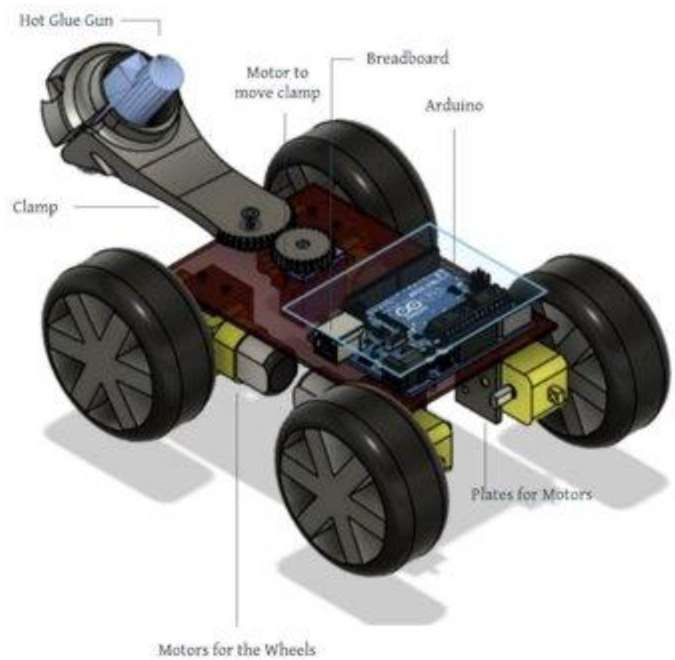
Miniature 3D Printing Termite Inspired Robot



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Introduction

The construction sector continues to remain one of the least automated industries in the world with numerous large machineries required for a single operation [1]. However, the recent implementation of additive manufacturing (AM) looks to develop modern techniques in a rather archaic profession. By automation, AM allows construction firms to rapidly prototype designs in the planning phase, produce geometrically complex models with high precision, and test various materials according to its function, opening a wide range of possibilities for the future of construction [2]. On the other hand, AM comes with its own limitations. Standard printers purposed for construction fall into one of two types – gantry or arm based. Gantry based printers run a printhead along a gantry, depositing material along a plane and printing designs through layers by raising the printhead. With gantry-based systems, scalability rises when used in construction. The first house constructed in this matter in Antwerp, Belgium measured roughly 90 square meters, but it required a square printer 10 meters in length [3]. In construction where large scale structures are commonplace, it becomes unrealistic to utilize printers larger than the structure itself when looking at the scope of the construction projection. The alternative arm-based systems utilize an extendable arm to revolve the printhead at its tip from which it extrudes the material but too has its limitations. Arm-based printers similarly require large, open spaces to be utilized and the arm's area of reach becomes an obstacle when planning large structures [5]. The physical relocation of the printer or the investment in numerous printers may be required, raising issues of cost as each printer values at tens of thousands of dollars [6].

Innovative AM techniques in construction have become widespread with the use of gantry and arm-based printers being the preferred method of choice on projects. However, these systems become impractical when looking at the scope of modern structures, raising concerns with scalability, spatial requirements, and increasing costs. Our project takes inspiration from the termites who in a similar fashion deposit material to create large intricate structures such as their mound [7]. Looking at the termites' small stature yet complex construction, our solution involves straying away from spacious heavy body machinery in favor of a smaller, drivable printer capable of depositing material from behind. In doing so, our solution offers a cheaper, miniature alternative capable of performing the same duties that a gantry or arm-based printer would accomplish. Our approach provides another opportunity to implement AM techniques in the construction world with hopes applications of hazardous operations to improve worker safety.

The bio-inspiration behind our solution was termites' general ability and behavior when constructing their homes [10]. They can work as a colony to create some of the most complex and sophisticated infrastructure found in nature. Our project was focused on the idea that a small organism is able to create a structure far larger than itself, and in the future this idea can be expanded to include termite colonies abilities to collaborate using swarm intelligence [11].

