University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document
HERMES
Hazard Examination and Reconnaissance Messenger for Extended Surveillance

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Approvals

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Nomenclature

CD	Child Drone
CHIMERA	CHIld drone deployment MEchanism and Retrieval Apparatus
CSR	Child Scout Rover
DRIFT	Drone-Rover Integrated Fire Tracker
GS	Ground Station
HERMES	Hazard Examination and Reconnaissance Messenger for Extended Surveillance
INFERNO	INtegrated Flight Enabled Rover for Natural disaster Observation
LOI	Location of Interest
MR	Mother Rover

1. Problem Statement

The effects of climate change include steadily increasing global temperatures, permanent changes in precipitation patterns, more frequent droughts and heat waves[3]. Year after year, these effects have extended the duration of the wildfire season in geographical locations with a dry climate, especially the western United States[5]. The wildfire prevention, suppression, and rehabilitation budget of the United States Forest Service has increased with this trend. In 1995, fire made up 16% of the US Forest Service's annual budget and in 2015, 50% of the budget was devoted to fire. Scientific statisticians estimate that in 2025, this number could exceed 67%[8]. The current method of wildfire prediction, identification, and rehabilitation will clearly not be cost-effective in the future, which motivates the development of the Jet Propulsion Laboratory's Fire Tracker System. This system aims to be a low-cost, hands-off approach to forest fire identification that will lead to earlier containment and elimination of forest fires.

The Fire Tracker System is composed of four distinct projects, with HERMES, the project sponsored for the 2018-2019 academic year, being the most recent in the continuum. The prior projects have consisted of INFERNO, CHIMERA, and the most recent DRIFT. The current Fire Tracker System is composed of a large mother rover (MR), launched from a ground station (GS), that is capable of travelling to and from an open area and deploying an autonomous, flying child drone (CD) that drops a sensor package in an area prone to wildfires and returns to a self-leveling landing platform. The MR is large and bulky, which is not ideal given that the desired, searchable wildfire environment is characterized by dense forest, underbrush, and uneven terrain. This situation prevents the system from reaching critical areas of forests where the most scientific data can be accrued. In addition, operating the large system in these tight spaces is a risk to the system's health and safety.

HERMES aims to improve the Fire Tracker System by assisting the MR to avoid potential risk of damage by large obstacles and uneven terrain while traversing the forested environment. The HERMES team will design and build a child scout rover (CSR) that will dock on the MR, deploy on command, take images/video of its surroundings using an image capturing system, and then be picked up and re-docked on the MR. The CSR will investigate these forested areas within a 250 meter radius from its deployment point from the MR, detect obstructions, and determine a viable path for the MR to travel to a location of interest (LOI), defined by an operator. It must perform these operations while navigating the dense environment with mobility and maneuverability. The specific actions it must perform are driving forward and reverse, executing a 360° turn, driving up and down slopes of 20°, and driving over discontinuities of 1 ft. With the success and integration of this mission, the full system can perform more effectively with less risk.

2. Previous Work

As stated, there are three previous heritage projects in the Fire Tracker System. INFERNO, first in the series, was responsible for the autonomous CD and sensor package. CHIMERA's objective was to build the landing platform for INFERNO, with the capabilities to secure and recharge INFERNO. The most recent DRIFT built the MR that attached the landing platform, and integrates data processing and communication among the GS, the MR and the CD. The MR has the ability to carry and level the CD and CHIMERA. HERMES will further the system by investigating the areas of interest.

Other low-cost efforts that aim to identify and monitor areas susceptible to wildfires also exist, separate from JPL's Fire Tracker System. One of these efforts is Boeing's Insitu, which developed a UAS, ScanEagle, with the capabilities of providing firefighters with information on fire spots, fire movement, geospatial imagery and incident perimeter maps[4]. ScanEagle flies in areas that are high risk for manned aircraft, such as in dense smoke and at night. It also has the capability to stay in flight for up to 20 hours, which allows full functionality throughout the mission without a MR, making it similar to the HERMES's CSR. Another project, that is specifically related to the CSR of HERMES, is Ryonic Robotics' rugged EVA rover, The Ryonic Armadillo, used for underground and mining operations[7]. The rover is built to withstand rough outdoor terrain and is designed to overcome any obstacle. It also communicates with a ground station and sends live video feed, with a 100 meter range. The novel aspect of HERMES is that it will utilize image processing and path finding to serve as a guide for a larger rover, as opposed to being a surveillance rover. HERMES will not only communicate with a GS, but will also be dependent on the communication with a MR. HERMES must have obstacle detection and avoidance, while Ryonic Armadillo was designed for "any" obstacle. The goal of the previous works is to provide information on a subject (fires/ caves) firsthand, whilst HERMES will find a viable path for a MR to further the Fire Tracker System.

