final report

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Autonomous Range Management Vehicle: Phase IIIa – Final Report

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Executive Summary

Over the past nine years MLA, 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. We have sold a number of these vehicles to the US Army, which have been used in different field evaluations. For the Australian livestock market, we believe 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. In addition, the vehicle should facilitate – with mechanical, electrical, and software interfaces – the integration of *attachments* that perform tasks that increase productivity of livestock operations.

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. Some of the potential applications proposed by the Steering Committee are listed below:

- 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, among others…

This phase focused on environmental and life-cycle testing (and consequent engineering changes), the development and integration of a low-ground pressure kit, and *proof-of-concept* prototypes of a dry-supplement delivery attachment, and an autonomous trailer pickup/drop-off kit. This project was the third step in the development of a ground vehicle – the Drover WOLF® - that serves the needs of remote cattle and sheep stations.

Figure 1 – (top) Picture of Protector (the precursor device), (2nd from top) Hunter WOLF v1, (3rd from top) Drover WOLF (v2); vehicle which integrates the autonomous navigation kit, (bottom) Drover WOLF integrated with the dry-supplements distribution system.

To continue improving the functionality and productivity of the Drover WOLF we recommend follow-on efforts that:

1) improve the robustness and reliability of the autonomous navigation capabilities,
2) finish the development of the *proof-of-concept* attachments developed in this phase, and
3) expand the user, and control (communications) interfaces in order to facilitate the integration of 3rd party developed attachments.

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1 Background

Over the past nine years MLA, 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. 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 third step in adapting this vehicle to serving the needs of remote cattle and sheep stations and focused on environmental and life-cycle testing (and consequent engineering changes), the development and integration of a low-ground pressure kit, and *proof-of-concept* prototypes of a dry-supplement delivery system, and an autonomous trailer pickup/drop-off kit.

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: Hunter WOLF – 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)

1.1.4 Phase 2: Drover WOLF – Experimental Autonomous Prototype

The Phase 2 Drover WOLF™ expanded the capabilities of the Hunter WOLF by integrating additional fuel tanks, a drone landing platform, and an autonomous navigation system.

Figure 5 – HDT Drover WOLF (i.e. Hunter WOLF with AUV deck, waypoint navigation (NAV) kit, and additional fuel tanks.)

1.1.1 Phase 3: Drover WOLF – Functional Prototype

The Phase 3 Drover WOLF included the development and integration of a fiducial marking (i.e. land-marking) system, as well as the development of *proof-of-concept* attachments specifically a dry-supplement distribution system and an autonomous trailer drop-off/pickup kit.

Figure 6 – Picture of the HDT Drover WOLF during dry-supplement delivery demonstration.

2 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 third step in adapting the WOLF vehicle to serving the needs of remote cattle and sheep stations. Eventually, this vehicle would be able to autonomously distribute fodder, supplements, and/or supplies, as well as 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 continues to expand the capabilities of the Drover Wolf platform by:

1. Environmental and life-cycle testing and consequent engineering changes
2. Design a low ground pressure kit to enable autonomous cropping activities on wet fields
3. Design an *autonomous delivery* dry lick distribution attachment
4. Design an automated engage/disengage hitch solution for remote pickup and delivery applications (i.e. deliver/pick-up a trailer)
5. Develop, integrate, and test a modular fiducial marking solution to allow precise manoeuvring in close spaces

3 Methodology

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

1. Evaluation testing and Engineering Changes – address lessons learned from US Army evaluation testing
2. Design of a Low-ground pressure kit
3. Design of an autonomous supplements delivery system
4. Design of an automated hitch engage/disengage mechanism

5. Demonstration of an autonomous trailer pickup/drop off

4 Results

4.1 Evaluation and Life-cycle Testing

HDT built twenty (20) Hunter WOLF systems at our Fredericksburg, VA facility for validation (including destructive) testing in an operational – military – environment. Engineering created the Bill of Materials (BOM) and make/buy decisions have been made for all components. The system design, component selection, and production processes continue to be optimized for production cost while providing the required performance, making the Hunter WOLF an affordable platform for both military and commercial use. HDT has in place a manufacturing team of mechanical and electrical technicians to build the required systems.

As the system is still at a prototype level, the manufacturing team was supported by engineers and quality personnel that performed acceptance testing; every vehicle received at least 16 hours of testing to ensure full motive force and movement, remote control function, full power offload capacity, and battery charge performance.

These units were used to validate the Hunter WOLF's functional capabilities in an operational environment as well as for environmental (i.e. temperature, vibration) and life-cycle testing.

Some of the specific tests that were perform, include:

- Tests performed by HDT include
  - Successive 16 km rough-handling tests on unimproved surfaces
  - Low temperature starting and operating
  - Slope stability
  - Battery cell characterization at high and low temperature
  - Battery pack charge and discharge tests
  - Emergency stop tests
  - Braking and top speed tests
  - Peak load tests on dynamometer
  - Cyclic load tests on dynamometer
  - 1 kW and 3 kW power offload tests
  - Cooling system performance tests
  - Tests performed at the US Army Aberdeen Test Centre include
    - Emergency stop tests
    - Braking and top speed tests
    - 20 and 30 hr rough-handling tests (both driving and being towed) on washboard surfaces, in mud, on cobbled surfaces, and on other unimproved surfaces
    - Gap crossing and step climb and descend
    - Water fording
    - EMI and ESD susceptibility
    - High temperature starting and operating
    - Low temperature starting and operating
    - Reliability and Maintainability
    - Winch pull tests

- Lift and tie-down strength tests
- Blowing rain
- Slope stability
- 1 kW and 3 kW power offload tests
- Load vibration testing which includes:
    - Spaced bumps – 232m linear of 7.5cm tall speed bumps at various angles
    - Radial washboards – 74m linear of 5cm to 10cm tall washboard at various angles
    - Imbedded rock – 243m linear of closely-spaced rocks protruding 5 cm to 10 cm from concrete surface
    - Belgian block – 1200m linear of uneven Belgian block
    - Washboard – 243m linear feet of 15 cm tall washboards at 1.8m intervals
    - Gravel road – 987m linear feet of gravel road

Design weaknesses that were uncovered during validation, environmental and life-cycle testing, manufacturing, serviceability lesson's learned, as well as new requirements were addressed with engineering changes (ECs).

4.2 Low Ground Pressure (LGP) attachment

A low ground pressure kit was designed, fabricated and tested. It performs well in challenging conditions, and has been shown to be robust and reliable. The ground pressure of the vehicle with the kit was lowered to 8.9 kPa (1.3psi), exceeding the objective improvement to the ground pressure rating.

Figure 7 – Picture of the WOLF using the Low-ground pressure kit.

Ground pressure is a characteristic of off road vehicles of functionality. The weight of a vehicle is supported on a limited surface area of the tires contacting the ground. The mass divided by the surface area gives a certain pressure that the vehicle applies to the ground. Ground surfaces vary in the amount of pressure that can receive before they deflect and move out of the way, allowing a vehicle to sink.

The standard Drover WOLF vehicle with a full load has a ground pressure of about 38 kPa (5.5 psi). This is calculated from 6 wheels with a 23cm (9") x 30.5cm (12") contact patch supporting a 1580kg (3500 lbs) vehicle. With a full 450kg (1000lbs) payload the pressure goes up to 48 kPa (7psi). For comparison, a typical automotive utility vehicle has a ground pressure of about 172 kPa (25 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 design effort will attempt to lower the ground pressure of our fully-loaded vehicle to about 14 kPa (2 psi). This very low ground pressure will allow our vehicle to operate over freshly tilled crop fields without causing damage, even when those fields are wet from recent rain or irrigation.

Modifying the wheelbase, adding axles or adding wheels to the vehicle would be much more involved and complex than changing the width, and would be too involved for an add on kit. The only realistic option is to increase the width of the contact patch, and adding a track around the tires to increase the contact patch to include the area between wheels.

4.2.1 Calculating track width

In order to meet a 14 kPa (2psi) objective ground pressure, the 1580kg (3500 lbs) vehicle plus 450kg (1,000 lbs) payload would need a contact patch of 1.5 m^2 (2250in^2), or .75 m^2 (1125 in^2) for each side. If we consider the contact patch length to equal the wheelbase of 1.4m (56"), then the width needs to be .5m (20").

4.2.2 Track development

Tracks consist of a belt, a tread pattern on the outside (commonly in the form of grousers) and wheel guides on the inside of the track.

Figure 8 – commercial skid steer track kit from Right Track showing belt, external grousers, and internal wheel guides.

There are multiple aftermarket track kits for heavy equipment, but most are tailored to a specific model or brand. HDT needed to analyse the products on the market and develop something that would fit our unique application. We chose to limit ourselves to stock material shapes to reduce cost. Custom manufactured grousers or wheel guides would have increased cost and lead time.

One of the challenges to adding .5m (20”) of width to each side was the stock position of the wheel being on the inside of the track, not supporting uneven loads on the track.

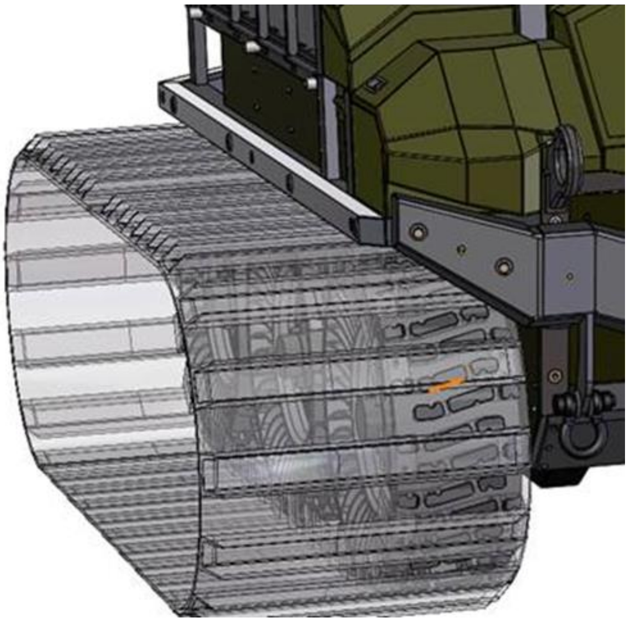


Figure 9 - Stock wheel position unevenly supporting the wide track

Multiple ideas were considered including doubling up on the Tweels (this added too much weight) .

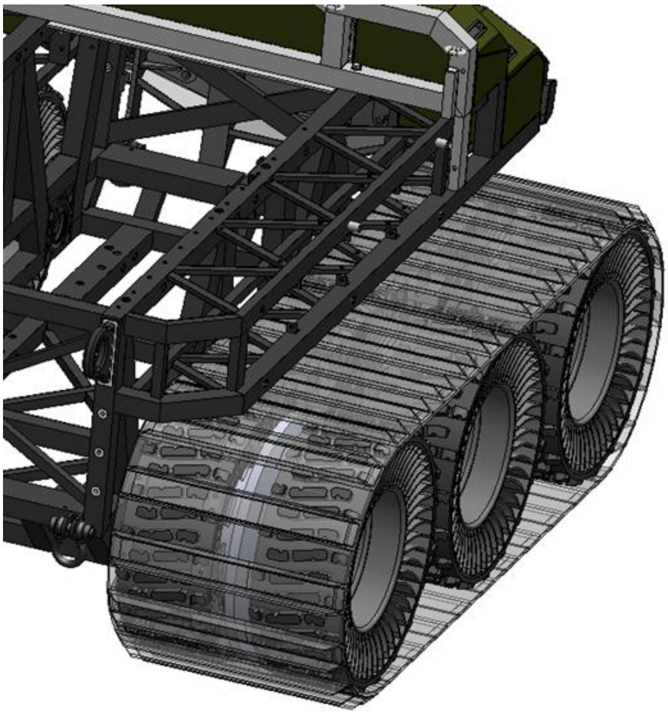


Figure 10 – Discarded concept showing double Tweels to support track width.

