2021 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
ADDITIVE MANUFACTURING TECHNICAL SESSION
AUGUST 10-12, 2021 - NOVI, MICHIGAN

AUTOMATED MANUFACTURING FOR AUTONOMOUS SYSTEMS SOLUTIONS (AMASS)

Jacob W. Robinson[1], Thomas W. Lum[2], Zachary J. Larimore[2], Matthew P. Ludkey[3], Larry (LJ) R. Holmes, Jr.[1]

[1]University of Delaware, Center for Composite Materials, Newark, DE
[2]University of Delaware, Electrical and Computer Engineering Department, Newark, DE
[3]US Army DEVCOM-GVSC GVME-2AM, Detroit Arsenal, Detroit, MI

ABSTRACT

The University of Delaware (UD) and the US Army DEVCOM-GVSC (GVSC) have partnered to show the feasibility of fabricating mission specific, man-packable, autonomous vehicles that are created by Computer Aided Design (CAD) and are then produced, from start-to-finish, in a single manufacturing unit-cell without human intervention in the manufacturing process. This unit-cell contains many manufacturing processes (e.g., additive manufacturing (AM), pick-and-place, circuit printing, and subtractive manufacturing) that work in concert to fabricate functional devices. Together, UD and GVSC have developed the very first mission specific autonomous vehicle that is fully fabricated in a single manufacturing unit-cell without being touched by human hand.

Citation: Jacob W. Robinson, Thomas W. Lum, Zachary J. Larimore, Matthew P. Ludkey, Larry (LJ) R. Holmes, Jr. "AUTOMATED MANUFACTURING FOR AUTONOMOUS SYSTEMS SOLUTIONS (AMASS)", In Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium (GVSETS), NDIA, Novi, MI, Aug. 13-15, 2019.

1. INTRODUCTION

PEO CS&CSS has published gaps and needs for future Unmanned Ground Vehicle (UGV) systems. One of these needs is: "A man-packable (<12kg), miniature, highly mobile, unmanned robotic system with advanced sensors and mission modules for dismounted forces. Designed so that operators can quickly reconfigure for various missions by adding/removing modules and/or payloads[1]." It should also be noted that TRADOC document 525-3-6, Movement and Maneuver 2020-2040[2], signed into place by Generals McMaster and Mangum, calls out, several times, the need for flexible reconfigurable autonomous systems. This project addresses all of the above gaps and needs, with the benefit of easy reconfigurability, due to the process being additively manufactured for specific missions, as well as being low cost and fully attritable.

2. Scope

The effort is focused on additively manufacturing a mission specific unmanned ground vehicle in direct support of the U.S. Army's Goals of Modernization and Readiness and more specifically in direct support of Remote Combat Vehicles and Robotic Platforms under Next Generation Combat Vehicle (NGCV)[3]. In the past ten years, interest in AM has grown significantly. As interest in AM has built momentum, many have suggested the concept of "printing" vehicles. This is not possible yet, but is entirely possible in the future, and this effort is the first step on the path to fully printed vehicles. UD has a large research portfolio in advanced manufacturing and specifically in AM. The major research focus within AM at UD is in multi-material functional device manufacturing. This includes combining AM with other manufacturing technologies, including subtractive manufacturing and electronics printing, in a single manufacturing unit-cell, working in concert, in order to fabricate complex devices like: antennas, sensors, communication devices, and radar systems. This project leverages UD capabilities in functional device manufacturing and GVSCs expertise in autonomous vehicle design in order to "print" a robotic vehicle. Our overall research objective is what we term "Product Agnostic Manufacturing." Material agnostic 3D printing is the concept in which a machine doesn't care what types of materials that machine prints. Product agnostic manufacturing includes another degree of complexity. For example, an automotive assembly line may consist of hundreds of robots that each conduct one fabrication job. For instance, a robot on an assembly line may only provide one weld. That robot may do it very precisely and may do it many thousands of times, but it is just one action, over and over again. If that assembly line has to be changed over from manufacturing cars to trucks, it may take many months to re-fit and re-program all of the robots on that assembly line. If a robot or manufacturing tool didn't care what material was being used **and** didn't care what component was being made, then every product off of that line could be fully customized and/or completely different. One day that line could be manufacturing 30 smart phones, and the next day that line could be manufacturing 100 toaster ovens, and at some later date the same line is manufacturing a handful of supercars. That is product agnostic manufacturing. For large scale items with broad complexity, product agnostic technologies do not exist, yet. However, UD and GVSC are working to create these processes and this project is a necessary step toward product agnostic manufacturing. Figures 1 and 2 show the multi-material manufacturing unit-cell (nScrypt[4], SuperScrypt) used in this effort.