3. Specific Objectives

The Levels of Success corresponding to this project are shown in Table 1. The team shall design to accomplish the highest level of success, Level 3, for all categories. However, if unforeseen issues arise, the rover will still be functional at the first two levels of success. To clarify Table 1, it should be noted that the the word 'obstacle' is being defined as a discontinuity, underbrush (of varying TBD densities), roots (TBD sizes), or trees. A 'waypoint' is defined as a location where the CSR encounters an obstacle, and 'open areas' are being defined as areas without any trees, however the area could have a varying slope. The LOI, defined as the location of interest, is the final location that the CSR will navigate to, and is not the same as a waypoint. The waypoints are the obstacles the CSR may encounter on the way to the LOI. The LOI is received from the GS, and is the final destination the CSR and MR will travel to.

Criteria	**Level 1**	**Level 2**	**Level 3**
Control	• The CSR shall be able to navigate by received control commands from the GS. • The CSR shall be able to dock/deploy to the MR. • The CSR shall be able to perform a 360° turn. • The CSR shall be able to travel forward and reverse.	• The CSR shall navigate to a LOI and shall detect obstacles en route to the LOI, but manual control is needed to circumvent the obstacles.	• The CSR shall be capable of autonomous navigation, obstacle detection, and avoidance. • The CSR shall be able to return to the last known GPS location if connection is lost. • The CSR shall be capable of autonomous deployment and docking with the MR.
Communications	• The CSR shall verify connection to the MR/GS. • The CSR shall send at least one GPS data packet to MR/GS upon command. • The CSR shall have functional communication up to a 250 meter radius from the deployment point in an open area. • The CSR shall be able receive control commands from MR/GS.	• The CSR shall be able to record and send waypoint locations after encountering an obstacle.	• The CSR shall be able to transmit GPS location at TBD frequency and send continuous video feed. • The CSR shall be able to verify its location from the LOI within ± 5 meters. • The CSR shall have functional communications through a forest up to a 250 meter radius from the deployment point.
Range	• The CSR shall be able to drive in up to a 250 meter radius from the deployment point on flat terrain.	• The CSR shall be able to drive up to a 250 meter radius from the deployment point on flat terrain with obstacles present.	• The CSR shall be able to drive in a 250 meter radius from the deployment point at a 20° inclined slope.
Environment	• The CSR shall be able to traverse the following: 1) Open areas 2) 20° incline slopes	• The CSR shall be able to traverse the following: 1) Light underbrush 2) Roots	• The CSR shall be able to traverse the following: 1) Heavy underbrush 2) 1 foot of discontinuity
Video/Image	• The camera on the CSR shall capture a FOV greater than 100°. • The image processing system shall send time-stamped images to the MR/GS.	• The CSR shall be able to send videos to the MR/GS. • The MR shall be capable of toggling on/off the video capture from the CSR.	• The CSR shall be able to send and receive continuous video feed to MR and GS at TBD framerate.

Table 1. Levels of Success for the HERMES Mission

4. Functional Requirements

4.1. HERMES Functional Requirements

1. The CSR shall be able to send time-stamped data to the MR or the GS.
2. The CSR shall be able to receive commands from the MR or the GS.
3. The CSR shall be able to drive up to 250 meters in any direction from the drop off point
4. The CSR shall be able to travel to a location of interest.

5. The CSR shall be able to drive forward and reverse.
6. The CSR shall be able to make a 360° turn.
7. The CSR shall be able to drive in underbrush.
8. The CSR shall be able to go over discontinuities up to 1 foot.
9. The CSR shall be able to go up or down a slope of 20°.
10. The CSR shall return to the last known GPS location upon loss of communications with the MR.
11. The CSR shall be able to take video and pictures while driving or in position-hold.
12. The CSR shall be able to dock and deploy from the MR.

