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Design and Development of Low-cost Portable Centrifuge using Additive Manufacturing

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Abstract

This paper describes the design flow, fabrication 3D printing, assembly and embedded system design for constructing a portable centrifuge for laboratory applications. The main goal is to reduce the cost of commercially available centrifuges using additive manufacturing technology. The embedded controller allows for electronic control of the functionality of the centrifuge. The designed system also includes temperature and moisture sensors to provide additional data to the user. The low weight and compact design allows for assembly as per the user requirement.

Keywords: Additive manufacturing, Analytical instrumentation, Chemical laboratory, Sensors

I. INTRODUCTION

The chemical and biological laboratory involves mixing of reagents in different states. Filtration and sedimentation are the two most important principles used for separating different types of mixtures. Separating of butter from milk is one of the oldest methods of sedimentation which uses the rotatory motion called churning [1]. Scientific usage of centrifuge started with Benjamin Robins who came with the idea of whirling arm for calculating drag in fluids [2]. This later led to the development of butterfat extraction machine during the industrial revolution in 1864 by Antonin Prandtl and Alexander Prandtl [3]. As the technology progressed the mechanized rotation were replaced with motors. This led to the subsequent evolution of centrifuge as a common instrument in laboratories. This paper focuses on the multipurpose centrifuge used in chemical and biological laboratories.

A. Centrifuge

A centrifuge is a laboratory instrument used for separation of the materials through filtration and sedimentation. Especially where there is a requirement for chemical or material analyses. The basic operation principle of the centrifuge is the sedimentation principle in which the rotator accelerates the centrifugal force to separate the heavy particles in the samples. This allows for separation of different reagents at different speeds to gives the result instantly [4-6]. The block diagram of a centrifuge is shown in Fig 1.

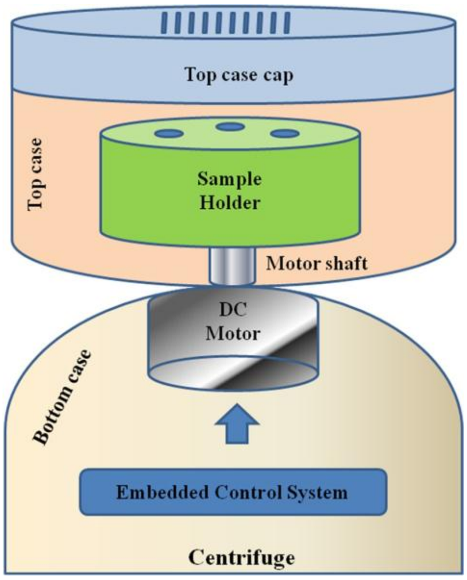

Fig 1: Block diagram of centrifuge.

This system includes the embedded system, DC motor, power supply and speed regulator. The microcontroller program allows the user to customize the speed of the motor as per the requirement. The instrument also has a sample holder and separates the heavy material in the samples through the centrifugal force. The bottom case and top case give the mechanical strength and support to the body. The top cover (Lid) gives the safety to the user from the chemical hazard [7]. And prevents any kind of spill over that may happen during high speed rotations incase of vial not being properly locked or closed.

Most of the commercially available centrifuges for laboratory usage are range between 300 $ to 10,000 $ dollars [8]. The costs are mainly for software and electronic hardware which provides flexibility for the user. In order to bring down the cost with similar functionality and flexibility, additive manufacturing and low cost embedded system are used in this prototype development.

B. Additive manufacturing technology

Additive manufacturing technology is broad term which encompasses all kinds of techniques wherein material is added gradually to achieve desired shape or structure. In the most recent advancement additive manufacturing is technique is 3D printing technology. In additive manufacturing 3D models are printed layer by layer. This has seen rapid progress in recent years with respect to manufacturing industrial process like molding, bending, cutting and welding etc. The designs for printing are generated with Computer-Aided Design /Computer-Aided Manufacturing (CAD/CAM) tools like Fusion 360, SolidWorks, OpenSCAD, and Blender etc [9, 10]. Most of the tools are open source tools which provide flexibility for further development and adding new library files.

