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2022 MRC-ARL Summer Student Team Research Experience: Air-Deployed Robots for Mobile Sensing

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14. ABSTRACT
The MRC-ARL Summer Student Team Research Experience, a joint effort of the Maryland Robotics Center (MRC) and the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL), engaged 20 undergraduate students from the University of Maryland, Baltimore County and the University of Maryland, College Park. Their mission centered on the conception and construction of a system for the airdrop deployment of a ground-based robot. This was motivated by the quest for safer, more efficient alternatives to current methods of delivering critical supplies and personnel in high-risk scenarios, reducing both danger and resource intensiveness. Over the course of an 8-week program, the students focused on creating an impact energy mitigation system and developing algorithms to facilitate ground navigation post-impact. Their collective efforts culminated in a final, real-world test scenario at ARL's Robotics Research Collaboration Campus. Here, robots were dropped from a 12-m building. Although the students' demonstrated solutions were only partially successful, they learned valuable lessons on teamwork and project management and set the stage for future advances in air-dropped robotic systems.

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1. Introduction

1.1 Context

As a part of the AI and Autonomy for Multi-Agent Systems Cooperative Agreement (ArtIAMAS CA), the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) and the Maryland Robotics Center (MRC) completed the first annual summer student team research experience. Nineteen students, 10 from University of Maryland, College Park (UMCP) and 9 from University of Maryland, Baltimore County (UMBC), worked over 10 weeks to develop a system to air deploy a ground mobile robot and collect visual data after landing. The students worked at their respective universities and completed a final demonstration at ARL's Robotics Research Collaboration Campus (R2C2).

1.2 Project Motivation and Background

Presently, the process of deploying equipment from an aircraft involves parachute-assisted drops, followed by subsequent unpacking upon landing. This approach not only consumes valuable time and human resources but is also limited to specific terrains, thus potentially posing risks.

The practice of airdropping supplies and equipment traces its origins back to World War II. Aircraft delivered small personal supply packages to regions that were otherwise inaccessible to friendly ground forces. These daring missions marked the inception of airdrop operations, setting the stage for the evolution of techniques and technologies that would follow (Emery 1991).

As the world entered the Korean War, airdrop capabilities expanded significantly. Not only were essential supplies delivered from the sky, but even larger equipment and Soldiers themselves were airdropped. Aircraft of that era allowed for Soldiers and equipment to be released from the rear of planes, a leap forward in the art of tactical insertion (Emery 1991).

For more dangerous scenarios, such as parachuting into hotly contested battlefield environments, speed was of the essence. In such cases, Soldiers opted for round parachutes instead of the more controllable but slower descending ram air parachutes. While these round parachutes got them to the ground faster, the trade-off was a considerably harsher landing. To mitigate the risk of leg injuries upon impact, Soldiers adopted a technique known as the parachute landing roll where the parachutist hits the ground with the knees together then rolls to the side onto the outer leg, thigh, buttocks, and across the back (Bricknell and Craig 1999).

Outside of parachuting, to protect themselves from harsh landings humans have explored various landing strategies. Concepts like drop landings (Santello 2005) and parkour landing rolls (Puddle and Maulder 2013) are used to enhance the survivability of human landings off high ledges. Nature, too, offers inspiration, as animals have developed mechanisms to dissipate energy during falls. Cats, for instance, employ their forelimbs and flexible spines to mitigate the force of a fall (Zhang et al. 2014), while frogs use their forelimbs to reduce the impact of vertical and lateral landings (Nauwelaerts and Aerts 2006). Even gliding geckos use their tails to stabilize impacts with objects like trees (Siddall et al. 2021).

In the realm of planetary exploration, space agencies like NASA have a rich history of delivering robotic explorers from the skies. Notable missions, such as those involving the Pathfinder, Spirit, and Opportunity rovers, used a unique combination of techniques. These rovers made use of parachutes to slow their descent through alien atmospheres and airbags to cushion the impact upon landing (Crisp et al. 2003).