Design and Build

Looking at the sheer size of the printer required for a single construction project and the limitations the arise, whether it being arm or gantry based, we quickly settled on designing a printer significantly smaller in size capable of performing the same duties that a larger printer would be able to complete. With the addition of depositing our material of choice, we envisioned our solution with the ability to move. In combination of these two ideas, our solution would overcome the spatial requirement needed to implement conventional AM printers while increasing the printer's area of influence by bypassing the arm and gantry system's stationary condition.

	skill required	cost	build time	usability	interest	totals
weight	3	2	3	2	2	
robot dog	0	0	0	0	0	0
tank with a stationary printer	2	2	2	-1	1	16
tank with scissor lift	1	2	1	-2	0	6
tank with arm	0	.5	.5	0	0	2.5
wheeled stationary printer	2	2	2	-1	1	16
wheeled with arm	0	.5	.5	0	0	2.5

Figure 1 – Solution matrix with preliminary designs with different wheel arrangements and the possibility of lift

With those two ideas in mind, we drafted potential solutions with different designs including wheel type and debating whether our project would acquire the ability to lift itself. Seeing our time constraint and scope of our abilities, we settled on two similar designs, scrapping the printer's ability to raise itself concluding it too difficult to implement with the other specifications. Ultimately, we settled on a wheeled, stationary printer, as opposed to one with threaded, or "tank" wheels. Our choice of a standard four wheeled printer resembling a car would be of preference and simplification of design having similar experience in the past. Shifting our attention to the final printed structure, we initially saw our printer traveling circularly to slowly print rounded layers with the construction taking a cylindrical shape. However, much later into the design process, much of our time was focused on constructing the prototype and the idea of a cylindrical print became unfeasible. Our decision to instead print while driving straight with the final wall-like structure will simplify our project and instead focus on the printing and driving capabilities of our prototype by removing the ability to turn.

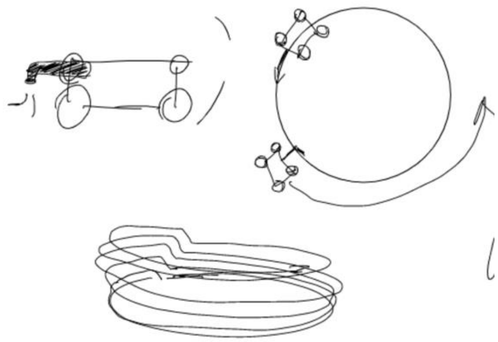

Figure 2 – Initial sketches the final printed structure taking a cylindrical shape

Body

The size of our project needed to be minimized while retaining its ability to deposit material. We finalized a requirement that the body of our printer, not including wheel size, to be no more than 4in x 6 in. This size would be adequate space for the electronics needed for our project while retaining the goal of our design. The finalized base would be 3.5 in x 5 in x 0.0063 in laser cut out of acrylic to be an inexpensive material. As we proceeded with our project, holes would be drilled to fasten the electronics and 3D printed components further into our design process.

Filament

The filament we ultimately would settle on needed to be extrudable through the nozzle placed on the back of the printer. Additionally, following a similar principle of conventional printers, our filament may be heated prior to extrusion, allowing the flow of material out of the printhead and hardening with the drop of temperature due to the environment. Being in the testing phase, there would be a cost concern to the amount of purchasable filament. Our options included:

- **Animal Fat** – tallow and lard become liquid when heated and solid when given the opportunity to decrease in temperature. However, animal fats would be difficult to handle and cleanup and costly to purchase in bulk.
- **Expanding Foam** – a substance like that of insulating foam, capable of spreading to fill large areas. However, many products of this type are toxic, making it difficult to handle, and costly.
- **Hot Glue** – like animal fats, hot glue becomes a liquid when heated and hardens when cooled. Opposed to the other two options, hot glue is easily accessible, inexpensive, and reusable when collected and reheated.

Our final decision to use hot glue simplified our printing mechanism, allowing us to utilize the hot glue gun's attached nozzle as well as its heating component. We wouldn't have to concern ourselves with budget as glue sticks can be bought in bulk at low costs. Instead, our focus needed to be directed towards not only attaching the printing mechanism to our base, but also having the ability to power the heating component.

Print Head Arm

Following a linear path in favor of the initial circular plan, we wanted our printhead to have a swaying reciprocal motion to create a wider print instead of one made up of a single line. Our initial sketches demonstrate our ideas to either utilize a four-bar linkage or a servo motor to rotate the arm that would hold our printhead. Initially researching four-bar linkage in attempts to implement a mechanical system, the linkage design went out of our expertise and too difficult for our printer.