The chosen concept uses COTS spacers to move the Tweel outboard to the centre of the track. Stock aluminium extrusions are bolted on to form the grousers and wheel guides.

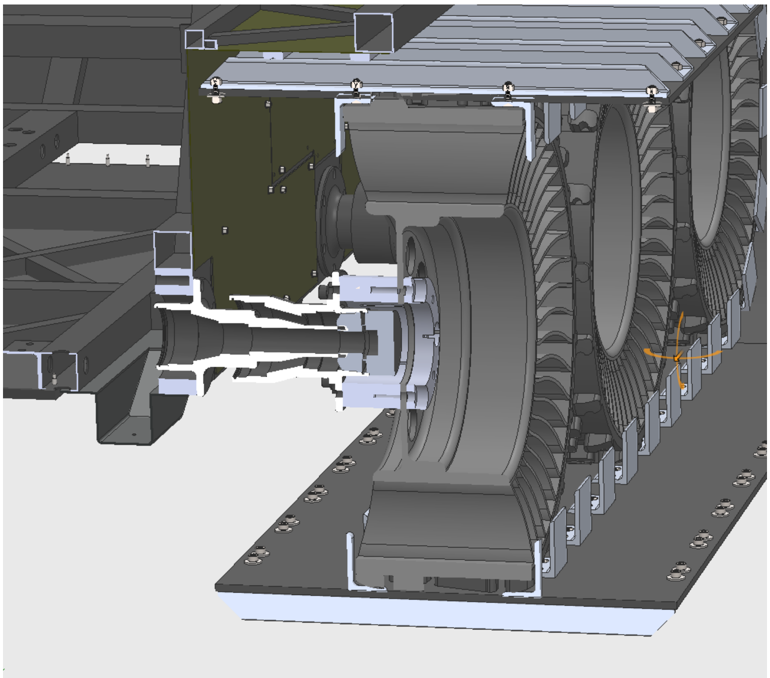


Figure 11 - Section view of tweel and spacers centering tweel on track

Figure 12 - exploded view of low ground pressure track kit components

The width of the track was increased to 24”. This was a stock width of the belting that forms the core of the track and therefore less expensive. COTS wheel spacers were available to offset the

Tweels to the centre of the track in order to accommodate this width. This increased width lowers the calculated ground pressure to 8.9 kPa (1.3psi) or 11.7 kPa (1.7psi) with full payload.

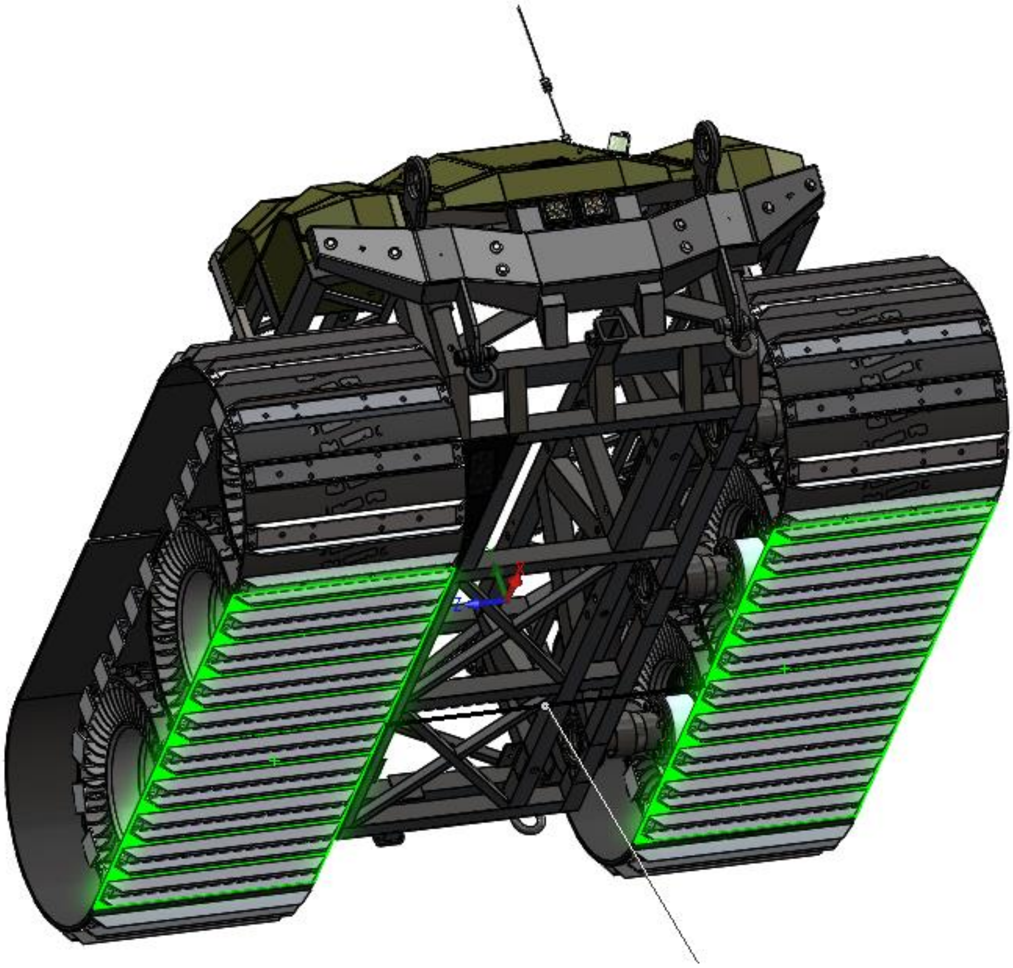


Figure 13 – Highlighted contact patch of each .6m (24") width track is .86 m2 (1344 in2)

4.2.3 Manufacture and testing

A prototype track was fabricated and installed on one of our test vehicles.   Fits and clearances were checked in low speed testing before the vehicle was taken off road for some challenging terrain tests.

Figure 14 - LGP track installed on test vehicle

The fit of the track to the tweels was looser than expected, allowing the track to occasionally rub on the bottom of the vehicle sponson. This did not create any real problems other than the wear on screw heads that protrude into this space. The solution to this was simply to use countersunk screws on this lower panel, providing a smooth surface with nothing for the tracks to catch on.

Testing of the vehicle in mud, tall grass, forest, and streams was exciting to watch. It seemed that nothing would stop the vehicle. It glided over mud and silt in the stream bed, and climbed the banks easily. Though the grousers left marks in the soft mud, there was little evidence of sliding or shearing of the ground surface.

Figure 15 - Vehicle testing on various terrain

Figure 16 - Test vehicle in a stream, showing minimal tracks on gravel and silt bed

4.3 Autonomous supplement distribution system (ASDS)

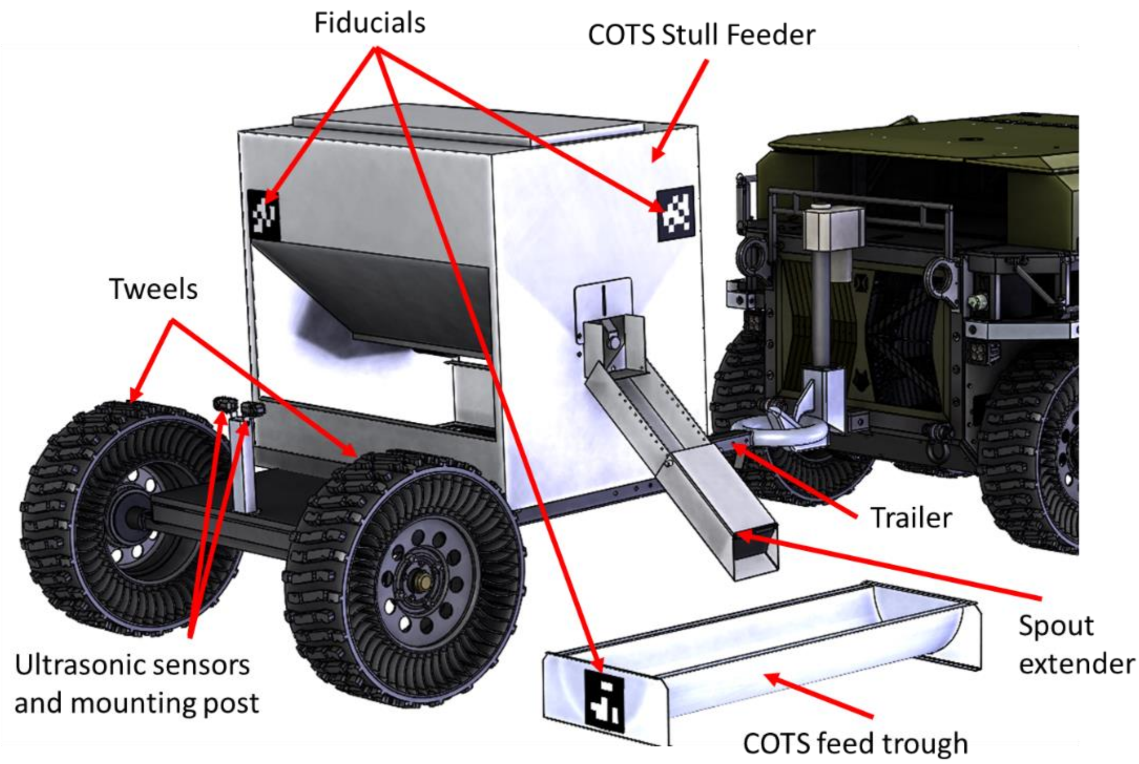


Figure 17 – Rendering of the autonomous supplement distribution system showing fiducial markers.

We have designed and integrated all the components required by an ASDS attachment to the Drover WOLF. Including:

- The design of a fiducial system for localizing and interacting with the feed trough.
- The integration of COTS feed trough
    - The system is trough agnostic.
- The integration of a COTS hopper/feeder
    - The system is hopper agnostic to the extent that it has a motorized auger.
- The design of a hopper spout extender in order to address the added separation (between hopper and trough) imposed by the integration of the Tweels.
- The design of a modular mounting post, and
- The design of aim-able ultrasonic sensor pods for maintaining the obstacle avoidance capability when a trailer based attachment is used with the WOLF.
- The design of a junction box for establishing an electrical connection between the WOLF and the ASDS attachment as well as interconnecting and distributing the power and sensor signals that are part of this attachment.
- The design, integration and layout of the ASDS electronic components.

Software algorithms have also been developed in order to allow the vehicle to autonomously deliver feed from an attached trailer onto a trough. The vehicle will account for the trailer when generating its route so as to avoid dangerous states where a collision with the trailer is possible, while also avoiding miscellaneous obstacles in its path.

4.3.1 The Fiducial System

4.3.1.1 Mechanical

Fiducial marks (or colloquially: fiducials) provide a means of establishing a point of reference (i.e. position and orientation) for an object/component using a vision system; as such fiducials will be used by the *Autonomous Supplements Delivery System* (ASDS) described in this report and all other attachments/kits that require autonomous interaction with the Drover WOLF. The vision system is able to recognize the *fiducial* marks that are affixed to known locations on equipment and structures. The system works not only for component identification, but also to establish relative positions between fiducials, and coordinate systems. By seeing a single unique fiducial mark, the system registers a ***component type***, ***size***, ***position*** and ***orientation***. For instance, if the camera picks up a fiducial on the rear corner of the supplement distribution trailer that it must pick up, it identifies the piece of equipment, and knows that it must drive around it, separated by a certain distance, to a certain location with respect to that mark, pointed in a certain direction, in order to back up and engage the hitch. Multiple fiducials on the trailer constantly update the algorithm with respect to all of these elements. The control algorithm is intelligent enough to track these references in real-time, constantly updating the coordinates.

