final report

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Autonomous Range Management Vehicle: Phase II – Final Report

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Executive Summary

Over the past nine years HDT and the US armed forces have invested millions of US dollars in developing a half-ton unmanned vehicle. The purpose of this vehicle is to carry heavy loads across rugged terrain to supply infantry soldiers. The precursor system (Protector) is powered by a 24 kW turbo-diesel engine and will travel 100 kilometres on 60 litres of diesel fuel. The vehicle produces about 2 kW of electrical power for payloads. HDT have sold a number of these vehicles to the US Army, which have been used in different field evaluations. More recently, working with Meat and Livestock Australia (MLA) it was identified for the Australian livestock market, that this vehicle needs to have an autonomous – GPS waypoint – navigation controller, obstacle avoidance, longer range (and duration), and a limited silent-run capability for operating near livestock.

This project focused on the development and integration of a prototype autonomous navigation controller (NAV) with baseline obstacle avoidance capability, as well as auxiliary fuel tanks and a drone landing platform. It builds on earlier collaboration with MLA under project P.PSH.1197. The NAV kit and obstacle avoidance algorithm was integrated onto a WOLF vehicle and tested at HDT's facilities in Fredericksburg, VA.

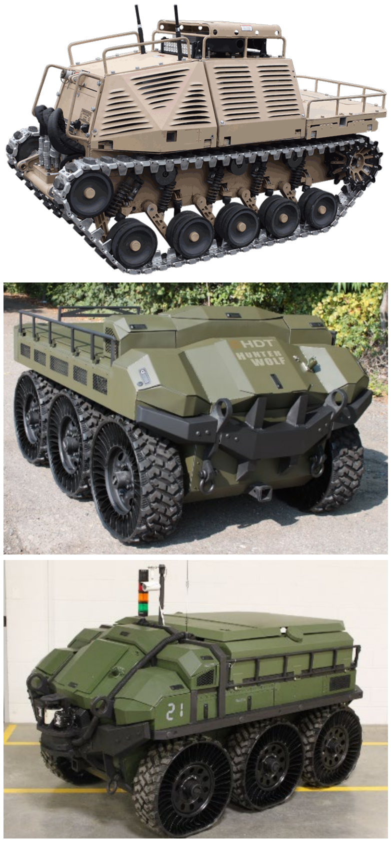

Figure 1 – (top) Picture of Protector (the precursor device), (middle) Hunter WOLF v1, (bottom) Drover WOLF (v2); vehicle which integrates the redesigned elements and autonomous navigation kit developed as part of this project.

There are many operations on remote cattle and sheep stations that are difficult to perform consistently, due to labour constraints that a rugged, autonomous ground vehicle could enable and/or facilitate. To this end HDT, through MLA, formed a Steering Committee for this project with representation from six Australian companies. It was found that potential key applications for an Autonomous Range Management Vehicle include:

- distribute nutritional feed supplements
- distribute fodder
- gather information about soil chemistry and moisture (i.e. Water and Soil sampling),
- deliver of supplements and/or feed to the cattle,
- refuel water pumps,
- fence line integrity checking

This project was the second step in adapting a ground vehicle from this initial US Army application – the Hunter WOLF® - to test possible applications needed for remote cattle and sheep stations. Given the project's successful completion (see Table 1), and to start equipping the vehicle with the capabilities/functionality required to address the specific tasks needed to improve natural resource management, labor productivity, and overall value the following is now recommended:

1) continue to expand the autonomous - control - capabilities of the Drover WOLF, and
2) continue to expand the operational capabilities of the Drover WOLF platform by developing capability modules (i.e. functional attachments)

3) include further travel to Australia to work with ranchers including cattle and sheep stations in order to better understand not only the tasks that an autonomous range management vehicle could add value to but also to observe the environment/terrain and how those tasks are being performed now.

Table 1 – Results against project objectives.

Project Objective	**Protector (precursor)**		**Hunter WOLF**		**Drover WOLF**
Further extend its range	100 km	→	456 km	→	1369 km*
Baseline autonomous – waypoint – navigation controller	-	→	Optional	→	Included
Video streaming	NA	→	Optional	→	Included
Baseline obstacle avoidance	NA	→	Optional	→	Included
Drone landing platform	NA	→	Optional	→	Included

*with dual auxiliary tanks installed (maximum capacity). Ranges specified are for driving on flat roads.

Finally, a demonstration of the unit is planned at Beef Australia (BA21), scheduled for early May, 2021 in Rockhampton, Queensland.

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1 Background

Over the past nine years HDT and the US armed forces have invested millions of US dollars in developing unmanned vehicles to carry heavy loads across rugged terrain to supply infantry soldiers. An opportunity to collaborate with Meat and Livestock Australia (MLA) to consider livestock and pastoral applications represented a novel application. The current system is a 6X6 hybrid diesel/electric system with a built-in 20 kW generator. It can carry 500 kg more than 200 km off-road on 60 litres of diesel fuel. The vehicle's generator provides power for an on-board storage battery and electric drive motors, as well as for payloads. We have sold a number of these vehicles to the US Army, which have been used in numerous field evaluations. For the Australian livestock market, we have developed the Drover WOLF variant of this vehicle with upgraded capabilities, including higher fuel efficiency, longer range, greater mission duration, a limited silent-run capability for operating near livestock, a drone landing platform, and an autonomous navigation kit.

This project is the second step in adapting this vehicle to serving the needs of remote cattle and sheep stations – building on past outcomes from project P.PSH.1197. It is envisaged should the Australian cattle-sheep-goat sector indicate positive interest, follow-on developments will address the specific tasks needed to improve natural resource management, labor productivity, and overall value.

Eventually, this vehicle will be able to autonomously or semi-autonomously carry out tasks as recommended by a Steering Committee such as surveying the land, delivering feed and/or supplements, inspect fence lines for any damage or breaches, take soil samples, etc.

1.1 Development History

1.1.1 Protector

HDT has been developing Unmanned Ground Vehicles (UGV) since 2011. HDT recognized the need within the military for a new class of robot. While small, man portable robots were available they had severe limitations in payload capacity, mission duration and terrain crossing capability. The Protector was developed to solve those deficits and allow greater effectiveness of US fighting forces.

Figure 2 – HDT's Protector

1.1.2 Wheels vs. tracks

Evolving requirements from the US Army have led to HDT investigating alternative system architectures than the Protector to better meet the need. Specifically, a faster, larger payload, longer range, and quieter platform was desired. Numerous tests were conducted and data was collected and analysed to determine the best drivetrain to meet the new requirements. Conclusions from these studies showed that a wheeled platform increased system efficiency, extending range, while also resulting in a quieter audio signature. Payload capacity and terrain mobility remained adequate when all wheel drive systems were used.

Figure 3 – Picture of MadDog, a battery only wheeled initial prototype

1.1.3 Phase 1: Proof of concept prototype

The Phase 1 Hunter WOLF™ prototype built in 2017 incorporated a hybrid-diesel electric drivetrain with a 400km range, the ability to carry 500kg (tow 2,000kg), and a 20kw generator.

Figure 4 – HDT's Hunter WOLF (v1)

2 Project objectives

2.1 ARM-v Project Objectives

HDT is developing a half-ton unmanned hybrid diesel/electric vehicle (WOLF) for the US military which is very rugged and capable. This project is the second step in adapting the WOLF vehicle to serving the needs of remote cattle and sheep stations. Eventually, this vehicle will be able to autonomously inspect fence lines for any damage or breaches, count livestock using a tethered multi-rotor unmanned aerial vehicle, locate pest animals, and take soil samples.

The present project is a limited precursor effort to create an "experimental" prototype that will:

1. extend its range and further increase its mission duration via the addition of a larger secondary - fuel tank,
2. incorporate an autonomous navigation controller,
3. integrate waypoint GPS navigation software and operator interface,
4. integrate video streaming and/or local recording,
5. integrate basic obstacle avoidance such as auto stop.

This project will culminate with the delivery of one Drover WOLF to a facility in Australia selected by MLA, where on-site operator training and capability demonstrations will take place. One (1) unit will also be built and remain on site at HDT's Fredericksburg, VA facility for further development.

3 Methodology

The project is outlined by five (5) main activities/tasks, those being:

1. Redesign effort – address lessons learned from Phase 1
2. Design for manufacturing effort – effort to reduce the cost of manufacturing of the base vehicle
3. Upgrade the Hunter WOLF controller
4. Build one (1) Hunter WOLF
5. Develop Drover WOLF capability (hardware and software)
6. Build one (1) Drover WOLF
7. Integrate & test – integrate and validate the Drover WOLF
8. Demonstrate the Drover WOLF

3.1 Terminology

Hunter WOLF – baseline remote controlled unmanned vehicle being developed for military applications.

Drover WOLF – adds the following additional features/capabilities to the Hunter WOLF:

- autonomous navigation sensor suite (ANSS),
- autonomous navigation controller (NAV),
- secondary fuel tanks for increased range, and
- drone landing platform.

4 Results

4.1 v1 to v2 Redesign Effort

From HDT's own testing, analysis, performance measurements, and observations during the Phase I Ft. Benning evaluation, and user comments, HDT has upgraded the Hunter WOLF vehicle between the Phase I and Phase II vehicles to improve performance and address all lesson's learned. Consistent with the Phase II SOW, the basic configuration of the vehicle is the same for both Phase I and Phase II vehicles:

- 6-wheeled, 6-wheel drive, with Michelin Tweel® non-pneumatic tires
- Dual water-cooled electric motors, fixed reduction ratio, and chain-drive
- Hybrid diesel-electric with 20 kW gen-set and lithium-ion batteries
- Steel box-section space frame
- Hand-held joystick remote controller

All dimensions such as size and weight remain similar from Phase I to Phase II. To improve manoeuvrability, the Phase II vehicle is one inch narrower and has one inch more ground clearance.

Performance of the Phase II vehicle against the key performance parameters (KPP) and Key System Attributes (KSA) is the same or better when compared to the Phase I vehicle.

Requirement	Phase I	Phase II
1,000 pounds	Yes	Yes
60 miles in 72 hours	Yes	Yes
3 kW / 1 kW power export	Yes	Yes
Traverse a vertical grade of 60%	Reverse only	Both directions
Traverse lateral grade of 30%	Yes	Yes
Cross a gap of 30" W x 18" D	Yes	Yes
Ford water 24" depth x 600'	Yes	Yes
Parking brake	Yes	Yes
Emergency-Stop	Yes	Yes
Max Speed	12 mph [19 km/h]	14 mph [22.5 km/h]

Table 2. Performance of Phase I and Phase II Hunter WOLF

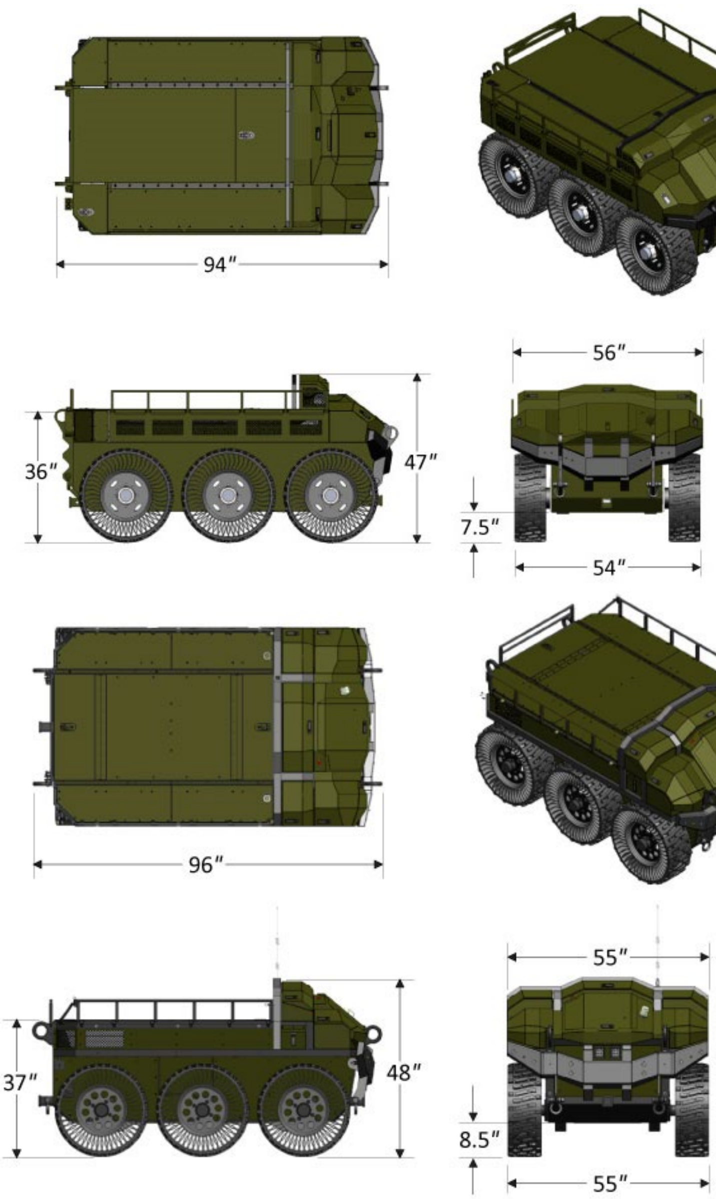


Figure 5. (top) Phase I and (bottom) Phase II Hunter WOLF vehicles dimensions

4.1.1 Chassis

4.1.1.1 Frame

At the Phase I trials, there were several lessons-learned, which prompted HDT to make design changes to the SMET vehicle. First, in heavily wooded areas the operators often used the vehicle's sponsons as a pivot point against a tree to manoeuvre in tight spaces. The base of the Phase I chassis was made of steel, but the sponsons were made of aluminium. Pivoting against trees placed loads on the sponsons aluminium structure that would eventually lead to their failure. To strengthen the sponsons, their material was changed to steel and they were made integral part of the chassis weldment.

4.1.1.2 Rollbar

The Phase I rollbar was a bolt on weldment made from 2" x 1", 6061-T6 aluminium tubing. This structure was a two-dimensional structure intended to protect the Phase I toolbox from loose cargo.

It was not intended to protect the vehicle in a roll-over event and was shorter than the Phase I toolbox. HDT made the Phase II rollbar both more robust and taller. It is now made from 2" square ATSM A500B Steel tubing. The new three-dimensional structure is better at handling forward loads from sliding cargo, and the rollbar has the height and strength needed to protect the vehicle during a rollover event.

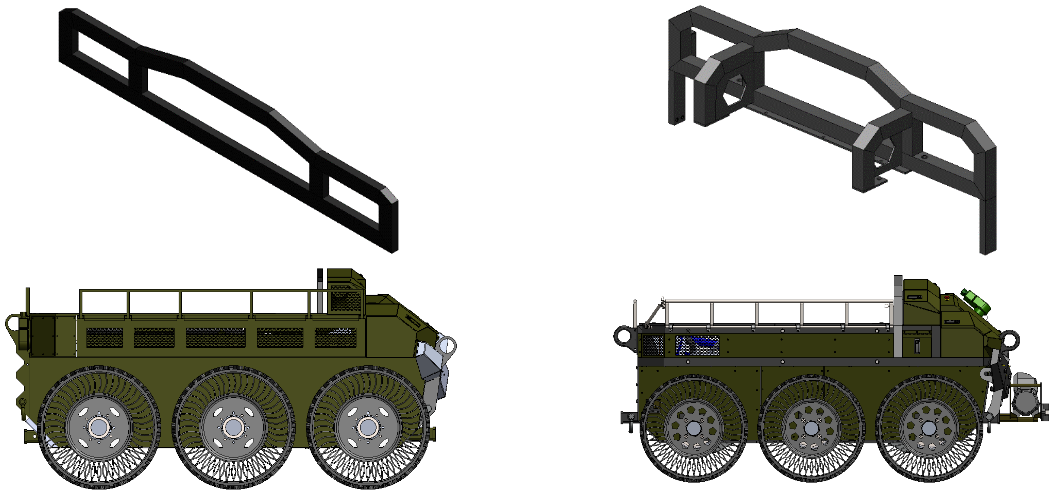


Figure 6 – (left) Phase I Rollbar. (right) Phase II Rollbar

4.1.1.3 Ground Clearance

At the trials, HDT's Phase I vehicle sometimes had difficulty clearing obstacles with its winch mounted in the forward position. The vehicle's operators recommended the approach angle of the vehicle be increased. To achieve this, the winch mounts were raised three and half inches. This resulted in a 24% improvement in approach angle.

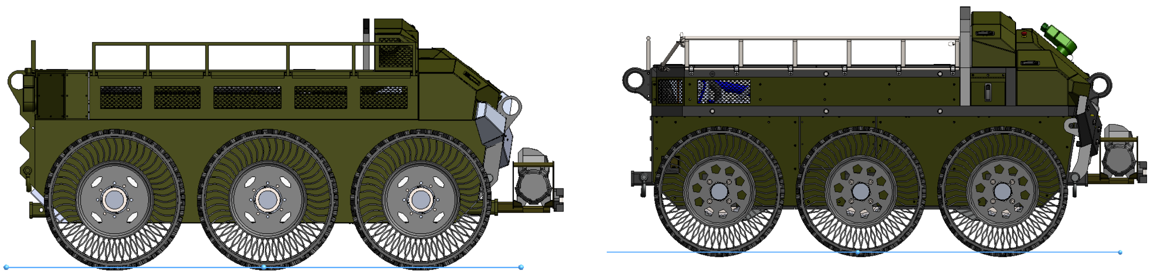


Figure 7 – (left) Ground clearance, Phase I. (right) Ground Clearance, Phase II

	Phase I	Phase II
Approach Angle (degrees)	23.0°	28.6°
Clearance at Hitch (inches)	9.5	13.0

Table 3. Approach Angle and Clearance

4.1.1.4 Hard Points

HDT's Phase I SMET vehicle had six threaded M10 hard points at both the front and the rear. For added modularity, Phase II retained the same number of hard points on the front and rear, plus added six M10's on both sides of the vehicle and six M12 hard points on the vehicle deck.

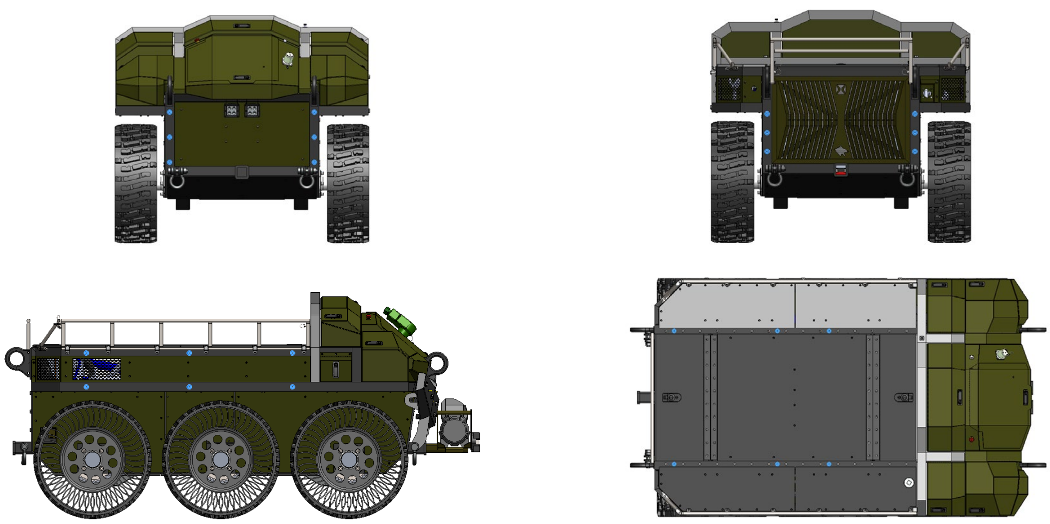


Figure 8 – (top-left) Phase II front: 6x M10 Mount Points (bumper hidden to show). (top-right) Phase II Rear: 6x M10 Mount Points. (bottom-left) Phase II sides: 6x M10 Mounts Points on Each side. (bottom-right) Phase II deck: 6x M12 Mount Points (aircraft tracks hidden to show)

4.1.2 Gen-Set

4.1.2.1 Air Filter

On the Phase I vehicle, a K&N universal clamp-on air filter was used. After the trials, the filter was inspected and found to be excessively dirty. The filter was located inside the front right of the toolbox assembly and did not include a centrifugal separator or multistage filter, both of which would have helped prolong its life in a dusty environment. To solve this problem on Phase II, a centrifugal separator was installed in line with a two-stage canister filter. The centrifugal separator is located inside the left toolbox and has a removable tray, which allows the user to easily discard accumulated dirt and dust. This change will increase the mean-time between maintenance for the canister filter. To reduce engine noise, foam insulation and baffling were added to the Phase II vehicle. The filter location changed as well from the front right to the front left of the vehicle to allow a more direct air intake path.

