Engineering World Health

2020 Design Competition

Thrifti Gyre Centrifuge

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1 Problem Definition

There is an increasing demand for economically affordable laboratory devices in the developing world. The inaccessibility of devices such as centrifuges, has left underfunded hospitals with substandard devices that are not reliable. As a result, the turnover rate for the diagnosis of diseases is significantly slower than in developed countries. This leaves sick patients more vulnerable, as medical professionals are not able to attend to their illness quickly. This project aims to contribute to a solution, through the innovative design and production of a centrifuge that performs at the same level as commercial clinical centrifuges but at a reduced cost.

Centrifuges separate solids, liquids or gases based on density by spinning samples at high speeds, forcing the higher density components to the base of the sample and leaving lower density components floating above due to the centrifugal force. This enables the analysis of the fundamental components of various different substances, an important part of the process for diagnosing many health disorders. Thus, it is often used in the treatment of blood conditions such as anemia [1] and Human Immunodeficiency Virus Type 1 (HIV-1) [2].

The design aims to:

1) Reduce the dependence on unreliable power supply in developing countries and increase the device's portability through the option to switch the power source between battery and mains power.

2) Carry out the functions of a centrifuge as effectively and efficiently as commercial clinical centrifuges. This will be achieved through meeting the international performance and safety standard requirements of a commercial clinical centrifuge.

3) Utilise innovative and economically feasible methods of manufacturing, thus increasing accessibility to underfunded hospitals in terms of cost and ease of production. This includes the use of 3D printing and readily available materials.

4) Allow easy operation of the device without specialised knowledge. This will further increase accessibility and increase the rate of diagnosis in underfunded hospitals.

The centrifuge produced will serve as an example of how innovative designs can increases the economic viability and accessibility of clinical medical devices.

2 Impact in the Developing World

The World Health Organisation (WHO) has stated that over 3 million cases of infectious diseases, such as Tuberculosis and HIV-1, are not detected each year [3] [4]. This can be reduced by having access to medical testing equipment, such as a centrifuge. However, areas that do not have access to the required equipment are unable to conduct common diagnosis procedures, and hence cannot identify pestilential diseases. This can cause a delayed response for treatment, increasing the likelihood of transmission of the disease to others. Facilities lacking common diagnostic equipment are often located in low-socioeconomic countries. Hence there is a need for an affordable and high-quality medical centrifuge.

Within the developing world, there are many Non-Governmental Organisations (NGOs) that strive to provide access to affordable medical equipment. These organisations, such as a Crossroads Global Hand in rural Uganda [5], fund the implementation of centrifuges in medical facilities. However, there are often issues that prevent these devices from being fully utilised.

WHO states that 80% of the healthcare equipment provided to developing countries was donated or funded by external organisations. However, only 10 - 30% is actually utilised in facilities in these countries [6]. This low percentage may be due to missing or faulty parts, inadequate instructions and training for the device to be used, or poor distribution of donated equipment. In Cambodia, Siem Reap Provincial Hospital is a well funded hospital found in a large city that has "*a surplus of working centrifuges*", as observed by Adam Hudson, an alum of the Engineering World Health Summer Institute program. However, in rural areas such as the Kampong Thom province, the Stoung Referral Hospital owns "*only one centrifuge that did not function at all*". Hence common medical practices such as blood test or separating coagulation solutions are not carried out efficiently in these areas due to limited or faulty centrifuges. Without working medical equipment, advancements in medical diagnosis will be halted and the quality of life disparity between major and rural areas will increase.

A laboratory centrifuge costs approximately $4,742 USD [7] but are mainly found in developed countries. This is not a realistic price for purchasing equipment in low-income communities. The proposed design for a centrifuge must be economically viable without sacrificing the quality and functionality. Sourcing robust and lightweight materials, such as ABS and wood, reduces the cost and increases portability of the design for improved accessibility in remote areas. Additionally, the ability of the device to be either mains or battery powered allows communities without reliable access to electricity to use the centrifuge. The built-in LED screen displays safety protocols and instructions permitting the user to easily enter the desired time and RPM without any prior training. Furthermore, the device requires minimal maintenance which will be cost effective in the long term. As mentioned by WHO, medical equipment in low-resource settings must "*improve availability, accessibility, appropriateness and safety,*" [8]. A design successfully addresses these objectives will vastly assist disadvantaged communities and minimise the disparities of healthcare equipment between developed and developing areas.

