University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Autonomous Rover for Ground-based Optical Surveillance (ARGOS)

Approvals

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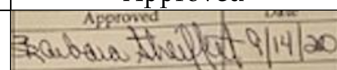
Customer	Barbara Streiffert	JPL		
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3. Problem or Need

Forest fires in the United States have continually gotten bigger and more destructive in recent decades, in part due to climate change. Increased global temperatures and lowered humidity are two key factors to fire risk [1]. With fires causing billions of dollars in damage and putting lives at risk, steps must be made to mitigate this danger. In an effort to assist in the suppression of fires, this team's project will work with the existing Fire Tracking System. This system is made up of five heritage projects, which are described in more detail in Section 4. The system as a whole seeks to remotely identify areas susceptible to wildfires and monitor the region surrounding ongoing wildfires. As of now, there is no method of high quality imaging from a clear vantage point except from the INFERNO aerial drone. This drone comes with disadvantages such as limited battery life, decreased visibility due to tree coverage and other obstacles, and unpredictable wind conditions [2]. ARGOS aims to provide a low-cost method for ground-based imaging from a height in which vegetation and fire fronts are not obscuring the desired target. It especially aims to survey dug-out trenches, known as fire lines. Fire lines provide a gap in vegetation, or other combustible material, to slow or stop the progression of a wildfire. With this method implemented, firefighters will be able to more easily and safely map the fire lines and determine if the flame front has breached the fire line.

4. Previous Work

The Fire Tracker System has five heritage projects all focused on combating the problem of forest fires: INFERNO, CHIMERA, DRIFT, HERMES, and ATLAS. The first of the series INFERNO is a child drone designed to drop sensor packages in a location of interest [2]. CHIMERA is a take-off and landing platform for INFERNO which would later be attached to the mother rover DRIFT [3]. The DRIFT project consisted of integrating CHIMERA to the mother rover in order to extend the range of the child drone through areas affected by forest fires [4]. HERMES is a child scout rover designed to dock and deploy from the mother rover and find a safe path for the mother rover to traverse [5]. ATLAS was a mechanical arm which provided the capabilities to dock and deploy HERMES [6]. This year's contribution to the Fire Tracker System, ARGOS, is another child rover with the task of monitoring and collecting data from a portion of the flame front with a camera that sits on top of an extendable and retractable mast.

To achieve the requirements set for the ARGOS mission, previous rover and future rover designs by NASA and other space agencies shall be looked at for insight. These insights shall include visual odometry, mast development, and wireless data transmission [7]. A current project working on the future development of these systems is the BAE SEEKER rover designed to increase the accuracy of wireless visual navigation and to increase the distance traveled per sol [8]. The research being done on the SEEKER rover and previous rovers shall be invaluable in aiding in the design decisions made on the ARGOS rover.

5. Specific Objectives

In order for the rover to successfully track the progress of a forest fire, key components must be considered when it comes to designing the vehicle. Such components will include the rover's movement, the rover's surveillance, and its communication abilities. It was determined that these three elements are crucial for the rover's capabilities and will be categorized in four levels of success that are shown in Figure 1. The specific deliverables for this project will include the child rover with all maneuverability capabilities, the rover's temperature sensor and extendable mast for video data collection, and the final deliverable is a functional communication system between the child rover, ground station, and mother rover all of which will be discussed further in the following paragraphs.

The first deliverable is a child rover capable of traversing various terrains, such as underbrush and forest floor, susceptible to forest fires. The maneuvering capabilities will be considered successful when the rover can drive over small obstacles (small rocks, sticks, etc. < 7 cm tall) and uneven ground and navigate around larger obstacles (big rocks, trees, etc. > 7 cm tall) as well as the ability to move up and down slopes of up to 20 degrees. The levels of which this deliverable would be successful are detailed further below in Figure 1. These functionalities will be tested by physically creating these scenarios and observing the rover's ability to navigate them without any damage to its systems or immobilization of the rover.

