016", maximum load: 0.65lb, spring rate k=0.89 lbf/in. These springs do not need high stiffness, since the contact legs need the ability to be displaced easily with a low force applied. The displacement in this case is initiated by the contact between the abdomen and the protruding legs of the probe. As the probe is moved to scan the different regions of the abdomen, the radius of curvature along the surface will vary, causing these legs to shift to different heights thanks to the springs.

The spring index can be calculated as the mean diameter D over the wire diameter d:

$$C = \frac{D}{d} \tag{13}$$

From Eqn (13), C was found to be 12.69. According to [2], for 302 Stainless Steel springs, the exponent m is 0.146 and A is 169 $kpsi \cdot in^m$ for a diameter of 0.016 in. Using Eqn (9), the ultimate tensile strength S_{ut} for the spring can be found to be 309 kpsi. Under torsion, the elastic limit of a spring made from 302 Stainless steel is estimated to be 45-55% of the S_{ut}. As such, the maximum allowable torsion stress can be approximated from Eqn (14) to be 139kpsi.

$$S_{sy} = 0.45S_{ut} \tag{14}$$

The legs with their covers were built to be at a slightly lower level than the probe when held in the mount at rest position to ensure that the legs will always be in some level of contact with the abdomen. Assuming the ends of the legs are at the exact same height as the probe's scanning surface, and that in the worst-case scenario, the user is rotating the probe 30° from the vertical, pushing the legs upward, and compressing the springs. In such a case, using trigonometry, the amount of displacement the user enforces on the spring can be found from the equation:

$$\frac{\Delta\, length}{original\ length} = \cos 30° \tag{15}$$

With an original length of 3.85", the displacement is found to be $\Delta x = 0.52"$. Knowing k=0.65 lb/in, the force applied on the spring from Eqn (4) was found to be 0.4628 lb. The shear stress correction factor, Ks, was found using Eqn (16) to be 1.039:

$$K_s = \frac{2C + 1}{2C} \tag{16}$$

Finally, the max shear stress in the spring can be found using Eqn (17) to be 60.65 kpsi.

$$\tau_{max} = \frac{K_s \cdot 8FD}{\pi d^3} \tag{17}$$

The max shear stress found was two times less than the maximum allowable torsion stress, meaning that the chosen spring will not yield under shear stress.

STRUCTURAL FEA

A significant element of the design was the ability to remove the probe from the device. Thus, a "sleeve" piece was created to encase the probe. This piece has hemispheres on two opposite sides to allow it to lock into place with the inner piece of the device. The hemispheres apply a small displacement on the material of the inner piece until the "sleeve" piece locks into place and the hemispheres are above the inner piece. To verify the stress on the inner piece would be within acceptable limits, a structural finite element analysis was done. An enforced displacement of 0.0465 inches was applied on the two flat inner faces while the outer faces were fixed to simulate how it would sit inside the outer piece. The stress results shown in Figure 2 show that the highest stress occurs at some of the edges and the opposite faces to where the displacement is applied. Since the maximum stress is below the tensile strength of PLA, the team determined that the displacement and stress were within acceptable limits.

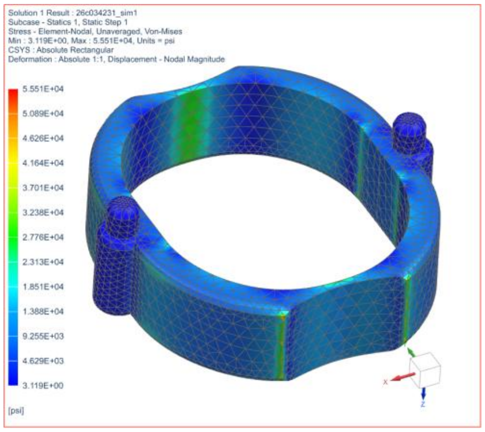


Figure 2: Fixed Displacement Simulation Stress Results

FUNDAMENTAL MECHANICAL ANALYSIS

A point of debate arose in the design of the perpendicularity indicator legs, whether the pair alone would be sufficient to indicate perpendicularity, or if a third leg would be necessary. A curvature analysis was performed to quantify the loss in angular resolution by approximating perpendicularity with two legs, the results of which are shown in figure N.