The fiducial system that we have chosen to use consists of an established pattern of high contrast squares that are easy for the camera to identify against a background of any environment. These patterns are non-symmetric across any plane, and therefore their orientation can be known.

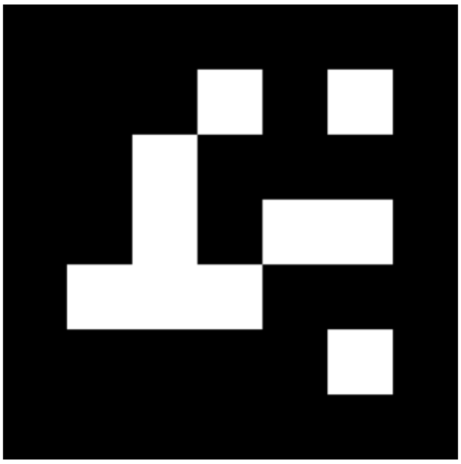


Figure 18 - example of a fiducial mark

From the view of the camera, a due to perspective, the squares will skew a certain amount, allowing the software to determine an angle between camera and fiducial. This is all that is needed to calculate an orientation of the piece of equipment that the fiducial is attached to.

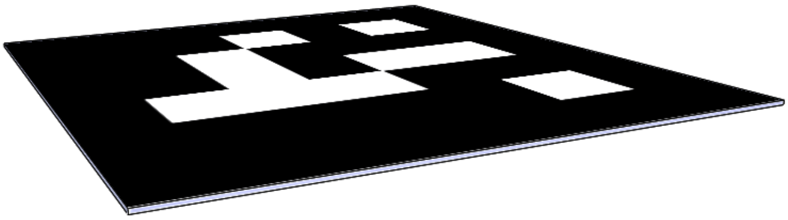
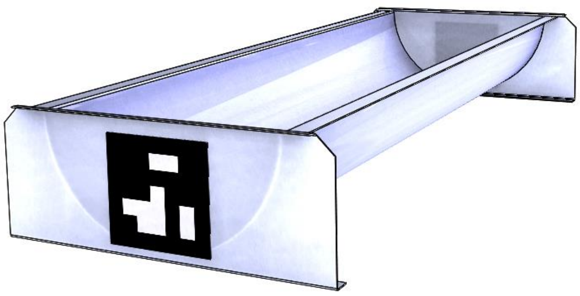


Figure 19 - the same fiducial mark from above, but seen from a steep angle

The physical objects that are these fiducial marks, then, need to maintain their color and contrast while being exposed to the outdoor environment. They must be low gloss, so light reflection does not obscure the pattern (see Figure 24). This requires using a rough surface finish on a light weight corrosion resistant aluminium plate and matte paints to create the fiducials.

Fiducials will be mounted at specific (i.e. known, measured) positions on the trailer and associated equipment. Enough will be mounted that one is visible no matter the orientation of the trailer to the Drover WOLF. For this application, fiducials will also be mounted to the front and back of a feed trough, so the WOLF can align to and accurately dispense feed into it.



4.3.2 The Hopper system

HDT searched the market for appropriate dispensing hopper. Our requirements were for a size and weight that allowed trailer mounting, would allow for a track width similar to the WOLF, and used an electrically driven auger (i.e. required for autonomous control). We chose a 600 lbs (272kg) feeder from Stull that fit these requirements.

Figure 20 - Stull 600 lbs (272 kg) feeder

The Stull hopper will require minimal modifications. Specifically, we will extend its spout in order to better reach (over the trailer wheels) and fill the trough with feed (see Figure 21). Electrically, we will bypass the battery power system that is provided with it and connect it directly to the NAV Kit controller (see Figure 23).

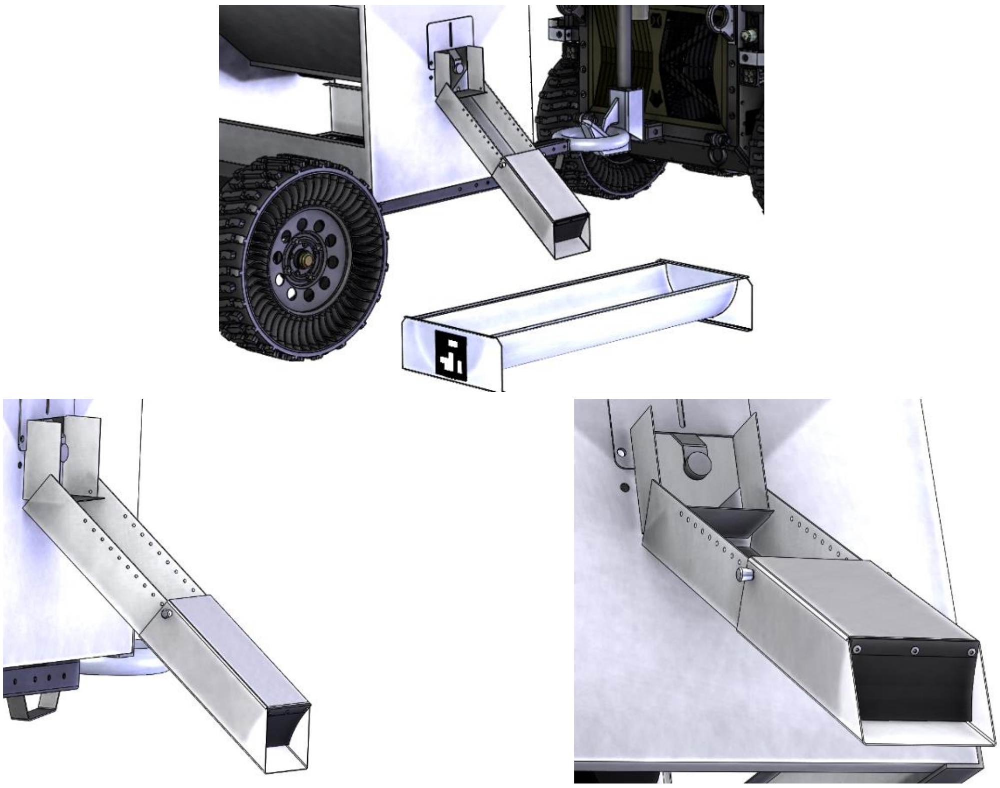


Figure 21 – (top) Rendering of the Stuff feeder with the extended spout and its interaction with the trough. (bottom) Close-up renderings of the spout extender

4.3.3 The Trailer system

For the trailer, we considered custom fabricating a frame that would hold the feeder, and be at the proper height to be level when hitched to the WOLF. However, purchasing and inexpensive COTS trailer (see Figure 29) saved considerable cost on the fully custom design. With minimal modification, the trailer was able to mount Tweels™ on the same track width as the WOLF, and provide a flat stable platform to mount the feeder; we changed out the pneumatic wheels that are provided by the trailer with Tweels because we believe that the trailer should survive in the same environment and conditions that the WOLF can.

Specifically, the modifications to the trailer include:

- reducing the width of the frame to accommodate the offset of the Tweels,
- changed out the trailer's wheels for Tweels,
- moving the axle rearward to allow the feeder to sit width wise, and
- bolting on a plywood platform.

The NAV autonomy system (developed in Phase 2) uses two rear-facing ultrasonic sensors that are mounted on the back of the WOLF. When a towed attachment (kit) is used with the WOLF these – back-facing – sensors are blocked by the attached trailer, and therefore cannot be used for obstacle avoidance. In order to not lose this NAV system capability, additional sensors will be mounted on the rear of the trailer. Since the goal for the Drover WOLF is to have multiple types of trailer payloads, a stand-alone sensor mount was designed that puts individual, aim-able sensor pods at the same height as the WOLF mounted sensors, and would be able to be mounted to many configurations of trailer.

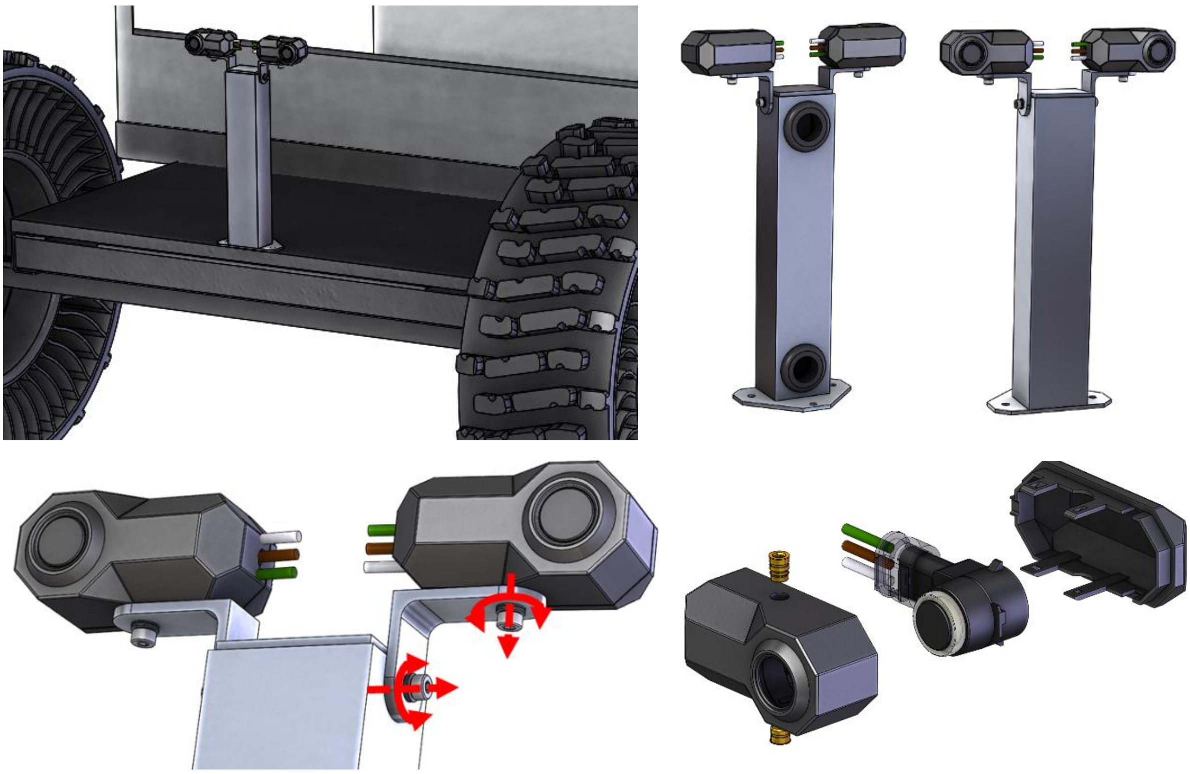


Figure 22 - ultrasonic sensor stand on rear of trailer

4.3.4 The Electrical Interface

The Autonomous Navigation kit's electrical enclosure will be modified to accommodate the electrical connections and electronics required for the ASDS, these include:

- A 2nd Ethernet connection for one **camera** (back-facing) on WOLF flat-bed. This back-facing camera is required for locating the trough's fiducials and registering the WOLF's coordinate frame with that of the Trough's in order to accurately navigate and interact with it.
- Connections for two (2) back-facing **ultrasonic sensor** on the hopper's trailer. These are required because the back-facing ultrasonic sensors that are on the WOLF are obstructed by the hopper when the ASDS is being used.
- One **motor driver** for powering and controlling the hopper's auger.
- One **junction box** for establishing the electrical connections required between the autonomous navigation kit's controller, the hopper, and trailer ultrasonic sensors, as well as provide a means of electrically disconnecting from the WOLF.