II. MATERIAL AND METHODS

A. Design and printing parts

The centrifuge parts are designed in fusion 360 CAD tool. Fusion 360 is a cloud based CAD design software which gives the simplicity, easy to design the model and gives the flexibility to simulate the mechanical parameters. The CAD file is exported in STL (stereo lithography file) format which allow converting designed model surface into cross section layers [9]. The 3D printing machine reads G-code coding. The designed STL file formats are converted to machine readable G-code. This allows the printer to print layer by layer. The designed CAD files part shown in Fig 2.

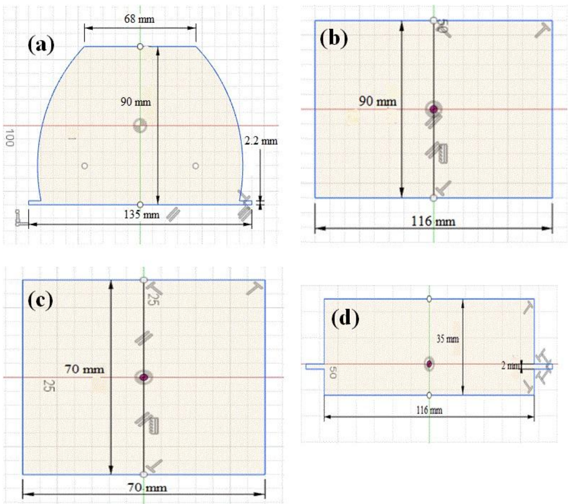

Fig 2: CAD files of centrifuge parts **(a)** bottom case, **(b)** top case, **(c)** sample holder and **(d)** top case cap.

B. Fabrication of Centrifuge parts

The Centrifuge parts has been printed by the INDIE and Prusa i3 3D printers [11, 12]. The parts like Bottom case, Sample holder and top case cap is are printed by INDIE 3D printer with Acrylonitrile butadiene styrene (ABS) and the top case of the system printed by Prusa i3 3D printer machine with polylactic acid (PLA) material. The ABS material is more flexible and durable with respect to PLA. The PLA material is strong, hard, biodegradable and non toxic material [13]. The centrifuge parts exported as STL file are shown in Fig 3.

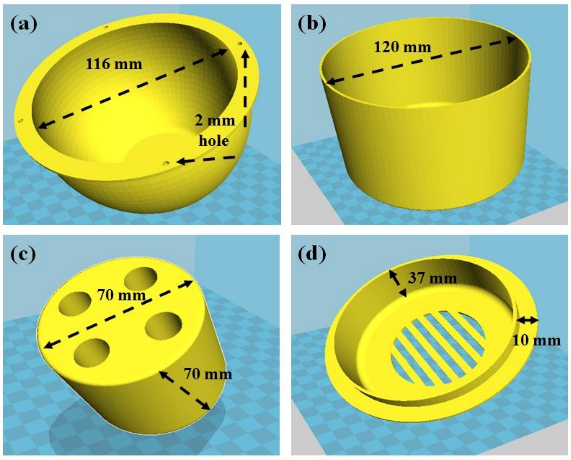

Fig 3: STL files of centrifuge parts **(a)** bottom case, **(b)** top case, **(c)** sample holder and **(d)** top case cap.

The ABS material has the ability to bear the mechanical forces, provide resistant to and mostly used for mechanical system design like gears which involve very high load, friction and speed. PLA material is mostly used for toy design, packaging and cosmetic paints. The 3D printers are shown in Fig 3.

