Autonomous Vehicle Protective Subsystem Prototype for the Warfighter

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Abstract

This project was designed for the Army Research Office (ARO) through the University of Colorado's Senior Capstone Course. The ARO serves as the United States Army's principal extramural engineering, physical, information, and life sciences research agency. The ARO's goal is to discover, exploit, and develop innovative technology to ensure the US Army maintains technological superiority. An overarching program envisioned by this team and ARO, the Squad Defensive Equipment Transport (SDET), is centered around this goal and enhances soldier survivability in combat, by detecting enemy gunfire, rotating in the direction of the threat, and deploying armor shields. This provides protection and a stable firing platform for nearby soldiers, as well as a safe zone for treating a casualty. The design developed and created by this team to-date is a half-scale prototype or proof of concept, for the SDET, which utilizes computer vision to detect simulated enemy gunfire. The detection of a threat causes the system to rotate and deploy its shields.

Introduction

As the U.S. Army envisions the battlefield of the future and continues to develop and modernize its technology, interest has increased in unmanned and autonomous platforms to support the Warfighter mission and save the lives of our soldiers. Existing manned platforms such as the High Mobility Multipurpose Wheeled Vehicle (HMMWV) and the Joint Light Tactical Vehicle (JLTV)[1,2] provide protection and storage for the Warfighter, increasing their overall capability to combat hostile threats. However, they place an increased logistical burden on Army Brigade Combat Teams (BCTs) deploying throughout the world, and are not suitable for all types of terrain. This increase on logistics is an aspect that the U.S. Army wants to avoid and instead, better leverage its resources and talent to protect life and limb of the Warfighter.

Since 2001, the U.S. Army has displayed interest in unmanned ground vehicles as part of its mission to modernize their combat capabilities. This interest was the driving force behind the Multifunctional Utility/Logistics and Equipment (MULE) [3] vehicle program, which ran during the early 2000s, and more recently the Squad Multipurpose Equipment Transport (SMET)[4] program. Notably, while the vehicles developed under these programs have displayed exceptional logistics capability, none have fulfilled the defensive and protective role of the larger, manned vehicle platforms they are meant to supplement or replace.

Multi Utility/Logistics and Equipment (MULE) vehicle

Joint Light Tactical Vehicle (JLTV)

Squad Multipurpose Equipment Transport (SMET) vehicle

Motivation

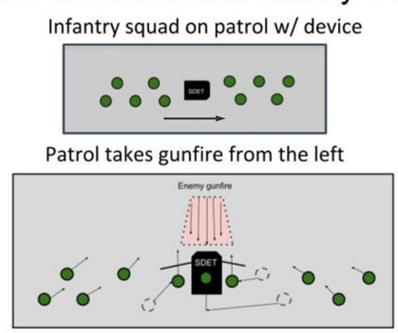
The lack of **active**, defensive capabilities in existing vehicles lead to the creation of the SDET concept. This system provides active, protective capabilities to provide expansive shielding from hostile forces, better ensuring the safe return of our Warfighters to their loved ones.

The SDET concept is expected to be a multi-year project, so future teams will continue to contribute to the overall design and build off of the existing hardware. This will allow the entire system to be further developed and eventually tested in the field. With the resources available to the United States military and considering the additional subsystems future teams will contribute, this project has a very real potential to be employed in the field and save many lives.

SDET Functions

The function of this project is to increase the warfighter's ability to survive combat scenarios. Accordingly, every design decision is based around this important goal. To help visualize what the system will accomplish in the field once fully complete, we visualized & predicted two main scenarios where our system would add extra capabilities for the Warfighter.

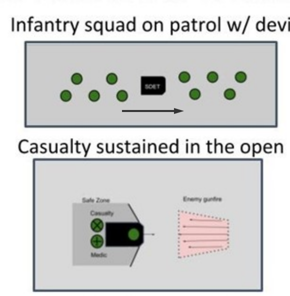
Scenario 1: Reaction to Enemy Contact



Contact Left! Device detects & deploys shields toward enemy contact

In the first scenario (upper right), the infantry squad and the full field-ready vehicle are on patrol when incoming fire from the left activates the protective subsystem. The alert is confirmed, and the vehicle rotates to face the detected direction of fire and deploys its shields. Two to three personnel are able to assume defensive positions behind the vehicle’s armor panels and return fire.