This diverse history of airdrop operations, from military exigencies to planetary exploration and innovative landing strategies, forms the backdrop against which contemporary developments in airdropping equipment and robots for resupply, tactical insertion, and planetary landing are situated. The core objective of this project is to build on existing airdrop solutions to engineer a ground mobile robot capable of autonomous air deployment from aircraft at various altitudes, eliminating the need for human intervention. This innovation aims to address the limitations of conventional air deployment methods by enabling access to currently inaccessible terrains. To bring this vision to fruition, the robot’s design must encompass the ability to withstand potentially harsh landings, self-unpack upon arrival, and possess mobility for tasks such as terrain manipulation and reconnaissance.

2. Methods

2.1 Project Guidelines

Students were tasked to develop a system to deploy a robot by dropping it from a 3+ story building with the following restrictions: the robot will not use parachutes, must survive landing, and mobilize via legs to collect video data near the landing site. ARL purposefully gave loose guidelines to allow for maximum creativity while still accomplishing the project goal. Students chose a reasonably priced (~$500) legged robot kit.

The final demonstration required two phases:

1) To demonstrate that the robot could survive a 12-m fall.
2) After the fall, the robot was to unpack itself and demonstrate that it was still mobile by performing a navigation task like locating and moving toward an Aruco marker in vicinity of the drop site.

2.2 Mentorship Strategy

Students were mentored by faculty and graduate students from UMCP and UMBC. In addition, three mentors from ARL met weekly with the students to discuss their progress and receive feedback on their work. At the midpoint of the project, both teams visited ARL to tour the robotics research facilities and have a joint meeting. At this joint meeting they shared their progress with each other and received peer-to-peer feedback. This interaction was meant to connect the students for networking purposes but also to re-emphasize that the experience was not a competition and that the two teams can work together to improve both of their designs.

2.3 Team Setup

A team of 10 students split themselves into sub-teams related to the phases of robot air deployment: descent, impact, and ground movement. Each team came up with two to three design or demonstration ideas in the first 2 weeks of the project and then narrowed them down to one to two ideas toward the end of the project.

2.4 UMCP Materials and Methods

The UMCP team designed a prototype capsule made from 3D-printed acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and rubber. The rubber nose cone was made of rubber from a toilet plunger and was designed to absorbed energy during impact. The team found during testing that the nose cone rebounded quite high after impact and the capsule flaps were unable to deploy properly. To help mitigate this problem, the team added sand to the nose cone to increase damping.

To attach the nose cone to the capsule the team 3D-printed a collar that screwed onto the capsule. The team attached one-way hinges to the collar to hold outer walls. The one-way ratcheting hinges allowed the outer walls to fold out during impact and then locked them in place to keep the capsule upright. Inside of the outer walls, a semicylindrical case made of sheet metal was designed to hold the robot.

During impact, the case slid down, guided by a rod, and pushed on the outer walls to cause them to fold out (Fig. 1).

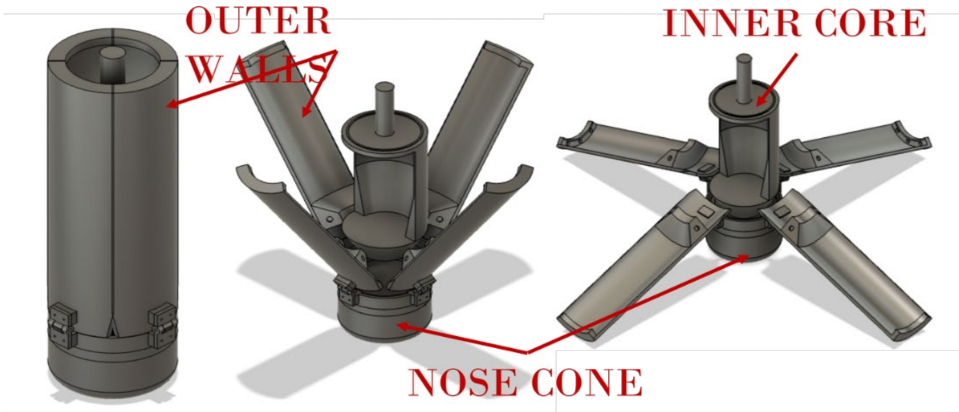

Fig. 1 UMCP capsule design. From left to right, the capsule is closed as it falls. Just after impact the nose absorbs energy, the robot holder slides down, pushes out the outer flaps, and then the flaps lock into place and hold the capsule upright so the robot can be released.