3 Required Performance Specifications

Table 1. Required Performance Specifications

	Requirement	Reference
3.1	The device should perform as manufacturer intended when used under normal conditions and should not compromise the health of the user when the device is operated to this standard	[9]
3.2	The performance and safety of the device should not be hindered when stored and transported correctly	[9]
3.3	The device shall not operate when an unbalanced load is placed within the chamber or the device has been placed on an incline	
3.4	The device shall have a means for levelling the centrifuge	IEC 61010-2-020
3.5	The Lid of the device should remain closed and locked with sufficient strength whilst the rotor is operating. Should power failure occur, the locking mechanism of the lid shall not break nor should the lid come into contact with any rotating components when in this closed position	IEC 61010-2-020
3.6	The rotor assembly shall not exceed 250mm in diameter	IEC 61010-2-020
3.7	The device should have a switch for power that exists independent of the lid position	IEC 61010-2-020
3.8	Movement of the device shall be limited such that no component of the centrifuge can move outside of a 300mm radius from its original position nor should any component become expelled during operation of the device	IEC 61010-2-020
3.9	There shall be no openings greater than 4mm in diameter in the top chamber nor should fragments exceeding 5mm in any dimension be able to penetrate the protective casing of the device	IEC 61010-2-020
3.10	The device should be easy to repair	[6] [10]
3.11	The device should be easy to disassemble, clean and reassemble should a spill occur within the chamber of the centrifuge	
3.12	The Rotor shall still be visible when the lid is closed	IEC 61010-2-020
3.13	The device shall have a timer that displays the period of which the centrifuge is running at max desired rotational speed	
3.14	The centrifuge must have a limiting device that maintains maximum desired rotational speed once it has been achieved and the rotational frequency of the rotor shall be displayed accurately and not exceed 3600 rpm	IEC 61010-2-020

4 Implementation of Prototype

4.1 Device Manufacture

4.1.1 *Skills required*

The manufacturing process for the prototype can be simplified into two major processes. The first focuses upon the construction of the inner circuitry followed by the manufacture of a custom case to safely contain these electrical components.

Manufacturing the centrifuge is simple and can be created by an individual with prior experience with laser cutting and 3-D printing. The physical assembly only requires knowledge on how to use basic tools such as saws, glue guns, screws, etc.

4.1.2 *Circuitry*

The mechanical function of this device is enabled through the use of several electrical elements.

These elements are:

- 12V DC Motor with Rotary Encoder
- Arduino UNO
- 240 V AC to 12 V DC 60 W Power Supply
- Buck Converter (Step Down Transformer)
- Motor Driver
- LCD Screen
- Rotary Encoder
- Rocker Switch
- Servo
- Impact Sensor
- Hall Effect Sensor

Refer to Appendix A for diagrammatic representation.

4.1.3 *Device casing*

The smaller electrical components are integrated into the outer case with the dimensions of $270\,\text{mm} \times 270\,\text{mm} \times 185\,\text{mm}$ to form the basis of the Thrifti device. The bulk of the outer casing is constructed from 3 mm untreated plywood. The template for the design of the case was rendered within CAD and laser cut. All horizontal panels were cut twice and bonded together with epoxy for additional support.

Refer to Appendix B for the template.

4.1.4 *Motor mount*

The 12 V motor with inbuilt rotary encoder is housed within a mount that has been 3D printed from ABS (Figure 1) and mounted to the base of the interior of the case with M5 x 35 mm screws. Two bolts located along the length of the motor mount shaft can be tightened to clamp the motor in place.