Scenario 2: Reaction to Wounded Soldier



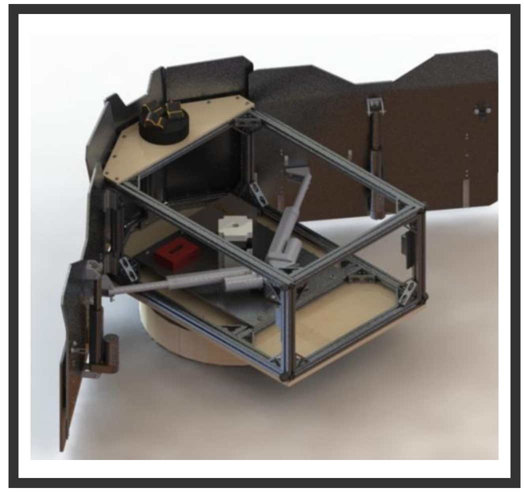
Corpsman up! Device faces incoming fire & deploys shields to provide cover for medic and casualty

In the second scenario (lower right), the infantry squad and the full field-ready vehicle are on patrol when they sustain a casualty in the open. The casualty is reported, and the vehicle moves between the casualty and the detected enemy firing location(s) and deploys its shields. The medic is then able to safely reach the casualty and provide life-saving aid. The casualty can be loaded into the vehicle, utilizing a litter located in the cargo bay (behind hardcover) to protect and transport the casualty. This will liberate two squad members for combat who would have otherwise had to carry the stretcher.

System Breakdown

The system (as depicted to the left) is comprised of five main mechanical sub-assemblies:

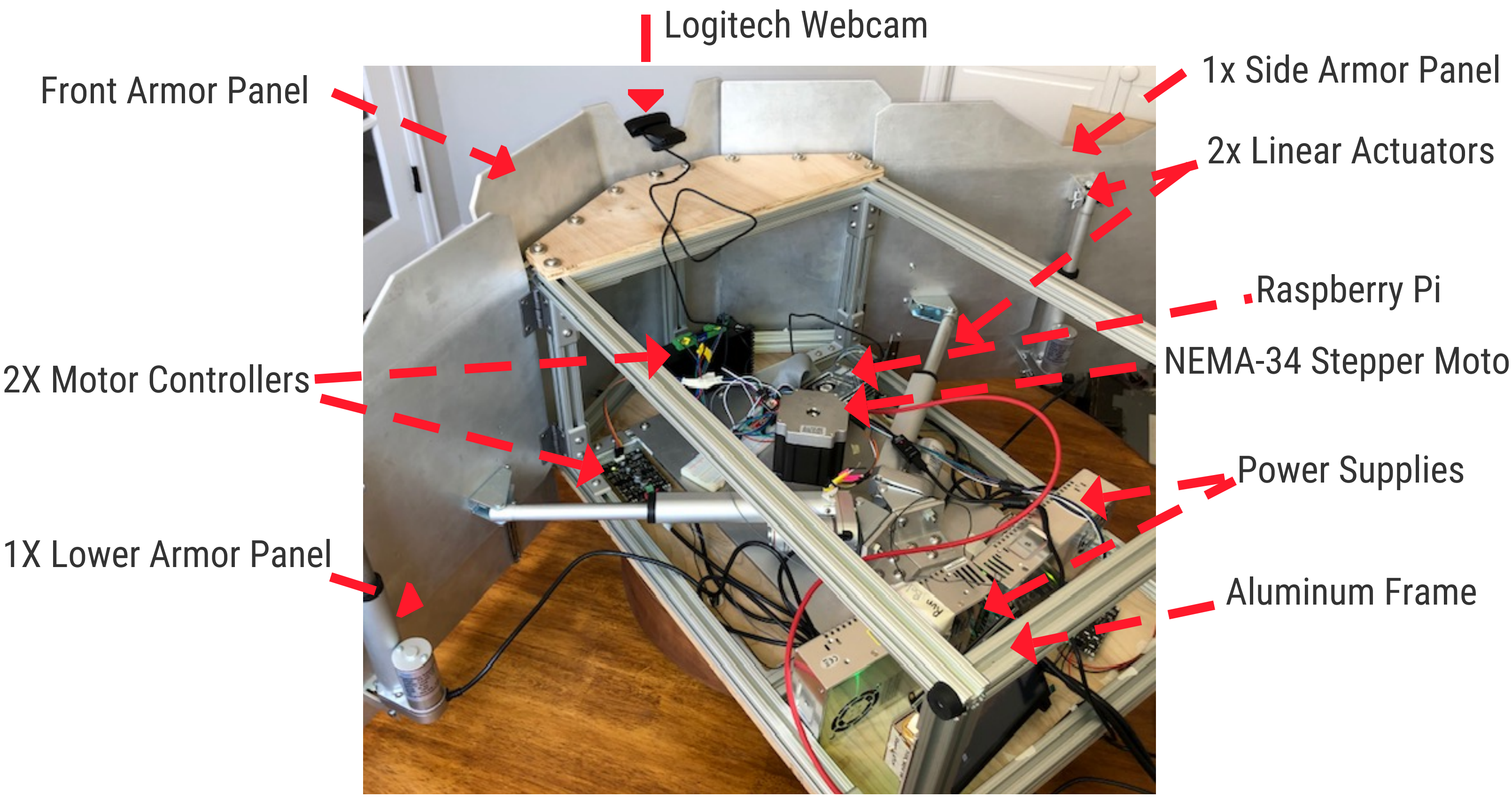
1. Aluminum Frame
2. Front Armor Panel
3. Side Armor Panels (Deployed with linear actuators)
4. Lower Armor Deployment (Deployed with linear actuators)
5. Rotational System / Base Stand