Figure 1:. nScrypt SuperScrypt (based off of the nScrypt 3Dx-500x platform)

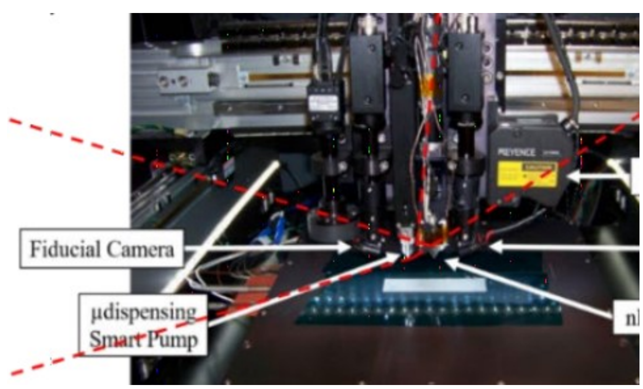


Figure 2:. Build chamber and capabilities of an nScrypt SuperScrypt

3. Additional Design Constraints

Based on requirements developed by the US Army, UD and GVSC conducted manufacturing experimentation with the goal of manufacturing a robotic ground vehicle that would cost less than $2000, could be "printed" in less than 24 hours, and could drive off the "printing" platform at the end of fabrication. One additional restriction is that the entire "print" must be automated and would not allow for "hands-on" fabrication.

4. Design Process

Design and manufacturing were based on constraints set forth by the US Army DEVCOM-GVSC (GVSC). Each iteration was designed around specifications unique to GVSC.

4.1. Two Wheel Concept Vehicle

Initial designs consisted of a 2 wheeled "tail dragger" concept in order to showcase the ability of a multi-dimensional additive process, taking place entirely within a unit-cell build chamber from start to finish. Manufacturing steps include printing of the body, the inlay of electronics and drivetrain components, followed by printing of the remainder of the body. The vehicle then demonstrated its ability to remove itself from the build sheet and drive out of the unit-cell without human assistance. The decision to manufacture a 2-wheeled vehicle over a traditional 4-wheeled vehicle was made based on size constraints set forth by GVSC for initial capability review. Additional constraints are as follows:

- Upon completion of the building process the robot must move within the build platform/chamber (20cm x 20cm) under its own power to demonstrate functionality.
- The robot must remain fully operational after withstanding a 1m vertical drop onto a concrete surface. The drop will be performed with the assumption that the robot will land with its top facing up (i.e., onto its primary propulsion mechanism).
- The robot must continuously operate for no less than 5 minutes on a single battery charge.
- The battery of the robot must be rechargeable or replaceable without causing permanent damage to the robot.
- The robot will be controlled/operated using a commercial off-the-shelf (COTS) hand-held remote controller.

Initial designs featured a chassis printed from polylactic acid (PLA) filament coupled with thermoplastic polyurethane (TPU) wheels. At a drop height of 1m, specified by GVSC, servo mounts printed from PLA experienced failure. Another challenge faced was that the TPU wheels were able to break free from the build plate but did not have enough traction to break the chassis' bond to the build plate. A following design featured a chassis, symmetric with respect to top and bottom planes, printed completely out of TPU. TPU was chosen because of its impact absorption properties and durability. This design was printed vertically such that only the wheels were in contact with the build plate, solving the adhesion issue. The drive train consisted of two Hitec HSR-2648CR servos (HITEC RDC USA, Inc. San Diego, CA) controlled by a RX4R receiver (FrSky Electronic Co., Ltd. Wuxi, Jiangsu) and able to produce 12kg.cm and 72rpm at 7.4 volts. For this design, the hull was partially printed, electronic components inserted by hand, and then printing was resumed. Figure 3 shows the design of a 2-wheeled ground vehicle meeting all specified requirements.