For the next deliverable, the surveillance capabilities, the rover will be equipped with a temperature sensor and an extendable and retractable mast, equipped with a camera, that is capable of raising to a suitable height in order to see above the flame front. Ambient temperature readings will be taken throughout its mission and at desired locations of interest. Once the mast is extended, the camera will record photo/video data and all information will be sent to the ground station and mother rover. The extent to which this deliverable will be considered successful is detailed further in Figure 1. This element will be tested by collecting temperature readings and photos of a simulated flame front and comparing this to accurate data taken prior to the test of the rover's surveillance capabilities. The mast will also be tested for proper extension height, operation without tipping over, and structural integrity.

For the final deliverable, a communication system will be implemented that allows the child rover to successfully transmit temperature and video data to the ground station and mother rover as well as receive GPS navigation coordinates from the ground station and mother rover. This deliverable will be successful if this communication can take place at the required distance of 250 meters in an area with densely packed obstacles (such as 0.25 trees/m^2) to both the ground station and mother rover. The levels to which this deliverable would be successful are detailed further in Figure 1. The child rover's communications with the ground station and mother rover can be tested by observing the rate and quality of data being transmitted at incremented distances, as well as at different sites with varying tree densities, such as an open area and a forested area. These tests will ultimately demonstrate the communication system's degradation with distance and accuracy through obstacles.

The levels of success for ARGOS are outlined below. It is implied that each level meets the previous level of success. The obstacle height for Rover Movements in Level 3 was based of the heritage project DRIFT who based their rover's success off of traversing rocks 3in high which is roughly equivalent to 7cm. [4]. The tree density metrics under Communications were based off of the Standard Density Index (SDI) used by Colorado Forest Services to measure tree density [9]. While SDI takes into account tree height, diameter, and species, ARGOS will only take into account the number of trees in the area for simplification purposes.

	Rover Movements	Surveillance	Communications
Level 1	Rover can travel on flat ground for 100m and can turn on zero degree incline in a forward direction	Temperature data is successfully recorded from a temperature sensor. Rover successfully records timestamped photos of the flame front via a mast.	Rover can successfully receive GPS commands from the ground station and the mother rover. Rover can successfully transmit temperature data and video/images to the ground station and mother rover up to 0m from ground station via radio remote control.
Level 2	Rover can travel on uneven terrain while staying upright on a 10 degree incline. Rover can follow GPS coordinated in the event of loss of signal. Rover can also travel in reverse direction.	Rover successfully records timestamped video of the flame front via a mast which successfully deploys.	Successful communication with the ground station and the mother rover up to 100m with no obstacles (0 trees/m2).
Level 3	Rover can turn 360 degrees and travel 250m on a 20 degree incline. Rover can avoid obstacles up to 7cm tall.	Rover can successfully recognize when a fire breaches a fire line via a camera on top of a mast which successfully deploys to its full length and retracts completely.	Successful communication with the ground station and the mother rover with obstacles (0.25 trees/m2).
Level 4	Rover has flipping detection. Waypoint navigation with +/-5m of waypoint.		Successful communication with the ground station and the mother rover up to 250m.

Figure 1: Levels of Success for ARGOS

6. High-Level Functional Requirements

1. The child rover shall be able to move from a starting point to a location of interest and return.
2. The child rover shall be able to survey a fire line while taking ambient temperature data that can be used for analysis.
3. The child rover shall have an extendable and retractable mast to take photos and video of the flame front from multiple positions.
4. The child rover shall be able to receive commands from a ground station and mother rover and communicate back photos, video, and temperature data.

Customer specified design requirements can be found in the Appendix.

The child rover is intended to be mobile so that it can survey various locations along the fire line. Added mobility also allows the child rover to be deployed away from the location of interest and navigate to it.

The ability to survey the fire line and flame front could allow the child rover to alert the ground station if the fire line has been compromised by an encroaching flame front. Any necessary analysis of the footage or temperature data, such as recognition of when the fire line has been breached, will allow firefighters to respond effectively and evacuate if necessary [10].

In order to gain valuable data from the rover about the progression of the wildfire, it is desirable to track the flame front, which could have varying height or size depending on the state of the wildfire. Therefore, the rover must have the ability to put its camera(s) at various vantage points or positions above the ground with an extendable and retractable mast.