The UMCP team used the Luwu Dynamics XGO Mini Quadruped Robot Dog (Fig. 2). For ground reconnaissance, the team attached a Raspberry Pi camera module. A Robot Operating System (ROS) package was used to detect Aruco markers, which were used as placeholders for ground navigation way points. The team also attached an ultrasonic distance sensor to detect larger obstacles like buildings.

Fig. 2 XGO robot with Raspberry Pi camera attached walked on gravel at the Graces Quarters Military Operations in Urban Terrain (MOUT) site

In early testing, the XGO robot struggled to move on rough surfaces. The feet were small enough to get wedged in gaps and crevices and get stuck. To prevent this, the team 3D-printed semispherical feet to give the robot a larger footprint that prevented it from getting stuck.

2.5 UMBC Materials and Methods

The UMBC team developed several prototypes, including a glider and roll cage made from PVC and nylon fabric. The final design consisted of a foam pad with a rope to prevent the robot from bouncing off the pad during impact (Fig. 3). A weight was placed underneath the pad to prevent tipping over.

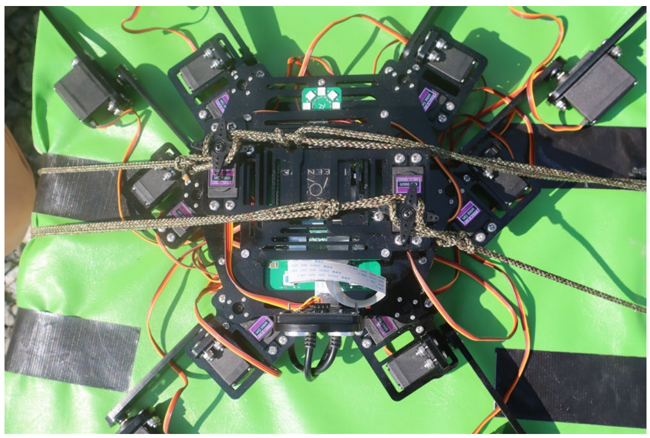

Fig. 3 UMBC hexapod robot strapped to foam pad. The pad dissipated energy of the fall and the two servos on top of the robot rotated to release the robot after ground impact.

UMBC used a Freenove Hexapod robot to demonstrate navigation tasks. The robot was made of acrylic and had 3 degrees of freedom per leg. Accessories for navigation included a stereo camera and laser range finder. Like the XGO used by the UMCP team, this robot also struggled to move on the rough gravel surface of the test site. The performance was deemed acceptable enough that no modifications to the feet or legs were needed for the navigation task.

3. Outcomes

3.1 UMCP

The UMCP robot was unable to autonomously complete its navigation task due to hardware problems. The team demonstrated the concept of locating multiple Aruco markers around the landing site by teleoperating the robot. Due to the possibility of damaging the robot during the drop test, the team demonstrated their navigation task first.

After the navigation task, the robot was placed inside the capsule and dropped from the top of the 12-m tower at the R2C2 MOUT site (Fig. 4). During the final demo, the capsule failed at impact. The ratcheting doors broke off, the capsule landed on its side, and the robot was unable to climb out. Despite the failure, the team learned valuable lessons for future iterations. Namely, that 3D-printed parts at high-stress locations should be replaced by aluminum or steel machined parts.

Fig. 3 UMCP testing their capsule with extra padding and a drag chute during the ArtIAMAS capstone demo week

3.2 UMBC

Like the UMCP team, UMBC demonstrated their navigation task prior to the drop test. The robot completed its navigation task successfully. It was able to locate an Aruco marker using its onboard camera and walk toward the marker (Fig. 5).