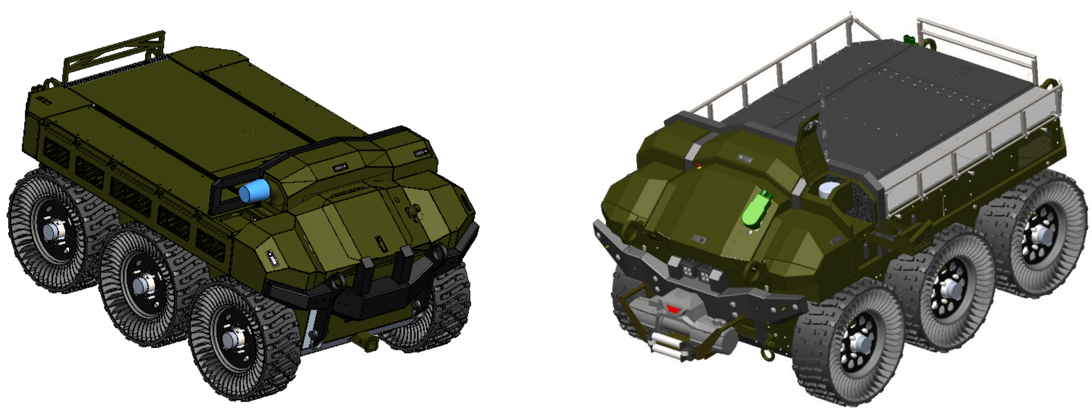


Figure 9 – (left) Phase I filter location (right) Phase II Filter Location

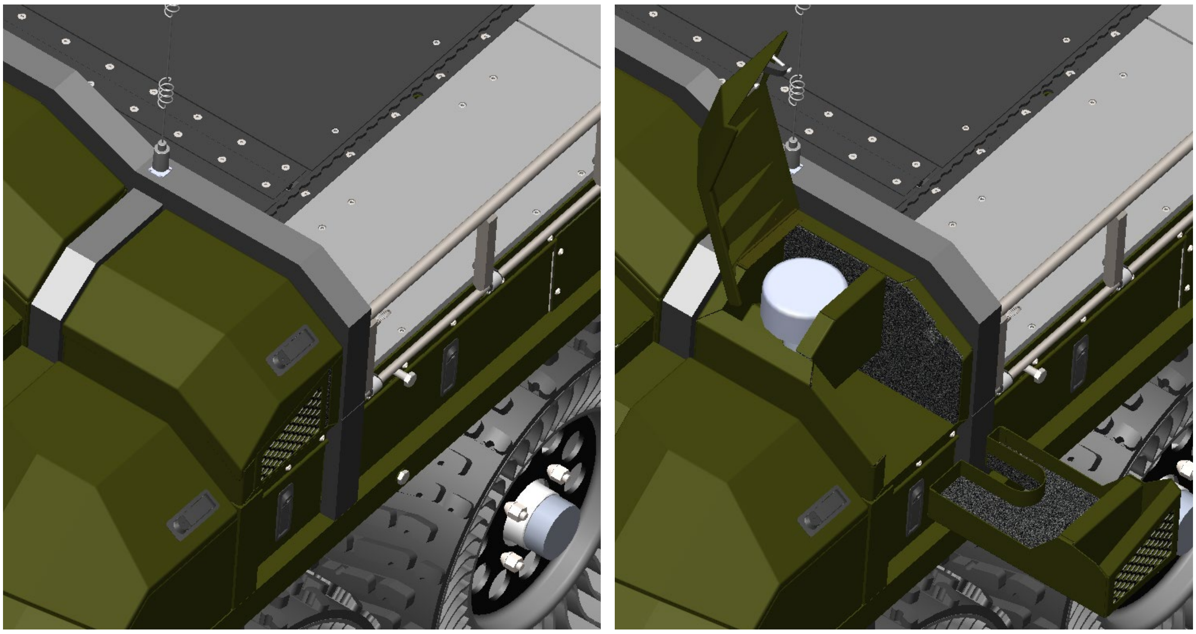


Figure 10 – (left) Phase II air intake, closed (right) Phase II air intake, open, tray removed (baffling and foam shown)

4.1.2.2 Engine

The engine for the Phase I gen-set was a turbocharged Doosan engine rated at 46 hp and driving an alternator producing 20 kW. The Doosan engine was more powerful than required for the alternator, so HDT changed to a 36 hp Yanmar engine for Phase II. Both gen-sets have common Polar Power alternator windings producing 20kW of electrical power for the vehicle. Without sacrificing vehicle performance, the Phase II engine is lighter, less expensive, less complex, easier to maintain, and more robust. Because the Yanmar engine is a better match for the generator's output power, it is more fuel-efficient. The Yanmar engine is normally aspirated, so there is no turbocharger or charge air cooler, which simplified the radiator system. A detailed comparison between the Phase I and Phase II gen-set is shown in the table below.

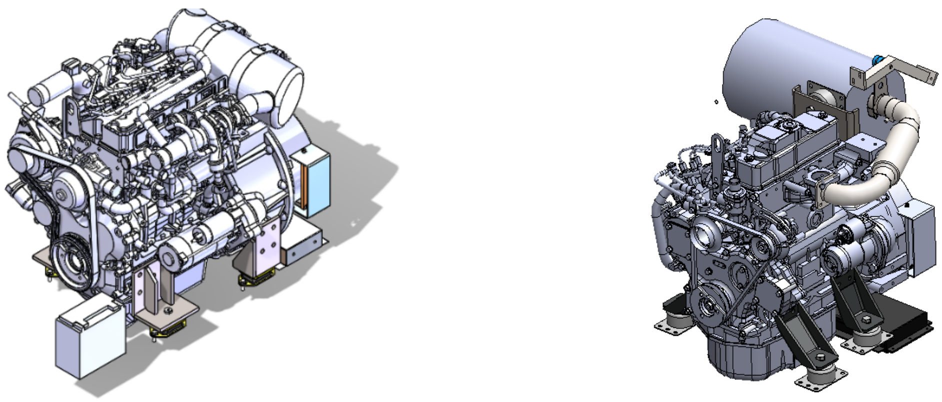


Figure 11 – (left) Phase I gen-set assembly (right) Phase II gen-set assembly

	Phase I	Phase II
Generator Model	-	-
Mechanical Power (HP/RPM)	46/2800	35.9/3000
Displacement (Liters)	-	-
Dry Weight (kg)	-	-
Charge Air Cooler and Turbo	YES	NO

Alternator Output (kW)	20	20

Table 4. Gen-set Comparison

4.1.2.3 Diffuser

When the engine was running during the Phase I trials, excessive dust was generated by the gen-set's exhaust, which is located on the bottom of the vehicle. To reduce the generation of dust, as well as exhaust noise, the Phase I diffuser was replaced with a larger diffuser that has a larger exit area. This larger outlet cross section reduces the velocity of the exhaust by approximately 80%. The larger internal volume increases the internal damping and reduces exhaust noise signature.

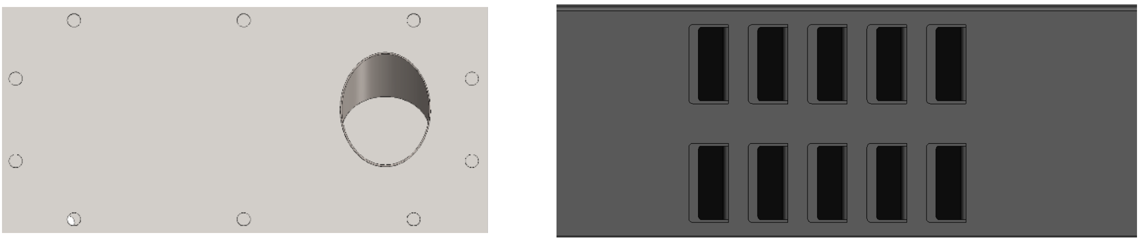


Figure 12 – (left) Phase I diffuser. (right) Phase II diffuser

4.1.2.4 Alternator

The alternator, in both the Phase I and II vehicles, is below the fording line. On the Phase I vehicle, the alternator was air cooled, which required special ducting to pull in cool air and exhaust hot air for the alternator. The Phase II vehicle has a water-cooled alternator. This change eliminates the need for special ducting components and makes it much easier to environmentally seal the alternator.

4.1.3 Battery Module

On Phase I, four Model-S Tesla battery modules were repurposed to provide electrical power to the vehicle. These are Lithium Nickel Cobalt Aluminum Oxide cylindrical cell batteries. This chemistry is susceptible to thermal runaway and fire in several scenarios:

- If internal cell temperature rises above 150°C (302°F)
- Damage due to puncture
- Damage due to small arms fire

To alleviate this danger, the Phase II vehicle uses a Lithium Iron Phosphate battery chemistry. This chemistry is much more tolerant to puncture and small arms fire, and has a much higher temperature limit generally. If a Lithium Iron Phosphate battery cell does enter thermal runaway, the cell smoulders rather than exploding into open flame. The temperature of a Lithium Iron Phosphate cell experiencing thermal runaway is not high enough to propagate that thermal runaway to neighbouring cells. Compared to the Phase I battery cells, the Phase II Lithium Iron Phosphate battery cells can sustain a 15X higher continuous discharge rate and a 2X higher continuous charge rate.

HDT's Phase II battery system is also packaged differently. For Phase II, the battery modules and the controls have been moved into a single, large IP-68 enclosure located near the centre of the chassis (Figure 14 (top-right)). Placing all these components in one enclosure reduces part count, and makes the battery module a line-replaceable unit for maintenance. Changing the batteries in our Phase II vehicle takes about 30 minutes, compared to several days for our Phase I vehicle. The change in location of the Phase II battery lowers the vehicle's centre of gravity and increases stability, particularly on side slopes.

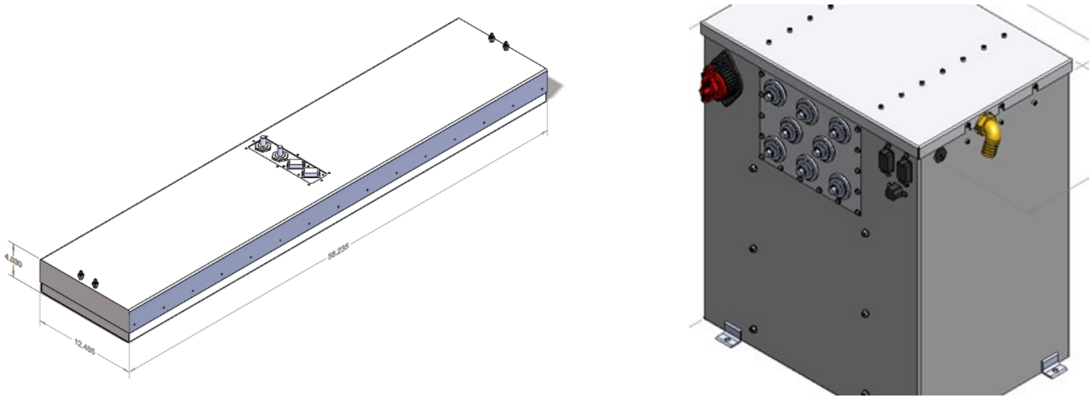


Figure 13 – (top left) Phase I battery system (other components hidden for clarity. (top right) Phase II battery system (other components hidden for clarity) (bottom-left) Phase I battery enclosure (one of two) (bottom right) Phase II Battery enclosure

	Phase I	**Phase II**
Chemistry	Lithium Nickel Cobalt Aluminum Oxide	Lithium Iron Phosphate
Thermal Runaway Temp	150°C (302°F)	270°C (518°F)
Thermal Runaway Spread	Yes	No
Susceptible to Puncture	Yes	No
Total Storage	-	-
Usable Capacity	12.72 kWh	5.3 kWh
Continuous Output Power	-	-
Peak Output Power <60sec	-	-
Charge Rate	-	-

Table 5. Battery Comparison

4.1.4 Drive Train

The Hunter WOLF uses heavy-duty power transmission chains (one for each side) for the final drive to each of the six wheels. Over time, each chain stretches and requires re-tensioning to remove the slack from the system. On the Phase I vehicle, the tensioning method was an adjustable pivoting arm, as shown in the figures below. This pivoting arm was difficult to access and operate during field servicing, and proved not to be reliable in maintaining proper chain tension. The chain selected for Phase I was also not pre-tensioned or self-lubricated, so a time-intensive "breaking in" process was required to stretch the chain to its normal service state. The Phase I chain also had to be lubricated at regular intervals, which was very difficult because the chain was relatively inaccessible and required removing many components. The Phase I configuration also produced undesirable chain skipping, which degraded the life expectancy of the chain and can lead to premature sprocket and chain failures.

4.1.4.1 Wheel Hub

The Phase I design was complex, making it difficult to assemble and maintain. In addition, the locking hub mechanism in the Phase I design could easily get stuck in the locked position due to internal forces binding the mechanism. HDT changed the Phase II design to reduce part count, increase load capacity, improve reliability, and make both assembly and maintenance much easier. We also eliminated the binding problem with the locking hubs. These changes had no negative effects on functionality.

Phase II Axle Assembly changes are as follows:

1. The stock Spindle and Spindle Spacer combined into one custom part
2. The Outer Hub, Inner Hub and Hub Spacer combined into a single part
    a. Reduces time needed for assembly and maintenance
    b. Increases system reliability and robustness
3. Bearings were upgraded with higher rated bearings
4. A bearing was added to support the cantilevered drive sprocket.
    a. Helps prevent the locking hub mechanism from getting stuck in the locked position.
5. The axle support bearing was moved closer to the locking hub
    a. Helps prevent the locking hub mechanism from getting stuck in the locked position.

4.1.5 Cooling System

4.1.5.1 Cooling Fans

The Phase I cooling system used two fans to cool three separate cores in the radiator. These three cores were for: the engine, the charged air cooler, and the vehicle electronics. Two fans were needed to cool these cores, but these fans had a high power draw and audio signature. With the elimination of a turbocharger for the gen-set's engine in Phase II, the charge air cooler was no longer required. Only two cores are needed in the radiator for Phase II. The reduction in heat load from eliminating the turbocharger and using a more efficient engine in Phase II allows the use of a single fan. This single fan reduces both the audio and power draw. The reduction in cores made volume available to move the batteries from the sponsons to the centre section.

4.1.5.2 Louvers

The Phase I radiator exhaust air generated a great deal of dust when the fans were running. The Phase I louvers pointed the airflow downward, which caused the blowing dust. For Phase II, the louvers were changed to point out toward the sides of the vehicle. This results in little airflow pushing against the ground and reduces the amount of dust generated.

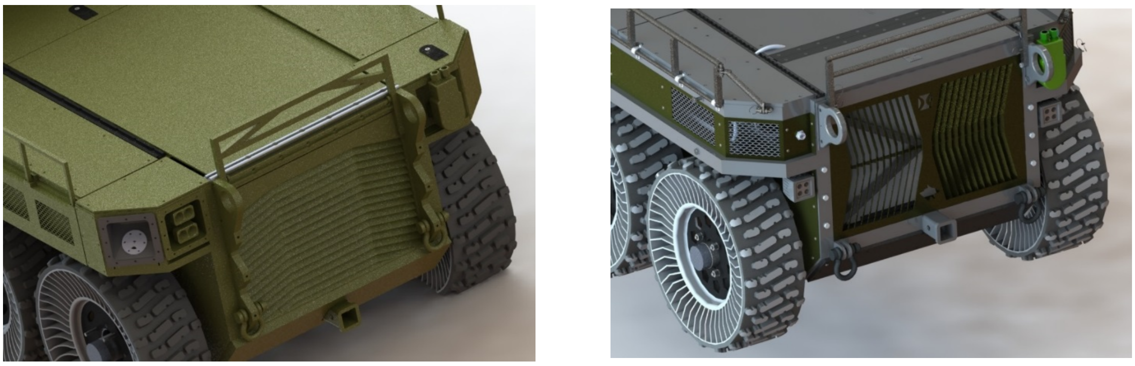


Figure 14 – (left) Phase I louvers (right) Phase II Louvers

4.1.6 Electronics

4.1.6.1 RC Controller

The remote controller was changed to allow for a tool-less replacement of the batteries. The batteries are now field swappable, which is more convenient for the user. As shown below, a battery charger was also added to the storage location for the remote controller, which recharges the remote controller's battery when it is not being used.

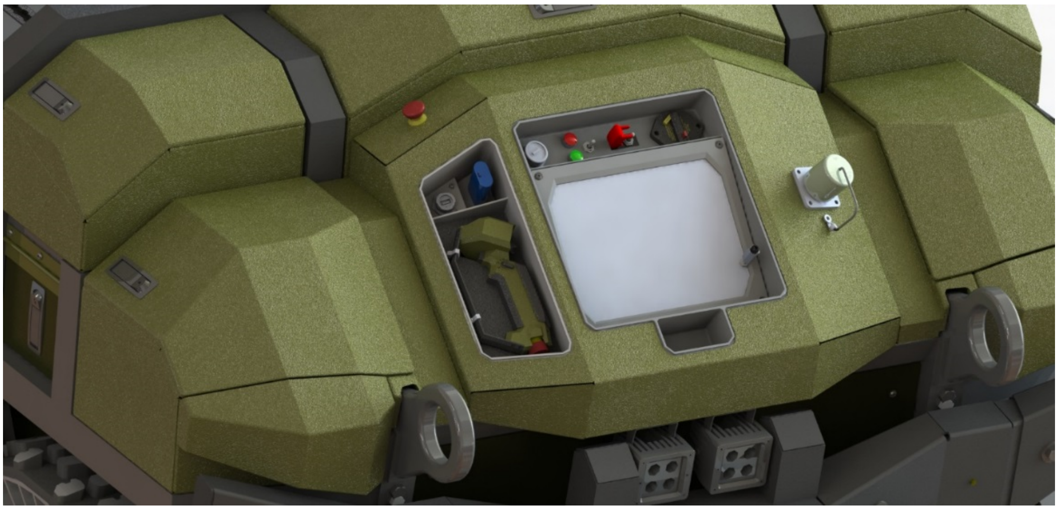


Figure 15. Phase II RC storage location and battery charger, cover hidden for clarity

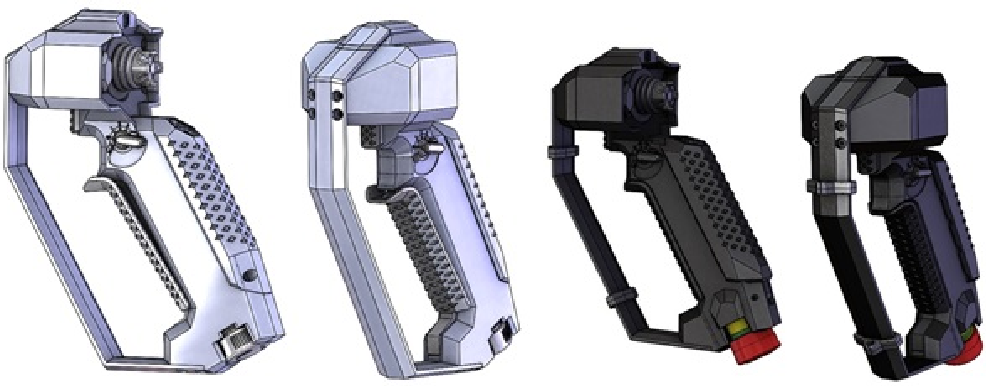


Figure 16. The Phase I (left) and Phase II (right) RC Controllers.