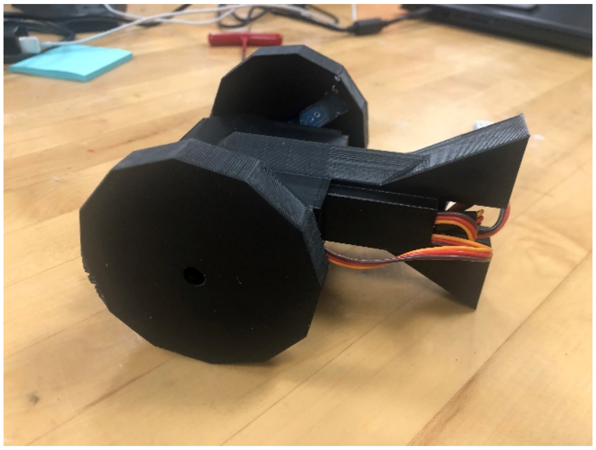
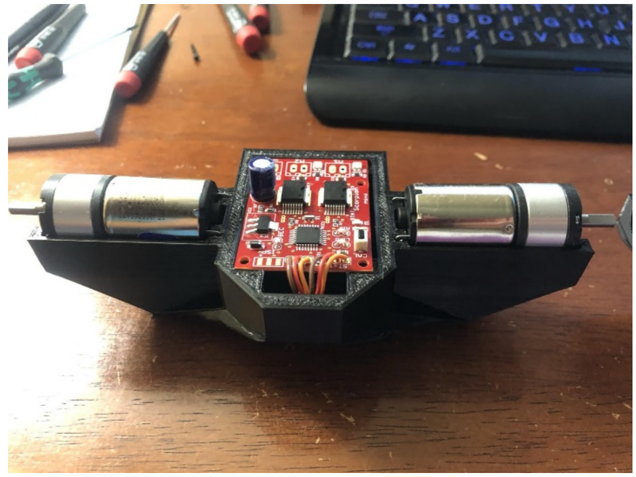


Figure 3:.2-wheeled "tail dragger" design printed in TPU

Further advancements were made including the integration of DC motors and an all-in-one receiver/dc motor controller. The motors used were 195 RPM Premium Planetary Gear Motors (Actobotics, Winfield, KS).

Figure 4: 2-wheeled "tail dragger" design printed in TPU with upgraded DC motors, receiver, and transmitter.



The rest of the drivetrain components consisted of a Spektrum DX6e 6-Channel 2.4 GHz RC radio Transmitter System (Horizon Lobby, LLC. Champaign, IL) paired with a Spektrum AR410 4-Channel RC Sport Receiver (Horizon Lobby, LLC. Champaign, IL). The improved design was printed in the same vertical orientation. Figure 4 shows the upgraded components inlayed into the first half of the print sequence.

4.2. Four Wheel Concept Vehicle

After demonstrating the ability to produce a functioning ground vehicle, assembled entirely within a unit-cell, GVSC relaxed build area constraints. New constraints allowed a build area of (30cm x 30cm) for a 4-wheeled design meeting the same design criteria as the 2-wheeled vehicle. The mentioned 4-wheeled vehicle was manufactured using four Hitec HSR-2648CR servos (HITEC RDC USA, Inc. San Diego, CA) controlled by a RX4R receiver (FrSky Electronic Co., Ltd. Wuxi, Jiangsu). The initial 4-wheeled concept was built entirely out of TPU. The vehicle was manufactured as two halves, which join through a printed hinge as the vehicle ends drive apart. Similar to the "tail dragger" design, the two halves are drawn together by magnets embedded within the hinge. The mentioned design was manufactured in three steps: initial print, inlay of electronics, and a final print encasing the electronics. Figure 5 shows the initial design model incorporating a hinge and magnetic locking components.

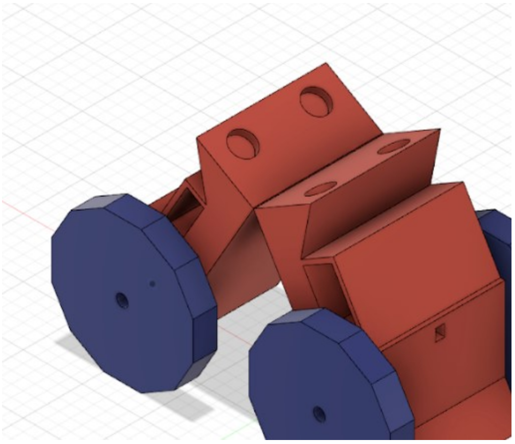


Figure 5: 4-Wheeled initial CAD model.