4.2. Functional Block Diagram (FBD)

The following image depicts the Functional Block Diagram for the Fire Tracker System, including INFERNO, CHIMERA, DRIFT, and HERMES. The scope of HERMES itself includes the CSR, portions of the MR, and the GS. The CSR is a ground based, motorized robot which mainly houses a camera to take images and video. The CSR contains its own power source so that it can be powered independently of the MR during operation as well as during testing. It can be further decomposed into a microcontroller, a camera, docking mechanisms and software, communication hardware, GPS hardware, and a mobility system. The camera serves to collect images and video feed. HERMES also implements a docking mechanism system and software for the CSR so that it can interface with the MR when it is not on a mission. The communication hardware ensures that any wireless data packets from the CSR or the MR are sent or received. The GPS hardware is what ensures that the path taken by the CSR is recorded. The mobility system is composed of the wheels or treads and the corresponding actuators. Mobility is responsible for driving the CSR to a desired location. Finally, the microcontroller handles commands sent by the GS or MR, send commands to the subsystems, and receive data (i.e. video, image, or sensor readings).

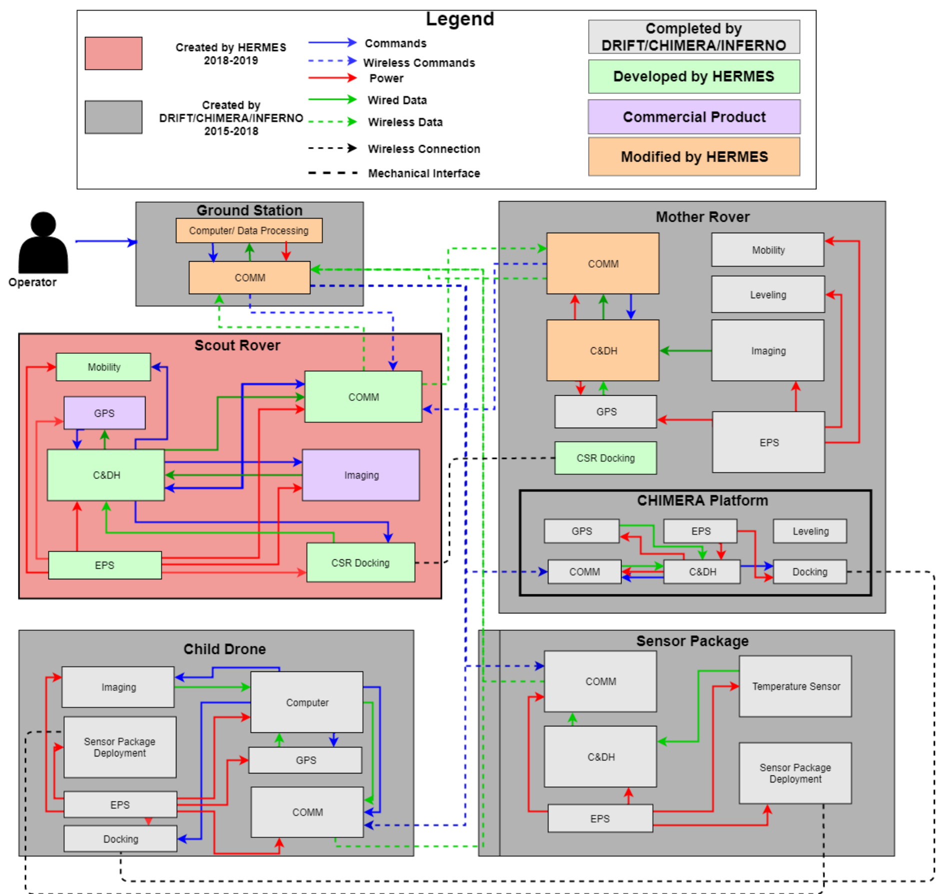

Figure 1. HERMES Functional Block Diagram

4.3. Concept of Operations (ConOps)

The Concept of Operations specific to the HERMES project demonstrates the main functions and requirements the CSR must fulfill in order to guide the MR to a desired LOI. The MR is limited to traveling over a maximum incline of 20 ° and between obstacles no less than 5 ft apart. The functions that the CSR will complete over this mission duration are displayed in the orange boxes and the requirements, detailed previously in section 4.1, are displayed in the blue boxes. Once the CSR is deployed from the MR, communications and functional checks will be made to ensure a successful mission. The CSR will receive the LOI from the GS, calculate a direct path to the LOI and proceed on said path. Once the CSR encounters an obstacle too large to maneuver around, it will scan its environment to find a new path viable for the MR, record its current location as a waypoint, capture pictures and video, and send this time-stamped information back to the MR. Ideally, the CSR will be continuously sending GPS data back to the MR and not solely at the waypoint. Before proceeding on the new path, the CSR will confirm two-way communications with the GS and MR. If the CSR has lost connection with either the GS or the MR, the CSR will return to its last known coordinates. If the communication checks pass, the CSR will continue on its path until a new obstacle is encountered and the process will be repeated. Upon reaching the LOI, the CSR will confirm communications with the ground station and MR, confirm it is within ±5 m of the desired LOI, and send back its current location, pictures, and video to the MR. The MR will then have a list of recorded waypoints it will be able to travel along. The MR will then be able to travel to its LOI on a viable path based on its operational abilities. Once the MR and CSR are at the LOI, the CSR will complete the mission by re-docking.