4.1.6.2 Fuse Box

For the Phase II vehicle, the two fuse boxes used in Phase I have been merged into one fuse box, which reduce the complexity of the electrical system and co-locates all of the fuses and relays in a single location. The fuse box is an IP-67 COTS box that provides better protection for the fuses and relays.

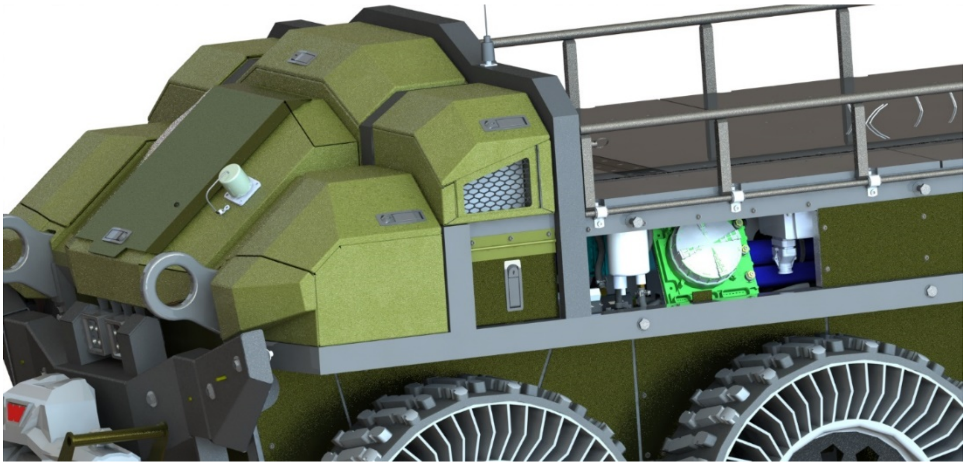


Figure 17. Phase II fuse box (green), access panel door hidden for clarity

Figure 18 – (left) Phase I BMS location, lid hidden for clarity. (right) Phase II front fender storage boxes, lids hidden for clarity

4.1.7 Exterior

4.1.7.1 Front Box Covers & UI Panel

The front boxes on Phase I sustained some damage during the trials from coming in to contact with various obstacles. For Phase II, the material and construction of the boxes are more durable to minimize damage to them and increase their longevity. The lids are made from a durable plastic that will increase lifespan. The center panel box now has storage for the remote controller and a battery charger.

4.1.7.2 Bumper

The bumper in Phase I was rigidly mounted with the result that impacts bent the bumper structure and most of the impact energy was transferred directly into the vehicle's chassis. The Phase II bumper has a hinged mount and compliant bump stops that absorb a greater amount of the energy from obstacle contact, resulting in less potential damage to the bumper and transmitting less impact energy into the rest of the vehicle. This improved design provides greater durability for both the bumper and the components inside the vehicle.

Figure 19 – (left) Phase I front bumper (right) Phase I front bumper wear.

Figure 20 - (left) Phase II bumper backside showing shock-absorbing blocks (right) Phase II bumper wings pivot independently when in contact with an obstacle.

4.1.7.3 Skid Plate and Decking

The skid plates in Phase I were XX thickness aluminium sheet. The skid plates functioned appropriately during the Phase I trials, but they sustained a large amount of deformation. To increase the durability of the skid plates the material was changed to a ½" thickness of plastic for Phase II. This plastic offers greater strength than the sheet metal, at a comparable weight, which will increase its durability. The plastic also has a lower coefficient of friction, which will help the vehicle to slide over obstacles with less damage to the skid plate. HDT has successfully used this material for skid plates on the GAARV rescue vehicle for the US Air Force.

The panels on the top deck were also changed to ½" thickness of plastic to give more strength, greater stiffness, reduced sliding friction, and increased durability.

Figure 21 – (left) Rear skid plate damage (right) Front skid plate damage

4.1.7.4 Side Rails

The side rails on the vehicle provide a guard for the cargo on the deck and also help to restrain the cargo. The side rails were changed from a sliding, loose piece, on Phase I to a hinged, captive piece on Phase II. This change allows for a better construction of the sponsons, less chance of losing the side rails, an easier method for raising and lower the rails, and a more secure attachment for the rails in either position. The rails were also increased in thickness to offer more durability.

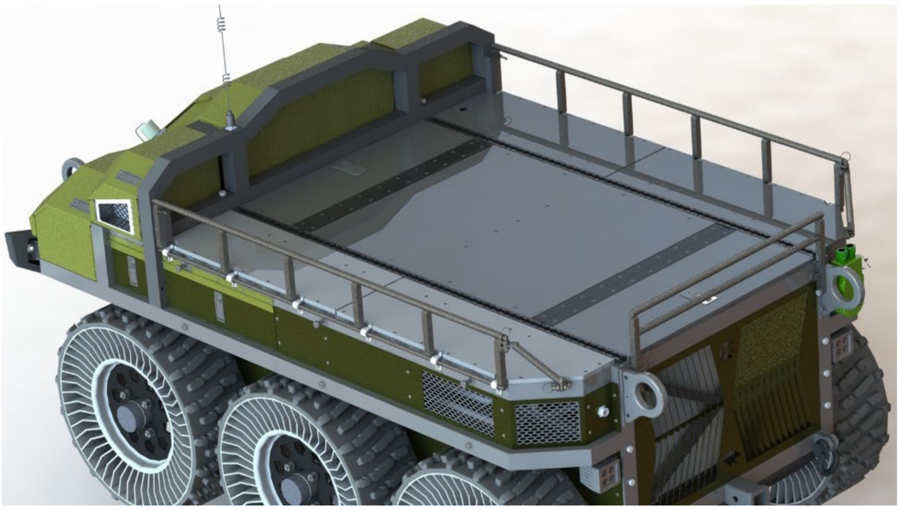


Figure 22. Phase II Side Rails in the raised position.

4.1.8 Fuel System

4.1.8.1 Fuel Fill Port

During the Phase I trials, it proved to be difficult to fill the fuel tank. A funnel or nozzle was needed to get the fuel into the small, angled opening. The fuel cap also came free, which exposed the fuel system to the environment and allowed fuel to spill out. The Phase II fuel fill has a much larger fill opening (4” vs 2” diameter) and allows for a vertical pour, which removes the need for a funnel or nozzle. The fuel fill point was also moved from the rear corner of the vehicle to the front right deck box. The fuel cap is now captive to the filler neck, so the cap cannot be lost, misplaced, or come loose. The box lid provides a second covering for the fuel system. The fuel fill point now has a catch-pan that contains any spillage. The catch-pan has a drain line with valve that can be used to drain any spillage into an appropriate container. The new filler neck incorporates a coarse screen filter to catch large debris in the fuel. This screen element can be removed for cleaning. A fitting for an auxiliary fuel tank was added to allow external fuel tanks to be carried as an optional payload, increasing the system’s range before resupply.

Figure 23. Phase II front fuel fill, box lid hidden for clarity.

4.1.8.2 Fuel Tank

The fuel tank geometry, location, and volume was changed to make room for the revised battery system and chain wrap configuration, as well as to reduce component complexity. The range provided by the 24-gallon fuel tank in Phase I greatly exceeded the 60-mile range requirement, and the gen-set engine for our Phase II vehicle is much more efficient, which further increases range, so we reduced the size of the fuel tank in Phase II to 18 gallons. The Phase II vehicle's range will still significantly surpass the 60-mile requirement in all terrains. The new fuel tank increases the amount of available volume within the chassis and reduces the vehicle's weight, without changing the required range performance. The Phase II fuel tank also has a breather line and a separate rollover vent breather line that ties into the filler neck and will prevent over-filling of the fuel tank. Preventing over-filling is important because an over-filled fuel tank can pull a vacuum that will damage the fuel tank, potentially splitting at the seams and resulting in a loss of fuel.

4.2 Design for Manufacturing

The Phase I vehicle, while performing well, was not optimized for manufacturability. One of the goals of Phase II was to make the vehicle easier to manufacture, both in terms of making piece parts and assembling the vehicle during production. To this end, each sub-system and component was scrutinized and evaluated for improvements to reduce cost, lead time and time to assemble.

In general, the following methodologies were applied to all parts and sub-systems of the vehicle:

- Where possible, the part count and feature count was reduced. This results in less components to be stocked, installed and accounted for. It also reduces part inspection labor and manufacturing costs.
- The parts and assemblies were also analysed to see if the number of set-ups required to machine, form and/or weld the parts could be reduced. An example would be a part that is made of formed sheet metal that is subsequently welded and machined would instead be re-designed to only be machined or made from formed sheet metal so only one process is required to produce the part, reducing cost and lead time.
- Where possible the assembly labour of components and sub-systems was reduced. This often meant that sub-assemblies were designed to be assembled outside of the vehicle as a module and installed in an assembled state, rather than assembling while in the vehicle or in multiple locations throughout the vehicle.

- Parts were also analysed to find the ideal manufacturing processes and materials for sourcing and manufacturability. An example would be a formed sheet metal lid may be more efficiently manufactured as an injection moulded plastic piece. All components that were changed in this fashion were checked to make sure no strength or performance was sacrificed.
- Dimensional tolerances on all parts were analysed to make sure they were increased as much as possible while still maintaining functionality. This allows for different manufacturing processes at different vendors to be used, increasing manufacturing flexibility and decreasing cost and lead time.
- Part and assembly drawings were re-structured to increase clarity of design intent and reduce ambiguity between HDT and our vendors. This results in less mistakes, less questions from the vendors and a more controlled design.

Here are some specific examples of DFM efforts on Phase II that have improved the manufacturability of the vehicle over Phase I:

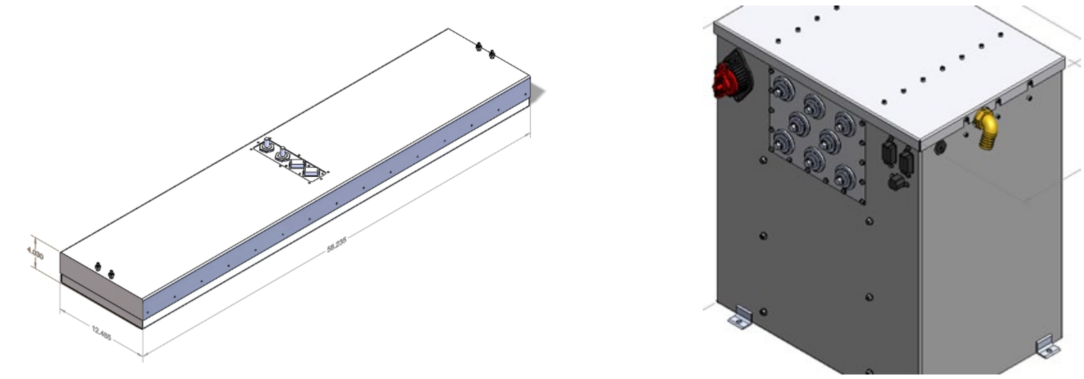


Figure 24. Phase I battery unit (left), Phase II battery module (right)

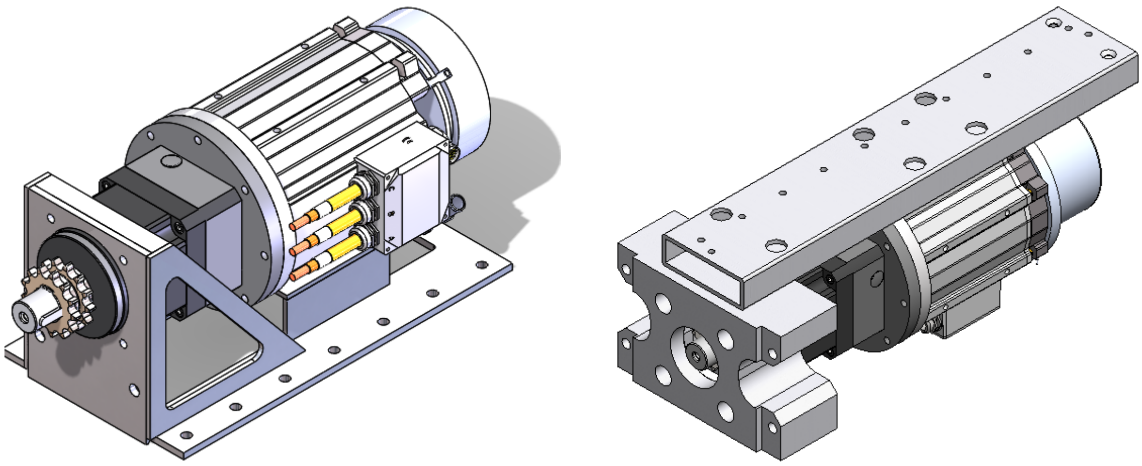


Figure 25. Phase I motor mount and motor (left), Phase II motor mount and motor (right)

The fuel tank, batteries, and motor mount all benefited from a re-design of the space between the gen-set and the radiator in the vehicle. Space claims were set aside in a manner that would result in efficient design of the components. The motors were moved to be side by side and towards the top of the vehicle which created a more efficient chain wrap. This also resulted in a far more manufacturable and common motor mount. The motor mount now works for both motors and has a lower part count, part feature count and reduced the manufacturing operations necessary as welding or sheet metal parts were eliminated. The fuel tank space claim was set aside to allow for a simple box shape rather than the very complex shape of the fuel tank in Phase I. This resulted in a significantly more manufacturable shape for the tank, as well as easier installation. The batteries also benefited from this large re-design, as it allowed for all of the separate enclosures and necessary systems to be re-configured, consolidated and optimized for a single integrated package. This allows for the batteries to be completely assembled outside of the vehicle as one module and installed easily into the vehicle. By making our own optimized battery system instead of re-purposing other independent systems we were able to make efficient use of the space and dramatically reduced the assembly labor, part count and manufacturing costs. This entire effort of re-configuring the fuel, drivetrain and battery sub-systems concurrently is one of the largest DFM efforts of phase II and has resulted in marked improvements in manufacturability of the vehicle.

Overall, the part and part feature count has been greatly reduced on the vehicle. This has resulted in lower part inspection and assembly labor. The parts themselves have also been analysed to reduce the number of manufacturing processes, select the ideal processes and materials, and increase the tolerance limits. This has resulted in greater manufacturability of the components and reduced lead time and cost.

The following sections summarize the main DFM results per subsystem.

4.2.1 Drive train

- Motor mount
    - Reduced part count
    - Reduced part feature count
    - The design changes inherently reduced assembly labor
- Chain drive
    - Reduced part count
    - Reduced part feature count
    - The design changes inherently reduced assembly labour
- Wheel assemblies
    - Reduced part count
    - Reduced part feature count
    - Adjusted tolerances for single-pass wire EDM spline cutting

4.2.2 Chassis

- Reduced part count
- Reduced hole / threaded insert count
- Optimized drawing for manufacturability
- The design changes inherently reduced assembly labour

4.2.3 Battery

- Reduced part count
- Optimized parts for manufacturing
- Optimized parts for assembly

4.2.4 General changes throughout the vehicle:

- Reduced part count
- Reduced feature count
- Reduced part inspection labour (due to reduced part and feature count)
- Reduced the number of set-ups for machining, forming and welding required to produce the parts

- Reduce assembly labour
- Selected ideal manufacturing processes for custom parts
- Selected ideal materials for increased manufacturability and sourcing availability
- Dimensional tolerances
    - Increased tolerances on all features where allowed
- Restructured drawings to reduce misinterpretations or unknowns and to help guide the manufacturing process

4.3 Upgrade WOLF Software Controller

Controller development has been focused on the improvement of several key aspects of the project. These improvements entail more robust safety systems, enhancements to vehicle maintenance tracking and fault logging, and the development of advanced algorithms.

4.3.1 Safety

Through utilization of a Real Time Operating System (RTOS) architecture, the system's software has been designed such that safety-critical or safety-significant functions are executed in isolation from other functions. This architecture guarantees that these functions will be executed in periodically scheduled jobs that will be optimally close to meeting deadlines.

4.3.2 Fault Logging and Vehicle Maintenance Tracking

In ensuring the long term operability of WOLF, the vehicle executes several different protocols which allow the user study its state over time as well as record data when necessary.

The fault logging architecture of the vehicle is designed such that each subsystem monitors and reports all faults that pertain to it (for example the battery subsystem may report higher voltage than expected in some of the cells). Improvements over the previous iteration of WOLF includes a considerable increase in the number of faults detected by each subsystem. This allows for a much higher degree of specificity which aids in narrowing down the root cause of any problem. Additionally, a fault manager exists which overlooks all faults the user may find are critical. The responsibility of the fault manager includes making the decision of whether a triggered fault is real or is a false positive. In doing so, a great deal of time and effort can be saved. If the fault manager decides that a fault has taken place, it will store in memory corresponding data of the ten seconds leading up to the fault. This utility allows the user to be able to study what happened and how to correct the issue.

Subsystem maintenance over the lifetime of the vehicle is another crucial component to ensure proper longevity. Over time WOLF keeps track of operating time and intensity of its main subsystems. If the GenSet or battery modules reach levels of use near those which are towards the end of their specified tolerance the vehicle will inform the user. This utility will ensure not only that WOLF is capable of functioning for a longer time, but also that the user encounters fewer issues along the way.

4.3.3 Advanced Algorithms

Smarter algorithms are a key component of some of the improvements made to the WOLF. The following algorithms were implemented:

4.3.3.1 Stall Protection

The motor controllers are able to detect if the vehicle's motors are in stall. This not only leads to fewer faults over time, but also improves the lifetime of the system components. These types of improvements can be found all over the revised software architecture of the vehicle, making it overall much more robust.

4.3.3.2 Priority Control

An improved controller management scheme provides a prioritized list of approved controllers. The algorithm in place reports which controller (if any) is currently controlling the vehicle. The algorithm does so for any number of active controllers. This management scheme allows users to override lower priority controllers with higher-priority ones (e.g. overriding an autonomous controller with a manual controller) and quickly detects missing controllers.

4.3.3.3 Feedback-controlled charging

To improve battery-charging time, the battery charging strategy was changed from constant setpoint charging to feedback-controlled charging. Additionally, to help prevent over-correction and oscillations in the Genset's current output, this system load measurement was passed through a low-pass filter.

4.3.3.4 Load-shedding

Because the vehicle's power offload capability exposes the power system to potentially overwhelming electrical loads, a simple load-shedding scheme was implemented. This power management algorithm measures the instantaneous voltage and current of the vehicle's power bus in order to detect sudden increases in electrical load. Once a bus-breaking load is detected, the system begins to shed loads by priority: offload power is dropped first, followed by the motion system and the cooling subsystem.

4.3.4 GUI Interface

The WOLF is equipped with a ruggedized Android tablet in its front user interface. The tablet has several screens that display useful information to the operator as well as allow them to activate certain features of the system.

The main UI screen is displayed by default. On this screen the user can read fault codes and clear them if applicable. The operating mode of the gen-set can be selected. Basic system feedback is displayed, such as: Controlled by (RC, Autonomy), RC battery Level, Vehicle Battery Level, Fuel Level, Odometry (in miles and km), Run Time, Speed and selected speed range, Radio signal strength. Additionally, the system lights are turned on/off through the GUI.