See Figure 23 for an electrical diagram of the electrical components, and connections required by the ASDS.

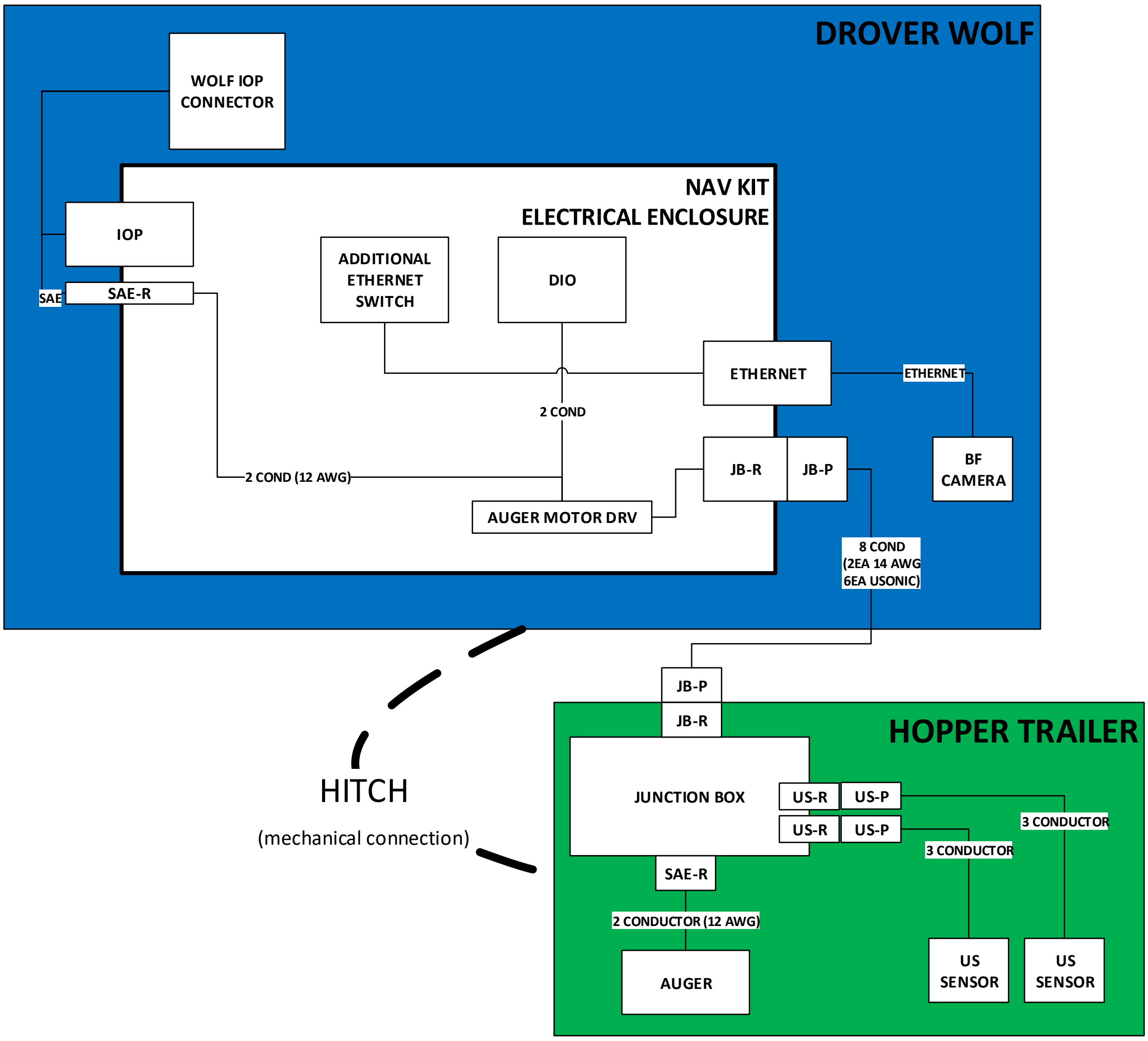


Figure 23 – Electrical diagram (topology) of the autonomous supplement delivery system.

4.3.5 The Software Simulation

Developing the autonomy package to include feed delivery with a trailer attached required several key additions to software. The foremost new feature is the implementation of fiducials in order for the vehicle to be able to accurately locate the feeding trough. Figure 24 depicts a sample fiducial on the left. Each marker is able to communicate to the computer a six degree of freedom pose (Figure 24 right). Several of these will be placed around the trough in order to ensure that the vehicle can locate it regardless of the direction of approach.

Figure 24 – (left) Picture of a Fiducial with ID, and illustrating the reflection issue caused by a glossy finish. (right) Computer algorithm identification (highlighted in green) of a fiducial captured by the video camera system.

Figure 25 shows a sample trough used in simulation for testing. Fiducials will also be placed on the trailer itself. This is done in order for the WOLF to be able to keep track of the angle between the trailer and itself at all times.

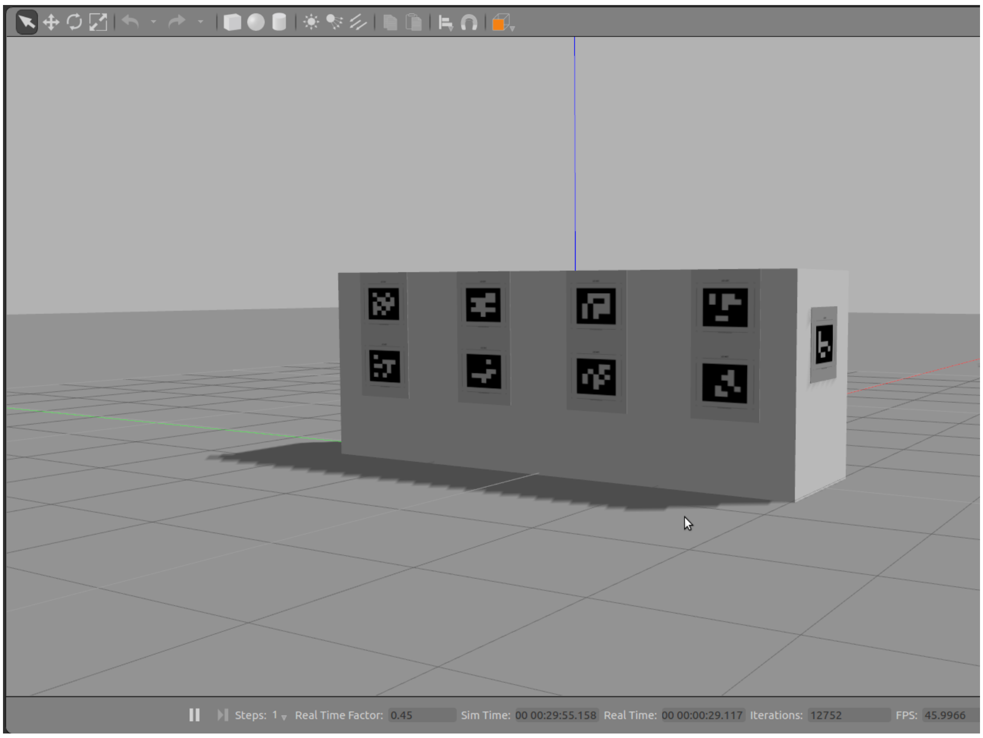


Figure 25 - Sample trough with fiducials used in simulation

In addition to the fiducials, the proposed system necessitates modifications to the path tracking and collision avoidance algorithms generated for previous – Phase 2 – milestones. With the incorporation of the trailer, it is important to ensure that, when backing up and making tight turns, the angle between the trailer and the vehicle be kept below a threshold. As a result, the collision avoidance algorithm previously used has been extended for the case when the vehicle is towing the trailer. Although there is an increase in complexity, the new algorithm is capable of creating a path around obstacles while keeping the trailer angle within safe bounds. In order to track this generated trajectory, the vehicle controller for following paths has also been improved in order to include the angle of the trailer. Together, these improvements should ensure that no dangerous states, which would cause the vehicle to collide with the trailer, are reached. Figure 26 depicts a test case where an obstacle is placed sufficiently close to the vehicle such that it has to back up in order to keep the trailer within a specified range.

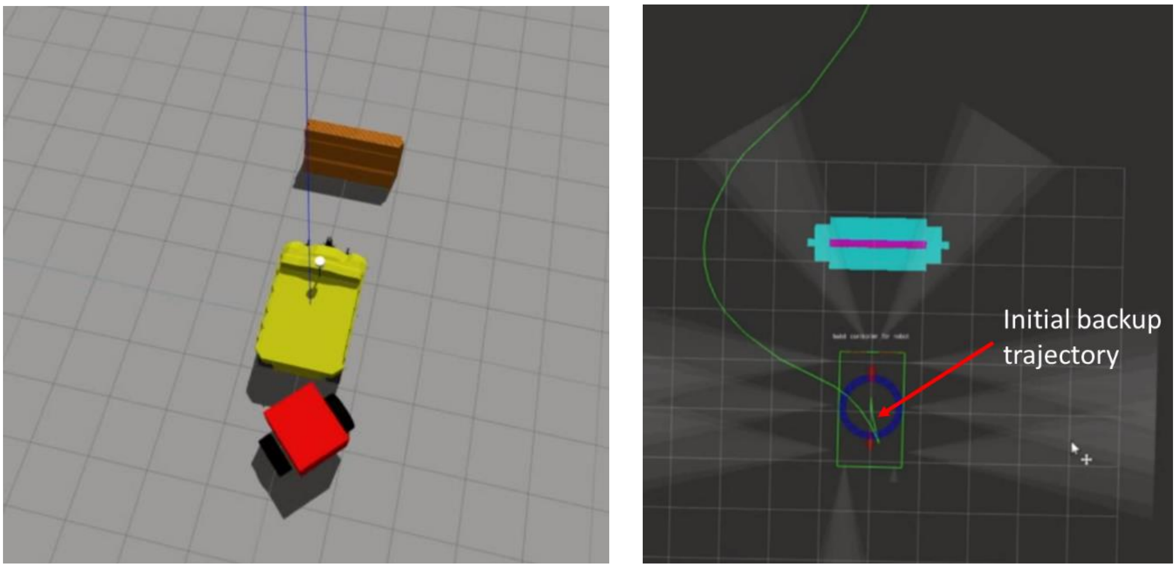


Figure 26 – (left) WOLF with trailer attached and obstacle placed in front. (right) Path generated to go around the obstacle in green. Notice that the path first tells the WOLF to back up as it cannot make turns tight enough to safely navigate the obstacle with the trailer attached.

All of the changes described above have been tested in software simulations. The procedure of delivering feed to a specified trough begins with the user giving the WOLF a path, as would have been previously done, and specifying a point on the path as the one where the trough is located (Figure 27). When the WOLF arrives at the provided GPS coordinates it will explore the environment for the corresponding fiducials in order to accurately characterize the trough. Afterwards, a series of small trajectories will be calculated and executed in order to line the vehicle up with the trough and drop off the feed before moving on to the next GPS coordinate (Figure 28).