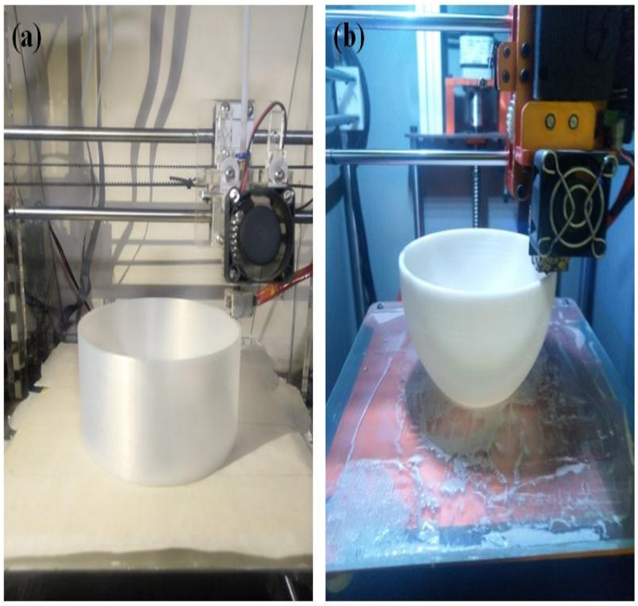

Fig 4: 3D printing Fig **(a)** Prusa i3 and **(b)** Indie.

The 3D printed centrifuge parts are shown in Fig 5. The material has been used to print the parts of centrifuge are ABS and PLA. For the mechanical strength and more flexibility of the parts like bottom case, sample holder and top case cap has been printed by ABS material and for the tough surface and strong support PLA has been used in top case printing. The nozzle temperature is maintained for ABS and PLA material for printing are 250 ºC and 210 ºC and the bed temperature is 80 ºC and 40 ºC. The thickness of the printing parts bottom case is 3 mm and a uniform thickness of 2 mm is maintained for other parts for easy integration.

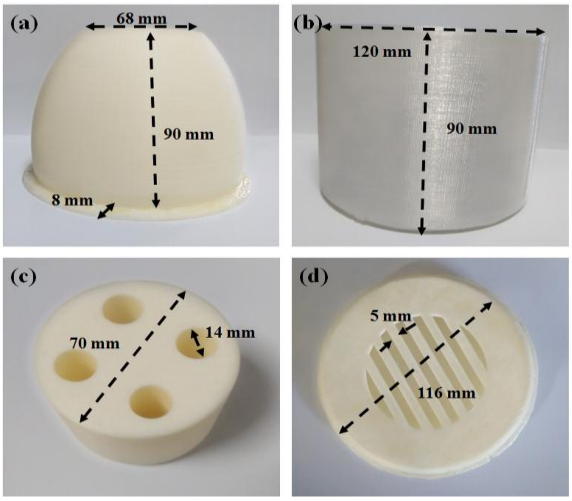

Fig 5: 3D printed parts of centrifuge **(a)** bottom case, **(b)** top case, **(c)** sample holder and **(d)** top case cap.

C. *Assembly of Centrifuge*

The centrifuge assembled using 3D printed parts is shown Fig 6. The assembly includes a DC motor. The motor shaft is 7 mm long and diameter 2 mm. The motor fixed using screws between the bottom and top case. The motor shaft is connected to the sample holder by Poly Vinyl Chloride (PVC) solution [14]. The bottom case has 116 mm and top case 120 mm in diameter. This provides stability for the mechanical structure and minimizes the vibrations generated through the rotation of the motor. The top side of both cases diameter is 68mm and 120 mm for the support. The printed parts dimension is shown in Fig 5. The sample holder height and diameter is 70 mm and the top case cap diameter is 116 mm with 5 mm mesh. The sample holder has 14 mm diameter and 40 mm cylindrical hole for vial. The cap has 5 mm mesh for air circulation inside the top case.

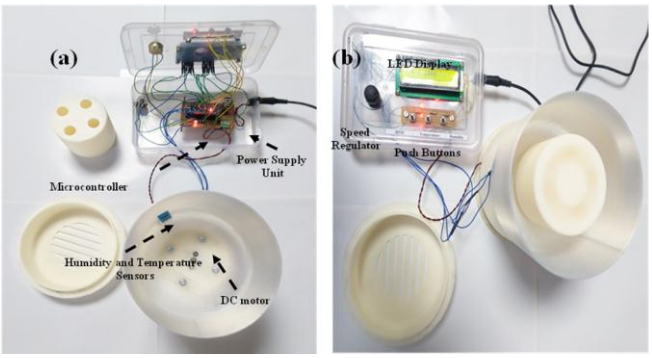

Fig 6: 3D printed Centrifuge.