Final CAD Rendering of SDET Design

Along with these mechanical assemblies, the system also has several electrical components. These allow the SDET system to utilize computer vision to detect the threat, rotate to face it, and deploy the armor panels. The electrical sub-system consists of the following components:

1. 2 x Power Supplies (One for the NEMA-34 Stepper Motor, and the other for powering all other electrical components)
2. NEMA-34 Stepper Motor (Responsible for rotating the system)
3. Raspberry Pi Micro-controller (Controls all functions of the system)
4. 4x Motor Controllers (Two for the latch catches in the back of the system and two for linear actuators for both side and lower armor deployment)
5. Logitech Webcam

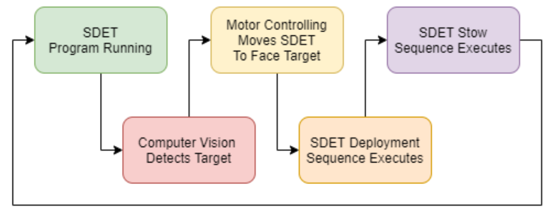


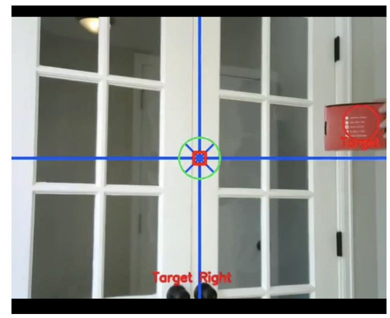
SDET System with Components Highlighted

System Program

The program was implemented as a sequence of events to be executed. The first portion of code is all the initialization of each component. This includes setup for the NEMA-34 Stepper motor, the electronic latches, the linear actuators and the webcam's computer vision. This initialization tells the computer which component is associated with particular hardware interfaces. The second portion is a number of functions that each execute a particular component's code. The last portion of the code is a running loop that continuously monitors the webcam output for visual thresholds. If a particular condition in the webcam output is met, it then calls the component functions as needed.

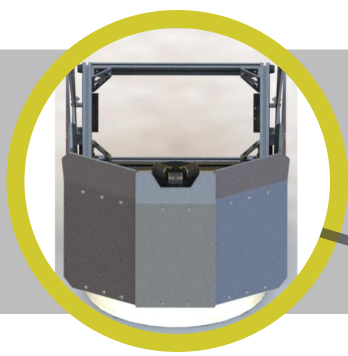
During program execution if an object containing a particular group of colors is introduced into the field of view (simulating a hostile threat), the device will track and move to face the center of that object. The program was written to demonstrate the flow path from detection to action (shown to the right).





Visual image from Webcam utilizing Computer Vision software to locate and target a simulated threat

Summary of Operation

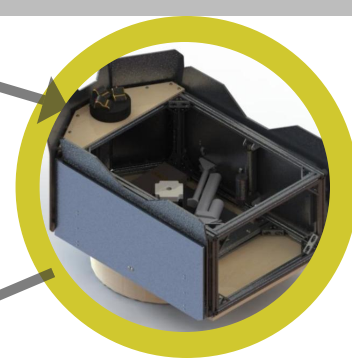


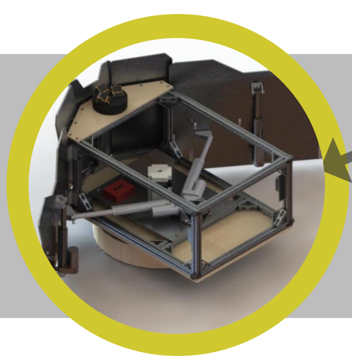
Detection:

The system utilizes custom computer vision to detect the simulated threat through the camera mounted to the front of the system

Rotation:

The system then rotates to face the location of the detected "threat" by engaging the NEMA-34 Stepper Motor and rotating the amount determined by the program

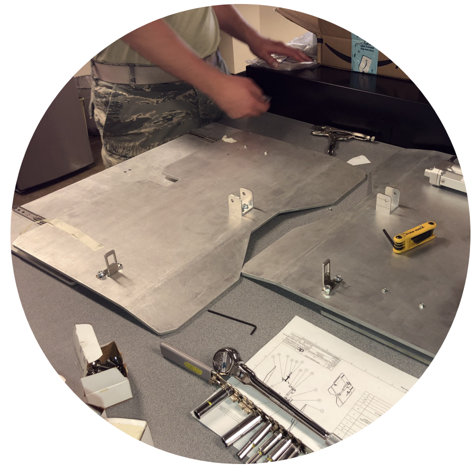




Deployment:

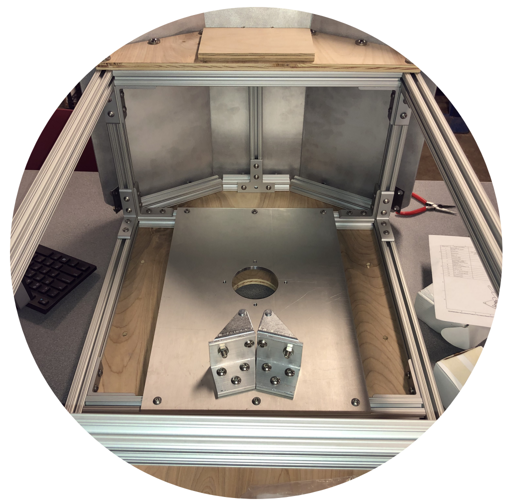
The system, once facing the direction of the simulated threat, first deploys its side armor panels and then deploys the lower armor panels. This provides the warfighter 240 degrees of cover behind the panels

Fabrication & Challenges



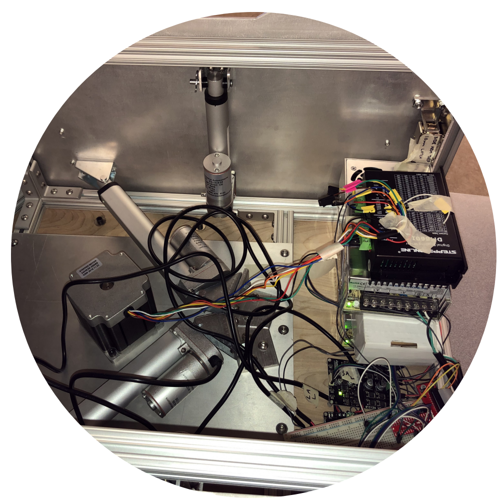
Fabrication of all components except for the armor panels was completed in-house. The armor panels were outsourced for two reasons - the quick water jet manufacturing offered by Colorado Waterjet improved the project timeline, and the equipment to add a 10° bullet-deflecting angle was not available in the campus machine shop. For this bend, the cut panels were sent to Accu-Precision.

The most challenging parts manufactured in-house were the door latch catches, although the assembly of the rotational sub-system also required the creation of a time-consuming shaft collar adapter plate. The small bend radius and material (6061) of the door latch catches required additional heating to anneal and create the desired bend, which was accomplished with the help of the machine shop staff in the IdeaForge. The design of the shaft collar adapter plate required extensive research in fastener selection, such as bolt preload, to ensure it remained static during rotation.



The team also made several adjustments to the electrical systems during the fabrication process. For instance, a new power source was required for the NEMA-34 motor as the assembly of the electrical system provided an educational opportunity on the power and voltage requirements provided on the specification sheets from the manufacturer.

Overall, roughly 70 hours were spent manufacturing custom components in-house. It took around one week's time to fully assemble the project and get it ready for initial testing. This short assembly timeline was intentional - the 80-20 base was designed to allow for rapid assembly and prototyping of system add-ons.



In addition to the challenges stated above, the team also worked virtually through a quarantine due to the COVID-19 pandemic, which caused issues in testing hardware and implementing changes to the programming. Despite all of these challenges, the team was still able to successfully complete all manufacturing and fully assemble the SDET system for testing and optimization with programming.

Results & Conclusion

Now fully manufactured, assembled, and tested, the SDET prototype is able to detect an object that resembles a simulated “threat", rotate to face the object, and then deploy its defensive barriers. Additionally, the team is able to manually control the rotation and deployment of the defensive barriers through commands given directly to the Raspberry Pi.

