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Implementation of design for additive manufacturing in rapid product development

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Abstract: Attempts to contain and prevent the spread of 2020's CoVID-19 pandemic resulted in major supply-chain limitations. Additive manufacturing provided a potential solution through which the manufacturing of critically needed medical equipment could be facilitated. Whilst this led to innovative initiatives with potentially feasible/beneficial outcomes, some solutions did not account for the limitations of the technology. Here a case study is put forward in which a Design for Additive Manufacturing approach is taken for the feasible development of an automated AMBU-bag based ventilator.

I. Introduction

The 2020 international COVID-19 pandemic resulted in major disruptions in both international and domestic supply chains as many countries enforced the cessation of international industrial operations including the transport of goods and services [1]. This had dramatic implications for the supply of critically needed medical equipment such as facemasks and ventilators to regions of concentrated infection. Such devices are typically made with injection molding and consist of multiple components which upon completion rely on established distribution channels [2]. Additive manufacturing provided an opportunity through which these limitations could be overcome. These included the technologies ability to produce parts of complex geometry allowing for part consolidation (minimization of assembly requirements) as well as the ability to localize manufacturing to where and when it is needed [3]. Additionally, the ability for AM to create parts from modifiable digital Computer Aided Design (CAD) files allowed for the rapid variation to products based on the dynamic needs of COVID-19 treatment facilities. This facilitated many innovations relating to the use of AM such as Bellus3D's integration of photogrammetry. Mobile phones and AM to produce customized face mask fitting frames. [4]. Whilst AM is capable of manufacturing a vast range of geometries, utilizing a wide range of production techniques and materials [5], some of these are not ideal for producing medically oriented products. One of the more popular forms of AM is Fused Deposition Modelling (FDM) 3D printing and many initiatives attempted to utilize this technique to manufacture COVID-19 related solutions. Unfortunately, this technique is susceptible to highly porous surfaces which can provide an ideal environment for undesirable germs such as viruses and bacteria. Additionally, FDM is associated with low manufacturing productivity [6]. That is not to diminish the usefulness of FDM, but just to highlight that, in order to successfully use a technology for a particular application, one must understand both the strength and weaknesses of the technology as well as the application context. The usefulness of AM is highly dependent on both the appropriate technique and the applied design knowledge. Selective Laser Sintering (SLS), for example, is another form of AM able to produce multiple parts without the need for support materials and at a faster production rate compared to FDM. Additionally, this technique has been identified as readily autoclavable and more appropriate for the sterilization required in hospital/medical applications.

This paper presents a case study which highlights the potential for the use of AM technology and a Design for Additive Manufacturing (DfAM) approach to accelerate rapid product development in relation to COVID -19.

II. Material and methods

Work presented in this paper was reliant on the use of equipment within the Creative Design and Additive Manufacturing Lab of The University of Auckland. Designs were based on mimicking the hand-based Ambu bag operation and leveraged recent work in automated Ambu bag systems. These were modelled in Solidworks 2017 and parts printed in nylon (EOS Formiga P110 SLS) and panels of acrylic were laser cut (EPILOG Laser Mini). Printing required a machine preheating time of 2 hours and cool down time equivalent to print time. Electronic componentry was controlled using an Arduino Nano. All costing information was derived from a commercial online bureau.

III. Results and discussion

This project presented an opportunity to automate the actuation of an assistive ventilation Ambu bag. This ventilator is not intended as a replacement for high-end ventilators. It is, instead, just intended to replace the hand of a medical person using a manual ventilator (Ambu bag / Bag Valve Mask) with an automated hand. This frees up skilled professionals to do tasks of greater value. The initial design Fig.1 demonstrates the ability to produce the majority of the device using 3D printed parts and laser cut

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panels. Of major significance in this design is the removal of major regions of material relating to the printed components and the substitution of these planar surfaces with laser cut panels. This operation leveraged SLS's ability to create overhang geometries without depending on support material and resulted in a reduction in required manufacturing time. The design took approximately 20 hours to complete with a print time of 10.2 hours and estimated cost being €455.18. It is worth noting that this print time refers solely to the production of a singular ventilator and does not account for the ability of the technology to nest multiple additional parts within the regions which would otherwise go unprocessed. This prototype allowed for experimentation of the operational requirements of the device. The most prominent revelations relating to modifications to the device paddles and reduction of 3D printed part volume. As the enclosed volume of the ventilator enclosure was relatively large, the resultant volume of powder, and therefore cost, was high.

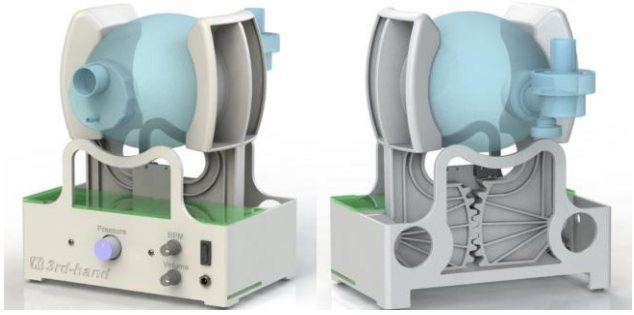

Figure 1: Initial design for predominantly 3D printed automated ventilator assistive device.

III.I Modifications to device paddles

The printed prototype allowed for the physical evaluation of the operation required to hold and compress the Ambu bag. The initial design had a large surface area upon which the paddles had to exert enough force to overcome the pressure generated by the internal air and elastic/resistive material of the Ambu bag. The utilized motor struggled to accomplish this, however upon further inspection of the operation and the ability to rapidly alter the paddle size (Fig.2a) identified the potential to overcome this limitation with a paddle re-design. Additional changes to the paddle included the painting of the base region for the use of infrared sensing to determine its position (Fig.2b) and control the tidal volume of air expelled by the device.

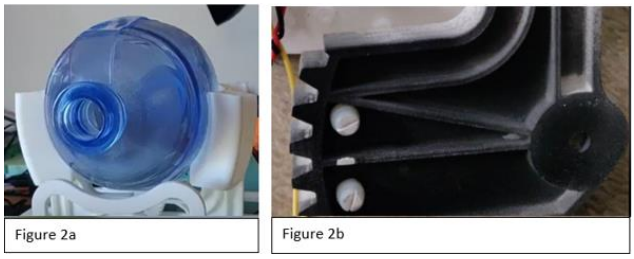

Figure 2a: Reduced/cut down ventilator paddles demonstrating modified prototype. Figure 2b: Modified paddle base with inserts and paint for IR sensing experiments/control.

III.II Reduction of 3D printed part surface area

The majority of AM cost can be related to part volume and the mass of material that must be solidified by the laser. The device was further evaluated from a DfAM perspective in an attempted to further minimize the required printing time by reducing the total height and mass of material, and the material cost by reducing the enclosed volume of the parts. The resulting ventilator design made use of a readily available injection molded ABS enclosure, laser cut paneling with only the complex geared paddles and electronic mounting regions (Fig.3a). Total printing time being 4.7 hours with the resulting AM cost being €163.88.

Figure 3: Resultant operational automated ventilator device.

IV. Conclusions

This study demonstrates the potential of the appropriate use of AM technology whilst leveraging alternative forms of manufacturing to rapidly develop feasible product prototypes. Within a time span of 3 weeks, the product went through 3 design iterations, by the end of which a working prototype had been produced for which the total cost would be around €241.41. This prototype allowed for user adjustment of the ventilator respiration rate, tidal volume, and inspiration / expiration ratio (I:E ratio). This work enabled rapid product development and provides a starting point for the products future clinical validation/assessment.

AUTHOR'S STATEMENT

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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