D. *Interface of Embedded system control*

Fig 7 shows the block diagram of the designed embedded system. It has microcontroller ATMEGA328P (arduino nano) [15]. Microcontroller receives input from potentiometer (knob), DHT11 temperature, humidity sensor [16] and three switches. As per the datasheet of DHT11, it uses serial wire interface for communication. The data is transmitted at 40 bits per second and the sensor transmits higher data bit. Knob is used for motor speed control. Three push button switches are used to select the parameters (motor speed, temperature and humidity). The measured values are displayed on 16 x 2 Liquid Crystal Display (LCD).

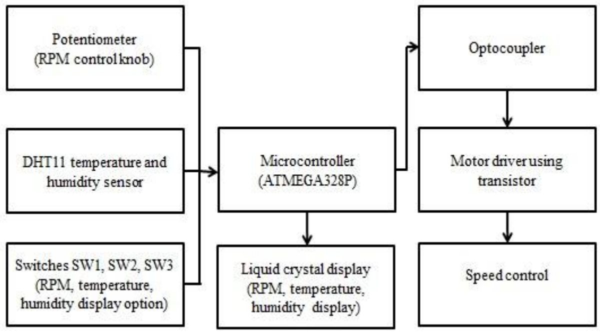

Fig 7: Block diagram of embedded system.

Using the switches as shown in Fig 6, the user is provided with the flexibility to select the specific parameter to be displayed. The motor speed is controlled using Pulse Width Modulation (PWM) signal. The speed is determined through seven levels of control provided through the potentiometer (Knob). The PWM signal is sent to the motor driver circuit via optoisolator to isolate the driver circuit from microcontroller for better safety [17]. The motor driver is built using KSP2222A NPN transistor [18]. As per datasheet the maximum output current of this transistor is 600 mA. The current required to drive the motor is 330 mA, hence this transistor is used. The circuit diagram of driver circuit is shown in Fig 8. The system is calibrated for 8 different RPM (Rotations Per Minute) of motor from 0 to 7000 with equal space of 1000 RPM. Thus, the designed system controls the speed of rotation, monitors temperature, humidity and displays the parameters as per the user requirement.

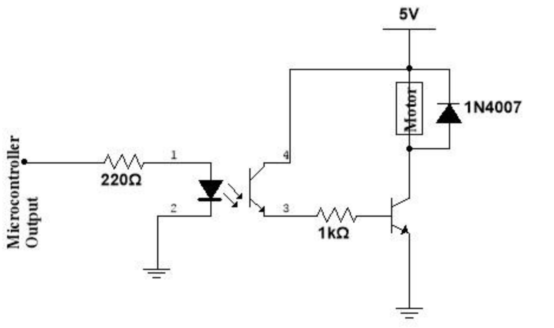

Fig 8: Circuit diagram of driver circuit.

III. RESULT AND DISCUSSION

The centrifuge worked properly and the results are calibrated using different sets of mixtures. The centrifuged sample results are shown in Fig 9. This shows the mixture of zinc oxide nanomaterial mixed in DI water (Deionized water) and the results obtained. The performance of the instrument was observed over multiple iterations with different types of mixtures.

The centrifuge is being developed as part of the portable mini-laboratory. The complete unit can be assembled and transported anywhere. By including a solar panel can be run on DC power at supply at any location. This panel is part of the mini-laboratory being communicated in a separate paper.

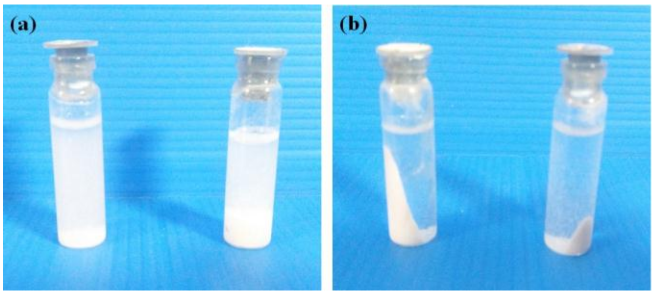

Fig 8: Centrifuge vial (a) before centrifuge and (b) after centrifuge.

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