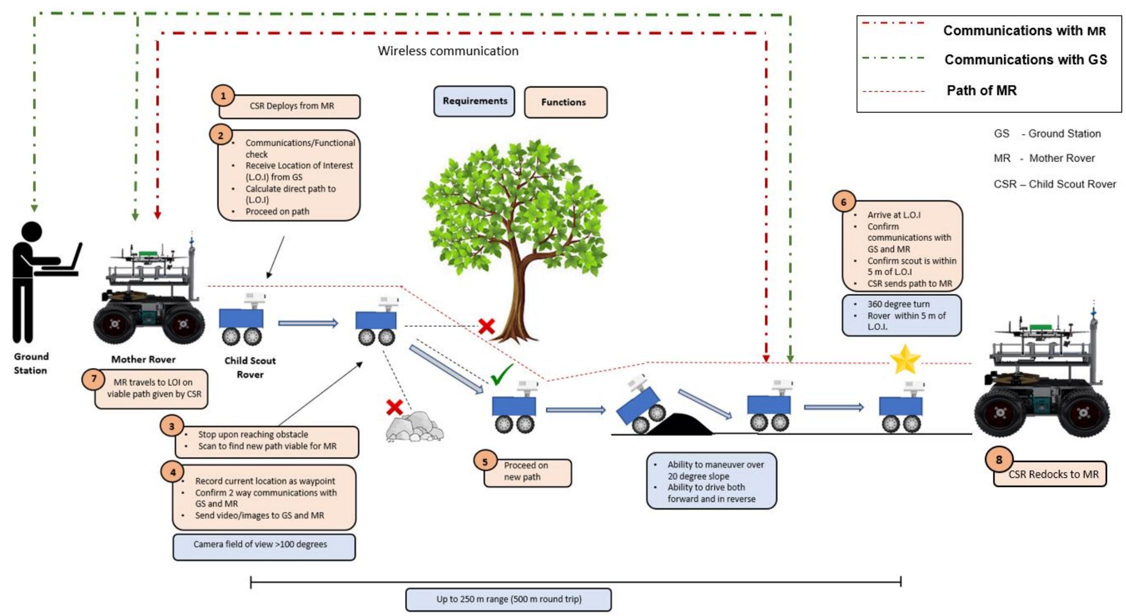

Figure 2. HERMES ConOps

The entire Concept of Operations of the Fire Tracker mission includes HERMES (CSR) and the projects completed in previous years: INFERNO, CHIMERA, and DRIFT. Figure 3 shows the flow of the entire mission and the CSR's involvement, displayed in steps 2 - 5. Due to the MR's limited maneuverability and range, the CSR will deploy to find a viable path to a LOI, (provided by the GS). After arriving to the LOI, the CSR will transmit the viable path to the MR. The MR will then travel to the LOI, and the CSR will dock. INFERNO will then be launched from CHIMERA through commands received from the MR. Once INFERNO deploys from CHIMERA, INFERNO will deploy a sensor package to collect and transmit temperature data to MR. The MR will be continuously transmitting data between the GS and INFERNO. After INFERNO completes it's mission, it will return to CHIMERA and the MR, receive a command to land from the MR, and use image processing to land on CHIMERA. CHIMERA's involvement is shown in steps 7 and 10 and INFERNO's involvement is shown in steps 8 and 9. Lastly, DRIFT's main steps involve departing from the GS (step 1), moving to the LOI found by the CSR (step 6), and returning to the GS (step 11).

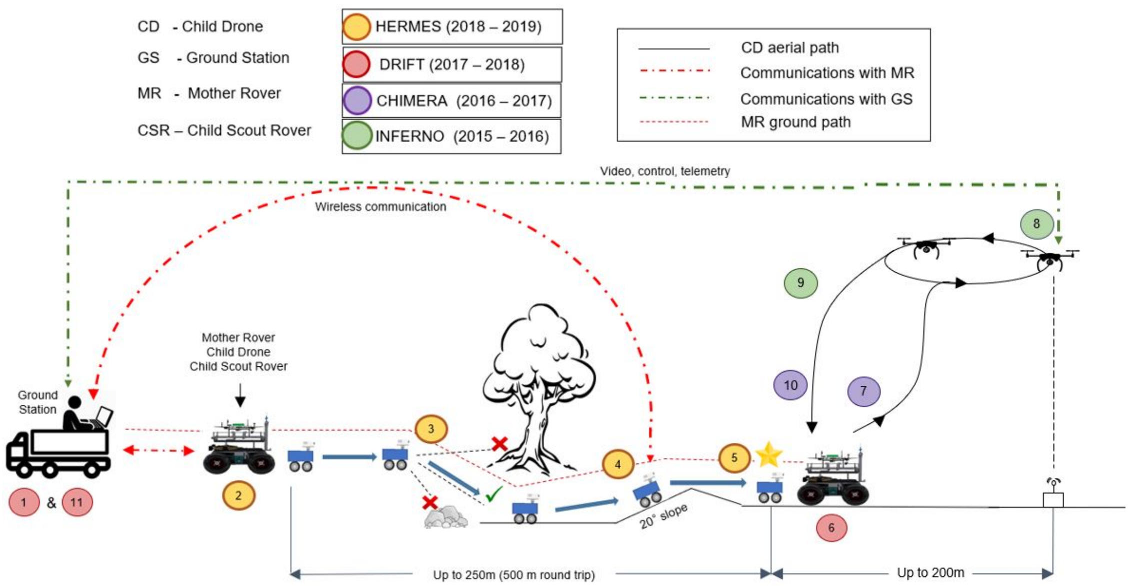

Figure 3. Fire Tracker System ConOps

5. Critical Project Elements

