Design for Abacus Clock – "Abaclock"

Predicting the Evolution and Adoption of Metal Additive Manufacturing Based on the History of Polymer 3D Printing

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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General Research Problem: How is 3D Printing Changing Manufacturing?

How is the incorporation of 3D printing changing the landscape of manufacturing, and what are the advantages of these processes in modern mechanical design?

Historically, most precision manufacturing can be classified as subtractive manufacturing, a process by which a larger section of material is ‘whittled’ down into a functional part. However, over the last fifty years or so, a new class of manufacturing techniques have emerged, known collectively as 3D printing. These processes come in many forms but all work by depositing material layer by layer to progressively create a net shape (Dev Singh et al., 2021). Many materials can be successfully 3D printed, but most processes focus on either polymers or metals, with metal 3D printing being a much younger collection of processes. Additionally, applications for these processes have been split into rapid prototyping processes and industrial end use ones, with the term 3D printing being associated with the first application, and the term additive manufacturing (AM) being adopted describe the second, whereas before the two terms were interchangeable (Bechtold, 2016).

To better understand the role 3D printing plays in mechanical design and product development, I will be working with a group to develop a mechatronic clock which, using an abacus-based display, will double as a calculator. It will utilize a system of magnets and electromagnets to move beads on a series of rods as a way to display time. This project will make heavy use of 3D printing for prototyping purposes, and as part of the final product. Designing and building this clock, the “Abaclock”, will allow our group to familiarize ourselves with this up-and-coming technology and understand how it interacts and compliments other manufacturing methods, as well as it’s drawbacks in mechanical design. At the same time, I will be tracing the distribution of intellectual property in the early days of polymer 3D printing to understand how patents effected the evolution and adoption of the technology. Plastics as a whole are fundamentally limited to what applications they are strong enough to accomplish, and as such developing metal 3D printing has greater benefits for end use applications and has attracted a great deal of attention in academia and industry. By understanding the path polymer 3D printing took, we can predict how metal additive manufacturing will change, a process which will be much more disruptive to modern manufacturing than its plastic counterparts.

Design for Abacus Clock – "Abaclock"

How can we supplement our mechanical engineering education with a hands-on project where we design and build a mechatronic wall clock with an abacus display meant to operate over a long period of time with little to no maintenance?

Despite the numerous hours involved in studying mechanical engineering, there are very few opportunities for University of Virginia undergraduates to demonstrate their knowledge and skills. Lab and course work provide adequate experience when it comes to the theoretical practice of mechanical engineering through simulations and closed experiments. However, such methods of learning often disregard real life variables such as feasibility, reliability, and practicality. A major cause of the lack of open-ended experimentation opportunities is of course due to online learning during peak Covid times. A study on engineering education during the COVID-19 pandemic stressed concerns with the severe lack of hands-on learning and argues that personal engineering kits can allow students to better grasp new technical skills by letting students learn via hands-on trial and error (Asgari et al., 2021). Our team's technical advisor utilized such a teaching method by providing extensive kits to each student in our third-year mechatronics course. This technical project will rely on skills learned in that course while also providing an opportunity for us to grow those skills through our own design iterations.

The object of this project is to create a mechanical wall clock in the form of an abacus. This clock will integrate mechanical and electronic systems that both demonstrate the practical skills of undergraduate mechanical engineers at the University of Virginia while paying homage to the origins of numerical methods. An abacus is a computing tool used for the four arithmetic operations (addition, subtraction, multiplication, and division). An abacus does not require pen or paper, works for any base number system, and such technology has over 2000 years of documented use (Samoly, 2012). This clock will move through the combination of mechanical, computer, and electrical engineering systems in order to physically display the time of day in the form of a number on an abacus. The design will consist of beads lined with magnets that travel along linear guide rails. The beads will be the only part of the clock visible in order to add to the mysterious aspect of the clock. An opaque sheet of acrylic will separate the beads from the mechanisms that move them. For each column of beads, a stepper motor and lead screw system will move a linear actuator up and down. The actuator will engage and retract a permanent neodymium magnet that will use its magnetic field to interact with magnets in the beads. The magnetic force combined with the force of friction will allow the lead screw system to move the beads while being hidden behind the acrylic sheet.