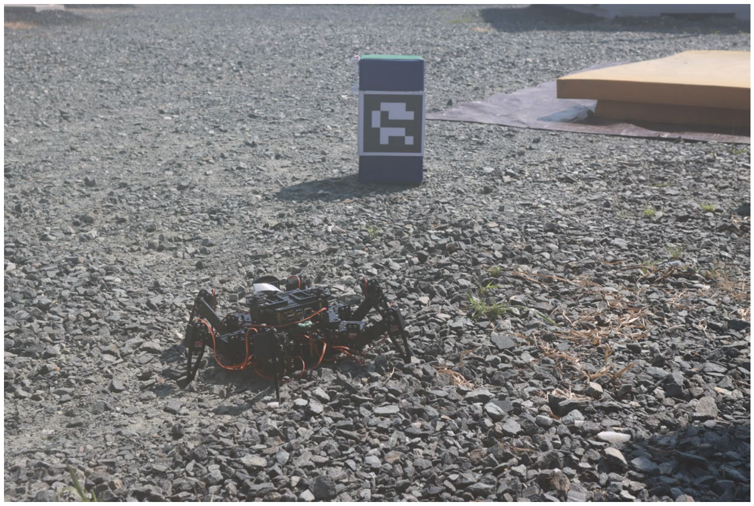

Fig. 5 Hexapod robot performs the navigation task of locating and moving toward an Aruco marker

The UMBC team demonstrated their drop system by releasing the robot from a 12-m tower at the R2C2 MOUT site. The robot survived the fall but was unable to release itself from its straps without some human assistance. In addition, the impact knocked some of the servos out of calibration, so it struggled to walk down off the foam pad.

3.3 Challenges and Solutions

Despite only partial success in the drop tests, the students gained valuable experience in project management, teamwork, and public demonstration of research. Observers positively received the drop tests, and the students found the experience enjoyable.

For future iterations of the summer research experience, the scope of the project could be narrowed to ensure successful completion of more concrete tasks within the given time frame. Teams could be balanced in terms of expertise by considering both major and student location preferences during team assignments. The requirement to use a legged robot was also challenging for the students given the rough gravel terrain of the demonstration site and the fragile nature of legged robots in the student's price range. This requirement will be relaxed in the future and the students will have the option to used wheeled or tracked vehicles as well.

4. Conclusion and Future Directions

The first annual MRC-ARL Summer Student Team Research Experience provided a valuable learning experience for the participating students and helped progress toward the objective of developing a robotic air assault drone. The collaboration between ARL, UMCP, and UMBC showcased the potential for future joint efforts in advancing robotic technologies for military applications and mentoring potential future Army researchers. The insights gained from this project will contribute to the improvement of subsequent summer research experiences and propel the development of cutting-edge robotics solutions.

Moving forward, future iterations of the summer research experience will include several changes. The robots will be dropped with an air vehicle instead of dropped off a tower. To enhance teamwork and expertise, future projects will strategically form teams based on students' majors and skill sets. By carefully balancing mechanical, computer science, and other relevant disciplines within each team, students can leverage their diverse backgrounds and knowledge to tackle project challenges more effectively. To improve overall project outcomes and optimize success rates, future projects will adopt a more focused approach. By narrowing the project objectives, students will have the opportunity to concentrate their efforts on specific tasks, allowing for a more thorough exploration of critical aspects. This will provide students with a better chance at achieving successful demonstrations and delivering feasible, tangible outcomes during the designated project duration.

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List of Symbols, Abbreviations, and Acronyms

3D	three-dimensional
ABS	acrylonitrile butadiene styrene
ARL	Army Research Laboratory
ArtIAMAS	AI and Autonomy for Multi-Agent Systems
CA	Cooperative Agreement
DEVCOM	US Army Combat Capabilities Development Command
MOUT	Military Operations in Urban Terrain
MRC	Maryland Robotics Center
NASA	National Aeronautics and Space Administration
PVC	polyvinyl chloride
R2C2	Robotics Research Collaboration Campus
ROS	Robot Operating System
UMBC	University of Maryland, Baltimore County
UMCP	University of Maryland, College Park

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