The table below details both the technical and logistical project elements. These critical project elements are defined such that failures of these elements will not allow the project to achieve even the 1st Levels of Success outlined in Section 3. For the CSR to be functional, all of the critical project elements must be achieved.

Technical		
T.1	Mobility, Docking, and Deploying	The CSR must be able to travel forward and backwards in forest fire prone areas and perform 360° turns. Otherwise it cannot navigate and would be unable to reach a LOI. Moreover the CSR must be able to dock on MR, remain on the MR during travel, and deploy from the MR.
T.2	Communications	The CSR must be able to communicate with the GS and MR in wooded and open areas. If this is not achieved, then the CSR will not be able to send viable path, images, and video to the MR or GS.
T.3	Guidance, Navigation, and Control	The CSR must be able to be controlled remotely by one operator. The CSR must always read its own GPS data accurately. Otherwise, the CSR will not be able to navigate or determine a viable path for the MR.
T.4	Environment Sensing	The CSR must be able to accurately sense the environment around it. If this is not achieved, a single operator will be unable to guide the CSR remotely, and in the case of self-navigation, the CSR will be unable to detect obstacles.
Logistical		
L.1	Integration with Heritage Projects	The CSR hardware and software needs to interface with aspects of previous heritage projects such as the GS and MR. Integration between all systems is crucial for HERMES because it's success furthers the objective of the Fire Tracker System.