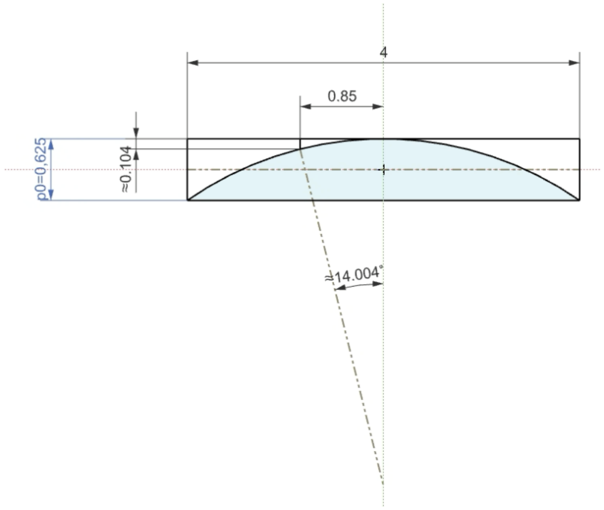


Figure 3: Curvature analysis results

To collect data for the analysis, measurements were taken at various points across the pregnant model. Using a straight ruler, the vertical deviations at 2 inches away from the tangent point were measured, resulting in a maximum deviation of 5/8”. Using these values, a radius of curvature was derived computationally in NX, where the maximum angular deviation could be computed for any leg distance.

The perpendicular distance between the probe and leg pair is approximately 0.85”, resulting in an angular deviation of 14° at maximum curvature. This exceeded our angular tolerance for perpendicularity and drove our design decision to include a third leg. Using this configuration, rather than an absolute perpendicularity scale, the operator would instead determine perpendicularity by comparing the positions of all three legs, ensuring that each are equally displaced.

MANUFACTURING

The main manufacturing method used for this prototype was 3D printing with PLA. Additive manufacturing via 3D printing enabled the team to create rapid prototypes until an effective design was reached. This was especially helpful for iterating the different components of the probe mount in the design phase. In the initial design, PETG was also used in 3D printing the probe mount due to the presence of a detent mechanism that allowed the probe to rotate and lock into two positions. In the final version of the design, the force, perpendicularity, and trajectory requirements of the prototype are achieved in separate design components; the use of PETG was omitted because the probe mount no longer required the detent mechanism. PLA was used in printing the force-indicative component of the probe mount due to its relative durability, since this part houses two springs and supports the weight of the probe, and is subjected to repetitive compressing forces. The perpendicularity-indicative component of the probe mount is in the form of long rods nested inside the outer probe mount casing. Since these rods must slide smoothly within the probe mount, machining them out of metal can prevent the issue of layer lines from 3D printing parts rubbing against each other, causing rough movement, and potentially jamming the parts. Each rod has a middle section that is bigger in diameter than the rest of the part to ensure the legs do not fall out of the probe mount. The diameter of the thinner rod section is 0.185 in and is 3.85 in long, and the diameter of the thicker section in the middle is 0.23 in and 0.5 in long. Considering the small diameter of the rod, it was challenging to 3D print the part with good quality or even machine 0.25-in aluminum stock down to 0.185 in on both ends—the rod would vibrate excessively on the lathe, making it too difficult to turn down the diameter. The alternative machining strategy the team came up with was to use a 0.185-in steel rod already available and hacksawed the stock into 4-in sections, from which they were turned down to 3.85-in pieces. From 0.25-in aluminum rods, the team created 0.5-in sleeves whose diameter is 0.01 in less than the steel rod. The team then used masking tape to mark the position where the sleeves should sit on the steel rod, and press-fit the pieces together.

The objective of this project involves working around a curved surface defined by the abdomen of the patients, which requires the use of highly conformable materials that can be fixed on or remain in good contact with such curvature. In the early iteration of the design, a flexible and lightweight frame made of UHMW-PE was used to serve as a reference for the scanning area. The two horizontal UHMW-PE sheets easily bend around the rib cage and the region above the pelvic bone, which helps narrow down the area of focus for the scanning operation, and acts as a rail for some 3D printed carriages with constant force springs to slide on and guide the probe mount to move on a straight path. However, after the design pivoted into a training apparatus and most of the functionality was centralized to the probe mount, the frame system was eliminated from the design to reduce complexity, and the trajectory requirement is satisfied by manually marking guide scanning lines onto the patients' abdomen.