The 4-wheeled ground vehicle produced was able to effectively break away from the build platform and maneuver out of the unit-cell. Like the 2-wheeled design, the mentioned vehicle survived repeated drop tests of 1m. Figures 6 and 7 show the manufactured ground vehicle utilizing the printed hinge mechanism.

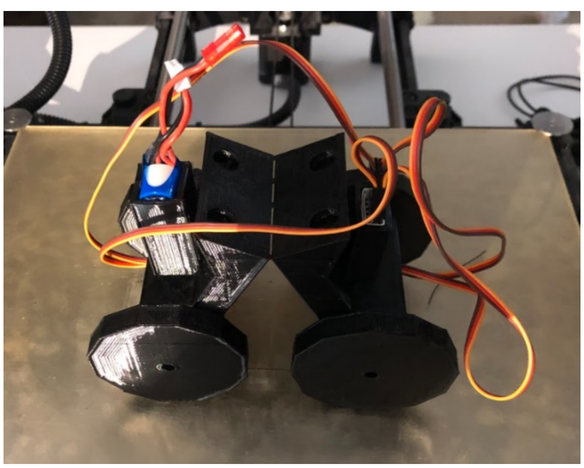


Figure 6: 4-wheeled vehicle in opened position before breaking away from build plate.

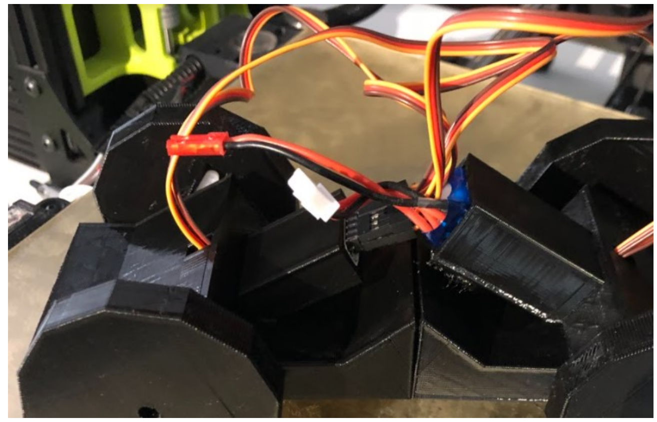


Figure 7: 4-wheeled vehicle in closed position after breaking away from build plate

5. Conclusion / Path Forward

This team was able to provide a fully functional robotic ground vehicle, meeting all the defined requirements. This project has resulted in promising prototypes which have laid the groundwork for more refined versions with the end goal of mission specific, fully attritable, man-portable ground vehicles. This project is an ongoing effort and improvements will continuously be made. Future work consists of:

Implementing nScrypt SuperScrypt Platform- Previous reported work was done by desktop printers and electronic integration had been done by hand. The work reported here uses the nScrypt SuperScrypt platform, which offers: [3]

- Product agnostic manufacturing
- Prints viscosities from 0-1 million cp
- Volumetric dispense control down to 100 picolitres
- Lines ~25-500µm
- Ability to print on conformal surfaces
- Quad deposition heads
- Ability to print thermoplastics (FDM)
- Positional control down to 1 µm

Sensor Integration- To include a GPS, cameras, thermal imaging, chemical sensors, and environmental sensors.

Printed Electronics- The nScrypt SuperScrypt unit-cell offers the ability to print transmission lines connecting the placed electronics. All “wiring” will be printed directly on the body of the robot after electronics are placed. The unit-cell will then continue printing the rest of the body without any human interaction.

Multi Material Integration- The nScrypt SuperScrypt unit-cell utilized in the next phase offers the opportunity to print a variety of materials. Printing transmission lines will require rigid and uniform surfaces, therefore a mixture of TPU and rigid materials will be integrated into the final product.

Propulsion Refinement- The final design will feature DC motors as opposed to the servos implemented in the early prototypes. Tracks are also being explored as opposed to tires.

6. REFERENCES

[1] 0604641A_94.pdf (dacis.com), last accessed, 11 MAY 2021

[2] TP525-3-6.pdf (army.mil), last accessed, 11 MAY 2021

[3] Preparing for future battlefields: The Next Generation Combat Vehicle | Article | The United States Army, last accessed, 11 MAY 2021

[4] www.nscrypt.com, last accessed, 11 MAY 2021