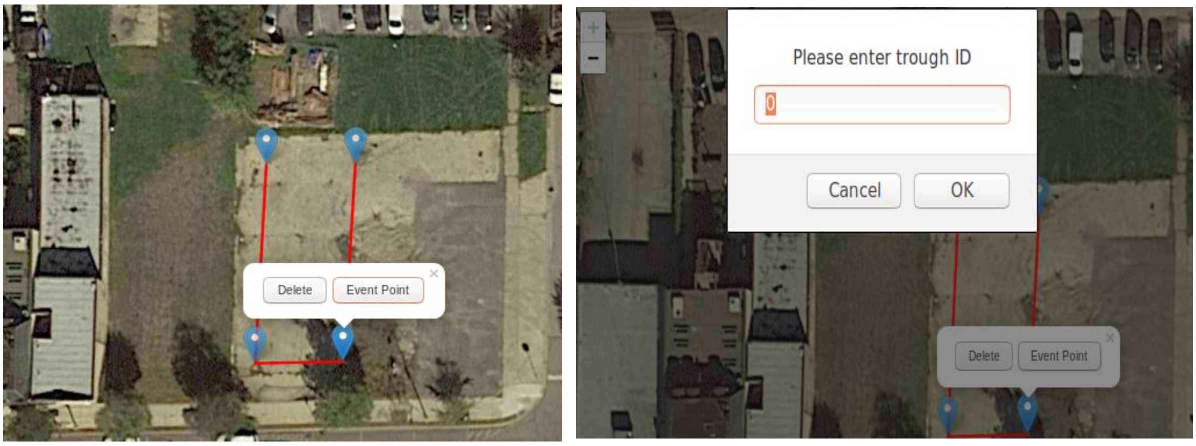


Figure 27 – (left) Using the GUI, the user can select a GPS point to mark as an event point (i.e. the location where the trough is expected to be). (right) Once clicked the computer will prompt the user to input the ID of the trough expected at that point. This will let the vehicle know parameters such as the trough's geometry and where the fiducials are placed on it.

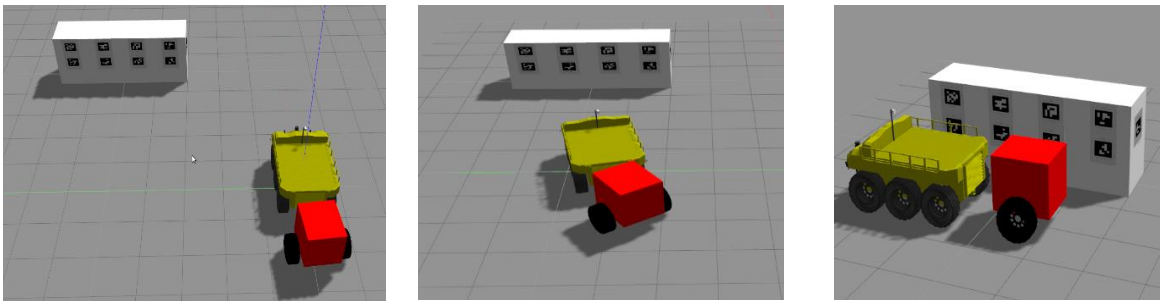


Figure 28 – (left) WOLF arrives at GPS location near the trough (i.e. the previously selected "event point"). (middle) WOLF explores the environment, looking for fiducials, until the trough is localized. (right) WOLF drives parallel next to trough deploying the feed.

4.3.6 The Proof-of-Concept Prototype

In addition to the requirements of this milestone we have started to implement the above described design as an experience prototype for demonstration purposes.

Figure 29 – (top left) Picture of the modified COTS trailer. (top right) Picture of the Drover WOLF integrated with the trailer, Stull feeder and hitched to the WOLF. (bottom) Picture of the integrated system.

Figure 30 – Pictures of early testing that was performed to confirm strength and stability of trailer as well as the range of motion of the hitch.

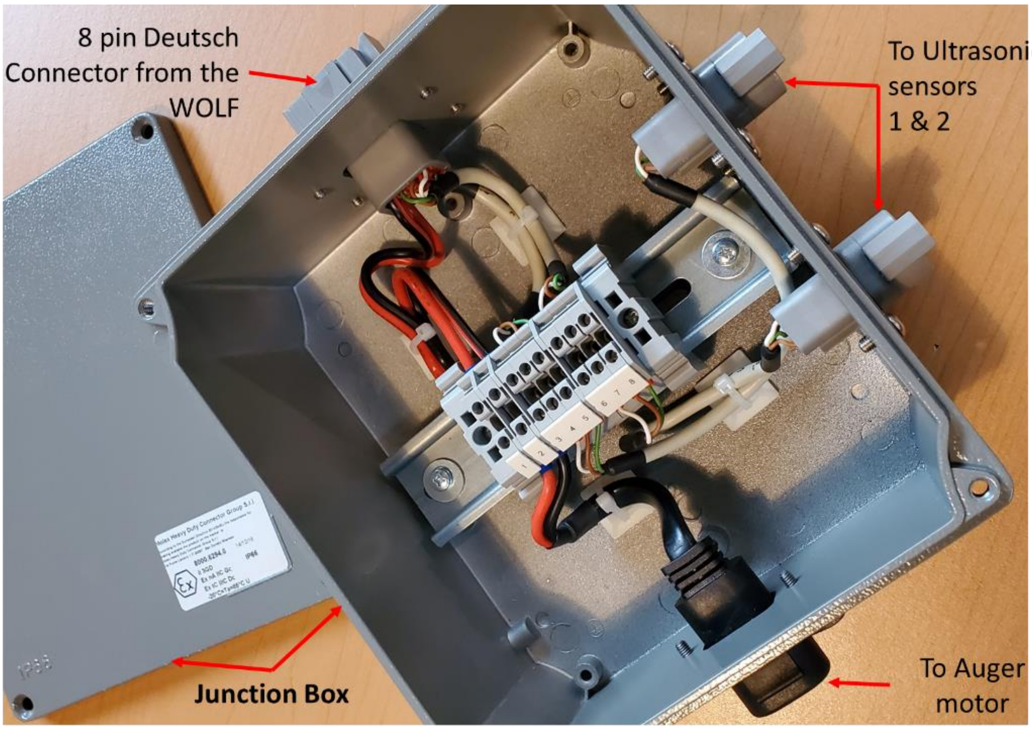


Figure 31 - Picture of the Trailer Junction Box

In addition to the integration of the physical prototype system, testing of the software has begun on the mock vehicle in order to verify what has been experienced in simulation. A mock trailer was built and equipped with fiducials as shown in Figure 32. With the availability of a physical unit for testing, the final integration into the WOLF should only require the tuning of a few parameters.

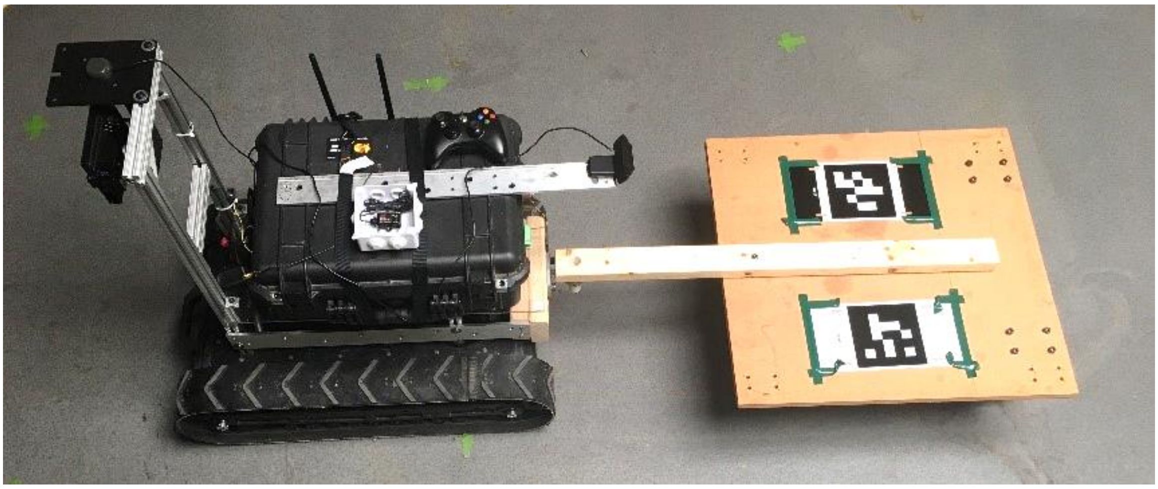


Figure 32 – Mock vehicle and trailer system used for software development. Notice the two fiducials and the camera facing them. This is how the vehicle can and will determine the orientation of the trailer at any moment in time.

For this application, large fiducials will be located at various points about the trailer, and smaller fiducials will be located on the tongue of the trailer (see Figure 33). This allows for an increased acquisition distance while locating the trailer; but once the camera is very close to the target, smaller, less cumbersome fiducials can be positioned in more confined spaces between the vehicle and trailer. A rear facing camera will track these fiducials.

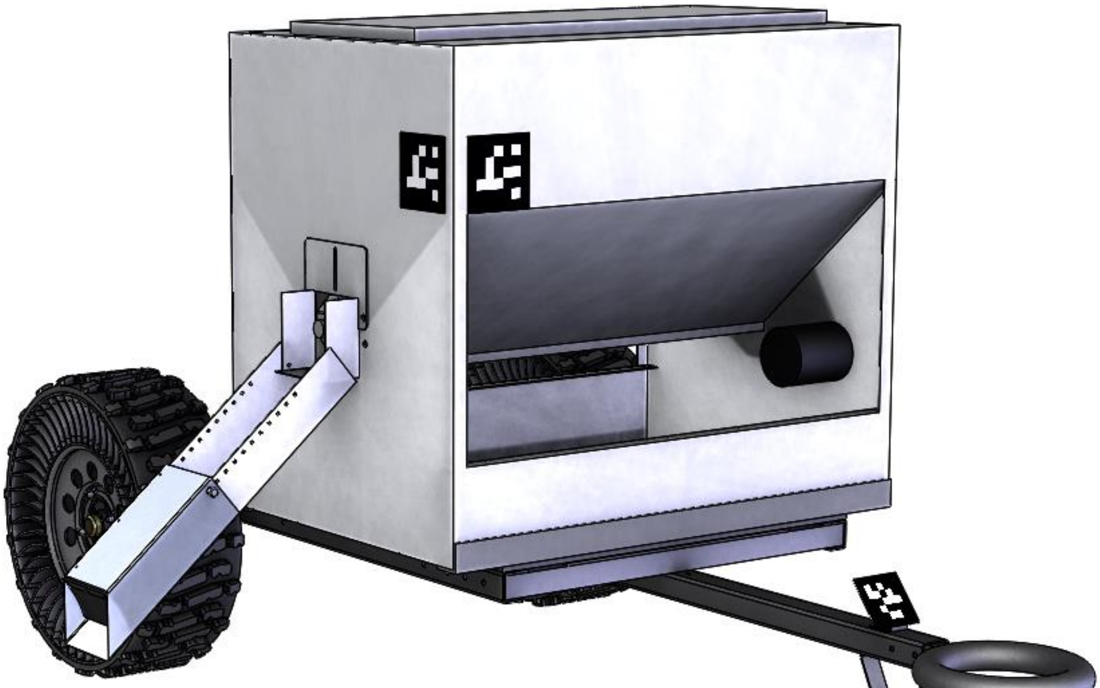


Figure 33 - Example trailer with large locating fiducials, and smaller fine position fiducial

4.4 Automated Hitch system

4.4.1 Engineering challenge

The automated hitch has several challenges to overcome. The system must lock and release when commanded. This seems to call for an actuated component somewhere in the mechanism instead of relying on only relative vehicle motion to accomplish this reliably and safely. A connected hitch must be a passive 3-dof (degree of freedom) joint between the trailer and vehicle. This allows for changes in steering angle, incline, and twist.