Table 5: Cost Estimate of System

Category	Description	Cost
Purchased Hardware	Steel Rods	$1.50
	Rubber Bumpers	$8.99
	Aluminum Stock	$0.95
Purchased shop time		$0.00
3D printing Material cost	PLA (119g @ $25/kg)	$2.99
Team Member Time	Manufacturing Time	$1,600
Total		**$1,611.44**

Table 6: Development Time Estimate per Team Member

Member	Time	Cost
Dominic Collins	45	$4,500
Hailey Epstein	106	$10,600
Elvis Imamura	84	$8,400
Bridgit Nguyen	113	$11,300
Total	**348**	**$34,800**

If the system were to be scaled for 1000 parts, there are a few changes that can be implemented to improve the cost and build time. The probe mount casing and the perpendicularity-indicative legs can be manufactured with injection molding to decrease the manufacturing time with higher build quality and consistency. The leg covers at the end of each rod can be cast in a mold and made with silicone to ensure the patient does not feel any discomfort from the legs pressing onto the abdomen, and that the part can glide smoothly in ultrasound gel.

TEST PLAN AND RESULTS

Table 7: Testing plan of specifications

Specification	Method of evaluation (brief description)		Pass/Fail/Not applicable
1	Total weight cannot surpass international airline travel restrictions	Measure final product on a scale	Passed
2	Total system's size when disassembled must fit within a carry-on bag based on airline travel restriction	Measure product with a tape measure	Passed
3	Maximum power contained in each Lipo battery used to run the system, if applicable, must be less than 100Wh to comply with airline travel restrictions	Verify with the battery's specification data	Not applicable - system is fully mechanical
4	The system maintains a constant scanning time of 18+/-5 min	Record the time each scan takes with a timer	Failed - Shifted focus to ensure perpendicular and enough applied force
5	The maximum force the system applies across a cross-sectional area of 3.08 in^2 (probe area) is 30 N.	Verify with a force sensor	To be tested
6	Each scan must use no more than 25 Wh.	Perform scans on multiple patients	Not applicable - system is fully mechanical

Table 8: Requirements pass/fail

Requirement		Pass/Fail/Not applicable
1	The device must be electronically compatible internationally	Not applicable-fully mechanical system
2	The device must be easily transportable via plane, boat, and bus	Passed
3	Manual must provide all necessary information for operation, without specialist assistance	Failed-Will be provided in revision
4	The device must be able to be disassembled and reassembled, if applicable	Passed
5	The device must be designed in such a way that it considers the patient during scanning	Passed
6	The device must not interfere with ultrasound functionality	Passed
7	The device must be designed in such a way that it considers the operator during scanning	Passed
8	The device must be designed to accommodate the 95th percentile of patients	Passed
9	The device must hold the ultrasound probe such that the probe is always in full and normal contact with the patient's abdomen	Passed
10	The gel must not interfere with the function of the device	Passed
11	The device must be compatible with different sizes of ultrasound probes	Passed

INTELLECTUAL PROPERTY

Patents exist for devices which accomplish similar goals to those outlined in this project. One such patent is titled:

"Ultrasound teaching simulator for critically ill obstetrics and gynecology" (Patent number; CN210722083U). This Patent is for a training device which uses a fake pregnant torso and a fake ultrasound probe connected to sensers and a computer. The user can perform a mock ultrasound scan and receive feedback from the device. This design is similar to the device that is outlined in this document; however, it uses electronic components such as sensors and a computer as opposed to being mechanical. By making the training device mechanical, the team mitigates the need for trainees to have access to electricity or be computer literate.

Another example of a patent that is related to this project is titled: "Ultrasound training apparatus" (Patent number: US5061187A). This device differs from the previously mentioned training device because it does not provide feedback on the execution of the ultrasound. This device is a model of a human's internal organs and can be used to practice ultrasounds. A device like this cannot be used by itself to teach others how to perform ultrasounds. It is assumed that the trainee already knows how to perform ultrasounds and the device is to be used to perfect one's technique.

The two patents mentioned above attempt to help people learn how to give ultrasounds, but they differ from the device outlined in this paper. After doing a thorough patent search, it was determined that this device serves a unique and in-demand purpose that does not replicate any product that is on the market today.