In order to allow the ground station team to effectively use the rover, the rover needs to have the ability to receive new waypoints, mission aborts or any other critical commands. The rover should also send images and temperature data as they are captured in order to provide low-latency information about the flame front to the ground station team. In order for ARGOS to fully integrate with the rest of the Fire Tracker System, ARGOS must be able to transmit useful data such as video, photos, and temperature data to the mother rover as well as be commanded by the mother rover to specified GPS coordinates.

6.1 Concept of Operations (CONOPS)

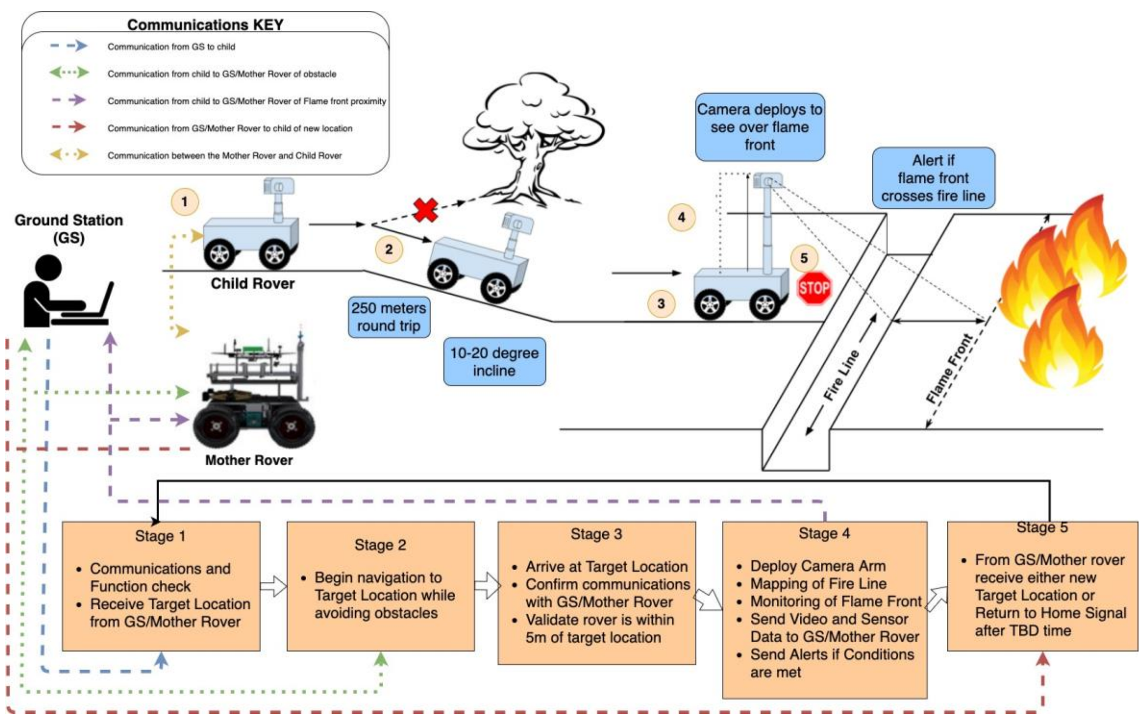

Figure 2: Mission CONOPS

The Concept of Operations (CONOPS) visually demonstrates the mission of the child rover. The operation of this rover as seen in figure 2 is divided into 5 stages; Deployment of Rover, Navigation, Arrival to Location of Interest, Deployment of Sensors and Monitoring, and Update/Return after TBD time.

The child rover, seen in blue, begins on the left in its first deployment stage. The ground station establishes communication and commands a new target location. The rover enters stage 2: Navigation, where it moves to the target location while avoiding obstacles. After navigating to the location of interest stage 3: Arrival, the child rover confirms communication with the ground station and validates the rover's current location is within +/- 5 meters of the target location. Following this validation, the rover then initiates stage 3: Deployment of Sensors to begin mapping the fire line and monitoring the flame front. Video and other sensor data will be sent to the ground station while the rover monitors the flame front and its development and proximity. If flames breach the fire line, an alert will be sent to the ground station. Finally, in stage 5: Update/Return, the rover will either return home after a TBD time or receive a new target location from the ground station operator.

Dashed lines connecting stages and the ground station represent critical points of communication. The blue line represents initial contact from the ground station to the child rover as well as the commanded target location. The green line shows communication between the child rover and the ground station concerning an obstacle encountered along its path. The purple line serves as the communication from the child rover to the ground station and mother rover. The red line indicates a new command given by the ground station to the child rover. The yellow line highlights direct communication between the heritage mother rover and the child rover.