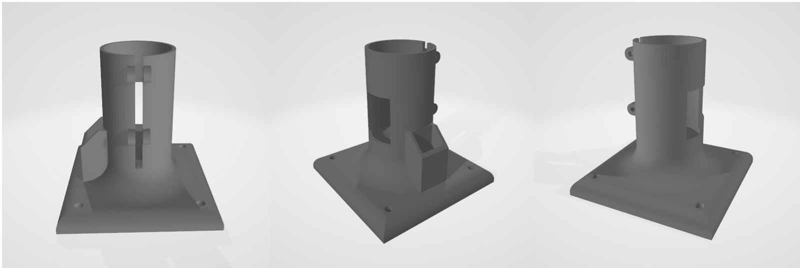

Figure 1. 3D Model of Motor Mount

4.1.5 *L-brackets*

The smaller electrical components are stored around this motor mount. Certain components such as the LCD screen, switch and knob have specific cut outs from the walls of the outer case such that they can be accessed without needing the whole device disassembled. These 3 components are fasted to the inner walls of the case via 3D printed L-brackets (Figure 2), also constructed from ABS.

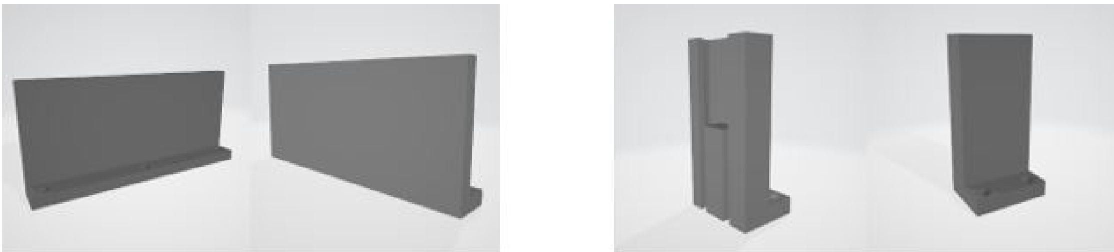

Figure 2. 3D Models of LCD and Encoder Braces Respectively

4.1.6 *Separating panel*

The inner components are separated from the rotor via a separating panel (Figure 3) that spans the opening of the lower half of the case. This panel has been cut alongside the template for the case. Small cutouts enable this panel to slot perfectly into place. There are also thicker custom L-brackets that have been screwed into place to act as a secondary support for this panel. The seam of this panel with the case has been glued together for extra reinforcement.

This separating panel has two openings:

- A large circle of diameter 230 mm
- A smaller rectangular cut out of dimensions 22 mm $\times$ 8 mm

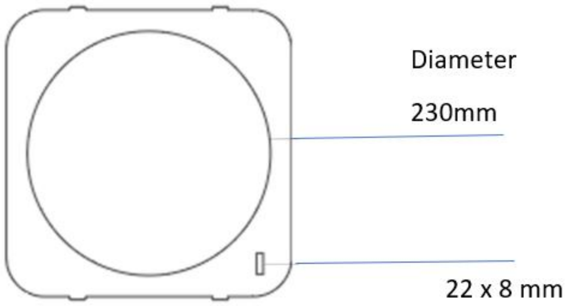

FIGURE 3. Template of Separating Panel

4.1.7 *Locking mechanism*

The locking mechanism is 3D printed from ABS, and has been bonded in place with epoxy. The hall effect sensor and servo motor have also been bonded in place within the locking mount. The key that functions in conjunction with this mechanism has been laser cut from wood, with the 20 mm magnet bonded in place at the extremity of the key.

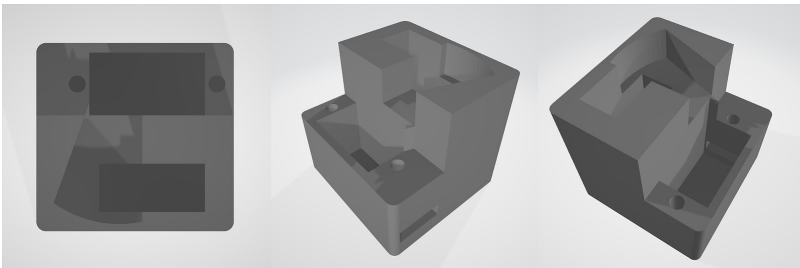

FIGURE 4. 3D Model of Locking Mechanism

4.1.8 *Rotor*

The motor feeds through a central opening in the Bundt pan, where it directly connects with a 3D printed rotor constructed from PLA. The base of this rotor has a cut out that perfectly matched the dimensions of the motor axle, with 3mm sized holes such that an M3 x 25 mm screw can be used to secure it into place.