It is, however, important to note that the nature of this design is inherently replicable. Additive manufacturing has introduced a new age of design in which people with access to a 3D printer are able to reproduce and distribute products shared online. The motivation of this project to create a device that brings accessible ultrasound care to LMICs can benefit greatly from the open source and open distribution of the product. Thus, while the product may be unique and patentable, making it publicly distributable and reproducible should also be considered.

SOCIETAL AND ENVIRONMENTAL IMPLICATIONS

The goal of this project was to help improve access to prenatal ultrasound screenings in LMICs. By creating a device that could reduce the amount of training operators needed to perform obstetric ultrasounds, more patients in these communities could get care and learn about possible complications early. The current VSI training protocol used in the communities allows operators to learn how to perform ultrasounds; however, once they are trained and have those skills, they often leave for positions in higher paying areas. The current device design would function as a training tool to indicate to the user if they are applying the correct force and keeping the probe perpendicular to the stomach. The user would use the badge reels to draw a line along the stomach to draw the desired trajectory along the stomach for each pass.

Throughout the design process, two of the subsystems went through many iterations. Many of the parts in the design are 3D printed as this worked better for the project timeline and ease of iteration in terms of cost; however, this leaves some PLA and PETG plastic waste from the multiple design changes which can be harmful to the environment. Both PLA and PETG can technically be recycled but often neither are due to limited industrial recycling infrastructure. PLA and PETG are classified differently than other materials and cannot be mixed with different plastics. To reduce waste and counter the negative environmental impact, previous iterations, or other sources of PLA and PETG waste could be ground down and re-extruded for recycling. Additional time could also be spent designing in CAD and including elements that changed in each iteration to reduce the number of prints and the amount of plastic filament waste.

RECOMMENDATIONS FOR FUTURE WORK

Over the course of the semester, the team implemented many design iterations in search of one that could accomplish all the requirements outlined by the sponsor. Previous designs involved strapping a rail system to the patient and using rolling carriages and constant force springs to move the ultrasound probe across the midsection of the patient. There were issues with the implementation of this design: The frame was not stiff enough to resist the force of the springs, and the springs themselves had sharp edges and were prone to coiling spontaneously if handled incorrectly. This ultimately led to the group abandoning the rail system and constant force spring mechanism.

If given an additional 6 months' work on this 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. This alternative would be challenging to find as it would not only be required to apply force onto the patient, but it would also need to keep the probe normal to the patient and allow for linear movement across the patient's midsection. Additionally, given 6 more months to work on this project, the team would be able to design a stiffer frame for the probe to attach to via the springs. The original frame used flexible plastic strips which were prone to bending and twisting. A stiffer plastic or metal frame could be made which would lead to less deformation. This would be a challenge to implement and would require some trial and error since the frame must be adjustable so that it can fit on patients of all sizes.

Due to the time constraints of this project, the team had to implement design concepts quickly with a "fail fast" approach to product design. Given 6 additional months working on this project, the team could have explored other ways of solving the problem using electronic sensors and robotics. This approach may be the best way to satisfy all design requirements but would require much more time and planning to implement.