Figure 34 - Hitch with 3 degrees of freedom

However, these same DOFs also allow motion and therefore unknown component position during the union process. These joints are normally manipulated by the user in a manned system. In addition to this, there will be some tolerance in the position and orientation between the vehicle and the trailer.

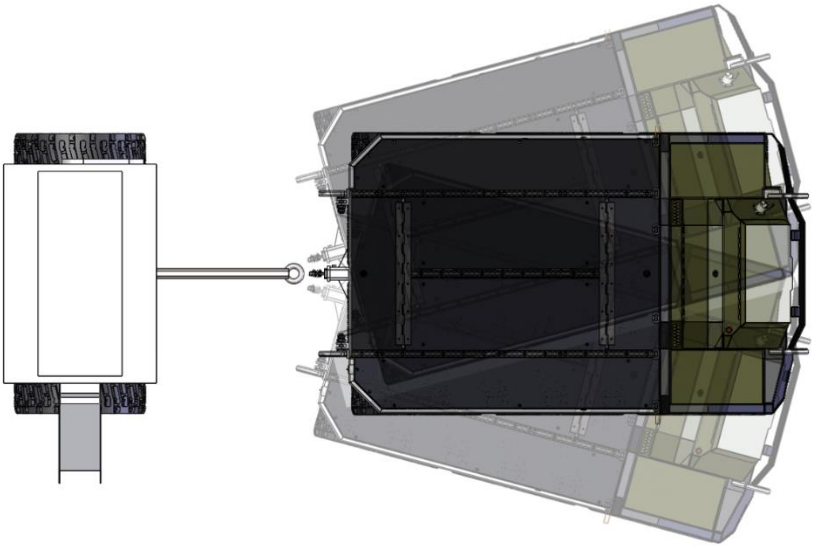


Figure 35 - Misalignment tolerance between vehicle and trailer during coupling

Another challenge is that two wheel and some 4-wheel wagon style trailers will have their tongues on the ground when uncoupled. Therefore, during the coupling process either the tongue, or the hitch itself must be actuated vertically.

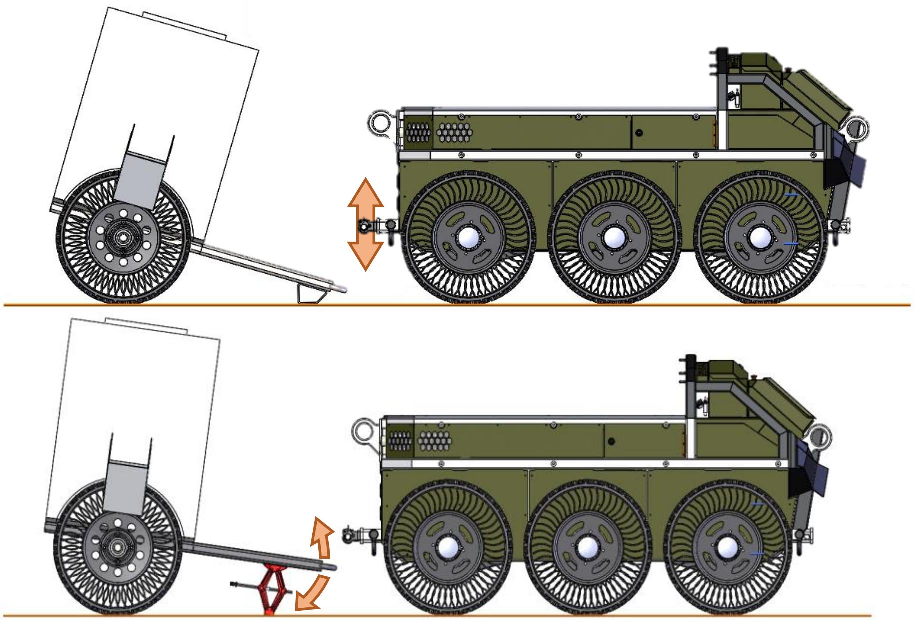


Figure 36 - Either the trailer or the hitch will need vertical actuation

An additional challenge is the that an uncoupled trailer will potentially be unstable and may roll or spin if the drop location is not level. Some sort of brake or grounding system will be needed.

4.4.2 Design Approach

The trailer will have a lunette ring that is picked up by an actuated pintle hook on the vehicle. The pintle hook will need to not just capture, but securely retain the ring. This retention is not just during the union process, but also during high force manoeuvres in motion.

Figure 37 - COTS ring/pintle hitch

For this automated system, the lunette ring will be oversized to allow for position tolerance between vehicle and trailer. The proposed system uses a vertically actuated pintle hook that can be lowered to a point where it can be inserted under the ring. Lifting the hook will settle the ring into the lowest point of the hook as the weight of the tongue is lifted. The hook will raise until the ring is captured under an opposing plate.

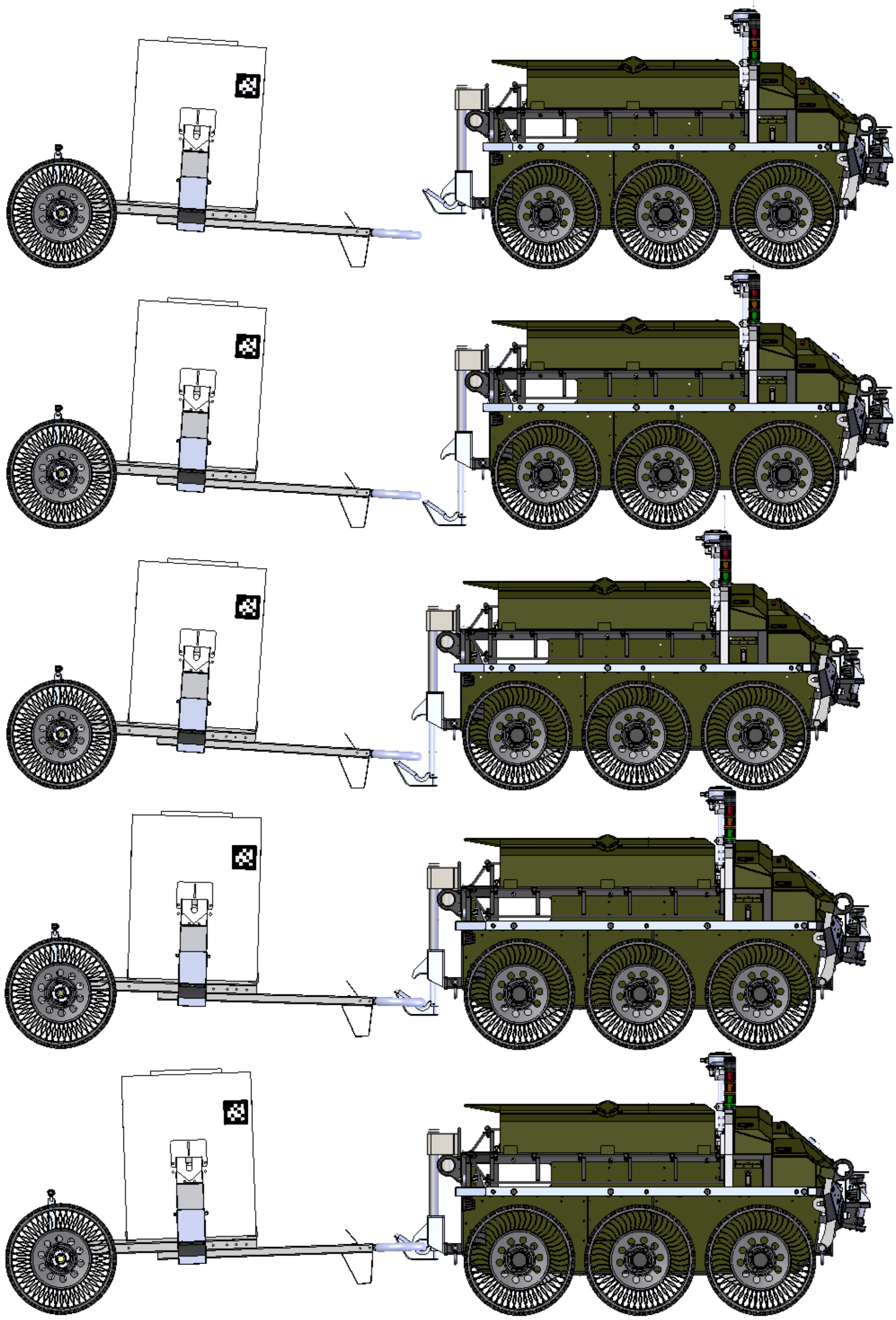


Figure 38 - Steps of the coupling process

The actuated hook system will be a COTS trailer jack, that has a custom mount to fit into the vehicles hitch receiver. This will also be the mounting point for the rear facing camera.

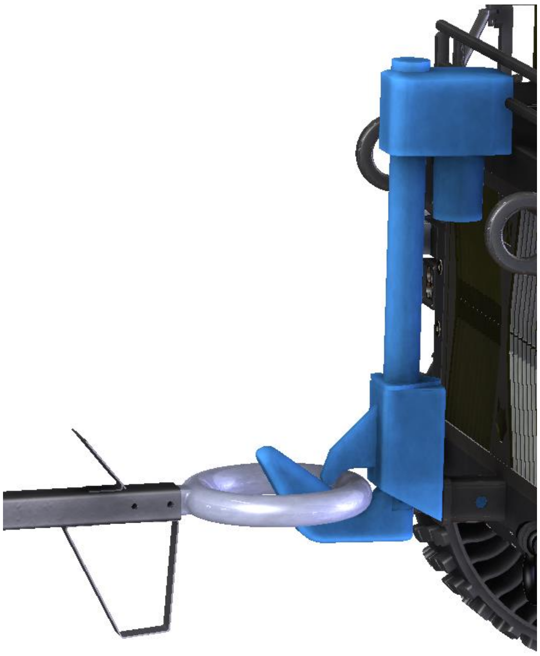


Figure 39 - Actuated hook highlighted in blue

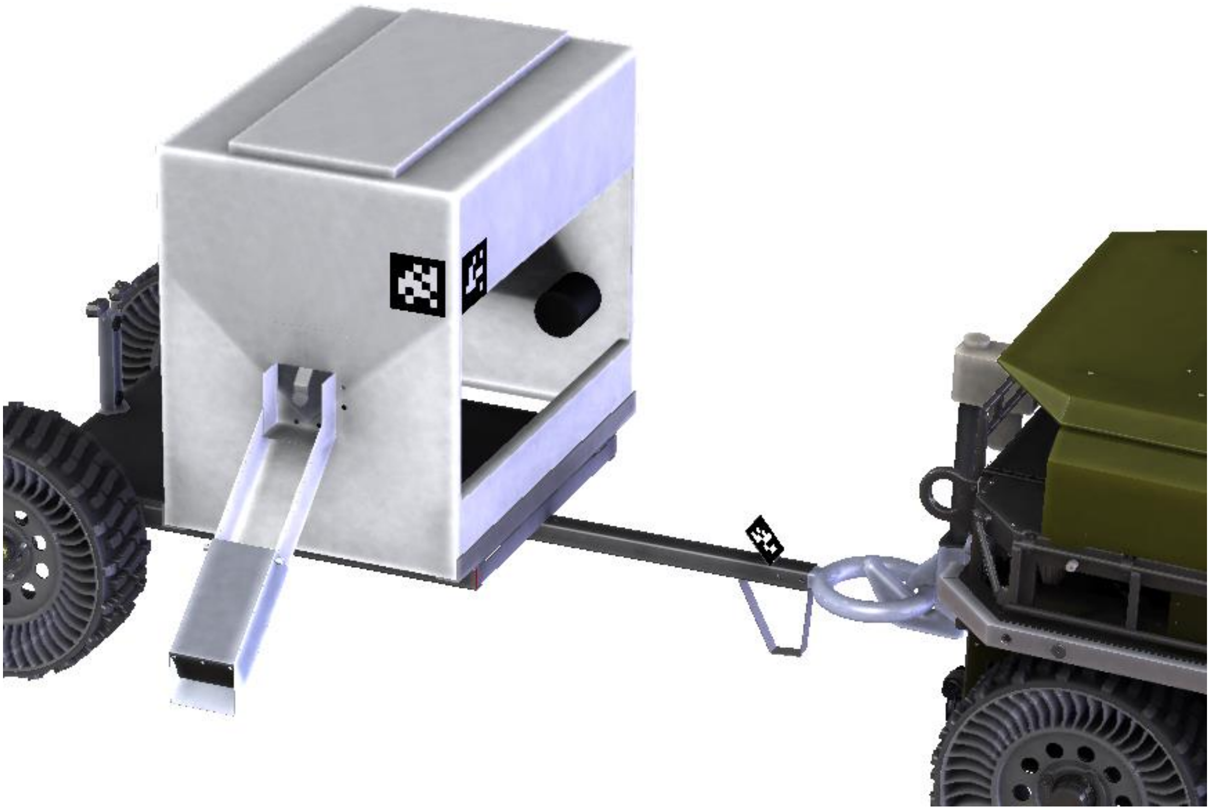


Figure 40 - proposed automated hitch system showing potential trailer payload, hook and pintle, and various sized fiducials

In the concepts above, notice that the payload is biased well in front of the trailer axle. This intentional tongue weight will be used when the trailer is uncoupled to act as a stable point to keep the trailer in place.