FIGURE 5. 3D Model of Rotor

5 Proof of Performance

The centrifuge successfully demonstrated its ability to separate insoluble mixtures into its components, as shown in Figure 6. Table 3 recorded all testing trials that were conducted. Most trials have achieved transparent layers. However, some trials, did not demonstrate clear separation due to the physical properties of the components. Milk and dye are slightly soluble in water, especially when present in small amounts. Hence it was not possible to separate the components using the centrifuge speed and run times that were tested.

The centrifuge RPM and timer precision has been proven to be very accurate with an average RPM error of 2.11%. Table 2 compares the selected RPM and experimental RPM calculated by slow motion footage analysis.

The embedded safety protocols adhere with requirements outlined in IEC 61010-2-020. A locking mechanism prevents the centrifuge lid from being opened during operation. Additionally, any abnormalities during rotation such as unbalanced load or undesirable lid opening will pause the function immediately. The error will be reported and indicated on the LCD screen for users' convenience.

A video showing the operation and features of the centrifuge is available.

Safety protocol criteria:

- Pass: the centrifuge is able to detect abnormalities and only function when the specific condition is satisfied.
- Fail: the centrifuge is not able to detect abnormalities and function when the condition is not met.

Results criteria:

- 2 marks: the mixture is separated into clear layers and each layer is transparent.
- 1 mark: the mixture is somewhat separated into layers, but there are still visible contamination in each layer.
- 0 mark: the mixture is not separated.

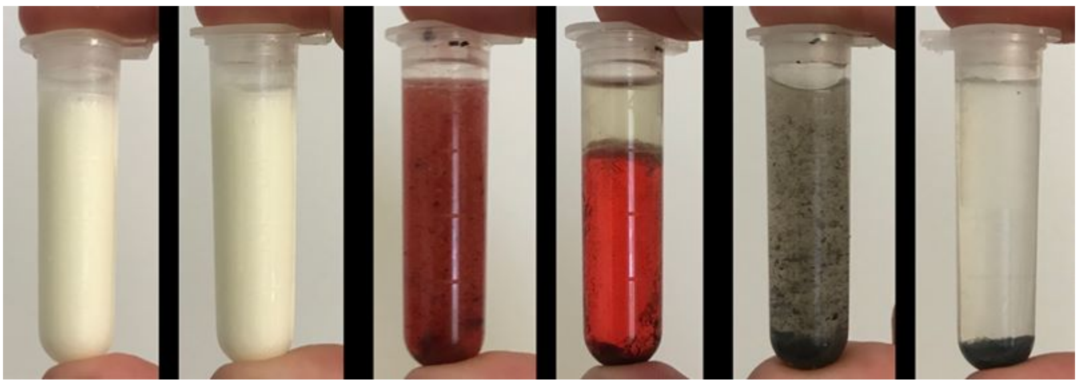

Figure 6. Examples Of Before and After Centrifuging; Indicative of 0 Marks, 1 Mark and 2 Marks Respectively

Table 2. Results from RPM Accuracy Tests

Mass (g)	Selected RPM	Calculated Experimental RPM	Error (%)
42	1000	1040	4.00
	2000	1980	1.00
	3000	2960	1.33
126	1000	980	2.00
	2000	2060	3.00
	3000	3040	1.33