This project provided a valuable learning experience for the team, with many challenges and unforgettable experiences. The team produced a complete prototype that is functional despite all of the adversity encountered during the COVID-19 pandemic. This project was a huge success and will provide a launchpad for future progress. This project will continue to be developed by future teams with the same goal of providing our Warfighters with the protection and assistance they need to save lives and come home to their loved ones - safe and sound.

Special Thanks

We would like to thank some individuals and companies who have provided assistance to the development of this project. Without their generous contributions of their time, insight, equipment, and donations, this project would have not achieved the same positive result. We would like to thank:

- Stefan Berkower for serving as our advising director, helping us to stay focused on project requirements, overcome technical challenges, and serve as an essential advisor to our overall performance as a professional team of engineers.
- Army Research Office for their continued support and advice throughout the entirety of the project, and allowing the team to make the project their own, creative solution without limiting/restrictive requirements.
- Accu-Precision supported the manufacturing of the panels in their gracious donation of time and equipment to bend our panels to their desired form.
- Sparkfun Electronics for their scholarship in support of student academic projects, whose donation aided in the development of the electronics and software.
- IdeaForge staff whose advice, instruction, and expertise proved invaluable in the development of a complex piece of equipment. Their continued support of student projects results in the development of practically trained engineers.

References

[1] "Joint Light Tactical Vehicle (JLTV) Programme". Army Technology.

[2] Oshkosh Corporation Company. “Light Combat Tactical All-Terrain Vehicle: L-ATV.” Oshkosh Defense, 2019, oshkoshdefense.com/vehicles/l-atv/#performance.

[3] "DARPA Picks Eight Teams For Unmanned Ground Combat Vehicle Prototypes". Defense Daily. 9 February 2001.

[4] Massey, Kent. Squad Mission Equipment Transport (SMET). HDT Expeditionary Systems , 2019, HDT Expeditionary Systems .

Team Biographies

Chris Lehr

Chris is the team's Systems Engineer after holding an internship with Sierra Nevada Corporation as a Systems Engineer Intern. He will graduate in December with a degree in Mechanical Engineering and commision as a 2nd Lt in the United States Air Force where he seeks to acquire a masters in Maritime Architecture and then pursue his goal to design the world's elite yacht fleet.

Luke McConnell

Luke is a capstone exchange student and the team’s Computer Scientist. He will be graduating this August with a B.S. Computer Science. Luke was an enlisted sailor in the Navy Nuclear Power Program for six years. Afterward, he worked as a gauge calibration technician while earning his Associate of Science degree from the Community College of Denver. Luke continues to overcome academic challenges here at CU Boulder.

Daniel Malek

Daniel is the team’s Manufacturing Engineer, graduating this May with a major in mechanical engineering and a minor in Business. Having held six summers of internship positions in construction, manufacturing, and mechanical design, Daniel hopes to apply his knowledge to developing new technology. He is currently seeking full-time positions focused especially on mechanical design or manufacturing.

Dan Nave

Dan N. is the the team’s CAD Engineer. Dan is a dedicated aspiring Mechanical Engineer committed to being a valuable team member while leading by example. He has 5 months of industry experience designing space craft wing structures at Sierra Nevada Corporation, 4 years of experience honing engineering skills through extracurricular engineering clubs and 6 years of military service as a Navy Corpsman.

Natasha Ouellette

Natasha is the team’s Lead Test Engineer and a mechanical engineering major. She has held several full-time industry internships, and recently accepted a full-time engineering position with the U.S. Navy. She has a minor in leadership studies and is graduating from the Presidents Leadership Class, the Engineering Honors Program, and the College of Engineering and Applied Sciences this May.

Noah Verspohl

Noah is the team’s Financial Manager, and will be graduating in May with a Bachelor of Science in mechanical engineering. In addition to graduating, he will be commissioning as a 2nd Lt in the United States Air Force. He will be continuing on to Euro-NATO Joint Jet Pilot training this summer where he hopes to earn his wings.

Austin Ross

Austin is the team's Logistics Manager and will graduate this May with a Bachelor of Science in mechanical engineering. Along with this, he will commission into the United States Air Force as a 2nd Lt, slotted to begin Undergraduate Pilot Training at Vance AFB in March of 2021. From now until then, he plans on starting a Master's Degree and working in industry to gain more experience and apply his skills.

Dan Walton

Dan is the team’s Project Manager, and is a mechanical engineering major with a minor in engineering management. He has been selected for a fellowship with the National Security Innovation Network for the Summer of 2020, and hopes to continue into a career in the defense industry in the future. He is graduating from the Engineering Honors Program and the College of Engineering and Applied Sciences this May.