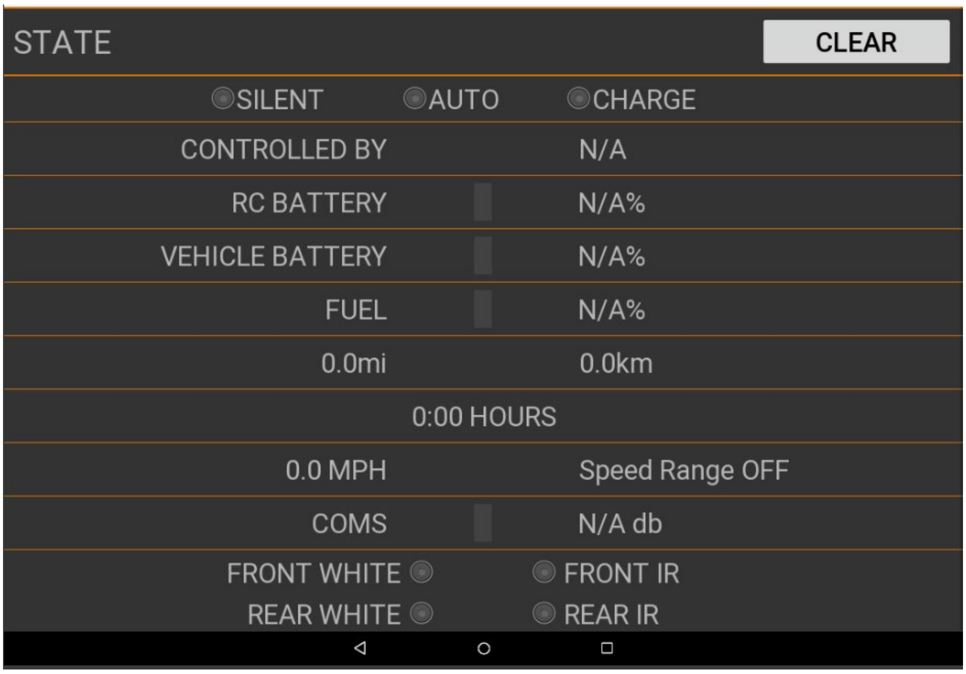


Figure 26 - Main GUI screen

The GUI provides a Maintenance Schedule screen. The routine system maintenance items are tracked on this screen as a function of time (system on-time, system in motion time, and engine run time are tracked separately). As a maintenance event approaches the text displayed changes to orange colour. Overdue items are displayed in red. Once maintenance is performed the operator can reset the tracking timer.

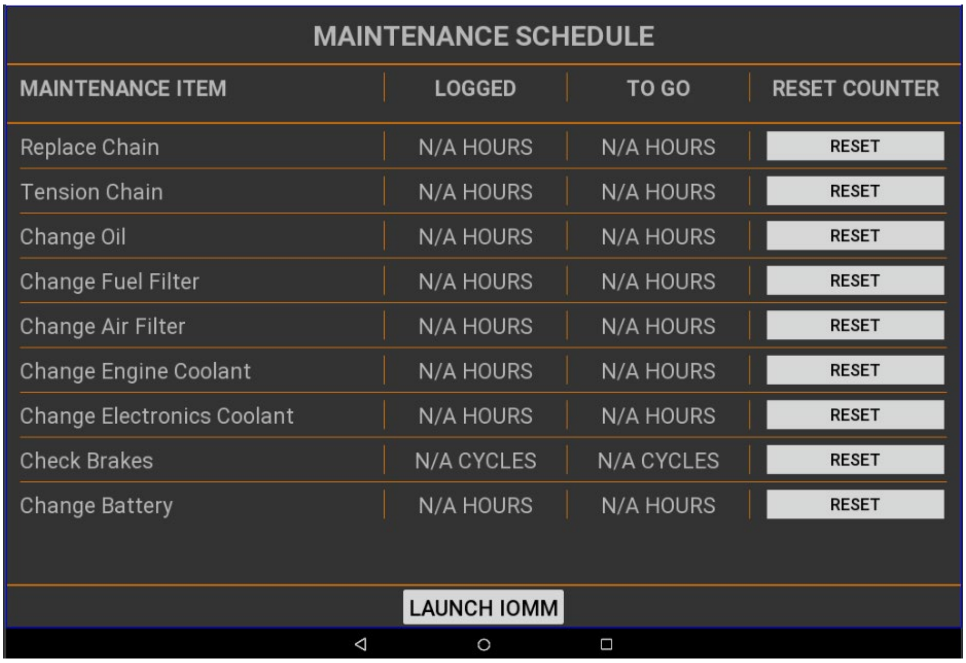


Figure 27 - Maintenance Tracking Screen

Figure 28 - Advanced Feature Set Screen

To facilitate operator use and maintenance an Interactive Operators Maintenance Manual (IOMM) is available through the GUI. This interactive application provides written descriptions as well as video demonstrations of all operations and maintenance items. Links to relevant pages in the operator's manual are provided for each item.

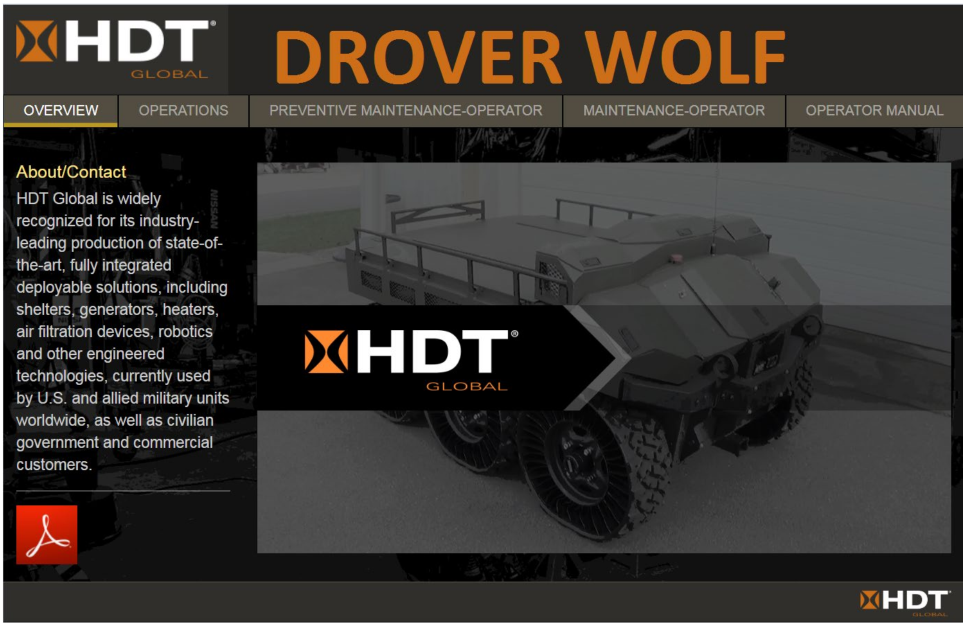


Figure 29 - IOMM Screen

4.4 Build Hunter WOLF

Utilizing the sub system designs from the phase I effort the systems were combined into a fully functional vehicle system. All items required for assembly were procured, all sub systems were assembled, all sub systems were integrated and the full system was tested for functionality.

All components and raw materials required for fabrication were procured. A system BOM was developed to track deliverables and manage cost. Items were inspected upon receiving to ensure proper form, fit, and function.

All the sub-assemblies were combined into the chassis. Plumbing and wiring between the systems was installed. Exterior panelling was fitted but left uninstalled until after functional checkout.

Once the system was assembled a full system checkout procedure was carried out. All the wiring connections were checked for point to point continuity as well as shorts to other signals or ground. The cooling system was filled and pressurized to check for leaks. The fuel system was filled and primed to check for leaks and evacuate air from the feed lines. The powertrain was inspected for proper assembly and the chains adjusted to initial starting tension. Once all systems were checked off functional testing progressed. Electrical systems were powered up one at a time followed by cooling systems. Finally, powertrain systems were tested with the vehicle suspended on blocks. Once all systems were verified as functional the system was lowered to the ground and tested driving around.

Figure 30 – Pictures of the assembled Drover WOLF.

4.5 Develop Drover WOLF Capabilities

4.5.1 Auxiliary Fuel Tank

One of the key performance parameters of the WOLF is how far it can travel before needing to refuel. As such, this milestone aims to increase the vehicles range significantly, without interfering with the WOLF's normal operations or decreasing the reliability of the system.

Testing from Phase I has allowed HDT to quantify fuel economy for various terrains and payloads. The range extension with the auxiliary tanks can be calculated with this data. The table below shows the calculated range with just the internal tank, one additional auxiliary tank or two additional auxiliary tanks, on different types of terrain. HDT's examination of the terrain on Australian ranges leads us to conclude the "Flat Road" column to be the closest applicable terrain type listed.

	Total Fuel capacity (Ga [L])	**Flat road (km)**
Internal (base vehicle)	18 [68]	456
+1 Aux Tank	36 [136]	913
+2 Aux Tanks	54 [204]	1369

Table 1 – Range – Terrain & fuel tanks.

The auxiliary fuel system is installed by attaching one or two fuel tanks to the main deck of the vehicle above the sponsons. A single hose passes through a normally-sealed port on the deck and attaches to a port on the fill neck. Hoses (supply and breather) would also be used to connect the auxiliary tanks, if a second tank is being used.

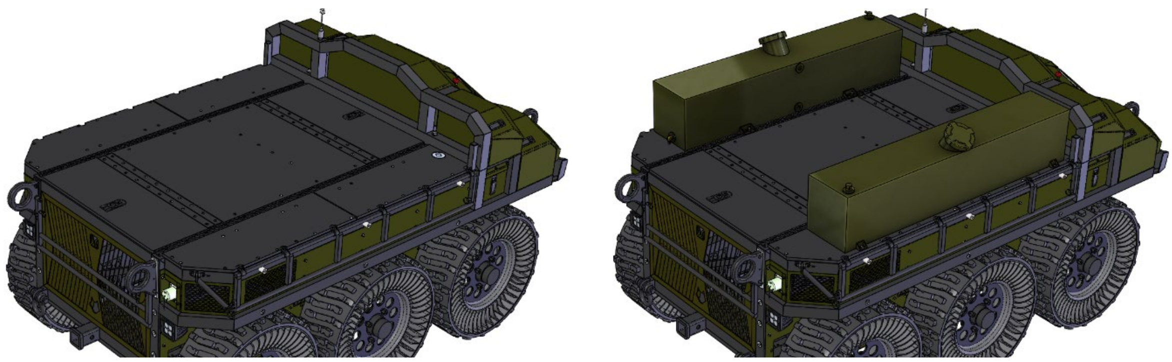


Figure 31 – (left) Base vehicle; 456 km range (flat road). (right) Base vehicle with additional fuel tanks; 1369 km range (flat road).

The fuel line from the auxiliary tank also has a solenoid in-line. This solenoid is in a normally closed position and would be opened when the primary fuel tank indicates it is below a specified level. Once the primary tank was full again the solenoid would close. This prevents the primary fuel tank from becoming over-filled which could cause the fuel system to pull a vacuum and rupture the tank. It also allows for the primary fuel fill point to still be used; without the solenoid the fuel from the auxiliary tank would pour out of the primary fill if it was opened.

Figure 32 – Pictures of the base vehicle with 1 auxiliary tank installed.

4.5.2 Drone landing platform

The process to design the landing pad for the drone has followed a typical iterative design loop. Learn, Ideate, Prototype, Evaluate, (Repeat). HDT has the advantage of evaluating a prototype drone system integrated onto Wolf from another project, and therefore came into the process with some level of background knowledge. This learning process allowed the creation of several viable concepts that were modelled virtually for evaluation, refinement, and selection. Care was taken to allow for integration with other systems on the Wolf, including auxiliary fuel tanks and an autonomy package. The result is a refined, lightweight system that will look and function well.

The landing pad for the drone needed to be raised above many obstacles on the vehicle, to provide a clear, flat area to compensate for inaccuracy in the drone landing position. The tether will pull the drone toward the centre of the pad, but crosswinds will tend to push the drone off course. This pad will also need to allow room in the Wolf cargo bed for flight electronics and the power tether spooling mechanism. It also needed to allow access to maintenance hatches for Wolf subsystems.

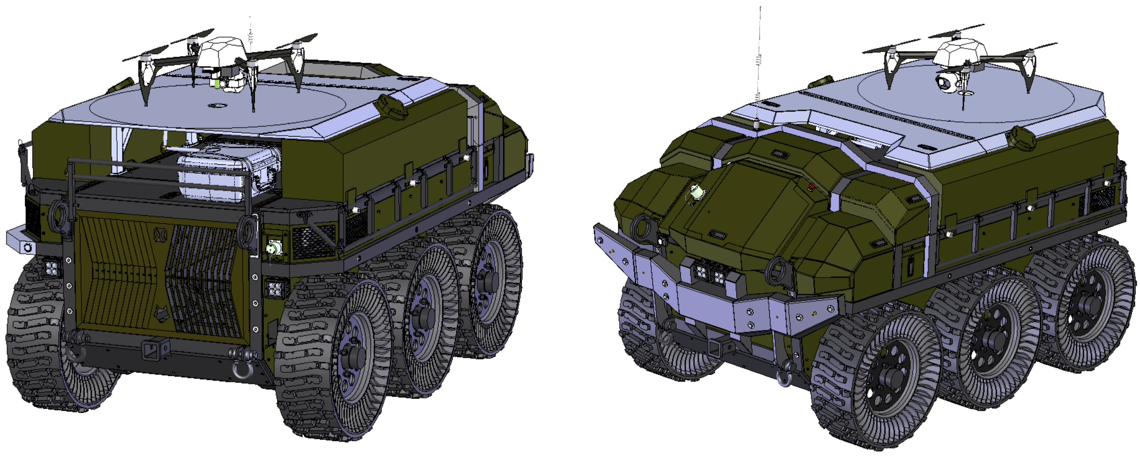


Figure 33 – (left) Wolf with drone landing pad. Shown with auxiliary fuel tanks. Rear view. (right) Wolf with drone landing pad. Shown with auxiliary fuel tanks. Front view

The landing pad consists of a welded lightweight aluminium frame that bolts down to the modular mounting rail on the bed of the Wolf.

A sheet metal deck is bent for stiffness and safety (to reduce exposed thin edges) and bolted to this frame. A second sheet is fabricated and mounted with a hinge to provide access to the front of the cargo bed. Flush mount latches secure this portion of the landing pad. A low-friction plastic insert (not shown) will be fitted to the center hole to provide protection for the tether sliding through.

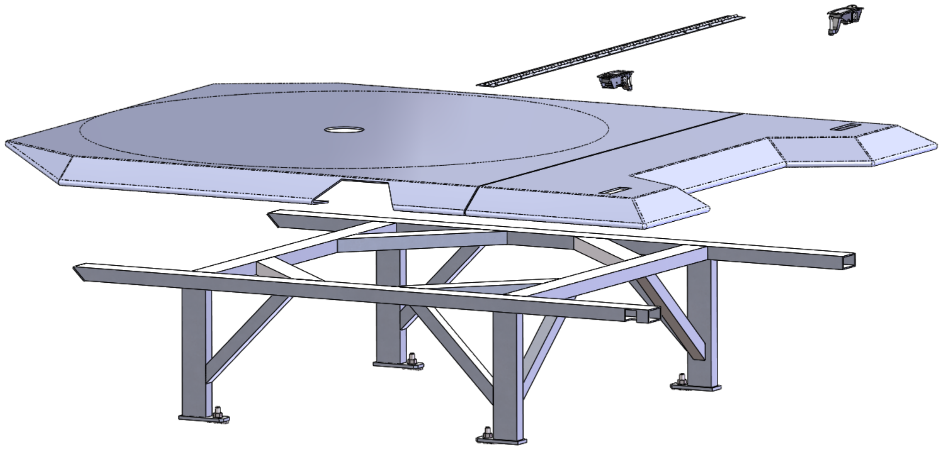


Figure 34 - The main parts of the landing pad

Materials, COTS equipment, and fabricated parts were received and test fit on a WOLF vehicle. The deck and frame will have paint (not shown in pictures). As with any concept development, minor tweaks to the prototype will ensure fit and function. The resulting system meets all of the objectives for the design.

Figure 35 - Flight Deck test fit onto WOLF

4.5.3 NAV controller development

The NAV controller software consists of a tracking algorithm which the vehicle executes to traverse through a predefined path consisting of GPS points. The robot, which is constantly looking ahead in the path, adjusts its velocity in order to smoothly transition from its current position to the desired one. For example, if the desired point is right ahead of the vehicle, then it will decide that the curvature needed is zero, and so accordingly, rotational velocity will be zero while forward velocity will be high. If instead the point is east or west of the vehicle (from the frame of the vehicle), then it will instead choose to decrease its forward velocity and increase rotational velocity. Figure 1 shows one of the tests performed in the tracking of a rectangular path in a parking lot.

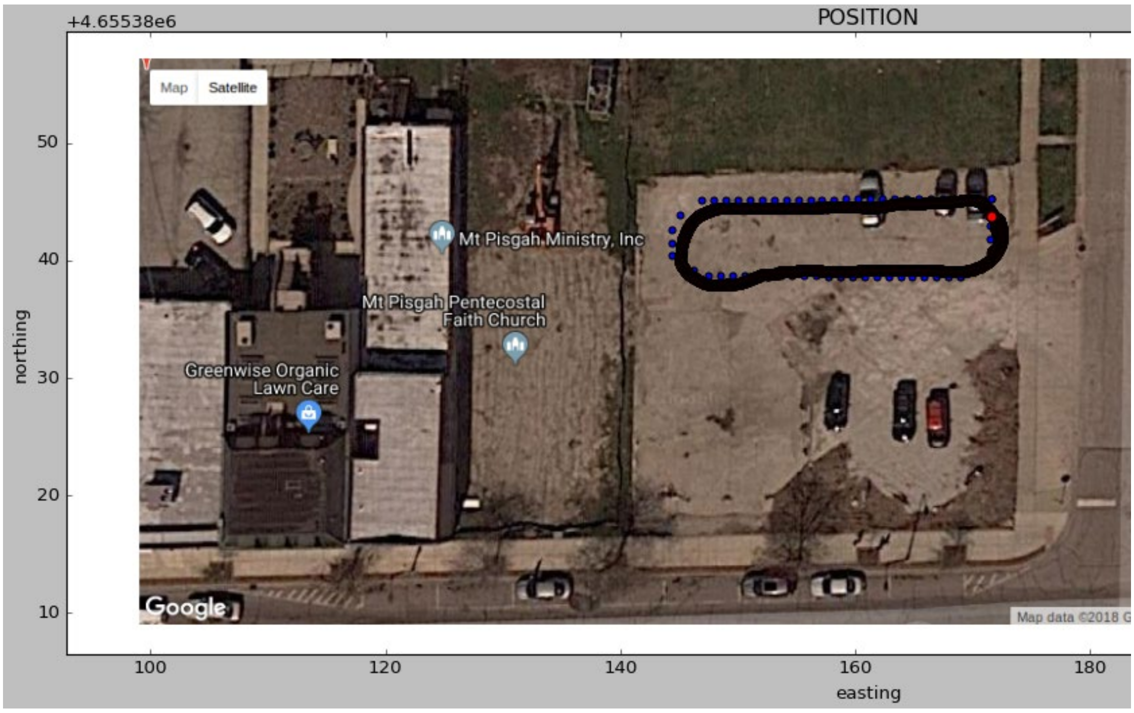


Figure 36 – Result of path tracking algorithm. Desired path consists of the blue dotted path, actual path traversed in black

A key component of the algorithm is the ability for the robot to localize itself in the world. In this vehicle there are three independent sources which give this kind of information. The primary source, GPS, gives us global positioning, and if studied over time, heading as well. The secondary is an inertial measuring unit (IMU), which gives orientation information as well as linear acceleration and angular velocity. Lastly, wheel odometry gives relative changes in position of the vehicle. All these sources of information independently can be noisy and under certain situations unreliable, however, if all are fused using a Kalman filter, then we can be confident that at any moment in time our understanding of where the vehicle is in the world is sufficiently accurate to execute the desired trajectory.