7. Critical Project Elements

Table 1: Critical Project Elements

Critical Project Element Number	Critical Project Element	Explanation
Technical		
T.1	Communications	ARGOS must have communications with the ground station as well as the mother rover and possess the ability to be controlled by the operator directly from the ground station. ARGOS must return visuals, location, and temperature data back to the operator in order to complete its main objectives. A communications failure would result in ARGOS being unable to complete this objective. An error in communication could also result in ARGOS being unable to return autonomously to the last known waypoint, which could result in complete loss of the rover.
T.2	Control	ARGOS must possess the ability to be controlled by the ground station and the mother rover. Controls would entail the movement of the rover and potentially the movement of the camera system. Failure would result in ARGOS being unable to correctly locate and travel to the target location or collect meaningful data, meaning a failure to complete its objective. Ultimately this would result in relying on the autonomy of ARGOS to return to its last known waypoint.
T.3	Sensors	ARGOS must be able to provide live video, temperature readings, and possess autonomous capabilities that enable the rover to move to given GPS coordinates. Sensors can provide the rover with autonomous capabilities as well as valuable data to meet the mission's objectives. If autonomy is not achieved ARGOS will be unable to return to its last known location in the case of lost communications. The Rover must also possess the ability to sense a tipping condition with the mast extended.
T.4	Maneuverability	ARGOS will travel through various terrains during the mission, including forest underbrush and/or open grassland with rocks, branches, and tree roots. It must be equipped to navigate through this terrain without becoming stuck on obstacles or tipping over into an inoperable position. Failure to do this would result in inability to collect the required data and the potential loss of the rover.
Logistical		
L.1	Integration with Heritage Projects	ARGOS needs to be able to communicate with the ground station and the mother rover which were developed in previous projects. This will allow for data transfer and control of the rover. This will also increase the capabilities of DRIFT as well as the Fire Tracker System as a whole.
L.2	Constraints	Due to COVID-19, the ability to procure, produce and test various components of the rover may be hindered because of potential campus closures.

8. Team Skills and Interests

Table 2: Team Skills and Interests

Team Member	Skills/Interests	CPEs
Daniel Stojsavljevic	Manufacturing, Control Systems, Circuits, and Writing	T.2, T.3, T.4
Luca Kushner	Communications, Data Analysis/Visualization, and User Interface	T.1, L.1
Nick Kuljis	Programming, Sensors, Data Analysis, Mechanical Design, ArcGIS	T.1, T.3
Victoria Gonzales	Structural Analysis, Probability/Error Analysis	T.2, T.3, T.4
Margaux McFarland	Programming, Microcontrollers, Soldering, Data Automation/Analysis	T.1, T.3, L.1
N. Thomas Noll	Mechanical Design, Solidworks, Manufacturing, C	T.2, T.4
Trevor Slack	Motion Planning, Controls, ROS, Gazebo Simulations, C, C++, Python	T.2, T.3, T.4
Henry Felstiner	Mechanical Design, Manufacturing, Electrical Design	T.3, T.4
Jarrod Teige	Communications, Programming, Management, Arduino, Electronics	T.1, L.1
Niko de Boucaud	Systems Design, Manufacturing, Mechanical Design, CAD,	T.2, T.3, T.4, L.1
Harrison Fitch	Programming Sensors, Controls, Data Analysis, Optics, C++, Python	T.2, T3, T4

9. Resources

Table 3: Resources

Critical Project Elements	Resource/Source
T.4	**Nathan Bol and Gray Hill.** Nathan and Gray are wildland firefighters from the Fourmile fire department at Poorman station. They can give information on forest fire fighting strategy and safety concerns.
T.1, T.3	**Trudy Schwartz and Bobby Hodgkinson** These technical support members of the PAB specialize in electronics and communications and will be able to assist
L.1, L.2	**Josh Mellin and KatieRae Williamson** These technical support members of the PAB work in the PILOT lab and will be able to assist us with any equipment and facilities in the PILOT lab including heritage projects of the Fire Tracker System.
T.2, T.4	**Matt Rhode and Zachary Sunberg** These PAB members will be able to assist with mechanical design and validation, as well as manufacturing.