4.4.3 The Software Simulation

Adapting the autonomy stack to allow the WOLF to hitch a trailer requires several additional features be added to the base software. To this end, the fiducial system implemented consists of a ROS package which detects and publishes frame transformations of perceived markers. The 2D fiducials used can be identified from a distance of several meters and are crucial in not only enabling the vehicle to find the trailer, but also in guaranteeing that the vehicle is correctly positioned for hitching. Figure 41 depicts a sample fiducial on the left. Each marker is able to communicate to the autonomy kit a six degree of freedom pose (Figure 41 right). Several of these are placed around the trailer in order to improve localization capabilities and accuracy.

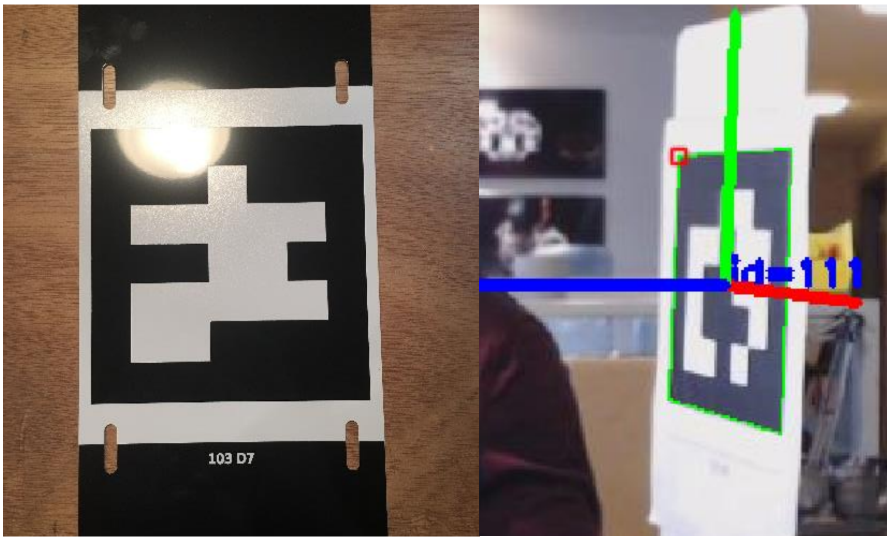


Figure 41 - (left) Picture of a Fiducial with ID. (right) Computer algorithm identification (highlighted in green) of a fiducial captured by the video camera system.

The procedure of hitching a trailer begins with the user giving the WOLF a path – as would have been previously done – and specifying a point on the path as the one where the trailer is located (Figure 42). When the WOLF arrives at the provided GPS coordinates it will explore the environment for the corresponding fiducials in order to accurately characterize the trailer position and orientation. Detection is followed by an initial setup period. In this phase the vehicle performs a manoeuvre which will leave it facing the trailer with its rear side (Figure 43). From this point, the vehicle will utilize the rear camera to track the fiducial placed near the ring on the trailer. Because precision now becomes very important, the final stage consists of the WOLF approaching the trailer slowly while periodically stopping in order to ensure good readings of the fiducial. By turning to accommodate for small deviations in the trajectory, the vehicle eventually reaches a position where it is within the bounds of error required for hitching, and the task is complete. Failure to reach the correct position or orientation will result in the vehicle resetting its position and starting over.

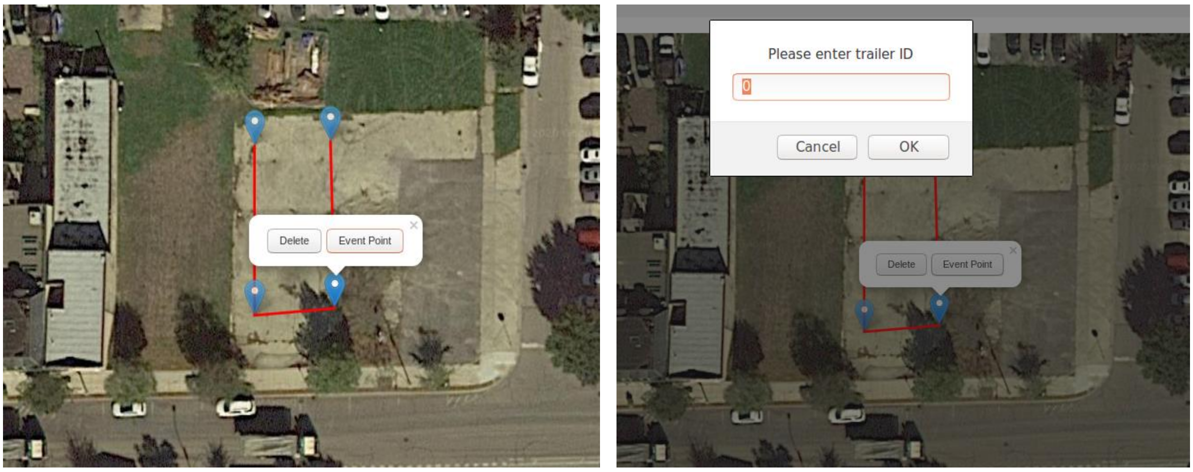


Figure 42 - (left) Using the GUI, the user can select a GPS point to mark as an event point – the location where the trough is expected to be. (right) Once clicked the computer will prompt the user to input the ID of the trailer expected at that point. This will let the vehicle know parameters such as geometry and where the fiducials are placed on it.

Experimental testing of the algorithm described above was done on the mock UGV vehicle. Figure 43 displays the environment setup and sensors used. Notice that the goal of testing was to measure the accuracy that could be achieved relative to a fiducial set with the current control scheme; no trailer was hitched for the purposes of this demo. Current trials show promise with regards to whether the task can be accomplished given the proposed mechanical design. Future work will look to integrate the software developed with the complete electro-mechanical system in the WOLF for a full proof-of-concept demo.

4.4.4 The Automated Hitch Proof-of-Concept prototype

For autonomous engagement and disengagement of a trailer, the vehicle autonomy system must accomplish several tasks. Determining the location and orientation of the trailer, manoeuvring into a position where the hitch can engage, and then physically engaging the trailer. The first tasks will be accomplished in a gross manner through GPS location, more detailed positioning via visual tracking of fiducials located on the trailer, and the last by a dedicated mechanism.

We have successfully designed the mechanical, electrical and software aspects of a prototype Autonomous Hitching System, and its software has been tested in mock platforms.

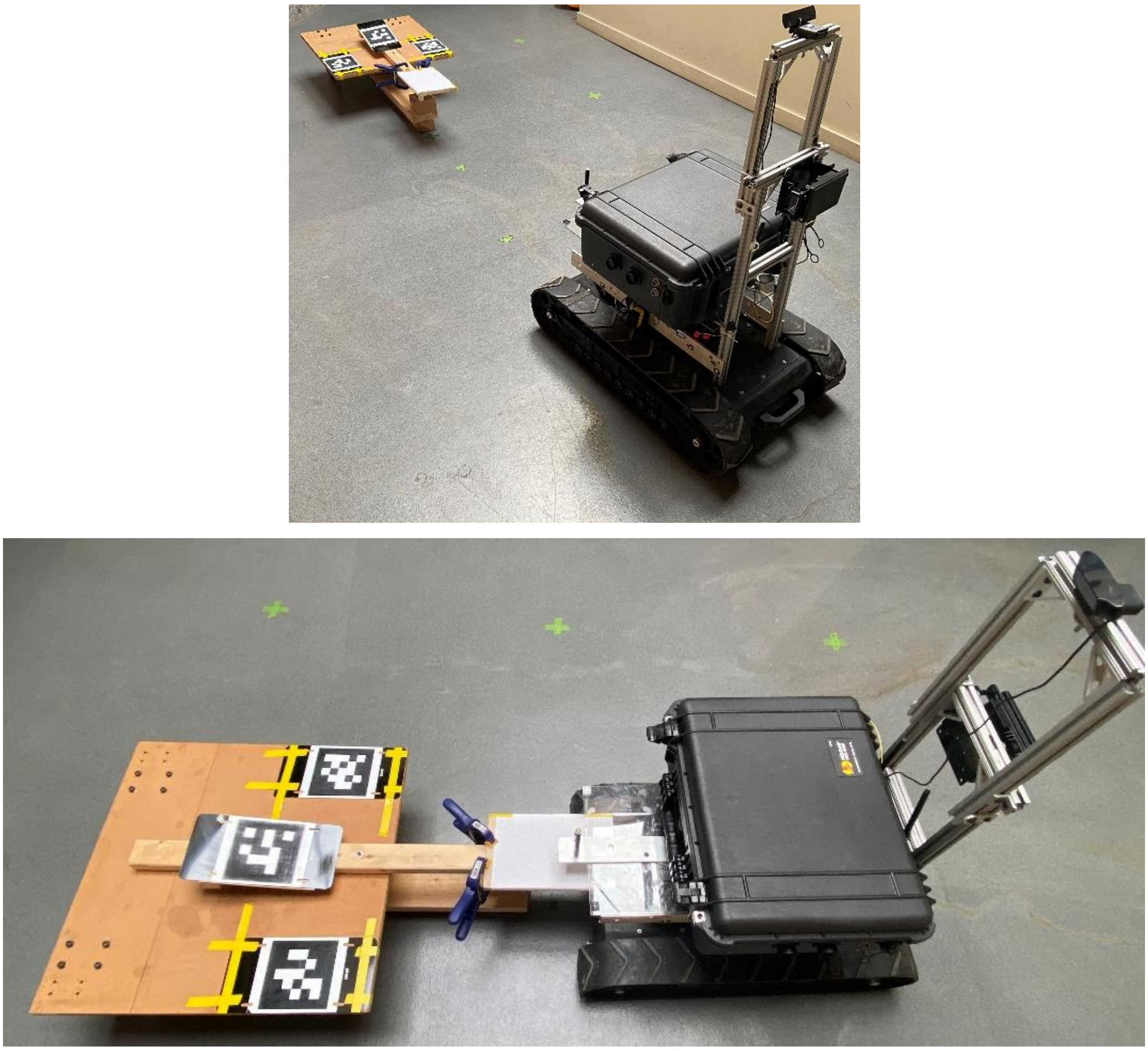


Figure 43 - (Top) Initial position of vehicle with respect to mock trailer. Notice that the vehicle is oriented with the rear end facing the trailer, and a camera aimed in that direction. (Bottom) Final position after vehicle has completed its task.