In the special case where there are buildings and other large structures around the vehicle, the LiDAR, sonars, and RADAR can be used as additional inputs to our localization filter. By knowing our distance to certain structures or landmarks using the sensors we can become more certain about our belief of where we are in the world.

The figures below show the small COTS vehicle on which the software is being tested, fitted with all of the sensors.

Figure 37 – From left to right: RADAR, Sonar, LiDAR

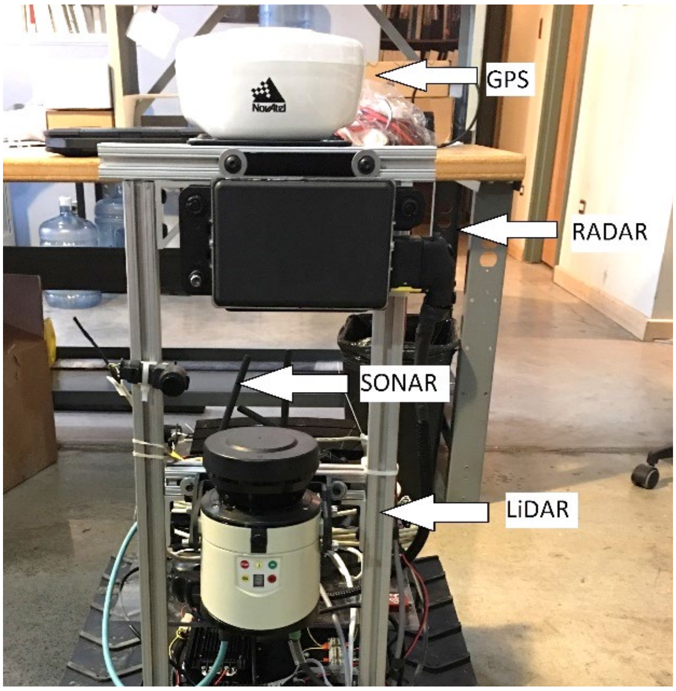


Figure 38 - Test vehicle fitted with the sensors described above (front view)

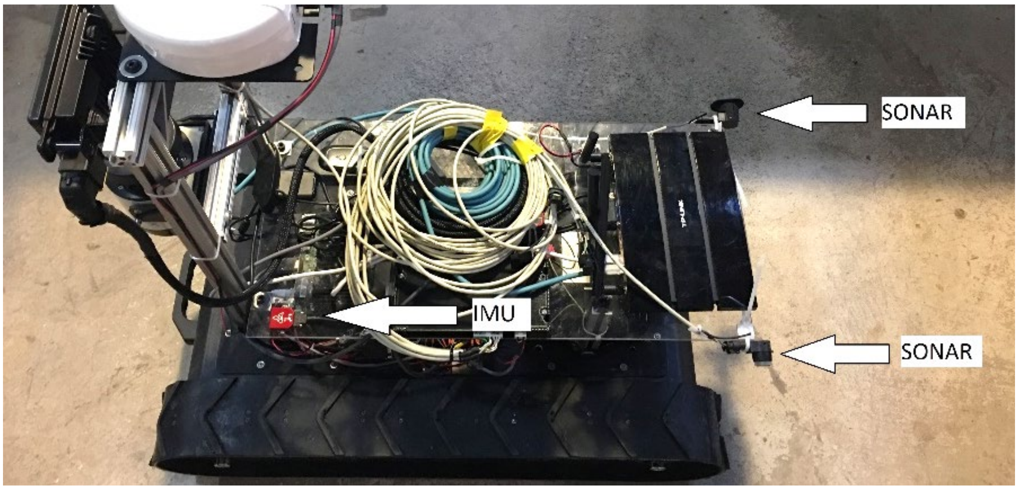


Figure 39 - Test vehicle showing the IMU and two additional sonars for collision detection in the back of the vehicle

4.5.3.1 NAV controller integration with Drover WOLF

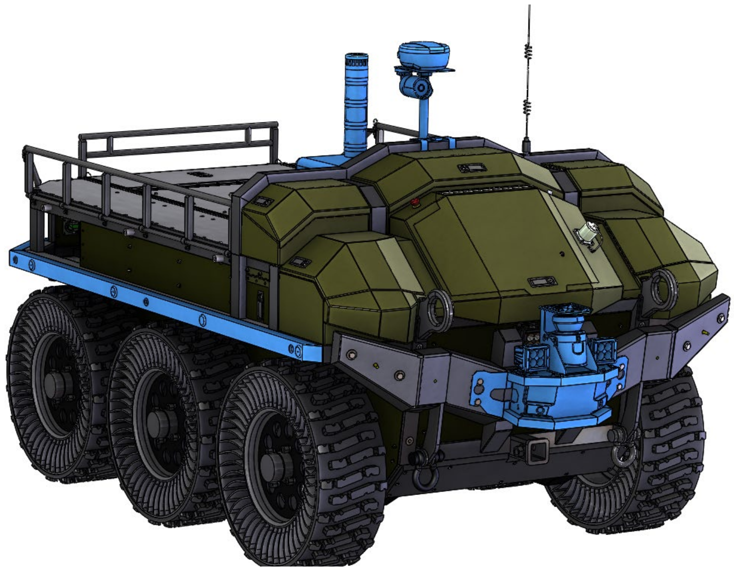


Figure 40 - Final Design of WOLF autonomy package highlighting the autonomy components (in blue)

In order to integrate the NAV controller with Wolf, a balance had to be struck between ideal sensor location and the physical risk that those positions incur on the sensors themselves. NAV sensors include a GPS antenna, a visual camera, a LIDAR system, ultrasonic sensors, and Radar. These sensors are designed for exposure to weather. The system also included 3 PCB assemblies that require a sealed enclosure.

The GPS, camera, and LIDAR are best located on the centreline of the vehicle. The GPS must be mounted high in order to have a clear view to the horizon. This height requirement led to a tower in the bed of the vehicle that was also a good location for the camera. Initially, the LIDAR was also mounted to this tower, but subsequent analysis of the field of view of the system prompted relocation to the front bumper module.

The RADAR also should be on the centreline of the vehicle, but mounted much lower. This sensor is intended to look forward to identify obstacles in the path of the vehicle. If mounted too high, short objects will not be observed unless the radar is tilted at a steep angle. This angle would reduce the distance that the sensor can see forward. A decision was made to mount the radar low on the front of the vehicle at a very shallow angle to maximize the distance (and therefore avoidance time) to obstacles.

A low front position puts the radar at risk from impacts with the environment. The Wolf is capable of driving over brush and trees that are substantial. The bumper is designed to protect the front of the vehicle as it rides up and over these small hazards. Mounting the radar forward of this bumper requires additional protection for the expensive sensor.

When the decision was made to move the LIDAR to the bumper module, a frame was designed to mount them stacked on the centreline. The LIDAR still has the ability to tilt to tailor the field of view of the sensor. This external frame provides a safety cage, and also made room for the front ultrasonic sensors to be protected by integrating them into a protective cover over the RADAR.

The ultrasonic sensors are arrayed around the perimeter of the vehicle to identify any obstacles that might be harmed by, or harm the Wolf. Selection of these sensors was determined by robustness and the amount of coverage each could supply. The lower on the vehicle they are mounted, the smaller the ground-based object that can be sensed. However, mounting to close to the wheels would put them at risk of damage from objects disturbed by the wheels. Mounting outboard of the protection of the perimeter frame of the vehicle put the sensors at risk of damage from the environment. It is likely that branches and other object will be dragged down the side of the vehicle.

The sensors selected were too big to nest within the frame perimeter. A decision was made to put them in a good location for sensing, and have to protect them with additional strong material. They will be imbedded into rails that are frame mounted so they can be both protected and well located. These rails mount to existing modular fastening locations provided in the frame of the WOLF vehicle. The aluminium tubing also provides a chase to run the wiring for the sensor array.

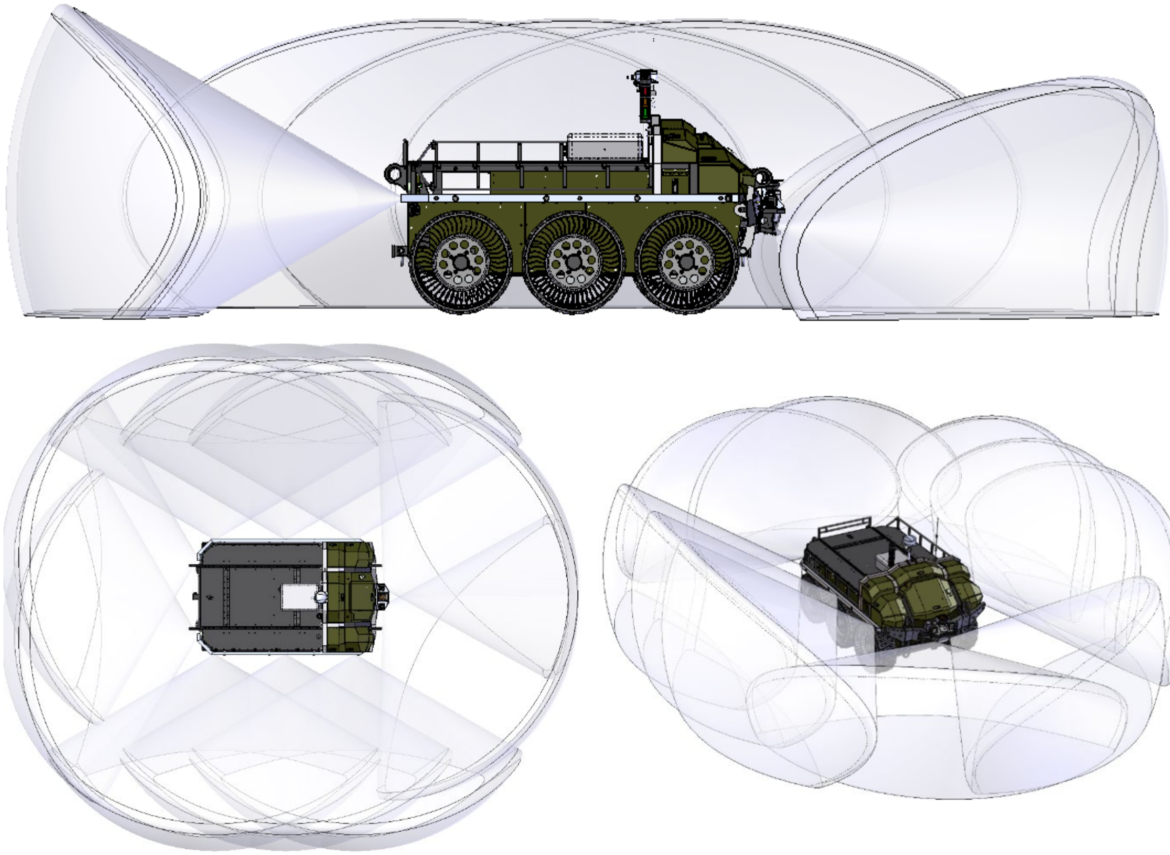


Figure 41 - Top view of Wolf showing coverage area of 10 ultrasonic sensors

The PCBs will be located in a rugged waterproof case that can be mounted in the cargo area of the vehicle. The case is large enough to provide a stable base for the centre sensor tower. It will have waterproof bulkhead connectors to run wires to the sensors and Wolf control. In addition to the centre tower, a warning light/siren stack has been added for safety. The stack will be mounted to the accessory rail on the bed of the WOLF. This system will be able to warn bystanders of impending movement or action, and potentially can be used to clear livestock that may have settled close to the vehicle.

4.5.4 NAV operator interface

The current state of the WOLF UI works as follows. Upon execution, the vehicle initializes a server. The user, once connected to the vehicle, can open any browser and ask the server for the main page. Figure 44 below shows the output of this request. From it several different things can be noticed. Primarily there is a map in the centre of the screen. Like other online map interfaces, it provides the ability to zoom in and out, drag the image, and get the latitude and longitude of mouse clicks.

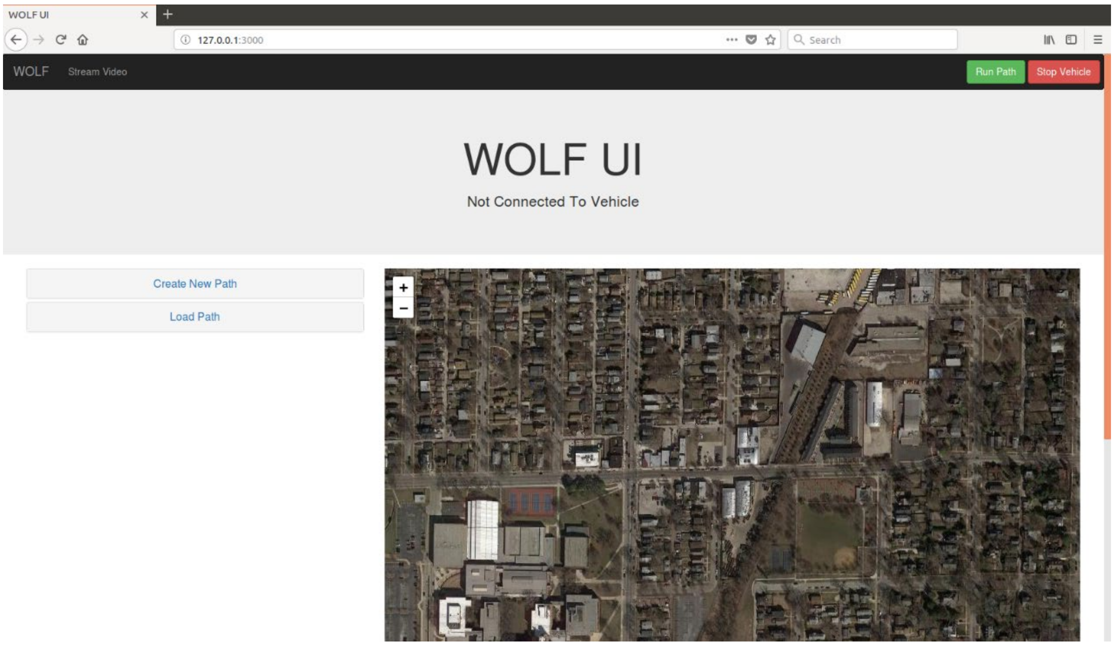


Figure 42 - Main view of the user interface

To the left of the map lay two expandable tables, one labelled 'Create New Path' and the other 'Load Path'. This gives the ability to, as the names imply, create a path by placing waypoints on the map, or to import one from a text file already created. Figure 45 and Figure 46 display each of these options. Notice on the table created in Figure 45 the row labelled 'Event Point'. Each marker on the map can be edited to be an event point. At these points the vehicle will perform some specific action for a designated amount of time. At the time being this only includes taking and storing a video. Additional features for the markers includes the ability to delete them, and to move them around in order to change their location.

Once satisfied with the path that has been specified, the user can press the 'Run Path' button. This will send the command back to the vehicle and the trajectory will be executed. At any point during this trajectory, if the user is still connected to the vehicle, a stop command can be sent by pressing the 'Stop vehicle' button.

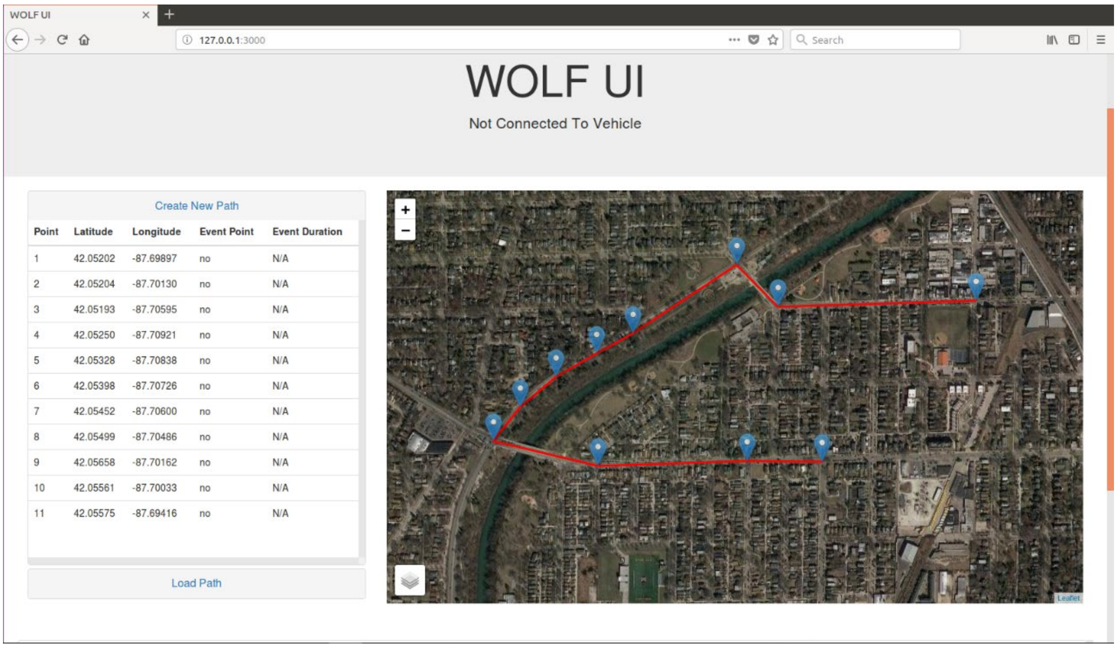


Figure 43 - View of creating a custom path

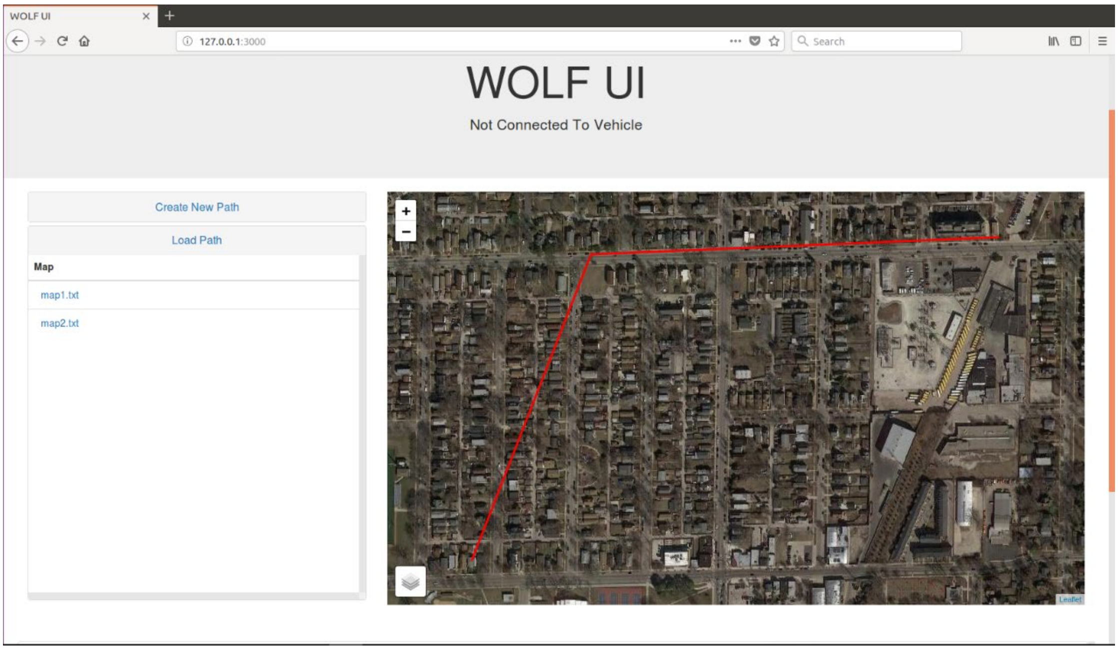


Figure 44 - View of loading an existing path

There are several other features to the website. As can be seen on the top left corner of Figure 44, if the camera is connected, the video can be streamed in real time. Additionally at the bottom of the screen (viewable in Figure 47 - Vehicle (red circle) tracking path), there exists a scrollable table which displays text deemed important by the vehicle. This text can include information pertaining to obstacle detection, or whether a sensor has stopped sending messages, etc.