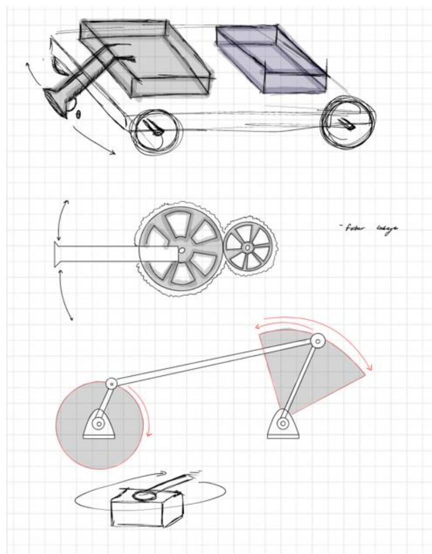

Figure 3 - Initial sketches for reciprocal motion of print arm by four-bar linkage, servo motor, and series of gears

Our final design would include a servo motor placed on the rear end of the printer with an attached gear. The print arm would include gear teeth to attach to the geared servo motor, allowing for motion when powering the motor. Having solved the issue of reciprocal motion, our final design additionally must be able to withstand the temperature emitted from the heating element of the hot glue gun.

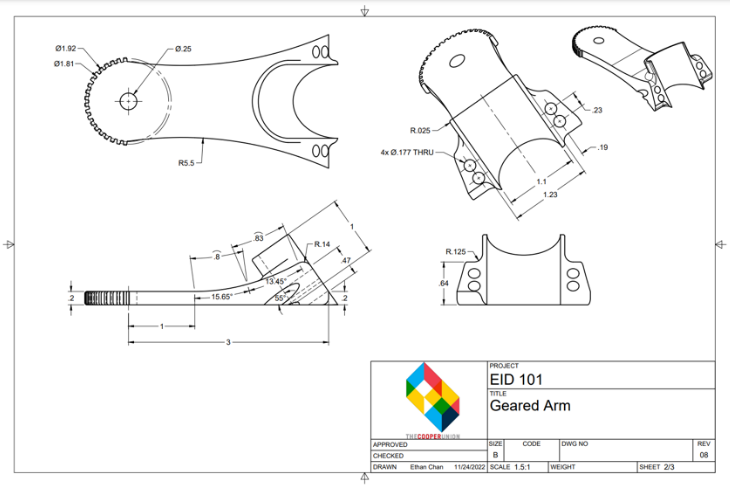

Figure 4 - Finalized print arm design to be 3D printed

Silicon Mold

Our solution to cast the shape of the hot glue gun parts we would utilize in silicon would provide a thick insulative layer between the material of the print arm and heating element. To make the silicon mold the dimensions of the hot glue gun handle (the metal portion excluding the nozzle) were measured using calipers. After the measurements we used TinkerCad to make a 3D printed model of the hot glue gun. We used cardboard to help make the casting, from there we created a cardboard ring around the 3D printed model. From here we used silicone and poured it to create the cast mold. After waiting 24 hours for the silicone to dry, we removed the 3D printed model to reveal our silicone mold.

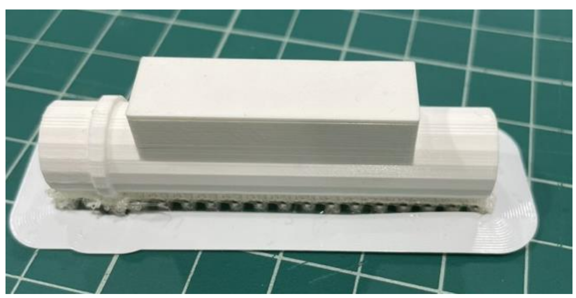

Figure 5 - 3D printed hot glue gun model

Figure 6 - Making of silicone mold for the hot glue gun

Wheels and Motor

With the set of four motors we purchased, there was adequate space to fit all four on the already miniature body of our printer. However, to attach the motors to the acrylic base, we designed a motor mount capable of both holding the motor and screwable to the base. Our design utilized the holes and peg already found on the motor allowing us to fasten the motor via a screw. The motors placed on the underside of the base pointed inwards having us print two of the mounts mirrored to be accommodated. The wheels will be attached accordingly with the motors wired to allow for movement of our printer.