ACKNOWLEDGMENTS

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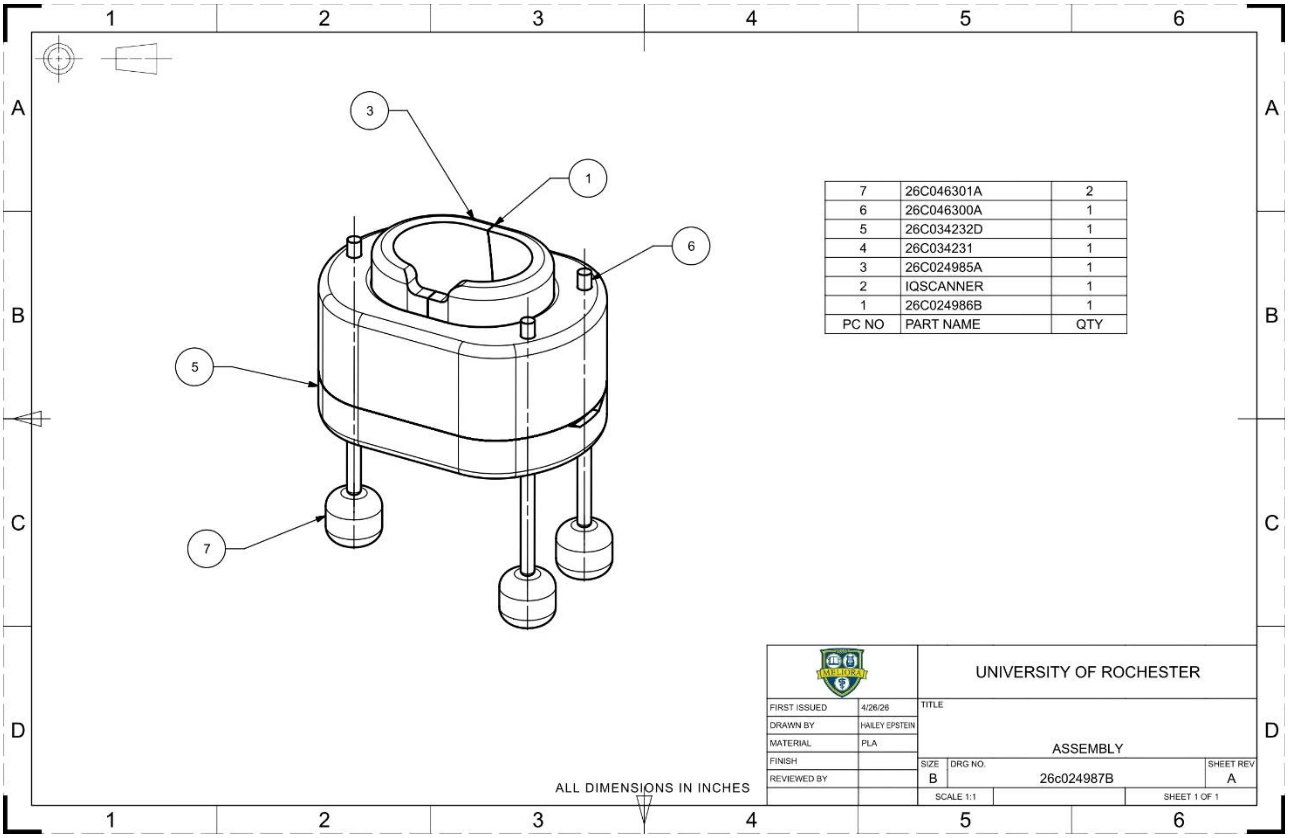
APPENDIX A – CAD ASSEMBLY



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6	26C046300A	1
5	26C034232D	1
4	26C034231	1
3	26C024985A	1
2	IQSCANNER	1
1	26C024986B	1

UNIVERSITY OF ROCHESTER

FIRST ISSUED	4/26/26
DRAWN BY	HAILEY EPSTEIN
MATERIAL	PLA
FINISH	
REVIEWED BY	

TITLE
ASSEMBLY

SIZE	DRG NO.	SHEET REV
B	26c024987B	A

SCALE 1:1
SHEET 1 OF 1

Figure 4: Assembly Drawing and BOM

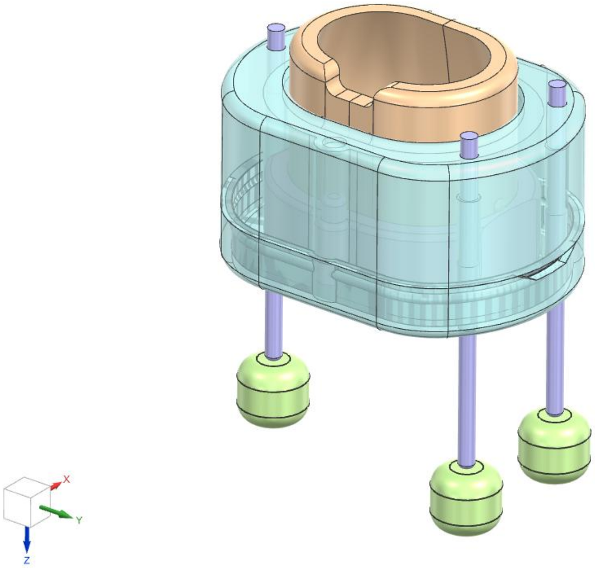

Figure 5: CAD Assembly