One key advantage to having the server run on the vehicle side is the ease in displaying data from the vehicle to the site. In the backend the server is interacting with ROS, which controls the vehicle and all of its sensors. As a result, all of the data which is streamed in ROS can be implemented into the UI.

This is evident in some of the features described above, like streaming video, or the information table, but also in being able to plot the position of the vehicle on the map at all times. Figure 47 displays an image of the vehicle tracking a path. Notice the vehicle displayed as a red circle on the map. Notice also the table of information displayed under the map. All of this information is updated in real time as long as the user is connected to the vehicle.

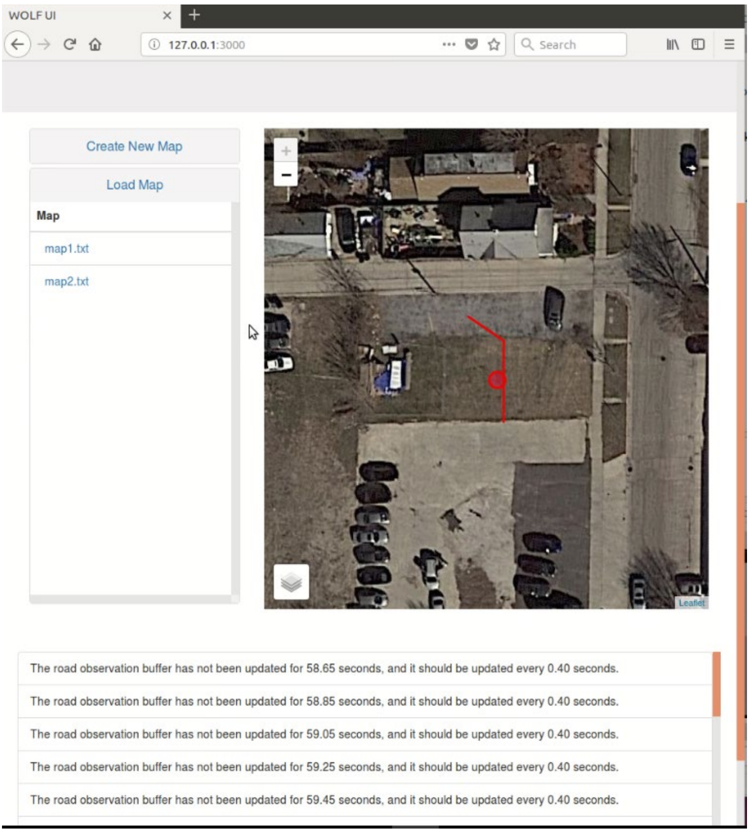


Figure 45 - Vehicle (red circle) tracking path

Furthermore, because the server lives on the vehicle side, the user does not need to worry about having any of the necessary software. All that is needed is a web browser to send requests and display the files.

The operator's commands are ultimately communicated to the vehicle through an IOP (Interoperability Profile) interface. IOP leverages standards such as JAUS (Joint Architecture for Unmanned Systems) in order to define a communication protocol for unmanned vehicles. It provides a consistent and uniform way to enable interoperability and modularity between different systems making future development more feasible and easier to integrate. Currently, there exists a ROS node which serves as a middle ground, transporting data to and from the vehicle IOP node. This can include vehicle velocity commands as well as possible faults and other messages that need to be communicated between the autonomy computer and vehicle controller.

4.5.5 Video Streaming

One of the most important forms of information that WOLF can provide MLA is visual data of key parts of the cattle and sheep stations. As such, this milestone aims at completing the following:

1. Engaging the vehicle's camera when it reaches a specified GPS location.
2. Streaming the data for a predetermined amount of time.

3. Recording the visual, and stamping the file with time and location information, for later extraction and processing.

The process works by launching a script to activate the camera when the vehicle reaches a specified location. The program will run for a specified amount of time in the background. If desired, the vehicle can still move while recording, providing a full view of an area instead of one fixed sight.

Once the camera is activated, the data is broadcasted to anyone connected to the vehicle wirelessly. In case no one is available to analyse the data while it is being streamed, the vehicle also saves a copy of all of it once it is finished. This saved file is named with the location and time at which the recording started.

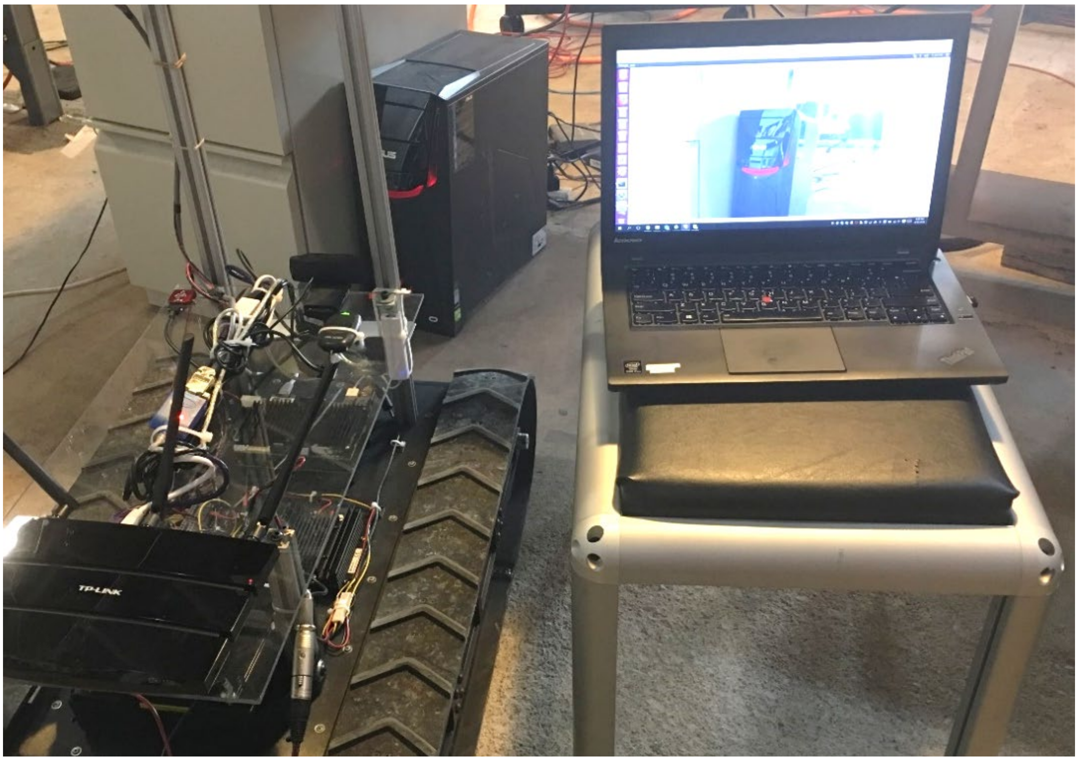


Figure 46 – Picture demonstrating a view of the test vehicle streaming data onto a laptop.

4.5.6 Obstacle avoidance

4.5.6.1 Hardware

Collision avoidance is primarily accomplished through the use of sensory information. For this task we are implementing a LiDAR, RADAR, and set of ten ultrasonic sensors positioned all around the vehicle (Figure 39). The LiDAR, RADAR and two sonars will be placed at the front of the vehicle with the remainder of the sonar sensors distributed in order to provide a full 360° view (Figure 43 - Top view of Wolf showing coverage area of 10 ultrasonic sensors). Note, that in the interest of keeping the cost as low as possible – for industry affordability reasons – and given our observations of the AU Western territory's terrain, our approach for the development of the obstacle avoidance controller was to start with a minimal set of sensors until sufficient testing is performed and the need for more (or more expensive) sensors becomes an absolute requirement; it is always easy to add more sensors, but very hard to justify them out.

NAV Kit sensor suite:

- LiDAR
  - **Primary purpose**: LiDARs are very high resolution sensors. They enable the vehicle to obtain a clear understanding of the geometry of objects around it. This is crucial in being able to safely traverse around them. It is the main sensor used in collision avoidance.
  - **Description**: The sensor has a working range of 20 meters and an aperture angle of ± 135° at 0.5° resolution. The sensor is rated for outdoor use with an IP67 enclosure rating.
- RADAR
  - **Primary purpose**: RADARs are very robust sensors. They have no moving parts and are widely used in the automobile industry. The use of a RADAR adds a strong redundancy to the LiDAR. Additionally, the RADAR's long range allows the vehicle to prepare for objects even before the LiDAR has detected them.
  - **Description**: The RADAR consists of a multimode coverage with a long range mode having a range of 174 meters and aperture of ± 10°, and the mid-range mode having a range of 60 meters and aperture of ± 45°. Like the LiDAR, the RADAR is rated for outdoor use and is used in the automobile industry for similar tasks.
- Sonar
  - **Primary Purpose**: The sonars are located all around the vehicle in order to ensure that objects in the back and on the sides can be accounted for. Although the sonars are not as precise as the LiDAR, they provide enough information in order for the vehicle to make decisions on whether to stop or keep moving.
  - **Description**: These sensors are designed for automobile applications and are widely used in vehicles as parking and short distance sensors. The sensors have a range of 1.5 m and an aperture angle of ± 70°. The sensors are rated for IP64K.

The performance of each sensor has been tested and confirmed as shown in Table 6. The ranges specified for the LiDAR and RADAR guarantee obstacles will be detected with enough time for the vehicle to stop if running at maximum velocity. In the case of turning or driving in reverse, low enough velocities will be used in order to ensure that a stop can be reached in the 1.5m range provided by the sonars.

Table 6 - Tested ranges and aperture angles of sensors

Sensor	Maximum Range Tested (m)	Aperture Angle tested (deg)
LiDAR	20	± 140
RADAR	> 50 long-range/ > 50 mid-range	± 10 long-range ± 45 mid-range
Sonar	1.5	± 70

The position of the LiDAR and RADAR on the vehicle is in the bottom front. This is done in order to ensure that no sizeable object will be missed. For the case of obstacle avoidance, the LiDAR is the primary sensor used. With an angular resolution of 0.5° an object 1 meter from the vehicle would have to have a width of less than 8.6 mm in order to be missed. In the scenario where the LiDAR malfunctions and fails to detect an obstacle the RADAR acts as a redundancy. Similarly, the Sonars have large areas in where they overlap, adding redundancies. Currently the sensors are setup as conservatively as possible. This means that if one sensor is reporting an obstacle but another is not, the sensor which is detecting the obstacle will be assumed to be right. The situation in where the vehicle fails to see something near it is highly unlikely unless that object is out of the line of sight of the sensors.

4.5.6.2 Software

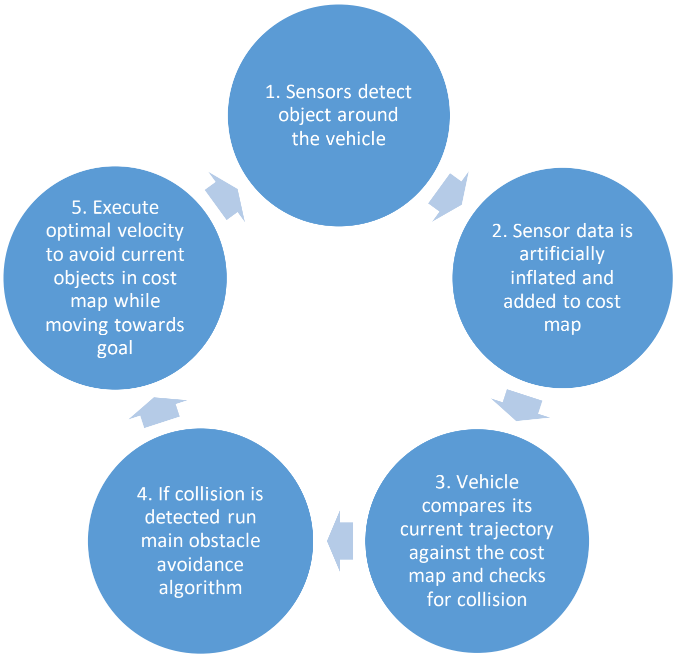


Figure 47 - Flow Chart providing basic idea of how obstacles are detected and avoided

Figure 49 provides a quick understanding of all the steps taken in order to ensure that the vehicle is capable of safely traversing through an environment with obstacles in it. Each step is described below in more detail.

The output of the sensors is used to create a cost map of objects the vehicle sees in the world. This map is created by *inflating* the sensor readings as shown in Figure 50 and Figure 51 below. The added *inflation layer* exists in order to add an extra safety level around obstacles. As the robot traverses through a path it is constantly checking if a collision is possible given its current state and the cost map. If it is the case that a collision is possible at some point in the future, then the collision avoidance algorithm takes control of the vehicle.

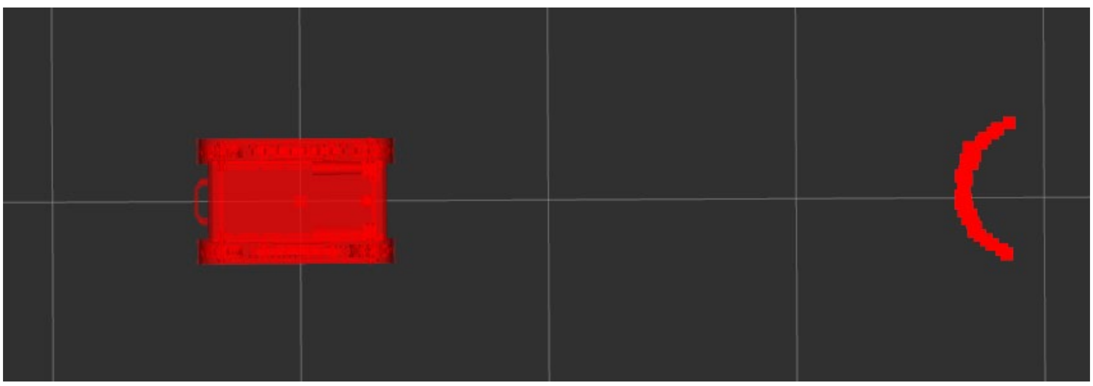


Figure 48 – Sensor readings for test vehicle placed 3 meters in front of cylindrical structure

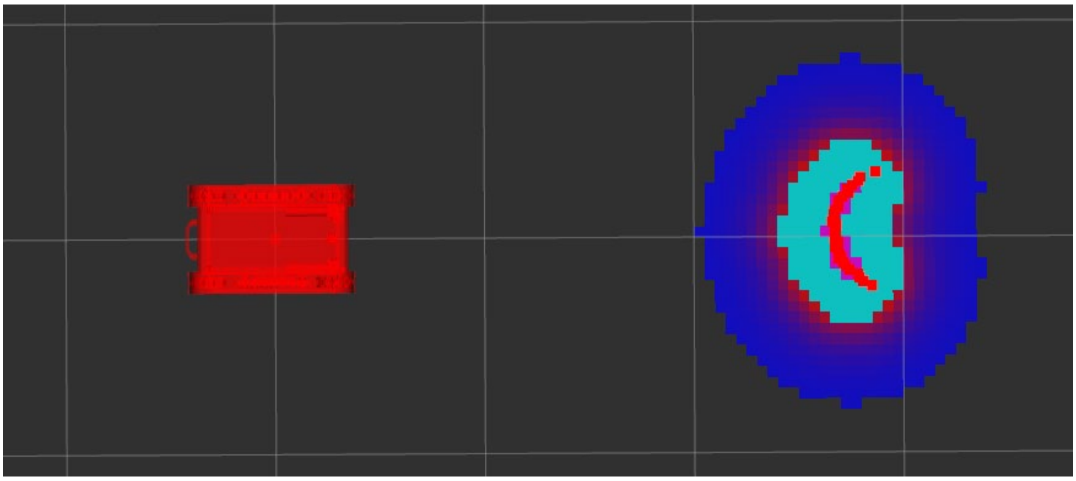


Figure 49 – Sensor readings with an inflation layer around it

The algorithm developed for obstacle avoidance is called *Dynamic Window Approach* (DWA) [1]. The algorithm is guaranteed to avoid static obstacles by considering only trajectories that can be reached within a short time interval and are free from collisions. It has been implemented in the past in several mobile robots and is the primary obstacle avoidance algorithm used in the *Robotics Operating System* (ROS) Navigation Stack.

In the presence of an obstacle there is no single velocity command which is capable of taking the vehicle from where it currently is to the next goal point. As a result, the collision avoidance algorithm works by iterating through a discretised set of possible velocities that the vehicle can take within the next small time frame. Figure 52 shows this effect. Notice that when the object is detected the vehicle no longer knows a direct route towards the goal (located directly behind the obstacle), as a result the vehicle considers a large number of possible trajectories (as shown in purple) each characterized by a linear and rotational velocity.

[1] 1. Dieter Fox, Wolfram Burgard, Sebastian Thrunn (1997). "The Dynamic Window Approach to Collision Avoidance". Robotics & Automation Magazine, IEEE. 4 (1): 23–33.

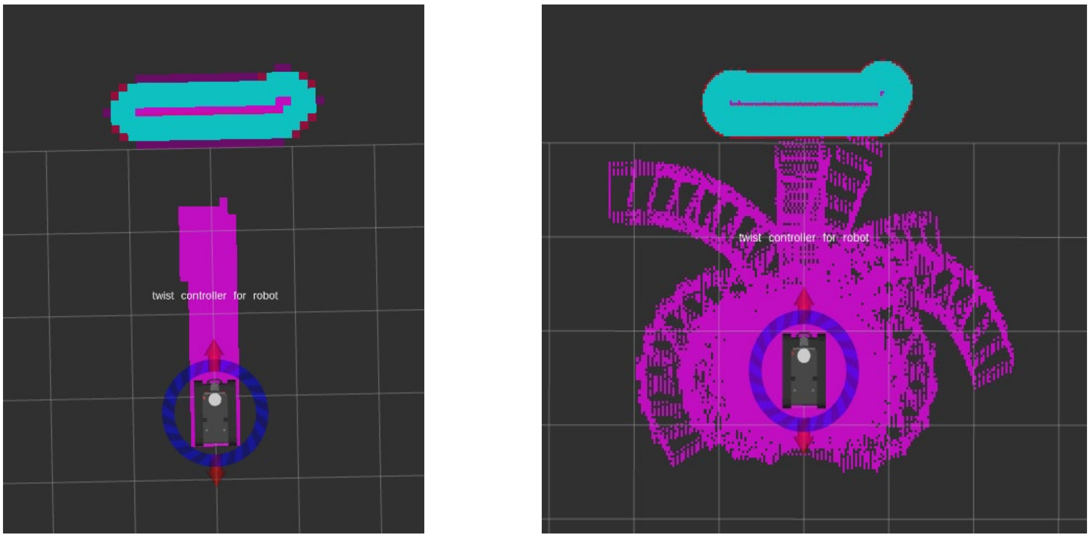


Figure 50 - Vehicle driving towards an obstacle(light blue). Image on the left shows the desired trajectory (purple) before a collision is detected. Image on the right shows the discretised trajectories (purple) considered after a collision is detected

Velocities that are beyond the acceleration range, or will lead to a collision are rejected immediately. The rest of the velocities are graded based on their ability to maximize a set of criteria. In general, we prefer velocities which turn the vehicle towards the goal, minimize time to goal, follow the generated path, and avoid obstacles in the future. The velocity with the highest grade is chosen for the next time step.