Table 3. Results from Separating Mixture Combination Tests

Type of Separation	Composition	Safety Protocols			Results			
		Locking Mechanism	Lid Closed Check	Balanced Load Check	Time (s)	RPM		
						1000	2000	3000
Solid and Liquid	Soil and Water	PASS	PASS	PASS	60	2	2	2
					120	2	2	2
					180	2	2	2
Liquid and Liquid	Water and Vegetable Oil	PASS	PASS	PASS	60	2	2	2
					120	2	2	2
					180	2	2	2
	Water and Milk	PASS	PASS	PASS	60	0	0	0
					120	0	0	0
					180	0	0	0
Combination of Impurities	Water, Oil, Soil, and Dye	PASS	PASS	PASS	60	1	1	1
					120	1	1	1
					180	1	1	1
	Orange Juice, Milk and Sawdust	PASS	PASS	PASS	60	2	2	2
					120	2	2	2
					180	2	2	2

6 Business Plan for Manufacture and Distribution

Improvements to the functionality of the centrifuge will continue to be explored such as adding a UPS and support for additional languages. Additionally, further design modifications to maximise the cost effectiveness and ease of manufacture of the device will be investigated.

Following the objectives of cost effectiveness and ease of manufacture, the design utilises a range of accessible off-the-shelf materials sourced from local stores and online. Each component was selected due to its robust and reliable nature to minimise the need for constant maintenance. The total cost of this device is $134.89 (see Appendix C for cost table). Another highlight of the design is the ease of manufacturing. This device contains no custom-built parts that can't be 3D printed, and hence eliminates the need for exclusive manufacturing. The assembly also does not require specialised skills which enables local reproduction. Hence the design is extremely accessible and cost effective.

Clinical centrifuges on the current market can cost up to $4,742USD [7], which is driven by the need to pass the regulatory requirements of developed countries and the expensive materials used. As the design of the centrifuge will be open-source, the electrical schematics and assembly instructions will be readily available for wider communities to replicate.

The end users for the centrifuge are under-funded clinics and hospitals. The initial target market is local hospitals in Cambodia, gradually expanding to cover most, if not all developing countries with improvements in production capacity. During the first stage, the EWH competition will serve as an opportunity to generate awareness of the design and begin fundraising to produce ten centrifuges, using UNSW as a platform. These centrifuges will be assembled by interested societies at UNSW and delivered to Cambodia by students participating in the EWH Summer Institute program. Students will be trained on campus and will instruct end users in aspects of manufacturing and device handling. These centrifuges will be distributed to generate interest in the local area and hopefully instigate local production of the centrifuge. The feedback received will determine the future distribution and manufacturing plans.

If the demand for the centrifuge is less than 100, fundraising will be broadened Australia-wide, using EWH to raise awareness for the project. The funds raised will be utilised to hold workshops with volunteers to manufacture the 100 centrifuges. Once manufacturing is complete, NGOs and other charities will be contacted to instigate the donation of the centrifuges to countries in need.

If the demand for centrifuge is high, local workers will be employed to manufacture centrifuges for their respective hospitals and medical clinics, thus making this project self-sustaining. At this stage, a profit margin may be created by selling the centrifuge model to learning institutions for research and demonstration purposes. The profits made, combined with grants from the Australian government and NGOs will be used to pay local workers.

Quality control and monitoring will be an important consideration. When the production of centrifuge is broadened to cover most developing countries, a committee dedicated to remote training will be formed. A manufacturing instruction manual will also be published and distributed to ensure high-standard reproduction and maintenance. The expansion of the design and the popularisation of the centrifuge will make a difference in the developing countries, thus help bridging the socio-political and economic disparity within global communities.