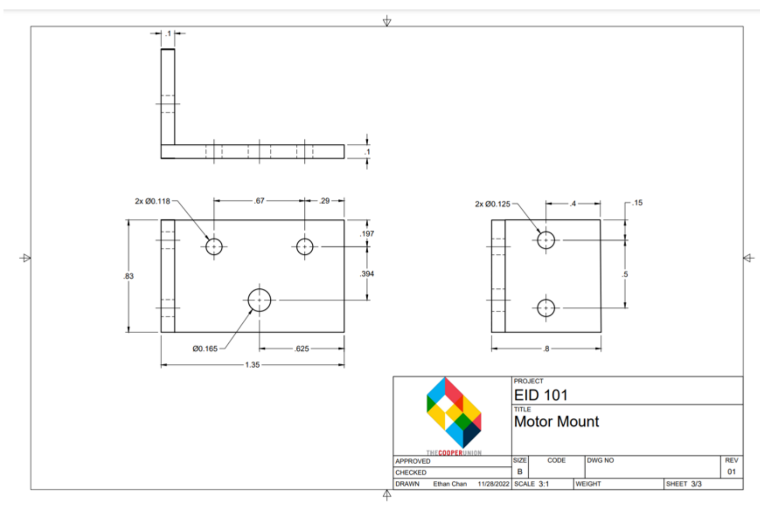

Figure 7 – Finalized motor mount design to be 3D printed

Electronics

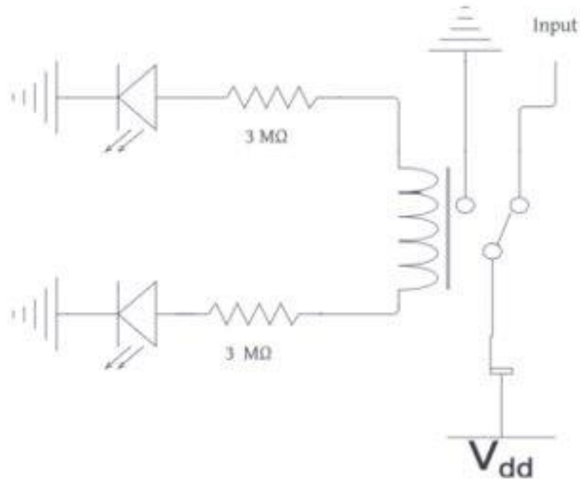

Figure 8 – Circuit Diagram of Relay

For our electronics, an 05VDC-SL-C relay was wired to activate the hot-glue gun. In short, the relay is an electrically operated switch. The 05VDC-SL-C relay has three high voltage terminals, three low voltage pins, and a 120-240 Volt switch, which is connected to an electromagnet. The outputs of the relay toggle between the Normally Closed (NC) pin, and Normally Open (NO) pin, depending on the amount of voltage supplied. As displayed in Figure 8, two LEDs were utilized to represent an on-state and off-state for the hot glue gun. Each LED was wired to either the NC pin, or NO pin, utilizing a 3 mega-ohm resister. When experimenting with the circuit, it was discovered that voltages between 0.2-2.3 activate the NC pin, while a voltage greater than 2.3 activates the NO pin. Utilizing this information, a total of 120V was utilized to power our hot-glue gun.

Success Metric

With our prototype, all electronics must work in unison. Our vision to create a driving printer only works where all four driving motors, the servo motor rotating the print arm, and the power directed to the heating component are wired correctly. In addition, our idea of controlling all the electronics remotely will complicate our final design but will give our printer a larger range and improve its aesthetic. In the end, our design plans to be remotely controlled while retaining the ability to deposit our hot glue filament similar to that of a conventional printer. Metrics for this success include volumetric output of material per minute, running time, and range of motion.

Testing and Results

We found our design capable of outputting about 1.56 cubic inches of material per minute, which could be improved with a more efficient heating tip. This is compared to the 1.15 cubic inches of material per minute of a standard FDM style 3D printer that uses 1.75mm filament at 100mm/s.

The robot moves at a linear rate of 3.5 in/min, and thus covers an area of 19.25sq inches every minute.

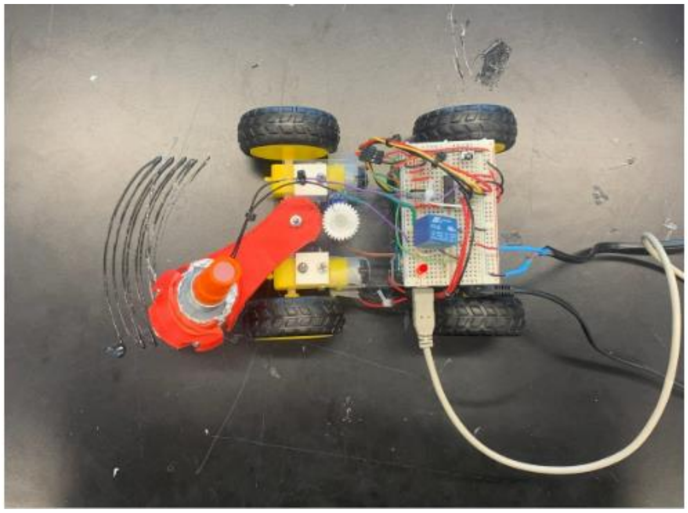

Figure 9 – Robot laying out material in a straight line done in a little less than 1 min.