The obstacle avoidance algorithm consists of four main components.

- **Orientation Cost:** When deciding which velocity to execute (purple paths in Figure 53) a primary concern is to choose a path which will not orient the vehicle too far from the goal. Although some deviation is necessary in order to go around the obstacle this parameter helps the vehicle not take trajectories which deviate too much. This cost is maximal if the difference between the heading of the vehicle and the goal point is zero, and minimal if it is 180°, where a high cost is desired.
- **Obstacle Cost:** As mentioned earlier, velocities which will result in a collision within the next time step are immediately discarded. This parameter concerns itself with trajectories that may encounter an obstacle at some time in the future. The advantage of this is in executing trajectories which will stay as far as possible from obstacles.
- **Velocity Cost**: Velocities which get the vehicle to the goal point faster are preferred.
- **Optimal Path Cost**: The optimal path (green line path in Figure 53) is solved using an A* algorithm. It consists of the set of points which minimize the distance from where the vehicle is to where it needs to go while avoiding obstacles. As a result, velocities which guide the vehicle along that path should be graded higher than those which deviate from it.

If there are any discrepancies between sensors on where an object is in the world the vehicle will stop until the issue has been resolved.

Figure 53 below provides a visual representation of the collision avoidance algorithm. In the scenario shown, the sensors detect a large box directly in front of the vehicle. This box is added to the cost map in the following frame. As the vehicle starts to move forward it realizes that a collision will occur in the future. At this point the DWA algorithm takes control and at each step an optimal velocity is picked in order to follow the new path and avoid the obstacle. Iterating these steps over time allows the vehicle to completely go around the obstacle and eventually converge in on the original path towards the goal. The frames shown in Figure 53 were taken during a real test with a visualization tool called RVIZ (ROS Visualization). RVIZ allows the user to visualize sensory data and makes it easier to display the trajectories.

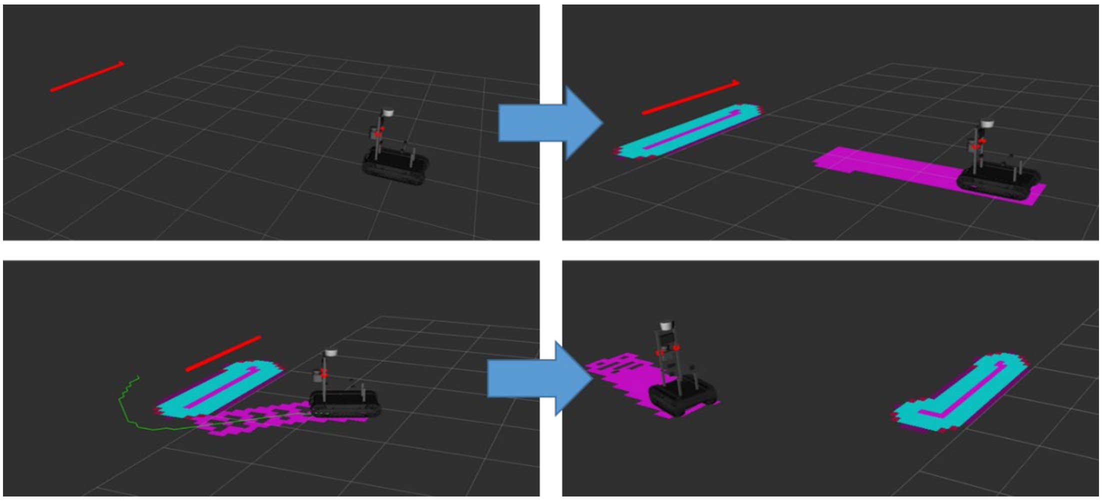


Figure 51 - Visualization data of test vehicle navigating around a large box. In the first frame the vehicle sensors detect the box in front of it (red line). As the vehicle starts moving towards the goal (purple trajectory) the sensor data is added to the cost map (light blue). Once the trajectory and cost map intersect a collision is detected. At this point an alternate path (green line) and optimal velocity (purple trajectory) are chosen. In the final frame the vehicle has passed the obstacle and begins to converge back into the original path.

Testing has been done in order to prove that a baseline version of obstacle avoidance works. Integration of the LiDAR, RADAR, and sonars with the algorithms described above has allowed the small test vehicle to traverse through multiple outdoor paths while avoiding static and dynamic obstacles successfully. As of this moment no sensor issues have been found regarding excess sun light, dust, or vibrations. Similarly, the software has succeeded in preventing the vehicle from crashing in every single scenario. In all the testing done there have not yet been any vehicle collisions or sensor hardware failures.

The software developed, sensors used, and tests completed are vehicle agnostic. The choice of vehicle being used is reflected in the software through the use of a configuration file. Parameters to be tuned in this file include values such as those concerning the geometry of the vehicle, maximum velocities, and sensor locations. If an interface is created which allows the autonomy module to send velocity commands to a vehicle, and the vehicle provides corresponding odometry data, then tests results should be similar to those performed. For the WOLF, this interface is IOP. By running both IOP and ROS, all of the software developed for this project is by default set to work with mobile robots which use those communication protocols. Integration is performed by simply changing the necessary parameters in the configuration file.

Limitations in the collision avoidance algorithm do exist. The vehicle is not guaranteed to avoid collisions with dynamic obstacles which jump into the vehicle's path at the last moment. Similar to how a human driver has reaction limits when an obstacle is suddenly placed in front of them, so too does the vehicle. In situations like these trade-offs exist. As the vehicle is driving down a road it cannot stop every time something appears on the side of the path. It must decide whether that object is going to move towards it or stay where it is. This decision parameter can be tuned by adjusting the inflation layer in the cost map, and vehicle maximum velocity, but it can also be improved by advancing object detection and state prediction algorithms. Additionally, current limitations in sensors limit the vehicle's sight. Objects that are below the plane of view of the LiDAR and RADAR can potentially cause harm to the vehicle, such as holes and ditches in the road. In general, autonomous vehicles would compensate for these kind of obstacles with the use of multiple LiDARS (each at complimentary angles), a 3D LiDAR, or computer vision, coupled with more advanced software algorithms, however in the interest of keeping the cost as low as possible we implemented this initial baseline controller with a minimal set of sensors until sufficient testing is performed and the need for more sensors is unavoidable.

4.6 Build Drover WOLF

HDT technicians assembled the Drover WOLF (SN21) using its manufacturing engineering work instructions (MEWI), inspected and tested as a standalone unit. See Figure 54 for proof of milestone completion.

Figure 52 – Pictures of WOLF SN21, the vehicle deliverable that is part of this Phase of development.

4.7 Integrate and test

HDT technicians assembled the Hunter WOLF (SN21) using its *manufacturing engineering work instructions* (MEWI), inspected and tested as a standalone unit. Subsequently it was integrated with the NAV kit, 2ndary fuel tanks, and the drone landing platform (i.e. the Drover WOLF deliverable), see Figure 54 (right) for proof of milestone completion.

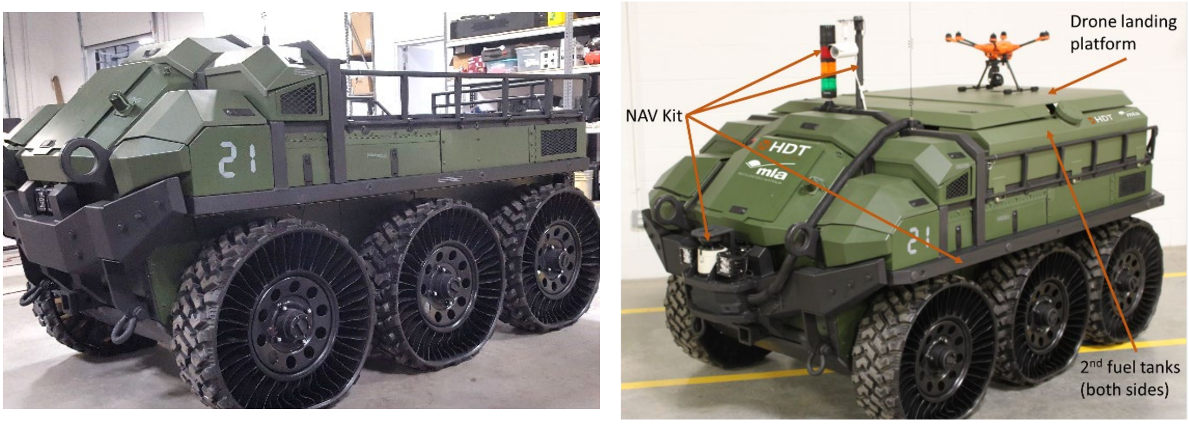


Figure 53 – Pictures of the (left) baseline Hunter WOLF vehicle, and (right) Drover WOLF integrated with the NAV Kit, secondary fuel tanks, and the drone platform.

Benchtop testing of the autonomy system as a whole was performed in HDT's Fredericksburg facility. Each individual sensor was confirmed to be in working order. The combination of 10 ultrasonic sensors, a RADAR, and a LiDAR provide the vehicle with a full 360-degree view in order to constantly be aware of objects near it.

Waypoint navigation (shown in Figure 56) was tested in HDT's ~12,000m^2 proving ground (refer to Figure 57 for a view of the field). The tests done consisted of using the autonomy GUI in order to select a set of points on the map and send the vehicle on its way. Multiple tests completed demonstrated a robustness in the ability for the vehicle to follow many different geometries of paths. The duration of the tests was also taken into consideration during integration. To ensure that the system is reliable enough to perform its intended tasking, several length tests were run ranging from several minutes to an hour.

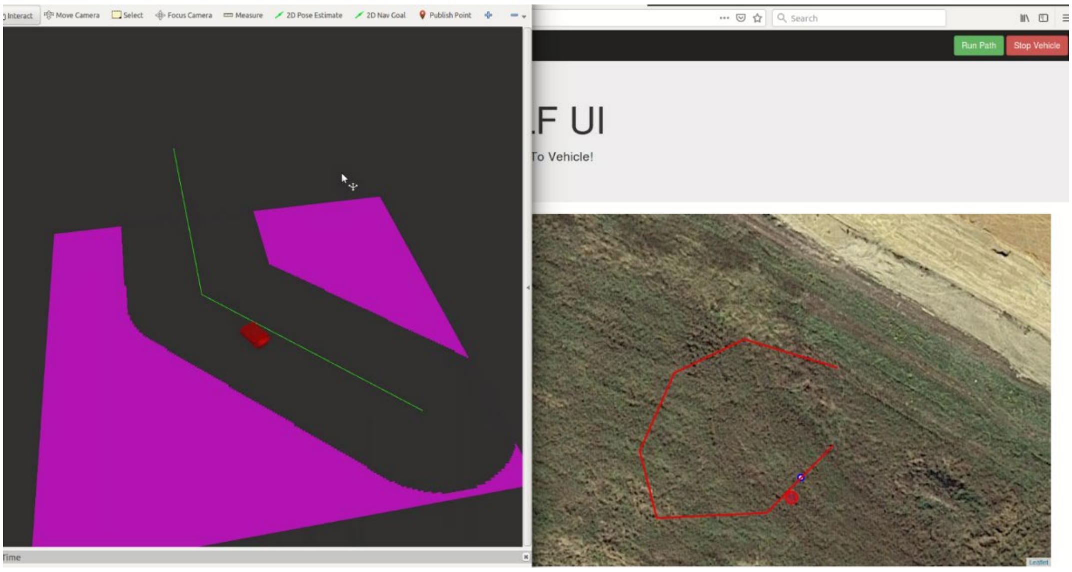


Figure 54 - Waypoint navigation. The image on the left is for visualization purposes and displays the vehicle (red) traversing the path (green) and the outer edges of the road (purple). The image on the right is a part of the GUI displaying the total path (red line) with the vehicle (red circle).

Obstacle avoidance was tackled with the use of all the sensors by placing both static and dynamic objects in the vehicle's trajectory. Static obstacles tested included objects of varying sizes ranging from smaller boxes to a large table laying sideways in the center of the road (note that all obstacles used were tall enough to be visible by the LiDAR). Dynamic testing consisted of a person walking in front of the vehicle at varying times. Robustness was verified both by repeatability and by pushing the vehicle to edge cases. Some scenarios involved getting very close to the vehicle, moving in front of it repeatedly as it attempted to find a way around the person, and sending it over noticeably rugged terrains. For the case where an object manages to get within a certain limit of the vehicle, the WOLF will attempt to back up so that it has space to go around the obstacle. If the vehicle detects something behind it as well, then it will simply stay in place until it finds a solution, like the road clearing. Figure 57 and Figure 58 depict some of the images collected while doing obstacle avoidance.

Figure 55 - WOLF Approaching a table laying on its side on the left. Navigating around it on the right.

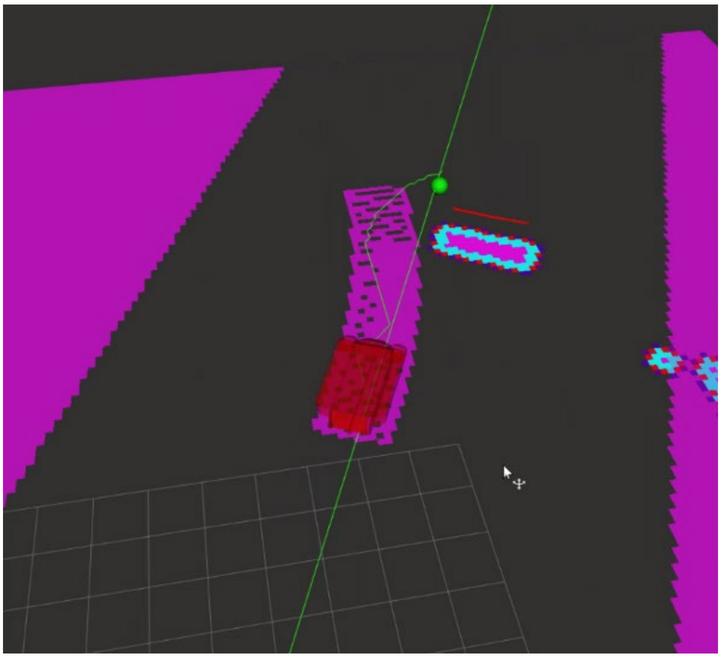


Figure 56 - Visualization of what the vehicle (red) sees as it approaches the table. As the obstacle (light blue/purple) is detected a new path is generated (green line) to go around the object. The vehicle adjusts its velocity to follow the new trajectory (purple path).

Other features tested and integrated include the light tower, camera, fuel tanks, and drone platform. The light tower, mounted in front of the vehicle in Figure 54, can be used in order to give the operator and nearby observers the ability to know when the vehicle is on standby, faulted, or autonomy mode. The camera, also shown in the front of the vehicle, can be activated and set to record for predetermined periods of time at specific locations by the user in the GUI. The fuel tanks were tested electronically and in software. This included verifying that the fuel sensor readings were reporting back correct values, and that the vehicle would automatically begin to use the fuel tanks in the case that the main fuel supply was depleted.

4.8 Demonstrate

HDT demonstrated system capabilities and cattle station tasks at Carwoola Pastoral Co. Pty Limited over four days, 1/19/2020 to 1/23/2020. Twenty different use case demonstrations, including traverse between numerous sites on the Pastoral, resulted in 70+km of distance travelled by the system.

4.8.1 Waypoint Following

Utilizing a laptop and web interface the WOLF is programed to follow a path of GPS waypoints. Along the route, the sensors on the WOLF provide obstacle avoidance. If an obstacle is encountered, paths around it are calculated and executed. Numerous automated routes were planned and executed of the course of the demonstrations.

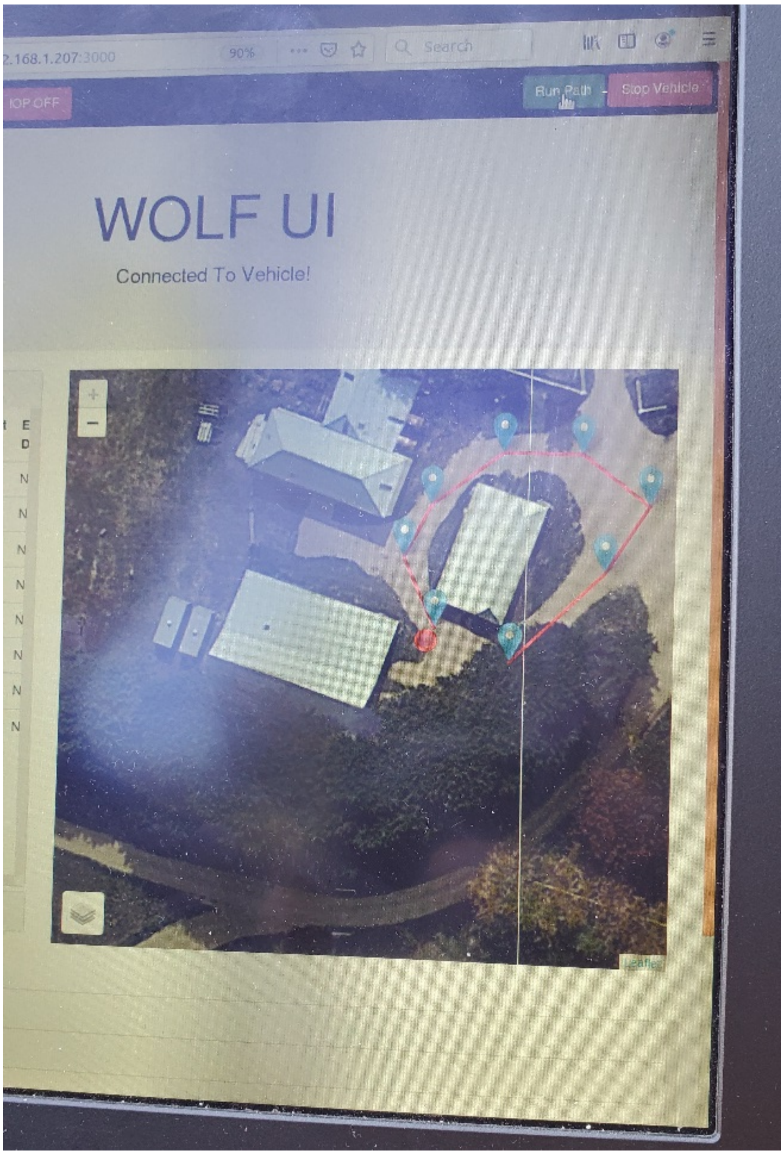


Figure 57 - Path planning UI

Figure 58 - Demonstrating path planning UI

Figure 59 - WOLF navigating a planned path

4.8.2 Gate traversing including cattle grid

Gates and cattle grids are used extensively in cattle station environments. The ability of the WOLF to traverse these points is important to its future use. Autonomous navigation through these points was demonstrated.

Figure 60 - Approaching cattle grid under autonomous control

Figure 61 - System manoeuvring to pass through gate

Figure 62 - System navigating through gate over cattle grid

Many other demonstrations were performed see the Milestone 15 report.

5 Discussion

5.1 Potential Applications

5.1.1 Cattle station productivity

HDT in conjunction with MLA conducted a survey seeking input and guidance from large pastoral station managers as to where the greatest needs were and thus where the developments of the device should focus.