References

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Appendix

A Diagrammatic Representation of Circuitry

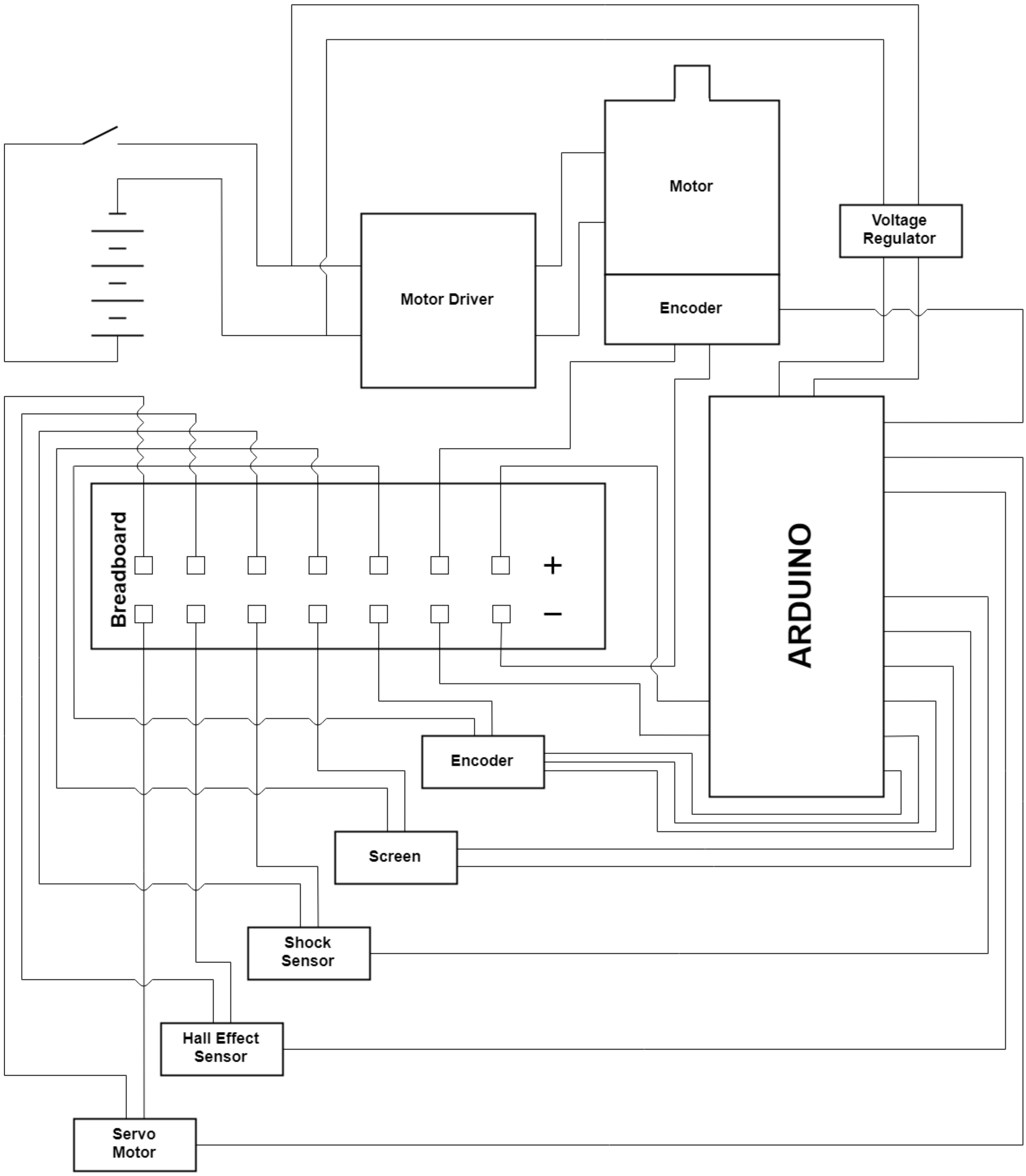

Figure 7. Diagrammatic Representation of Circuitry

B Device Casing Template

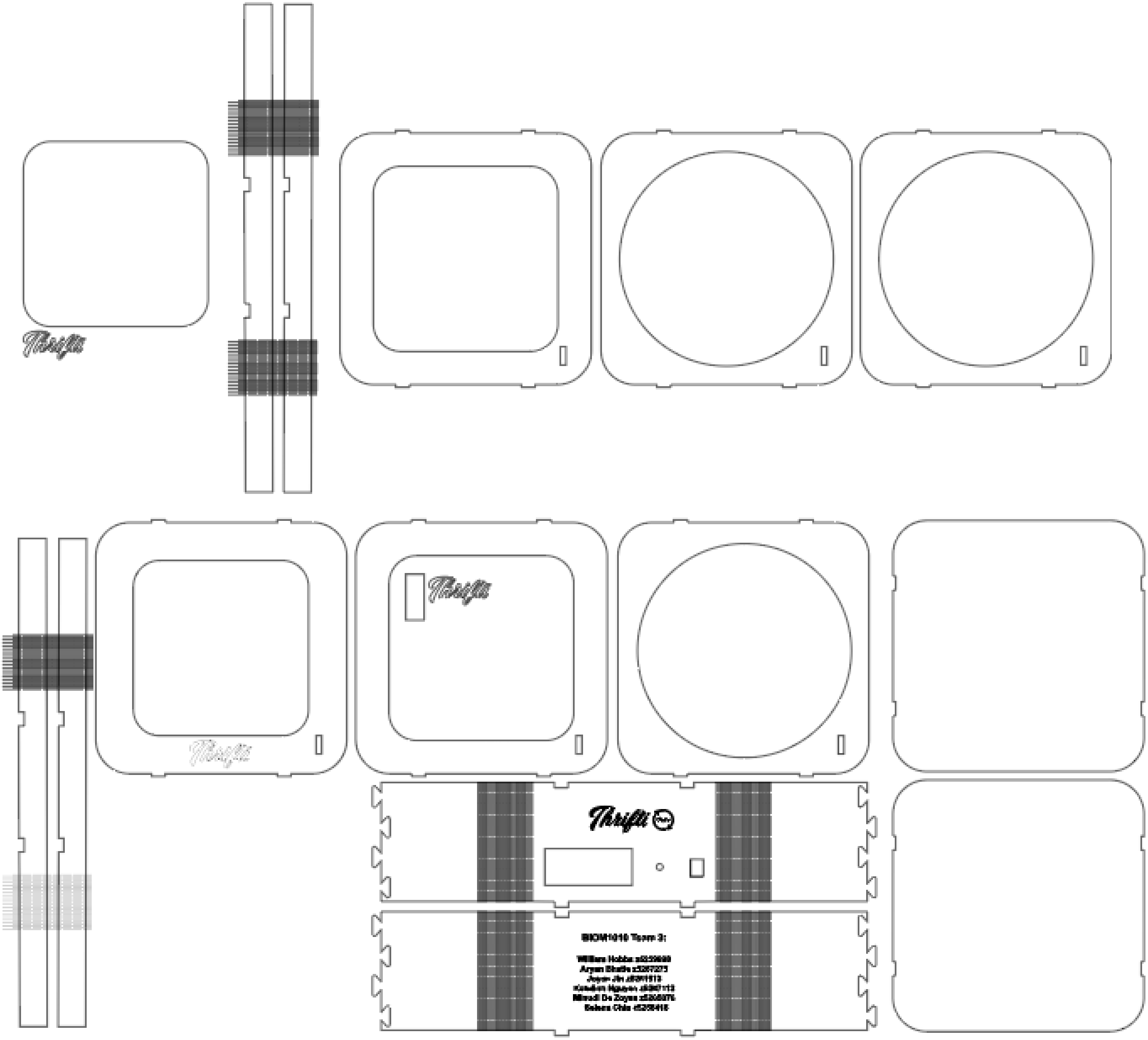

Figure 8. Device Casing Template

C Budget Table

Table 4. Unit Price for 100 Units.

	Component	**Cost ($)**
Electrical	12V motor with rotary encoder	19.50
	Motor driver	15.90
	LCD screen	13.50
	Shock sensor	4.20
	Rocker switch x 2	8.00
	Rotary encoder	2.95
	Arduino UNO	16.45
	Servo motor	4.99
	Buzzer	3.00
	Hall effect sensor	3.95
	Buck converter	6.00
	Power supply	7.50
Mechanical	3mm plywood	13.00
	Fastener	4.00
	Bundt pan	6.00
	3mm acrylic	2.95
	5mL test tubes x 12	3.00
Total		$134.89