The abacus clock will be designed, tested, and built during the 2022 fall semester under the guidance of Gavin Garner, a professor of mechanical and aerospace engineering in the Department of Mechanical and Aerospace Engineering at the University of Virginia. The design process used to complete the project will consist of the following steps: (1) define the problem, (2) identify constraints, (3)generate designs, (4) test prototypes, and (5) build and validate final design. All designs will be created using Solidworks and manufactured primarily using hand tools, laser cutters, and 3D printers. The team members included in this project are Jack Thomson, Timothy Peoples, Mrinaal Lorengo and Mollie Bauer. Each team member is a fourth-year student studying mechanical engineering at the University of Virginia School of Engineering and Applied Science. The final goal of this project is to have a clock display in a prominent location on grounds in order to demonstrate the practical skills of undergraduate engineers. This project will be fully documented in a technical report.

Most custom parts of this project such as the beads, magnet mounts, and superstructure of the clock design will be 3D printed using Stratasys uPrint Plus machines. As we work through the design process, we will be able to understand the advantages and limitations of polymer 3D printing as it relates to creating a final product meant to operate for years with little to no maintenance.

Anticipating the Evolution and Adoption of Metal Additive Manufacturing Based on the History of Polymer 3D Printing

How did the distribution of intellectual property affect the spread of polymer 3D printing technology, and based on this how can we anticipate what path the evolution and adoption of metal additive manufacturing will take?

The first 3D printing processes developed were the polymer processes fused deposition modeling (FDM) and stereolithography (SLA). These processes work quite differently, but what they have in common is that their inventors of these processes, S. Scott Crump and Chuck Hull respectively, leveraged these inventions to create patents and found dominant companies in the 3D printing space, namely Stratasys and 3D Systems (Bechtold, 2016;Savini & Savini, 2015). At the same time, additional innovations by other companies and universities were patented, further splitting the available technologies one could incorporate without expensive licensing. The first 3D printers were over $300K, and until the 2010's still cost around $50000, far more than the average individual could afford. However, eventually major patents owned by Stratasys expired, opening the door for new stakeholders, namely the Rep-Rap Project. The Replicating Rapid Prototyping or Rep-Rap Project was a push led by Dr. Adrian Bowyer at the University of Bath in England, with the goal of designing a 3D printer which could produce all of its major components to create a clone (Jones et al., 2011). The open-source nature of the project enabled people from all over the world to experiment with the previously inaccessible technology and begin improving it. Many 3D printing companies today have their roots in the Rep-Rap project including Prusa Research, Makerbot, Lulzbot, and more.

These innovations allowed the rapid iteration of designs, and great cuts to cost. Today a 3D printer with similar capabilities to the cutting-edge designs of the early 2010's can be bought for as little as $800, compared to $50,000. This massive cost reduction has only occurred in the last decade while the technology had already been around for almost a quarter of a century. Paralleling polymer-based 3D printing, metal additive manufacturing has seen a similar split in its base intellectual property in the form of patents, with various portions of the processes split between different competitors in the commercial and academic setting. These include the method to melt the feed material (laser vs. electron beam based), material feed systems, and powder chamber atmospheres. As these patents begin to expire and or combine, will we see reductions in costs and

To understand this, various patents on the technologies forming the modern FDM 3D printer, including the basic idea of extruding materials with a printhead and the heated build chamber, will be traced to their origin and costs of these technologies will be compared to the applications in which they were originally intended for. I will identify how these technologies came together and the effect it had on the spread of FDM 3D printer technology and accessibility, whether that be in general public awareness or reductions in costs. Additionally, comparisons between polymer and metal 3D printing will be made in four categories to help identify whether there are any fundamental differences between the processes that may preclude metal 3D printing from reaching a widespread audience. These four categories are namely: 1) technical complexity, 2) costs of base components, 3) safety concerns, and 4) ease of iteration in the design space. Technical complexity will be evaluated in terms of how many patents need to be incorporated together to create a functional machine, while safety concerns will primarily be concerned with the danger of operating a machine and handling their various feed materials (Anzalone et al., 2013). Additionally, topics of secondary interest include what potential impacts widespread metal 3D printing may have for society along the lines of STEM education, effects on traditional manufacturing, and the right to repair movement will be identified and evaluated.

Conclusion

Understanding how patent culture has affected plastic 3D printing will allow us to understand and anticipate how metal additive manufacturing will evolve, and the future effects it may have on our society. On the other hand, working closely with 3D printing while designing the Abaclock will give us an idea of what these processes can be used for today, and hint at what areas 3D printing may have yet to move into. 3D printing and additive manufacturing are a young group of processes, but by understanding where the technology stands now and where it will go is necessary to identify what kind of impact it will have on manufacturing as a whole, in terms of scope, application, and design.

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