Table 7 – Australian producers survey results

CAP#	Description	Avg. (1=highest priority)	Hancock	Harvest	Hewitt	Naryilco	Paraway	Rockybank	Remote Sensing
1	Detect leaks in water pipelines	**6.50**	3	5	12	4	10	5	Drone
2	Verify water levels at watering sites	**6.83**	6	2	15	3	10	5	Fixed
3	Refuel water pumps	**6.83**	5	8	11	2	10	5	
4	Distribute nutritional feed supplements	**7.00**	11	6	4	14	2	5	
5	Distribute fodder	**7.17**	12	11	3	11	1	5	
6	Count livestock in paddocks	**7.17**	7	3	6	12	10	5	Drone
7	Assess the quality/amount of forage in paddocks	**7.17**	1	1	10	9	10	12	Drone
8	Install new fence lines	**7.50**	14	14	2	6	4	5	
9	Monitor water quality in watering troughs	**7.67**	4	9	13	5	10	5	Fixed
10	Eradicate undesirable plants	**8.17**	8	12	6	8	10	5	
11	Assist in cropping	**8.17**	2	15	7	15	5	5	
12	Detect the presence of pest animals	**8.67**	13	4	7	13	10	5	Drone
13	Clear vegetation away from fence lines	**8.67**	9	13	14	1	3	12	
14	Deliver / pick-up supplies to/from remote sites	**8.83**	10	10	1	10	10	12	
15	Detect undesirable plants	**9.33**	15	7	5	7	10	12	Drone

About half of the tasks involve remote sensing and the other half of the tasks require carrying a load or physically interacting with the environment. Two of the remote sensing tasks could be accomplished with fixed sensors at watering sites, if these sensors could communicate with the homestead. The remaining five remote sensing tasks could be accomplished with an aerial drone, if the Australian government changes its regulations to allow operation of autonomous aerial drones beyond line of sight of the operator.

To help fixed sensors, there are several large companies competing to establish networks of low-Earth-orbit satellites to provide wireless Internet connectivity everywhere on the globe. This capability should be in place within the next five years. These services will be very affordable for users. The user connection hardware will not require much electrical power, so it should be possible to have solar-powered remote sensors at every watering site.

As for aerial drones, it is not possible to predict how regulations might change in the future, but it would seem possible that autonomous operations of aerial drones in very remote areas could be approved sometime in the next few years. Certainly, once Internet connectivity is available globally and free-flying drones can be constantly monitored, beyond-line-of-sight operations will be much easier to approve.

Because remote sensing tasks will likely be possible in the next few years through fixed sensors and aerial drones, MLA and HDT agreed to focus our efforts with the Drover WOLF on facilitating tasks that are physical in nature such as delivery, collection, and control.

After discussion with MLA about the estimated cost/benefit of automating the possible tasks, HDT arrived at the following rank ordering of tasks, from highest priority to lowest:

1. Refuel water pumps
2. Distribute nutritional feed supplements
3. Eradicate undesirable plants
4. Distribute fodder to paddocks
5. Assist in cropping
6. Distribute feed in feedlots
7. Clean feed bunks in feedlots
8. Clean pens in feedlots
9. Install new fence lines
10. Spread manure as fertilizer in cropping
11. Inspect and clear vegetation away from fence lines
12. Deliver / pick-up supplies to/from remote sites
13. Detect leaks in water pipelines
14. Verify water levels at watering sites
15. Count livestock in paddocks
16. Assess the quality/amount of forage in paddocks
17. Detect the presence of pest animals
18. Monitor water quality in watering troughs
19. Detect undesirable plants

5.1.2 Feedlots

The use of feedlots for finishing cattle has been expanding in Australia, in response to both domestic demand and the rapidly increasing demand for grain-fed beef in the Asian export market. Pacific Rim Asian countries are projected to import over three million tons of beef in 2018[2].

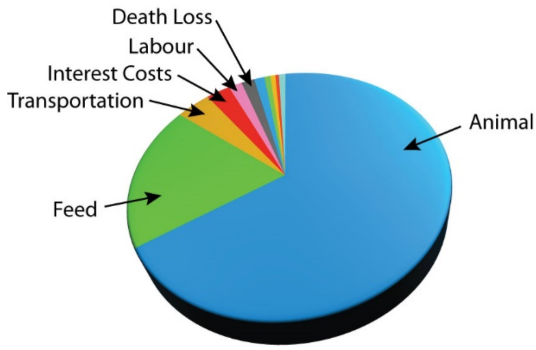


Figure 63: Feedlot costs.

In other countries, there has been little work on autonomous systems to improve the productivity of feedlots. As can be seen in the chart to the right, labour costs are less than 2% of the total cost of finishing cattle in a feedlot[3], so there has been little motivation to improve efficiency.

Australia's situation is different, because labour costs for feedlots are much higher[4]. Australia's hourly labour cost for feedlot workers is more than twice that of the United States.

Potential feedlot applications that lend themselves well to automation include:

- Feed delivery
- Feed bunk cleaning
- Pen cleaning
- Manure spreader

5.1.3 Invasive Species

MLA and HDT personnel visited a cattle station that is battling a rapidly growing infestation of non-native woody weeds. The information gathered during this visit helped raise the relative priority of using the Drover WOLF to assist in the eradication of these undesirable plants.

Australia has battled many different invasive species that have threatened the nation's environment and economy. The Australian Academy of Science reports that economic cost of invasive species is over A$ 13.5 billion per year[5].

The Australian Government Department of Agriculture and Water Resources says, "prickly acacia poses a serious threat to 20 to 30 million hectares of grazing land in Queensland, the Northern Territory and Western Australia."[6]

[2] Livestock and Poultry: World Markets and Trade, United States Department of Agriculture Foreign Agriculture Service, April 10, 2018
[3] Guidelines for Estimating Beef Feedlot Finishing Costs, General Manitoba Agriculture, Food, and Rural Development, 2015
[4] International Cost of Production Analysis, Canfax Research Services, 2013
[5] Dr. Michaela Plein and Professor Rick Shine, "Australia's Silent Invaders", 2017, https://www.science.org.au/curious/earth-environment/invasive-species (accessed August 1, 2018
[6] Invasive Plants and Animals Committee 2016, Australian Weeds Strategy 2017 to 2027, Australian Government Department of Agriculture and Water Resources,

Figure 64: Thorns of a Mesquite woody weed.

Prickly Acacia is one of several dozen invasive plant species that are very problematic for cattle stations. Prickly Acacia is categorized as a woody weed, along with Mesquite, Chinee Apple, and several others.

These woody weeds are small trees that propagate quickly. They also grow rapidly – as much as two meters a year. Their branches are filled with sharp thorns, which prevent cattle from foraging on their leaves.

Depending on the woody weed species and the geographic location of the infestation, in as little as five years a few woody weed seedlings in a paddock can expand to a dense thicket. No forage will grow under the canopy of these weeds. Cattle stay away from the infestation due to the weeds' sharp thorns. Once woody weeds have spread across a paddock, the carrying capacity of that pasturage is completely destroyed.

5.2 Value Proposition

The use of autonomous ground vehicles in livestock operations will have a positive economic impact in three major areas:

- Increase the productivity of cattle stations, primarily in Queensland, Northern Territories, and Western Australia through reduced labour costs and increased weight gain.
- Increase the productivity of feed lots through lower labour costs, higher weight gain, and lower morbidity and mortality
- Reduce the loss of pasture lands to invasive species by eradicating these plants at a lower cost and a faster rate than current manual methods.

5.2.1 Cattle station use cases

Drover WOLF vehicles could perform the following tasks:

- Distribute nutritional feed supplements
- Refuel water pumps
- Distribute fodder to paddocks
- Assist in fodder cropping

It is expected that this level of automation would reduce a station's labour needs. In addition, providing consistent feed supplementation during the dry season has the potential to increase weight gain.

Figure 65 – Fuel storage tank at a remote pumping station.

5.2.2 *Feedlots*

While some cost savings would be realized through a reduction of labour costs, the greatest cost benefit of autonomous systems will be through higher weight gain, coupled with lower morbidity and mortality. Unfortunately, the only way to accurately estimate these benefits will be to develop and test prototype systems.

5.2.3 *Invasive species*

There is a wide range of estimated economic impacts on livestock due to invasive plant species, but the amount of $1B annually seems to be widely accepted. This number represents the loss of about 5% to 6% of the available pasturage annually, which is clearly not a sustainable loss rate. In two decades, there would be very little remaining pasturage.

Eradicating all the invasive plant species using current manual techniques would require about $10B per year for a period of several years, followed by $1B per year to maintain the clear pasturage. While this cost is intimidating, what makes the situation even more difficult is that the effort would require around 100,000 workers during the initial years.

Based on HDT's earlier analysis with MLA, the cost of eradication using autonomous vehicles would be one fifth of the current manual cost. In addition, the need for additional labour would be almost entirely eliminated.

5.1 Potential 'breakout' products and/or Future R&D opportunities

5.1.1 Agricultural

An add-on kit to lower the ground pressure of the Drover WOLF would allow for operations over wet soil or mud without sinking in or getting mired. The standard Drover WOLF vehicle with a full load has a ground pressure of about 38 kPa (5.5 psi). For comparison, a typical automotive utility vehicle has a ground pressure of about 250 kPa (36 psi) and an agricultural tractor can vary from 80 kPa to 140 kPa (12 psi to 20 psi), or higher.

While our standard Drover WOLF's ground pressure compares favourably to these other vehicles, when operating on soft soil in the wet season, particularly when assisting in cropping operations, it is essential to have the lowest possible ground pressure. Our low ground pressure kit will lower the ground pressure of our fully-loaded vehicle to about 14 kPa (2 psi).

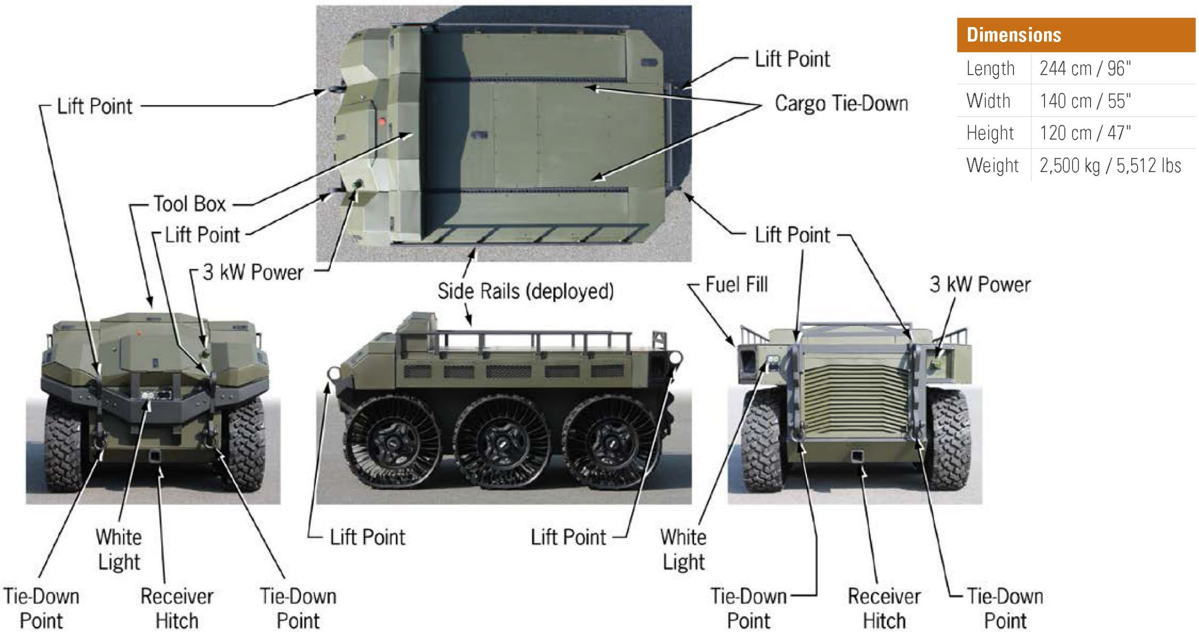
This very low ground pressure will allow the Drover WOLF to operate over freshly tilled crop fields without causing damage, even when those fields are wet from recent rain or irrigation. That feature together with the development of farming attachments would enable autonomous cropping applications.

6 Conclusion/Recommendations

This second phase concluded with the delivery and demonstration of an *Experimental Prototype* of the Drover WOLF vehicle. During the Phase 2 effort (co-funded by MLA Donor Co.), HDT iterated on the design (addressing lessons learned), built and delivered a Drover WOLF vehicle with a prototype implementation of an obstacle avoiding autonomous – GPS waypoint – navigation system.

Figure 66 – Picture of the Drover WOLF that was delivered to Australia.

6.1 Drover WOLF description



Dimensions	
Length	244 cm / 96"
Width	140 cm / 55"
Height	120 cm / 47"
Weight	2,500 kg / 5,512 lbs

Figure 67: HDT's Hunter WOLF unmanned vehicle is about the same size as a large quad bike, but far more powerful and stable.

HDT has developed the **Hunter WOLF** (Wheeled Offload Logistics Follower) unmanned vehicle for the US military. Working with MLA and an Australian producer steering committee, HDT is creating a variant of the Hunter WOLF remote controlled vehicle to an Australian livestock producer autonomous vehicle, the **Drover WOLF**. This variant has longer range and autonomous navigation system, without sacrificing any of its ruggedness or load-carrying capability.

The Drover WOLF can carry 500 kg on its payload deck and tow loads up to two tons. The vehicle can supply up to 15 kW of DC power to attachments. The power train of the vehicle is a diesel/electric hybrid, which combines very high performance with excellent fuel economy. It is a 6x6 skid-steered vehicle, which means it can turn in place.

After completing extensive user observations and interviews HDT is now completing an autonomous kit for the Drover WOLF vehicle, which will allow it to independently operate on cattle stations over a network of dirt roads. Initially, the vehicle will be able to travel more than 500 km per day, delivering tons of fodder, nutritional supplements, diesel fuel, and supplies. As the autonomous system matures, the vehicle's speed will increase, more than doubling its daily range of operations.

HDT is also developing the initial round of attachments, which will allow the Drover WOLF to perform specific tasks. Once testing of the vehicle and its attachments begins in Australia, HDT will seek out local partners to take over the development of attachments. We will also work with local universities and companies to improve and extend the system's software. The Drover WOLF supports open protocols for robotics software, including Robotic Operating System (ROS), Joint Architecture for Unmanned Systems (JAUS), and Inter-Operability Protocol (IOP).

7 Key Messages

The livestock industry in Australia is unique in the world because Australia has a combination of high-cost labour and large areas of low-density pasture lands, especially in the north and the west where the dry season limits natural forage. In other countries with high-cost labour, the livestock industry has become much more industrialized. Most of the animals in those countries are raised using fodder supplementation, before being sent to lengthy stays in feed lots. In other countries, where cattle are raised on natural pasturage similar to Australia, their labour cost is generally much lower.

The situation in the Australian livestock industry is comparable to the Australian mining industry, where the difficulty of attracting labour to work in a remote environment negatively impacted productivity and limited the ability to expand financially attractive opportunities. Autonomous vehicles fundamentally changed the economics of mining in Australia, and this technology could change livestock operations the same way.

On cattle stations, especially in the north and west, the vast majority of each station hands' day is spent driving in a vehicle from one place to the next. In the dry season, tons of feed supplements must be delivered across dozens of paddocks each day. All year long, remote pumping stations must be refuelled with diesel fuel. While fodder supplementation would increase weight gain and revenues, the high transport costs of fodder means that it must be grown on the station. The labour required for these small-scale cropping operations, however, is also financially impractical.

As in mining, autonomous vehicles can perform simple, repetitive tasks, such as delivering feed supplements, refuelling pumping stations, and cropping fodder. Automating these tasks will free up labour and financial resources on cattle stations to focus on increasing productivity in other areas and expanding operations.

Another unique challenge for Australian livestock operations is the loss of pasturage to invasive plant species. This problem is slowly consuming pasturage, with an estimated cumulative annual cost of one billion dollars. The current manual methods for eradicating these plants require labour resources that are simply not available.

Even though the combination of large areas of pasturage and high labour costs have biased livestock economics in Australia away from the use of feed lots, there has still been an ongoing presence of feed lots, which is small but steadily growing. The use of autonomous vehicles in these operations could greatly improve productivity and increase their profitability.

8 Appendix

DROVER WOLF

Autonomous Vehicle for Livestock and Agriculture

HDT GLOBAL

The rugged and dependable HDT Drover WOLF is an autonomous vehicle for livestock and agricultural uses. Based on the HDT Hunter WOLF unmanned vehicle developed for the US military, the Drover WOLF can perform repetitive and boring tasks – such as checking water bores and refilling feed troughs – allowing ranch labor to work on higher-value projects.

The small size, light weight, and low cost of the Drover WOLF make it an attractive alternative to large, heavy, expensive farm equipment. The Drover WOLF carries 500 kg and tows over 2,000 kg for hundreds of kilometers and will operate 24 hours a day, seven days a week. It can pull farm implements, autonomously fertilize and spray crops or eradicate woody weeds and invasive plant species. It operates in wet conditions where low ground pressure is essential. The Drover WOLF's internal 20 kW diesel generator provides power to a wide variety of attachments.

Originally developed for the US military, the Drover WOLF has proven its reliability and durability in a dozen field evaluations by the US Army. The civilian version was created as part of a joint project with Meat & Livestock Australia.

KEY FEATURES

- Autonomous navigation
- Drone landing platform
- Hybrid diesel / electric drive
- More than 500 km operating range
- 20 kW internal diesel generator
- 6 kW/hr storage battery
- 1,659 kg system weight that carries 500 kg
- Tows over 2,000 kg
- 6x6 drive with non-pneumatic Tweels
- Optional track kit
- Operating temperature range +60° to -40° C

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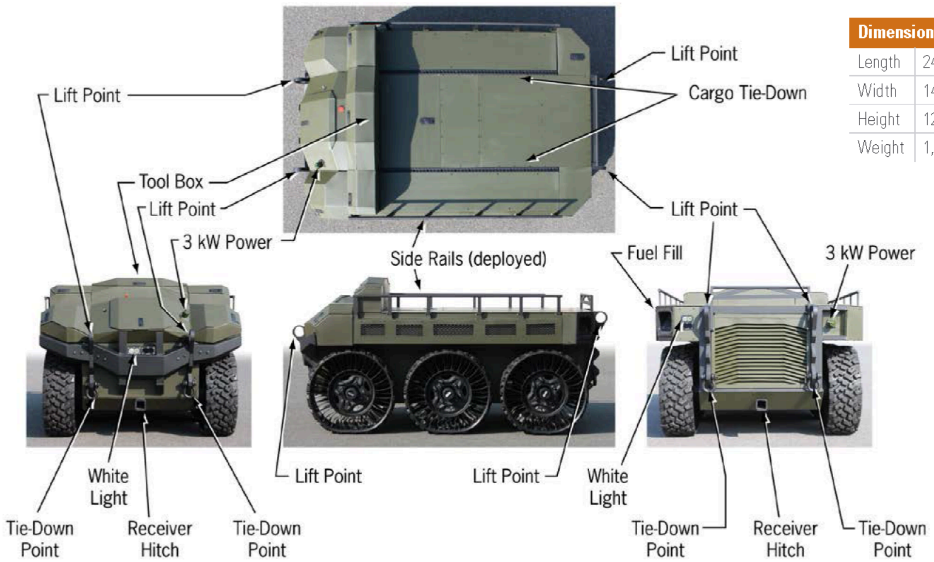
DROVER WOLF

Autonomous Vehicle for Livestock and Agriculture

HDT GLOBAL

Vehicle Overview



Dimensions	
Length	244 cm / 96"
Width	140 cm / 55"
Height	120 cm / 47"
Weight	1,659 kg / 3,650 lbs

Applications

CATTLE STATIONS

- Feed supplement distribution
- Water pump refueling
- Fodder distribution to paddocks
- Cropping assistance

FEEDLOTS

- Feed delivery
- Feed bunk cleaning
- Pen cleaning

INVASIVE SPECIES REMOVAL

- Autonomous eradication of woody weeds and other invasive species

AGRICULTURE

- 24/7 plant and spray capabilities
- Soft / wet / muddy soil operation

The Drover WOLF can autonomously distribute feed supplements 24/7.

The optional track kit gives Drover WOLF one tenth the ground pressure of a large tractor.

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