Given refills of the robot's hot glue storage, we found it to be very reliable. With the inclusion of foil around the silicone, it reached an equilibrium point where the nozzle can run near indefinitely, so the robot could run for just as long, given a cover on the exposed gears to prevent ingress of particulates. A cable system with on-board material storage, such a robot could drive and print for significant distances, though our system can move for a range of about 4-5 feet at a time due to the length of the tether.

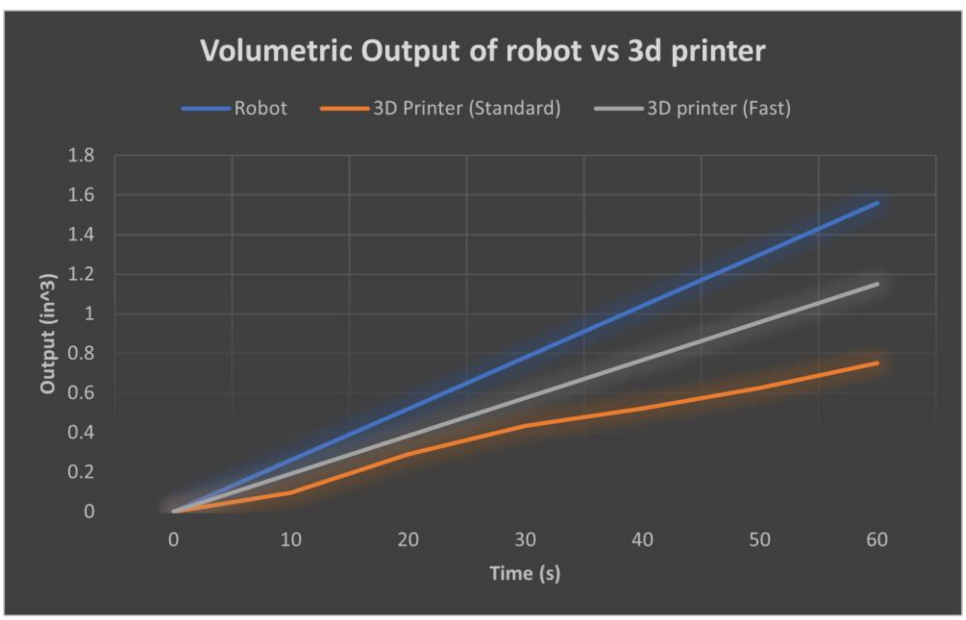

Fig 10 – Comparison of volumetric output of a FDM 3D printer compared to our prototype.

Conclusion

Overall, we believe that such a robot (and a group of) is fully capable of outperforming a standard FDM style 3D printer for similar sized structures. If scaled up, such a group could greatly improve upon current methods of additive manufacturing in construction by being able to work in dangerous environments, being easier to transport, and being less impactful to the surrounding environment. From our testing we see a great improvement in ability as compared to a standard FDM 3D printer, and if scaled up, we believe it could also show improvement compared to FDM style printers on a larger scale. Such a system would be significantly more flexible as well, if you need to change the dimensions of a structure, for example, you wouldn't need to deconstruct an entire printer's frame and rebuild it larger, you could simply reprogram the paths the bots take. In all, we believe this type of system to be totally feasible for building scale construction.

Process Reflection

Overall, the project and design process were executed efficiently, and was enjoyable for our team. From the beginning, our team's communication and time management did not cause any complications. Whether it be our weekly meetings or updating group members through messaging, our team's dynamic made group work simple to accomplish. By the end of the project, specific skill sets from each group member were utilized to reach our final design and complete the overall project. For instance, CAD, wiring, molding, drafting, and numerous other skills were implemented. This simplified specific occasions, as one or more members could tackle the same obstacle. When writing the final report and presentation, the documentation assisted us rigorously, especially because we tended to update it every week.

Contrarily, we did experience an issue with our initial research topic. In the beginning, we took inspiration from the termites' swarm mentality while envisioning a group of miniature printers working together. However, considering the time restraint, creating a group of individual printers was unfeasible. As a solution, we decided to focus on a single unit. While we could not imitate swarm technology, we were successful in adequately portraying "termite-size" robot. Thus, we were successful in significantly decreasing the size of the printer. In future projects, we can create more termite-robots to reciprocate termites' habits. Furthermore, we can adjust the speed of the wheel-motors, size of the robot, and wiring to increase efficiency.

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