Figure 44 – Accuracy was measured using a laser pointed at a gridded sheet of paper after each test run.

4.4.5 The Demonstration

The demonstration setup displayed in Figure 45 consists of the vehicle with an electric hitch and rear facing camera attached, and a trailer with fiducials installed. The task of hitching the trailer consist of several different phases. The first stage is an initialization step which only needs to be performed once. This consists of a user manually hitching the trailer with the vehicle and letting the camera record the relative orientation of the fiducials placed on the trailer. By doing this, the transformation between the fiducials and the ring on the trailer does not have to be measured, thereby minimizing the required software alterations that need to be made for different trailers.

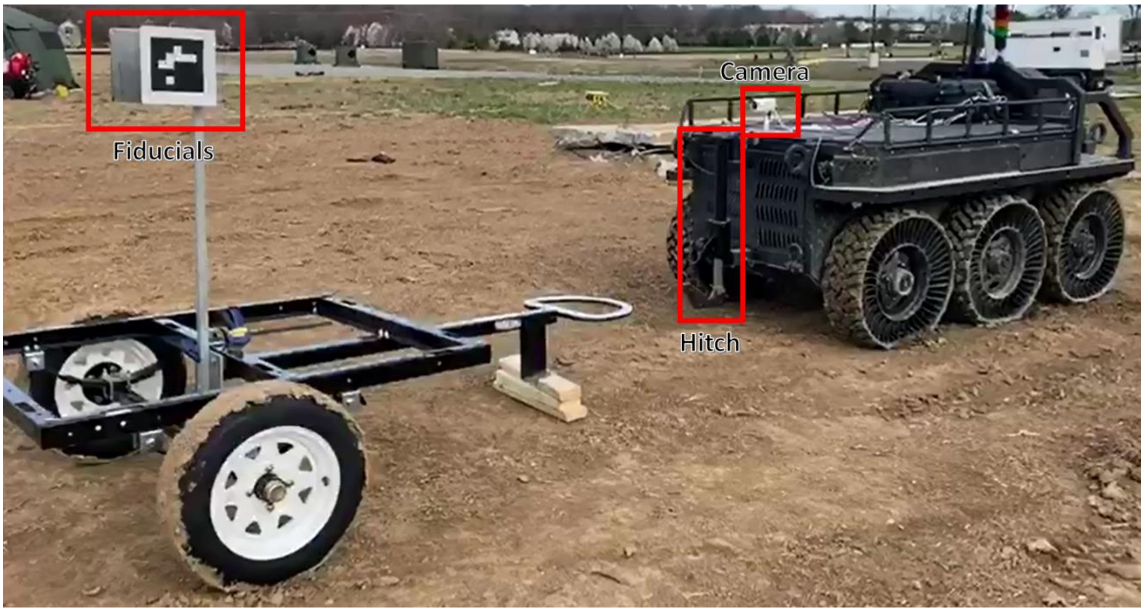


Figure 45 - System setup consisting of the WOLF with an electric hitch and rear facing camera attached, as well as a trailer fitted with fiducials.

With the initialization complete, the demo begins with the vehicle arriving at a location near the GPS coordinates of where the trailer was specified to be – these coordinates are set when creating a map in the user interface. This first step is shown in Figure 46; the vehicle has arrived at a site neighbouring the trailer and is ready to begin the hitching procedure. From here it is possible that the vehicle will still not have seen the trailer. If this is the case, the vehicle will continue to drive nearer to where it thinks the trailer should be (given the GPS coordinate) while using a camera to spot any fiducials. Figure 47 demonstrates the vehicle approaching the trailer in reverse until it finds a fiducial.

Figure 46 – Initial demo state. The WOLF has arrived at a location near the trailer, and is now ready to begin the hitching process.

Figure 47 - (Top) Vehicle begins to look for fiducials by approaching the trailer GPS location with the rear facing camera in front. (Bottom) The vehicle spots a fiducial and stops in order to record its pose. With this information the vehicle can now be sure of where the trailer is.

With the fiducials found, the vehicle now has an accurate local estimate of the pose of the trailer. The next step consists of the vehicle slowly approaching the trailer and periodically stopping in order to recalculate the goal pose – this is done in order to account for drift coming from the vehicle odometry and inaccurate fiducial measurements taken while moving. If everything is successful, the vehicle will eventually reach the point where it is within the bounds of error for hitching and the hitch can be engaged. Figure 48 displays the final step of hitching the trailer and then driving away to the next user defined location. If an error occurs where the vehicle has missed the target, or has lost track of the trailer for any reason, the recovery protocol dictates that it drive forward to measure the fiducials and starts again.

Figure 48 – (Left) Once in position, the hitch is engaged in order to pick up the trailer. (Right) with the trailer hitched, the vehicle drives away to its next goal.

Overall we were able to successfully demonstrate autonomous hitching of a trailer using the WOLF. Although promising, more testing and tuning needs to be done for a robust and reliable implementation. In terms of the mechanical design, current issues arise when the trailer does not budge forward as it is being hitched. This may result, as seen in Figure 49, in the trailer not being properly secured. With regards to software, more testing is required in order to better tune navigation parameters and minimize failed attempts.

Figure 49 – (Left) while being hitched it may occur that the trailer does not slide into the groove on the hitch. (Right) The trailer is left unsecured – and is likely to fall as the vehicle begins to move – as a result of it not sliding into the groove.

We have successfully demonstrated autonomous hitching of a trailer using the WOLF. The task shows promise, however as touched upon in the previous milestone, the assignment proposed in this paper relies heavily on accuracy. As such, more effort is required; and effective implementation relies on platform (i.e. WOLF) controllability, a robust mechanical system, and the ability to obtain a reliable stream of fiducial information when computer CPU usage is near capacity. At present, we've reached a point where a lot of progress has been made, and we've been able to identify what has worked well, and what hasn't. To this end, looking forward, more time and effort is required in order to transition this demo to a complete product for a customer.

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 1 – 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[1].

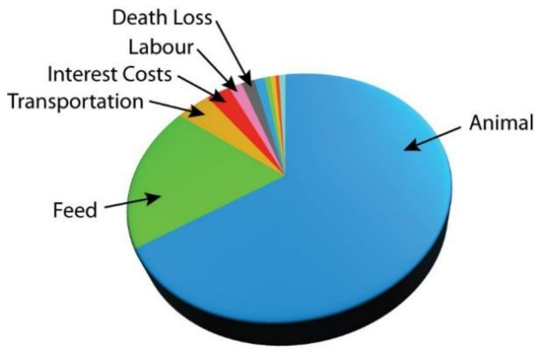


Figure 50: Feedlot costs.

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[2], so there has been little motivation to improve efficiency.

Australia's situation is different, because labour costs for feedlots are much higher[3]. 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

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[1] Livestock and Poultry: World Markets and Trade, United States Department of Agriculture Foreign Agriculture Service, April 10, 2018

[2] Guidelines for Estimating Beef Feedlot Finishing Costs, General Manitoba Agriculture, Food, and Rural Development, 2015

[3] International Cost of Production Analysis, Canfax Research Services, 2013

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[4].

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."[5]

Figure 51: 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.

[4] 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

[5] Invasive Plants and Animals Committee 2016, Australian Weeds Strategy 2017 to 2027, Australian Government Department of Agriculture and Water Resources,

5.2.1 Cattle station productivity

Figure 52 – Fuel storage tank at a remote pumping station.

In a good year, a “typical” northern cattle station with 15,000 head of cattle might have revenues of $5M. Two Drover WOLF vehicles on that station could perform these tasks, which are covered in HDT’s proposal:

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

We estimate that this level of automation would reduce the station's labour needs by one fulltime employee and two seasonal employees. In addition, providing consistent feed supplementation during the dry season would increase weight gain by 2% to 10%, depending on conditions. The increase in operating margin for the station, accounting for the depreciation costs of the vehicles, would be $150K to $250K annually.

If these increases in productivity were applied across all the northern cattle stations, the profitability of these stations would be increased by an annual total of $500M.

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 third phase concluded with the demonstration of proof-of-concept prototype of the Drover WOLF vehicle performing functional tasks, specifically autonomously delivering dry-supplements, and autonomously picking up a trailer.

Figure 53 – Picture of the Drover WOLF in a mock autonomous supplement distribution demonstration

We have successfully designed the mechanical, electrical and software aspects of a prototype Autonomous Hitching System, and its software has been tested in mock platforms. Early assessment demonstrates that the distance from the vehicle hitch marker to the desired trailer pickup point is within 5 inches [~13 cm] when using the mock platform setup displayed in the figures below. While this error profile would be enough to allow the WOLF to hitch a trailer given the current mechanical constraints, it is not evident how this value will scale when applied to the larger system. Complete integration of the developed system onto the WOLF platform will require more testing. Unlike previous milestones, the assignment proposed in this report relies heavily on accuracy. As such, the aggregation of errors originating from fiducials, coordinate transformations, vehicle control, and mathematical assumptions necessarily needs to be bounded for successful operation. Ultimately, this means that the task may require a higher level of effort; and effective implementation will depend on platform (i.e. WOLF) controllability, precise mounting of markers, and the ability to obtain a reliable stream of fiducial information when computer CPU usage is near capacity.

To continue improving the functionality and productivity of the Drover WOLF we recommend follow-on efforts that:

1. improve the robustness and reliability of the autonomous navigation capabilities,
2. finish the development of the *proof-of-concept* attachments developed in this phase, and
3. expand the user, and control (communications) interfaces in order to facilitate the integration of 3rd party developed attachments.

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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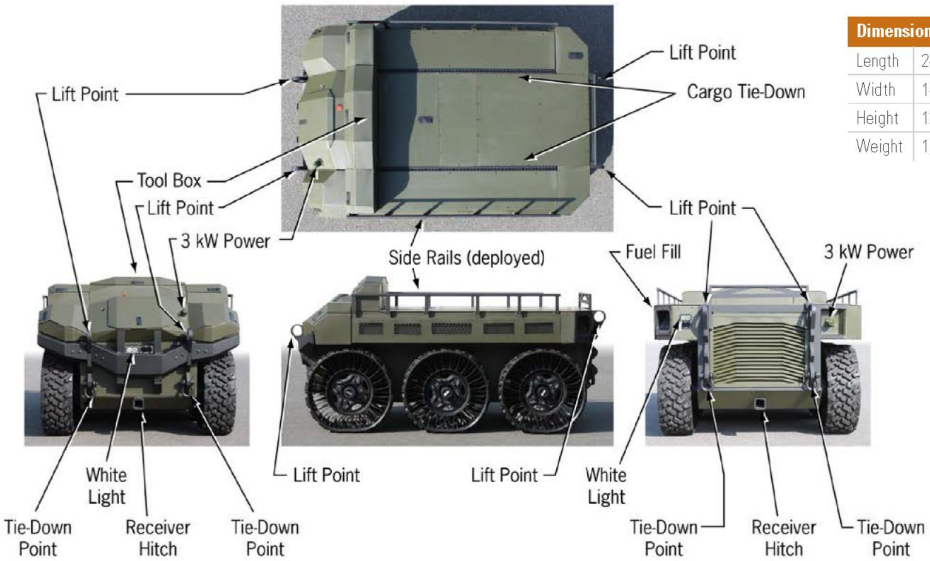
DROVER WOLF

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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