References

[1] Daisy Dunne et al.; *Explainer: How climate change is affecting wildfires around the world*. Carbon Brief, 2020

[2]Kaley Pinover et al.; *Project Definition Document: Integrated Flight Enabled Rover for Natural Disaster Observation (INFERNO)*. University of Colorado Department of Aerospace Engineering Sciences, 2015.

[3]Adam St. Amand et al.; *Preliminary Design Review: Child Drone deployment Mechanism and Retrieval Apparatus (CHIMERA)*. University of Colorado Department of Aerospace Engineering Sciences, 2016.

[4]Samantha Growley et al.; *Project Definition Document: DRIFT*. University of Colorado Department of Aerospace Engineering Sciences, 2017.

[5]Marcos Mejia et al.; *Project Definition Document: HERMES*. University of Colorado Department of Aerospace Engineering Sciences, 2018.

[6]Clara Bader et al.; *Project Definition Document: Articulated Transporter for Localized Ac- quisition and Storage (ATLAS)*. University of Colorado Department of Aerospace Engineering Sciences, 2019.

*[7]*Bell, J. F., A. Godber, S. McNair, M. A. Caplinger, J. N. Maki, M. T. Lemmon, J. Van Beek, et al.; *"The Mars Science Laboratory Curiosity Rover Mastcam Instruments: Preflight and in-Flight Calibration, Validation, and Data Archiving." Earth and Space Science 4, no. 7 (2017): 396–452. https://doi.org/10.1002/2016EA000219.*

*[8]*Woods, Mark, Andrew Shaw, Estelle Tidey, Bach Van Pham, Lacroix Simon, Raja Mukherji, Brian Maddison, et al.; *"Seeker – Autonomous Long-Range Rover Navigation for Remote Exploration." Journal of Field Robotics 31, no. 6 (2014): 940–68. https://doi.org/10.1002/rob.21528.*

[9]Micheal T. Thompson et al.; *Colorado's Forest Services, 2004-2013.* United States Department of Agriculture, March 2017.

[10] Idaho Firewise; *Fire management Strategies and Tactics* Idaho Firewise Inc, 2020

[11] Amber Bishop et al.; *Spring Final Review: DRIFT*. University of Colorado Department of Aerospace Engineering Sciences, 2018.

Appendix

0.1 Functional Design Requirements

1.1 : The child rover shall be able to make a 360 degree turn.
1.2 : The child rover shall be able to travel in forward and reverse.
1.3 : The child shall be able to command its mast to 1.5m at a maximum rover incline of 10 degrees.
1.4: The child rover shall be able to travel up to 250m roundtrip in any direction from its start location.
1.5 : The child rover shall be able to drive in underbrush.
1.6 : The child rover shall be able to drive to a location of interest.
1.7 : Upon loss of communication, the child rover shall return to its last known GPS location.
1.8 : The child shall be able to determine how far the mast can extend without creating a tipping condition.

2.1 : The child rover shall have an extendable mast.
2.2 : The child shall be able to determine the location of the flame front and/or fire line.
2.3: The child shall be able to determine if the flame front crosses the fire line.
2.4: The child shall be able to determine the temperature within +/-5 degrees at the location of interest.

3.1: The child shall have video capability with >100 degrees field of view.
3.11 : The video camera shall have >100deg field of view
3.12 : The video camera shall provide the operator with video and images of sufficient quality to support mission operations.

4.1 : The child rover shall be able to receive commands from the mother rover.
4.11: Upon loss of communications with the mother rover, both child rover shall return to the last known GPS coordinates.
4.2 : The child rover shall be able to receive commands from the ground station.
4.3 : The child rover shall be able to send time-stamped video, photos, and temperature data to the ground station and the mother rover.
4.4 : The ground station shall confirm if the child is within ±5m of the location of interest.
4.5 : The mother rover shall be able to command either child to navigate to specified GPS coordinates in real-time (Note: way-points might be used).
4.6 : The mother rover shall be able to command video feed on/off.
4.7 : The mother rover shall be able to receive commands from the ground station.
4.8: The mother rover shall be able to send data to the ground station.