Table 2. Critical Project Elements

6. Team Skills and Interests

Critical Project Elements	Team Member	Associated Skills/Interests
T1, T.2, T.3, T.4, L.1	Brindan Adhikari	MATLAB, C/C++, Python, Shell scripting, Arduino, Power Budgeting, Electronics, Technical Writing, Data Analysis, Microcontroller interfacing, RC systems, Modeling
T.1, T.4, L.1	Colin Chen	SolidWorks, Component Design, 3D Printing, Machining, Component Inspection, Technical Writing, Procurement, LabVIEW, MATLAB, Arduino, Power Budgeting
T.1, T.3, T.4, L.1	Katelyn Griego	Data analysis, MATLAB, SolidWorks, Controls, Modeling, Technical Documentation, Machining, 3D Printing
T.1, L.1	Junzhe He	Skills: SolidWorks,3D printing, Matlab, Force Analysis. Interests: Geometric Dimensioning and Tolerancing, software.
T.1, T.2, L.1	Marcos Mejia	Solidworks, MATLAB, Technical Writing, Previous Experience Writing PDRs and CDRs, ANSYS CFD and FEM, Laser Cutting , and Previous Leadership Experience.]
T.1, T.3, T.4, L.1	Ashley Montalvo	Testing, Data analysis, Modeling, Python, CFD, Machining, 3D Printing, Electronics, Technical writing,
T.1, T.4, L.1	Quinter Nyland	Data Analysis, Technical Documentation, Testing, Machining, 3D Printing, SolidWorks, C, C++, ROS
T.1, T.2, T.3, L.1	Chase Pellazar	Verification and Validation Planning, Python, C, C++, XBee Programming and Interfacing, Modeling
T.2, T.3, L.1	Alexander Sandoval	C/C++, Python, ROS, Microcontroller Interfacing, GUI Design, Low-level Networking, SMD Soldering, PCB Design
T.1, T.3, T.4, L.1	Brandon Santori	C++, Java, Matlab, Controls, Programming
T.1, T.3,L.1	Alexis Sotomayor	Data Analysis,ANSYS,Logistics,Planning, Technical Documentation, Controls
T.1, T.2, L.1	Michely Tenardi	Data Analysis, CAD, Modeling, Testing, Machining, Manufacturing, 3D Printing, Component Design, Planning, Technical Documentation, MATLAB.

Table 3. Team Skills and Interest

7. Resources

Element Number	Critical Project Element	Available Resource and Reasoning
T.1	Mobility, Docking, and Deploying	**Boulder Open Space, Matt Rhode, ITLL** - Matt Rhode has experience in mechanical design that will help with designing the child scout rover to be mobile and have the ability to dock and deploy to the MR. The City of Boulder has plenty of open spaces and parks where our team will be able to test the rover's mobility on outdoor terrain. The ITLL will be be available for testing the rover's mobility on indoor terrain.
T.2	Communications	**Trudy Schwartz, Bobby Hodgkinson, Dennis Akos, Marcus Holzinger, Boulder Open Space, ITLL, and the Senior Projects Room.** - Dr. Akos has extensive experience in GPS and signal processing, which will be crucial for the communications and positioning project element. The rest of the listed personnel have experience with electrical design, which will be crucial for implementing the communications and GPS systems.
T.3	Guidance, Navigation, and Control	**Dale Lawrence and Nisar Ahmed** - Both professors have experience in control systems in conjunction with vehicles and may offer valuable insight into navigation of difficult environments.
T.4	Environment Sensing	**Boulder Open Space, ITLL, Bobby Hodgkinson** - The CSR will have the Boulder Open Space and the ITLL to be able to test if the CSR can detect and sense it's environment. Bobby Hodgkinson is available to help with any issues that will arise.
L.1	Integration with Heritage Projects	**Jeliffe Jackson and Previous DRIFT members** - Dr. Jackson was the faculty advisor for the previous project, DRIFT, and is willing to assist us. All DRIFT members have been contacted and thus far, 6 have agreed to assist with any DRIFT and Ground Station related matters.

Table 4. Resources

References

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