final report

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Potential use of autonomous vehicles on cattle stations, feedlots, and processing plants

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Executive summary

A previous project between HDT Expeditionary Systems and Meat & Livestock Australia (MLA) developed an autonomous vehicle capable of operating on cattle stations (P.PSH.0850). In November, 2017, HDT and MLA personnel visited several cattle stations in the northern region of the Western Territories to better understand the tasks that this autonomous vehicle could perform on a cattle station (P.PSH.1003).

Figure 1 – HDT's prototype was successfully demonstrated to MLA personnel at the conclusion of a previous project.

For the current project, HDT and MLA personnel visited a cattle station in northern Queensland in June, 2018 and a feedlot west of Brisbane in July, 2018. At the cattle station, we studied their current methods for eradicating infestations of woody weeds. We developed computer models of their two most successful manual processes, and then we modified those models to evaluate the impact of using an autonomous vehicle. This work showed that an autonomous vehicle can eradicate woody weeds at a lower cost, with a long-term result that will likely be more effective.

At the cattle station, we also took several thousand high resolution photos of Chinee Apple (*Ziziphus mauritiana*), which is the primary woody weed invasive species that they are battling. We also took several thousand photos of native plant species. The purpose of these photos is to train an image recognition algorithm to determine if an autonomous system can reliably discriminate between plant species that should be eradicated and plant species that should be preserved.

Figure 2 – Wrotham Park Station is fighting the spread of Chinee Apple, which is a rapid-growing small tree. Thorny and densely branched, nothing grows underneath its canopy. Cattle will not push past its thorns nor eat its leaves. Birds and wild pigs, however, eat its fruit, then widely spread its seeds in their droppings. If not actively combatted, Chinee Apple can rapidly propagate and destroy the carrying capacity of a paddock within a few years.

At the feedlot, we studied their labour-intensive tasks. In cooperation with the feedlot manager, we developed several potential concepts for automating those tasks.

Figure 3 – Currently, there are almost no autonomous solutions available to improve the efficiency of feedlots. The primarily reason is that feedlots outside of Australia have relatively low labour costs, which means there is not a large enough demand for labour-saving automation to justify any investment in this area by large agricultural equipment companies.

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1 Background

HDT has developed the Hunter WOLF unmanned vehicle for the US military. Working with MLA, HDT is creating a livestock management variant of this vehicle, called the Drover WOLF. This variant has longer range and lower cost, without sacrificing any of its ruggedness or load-carrying capability.

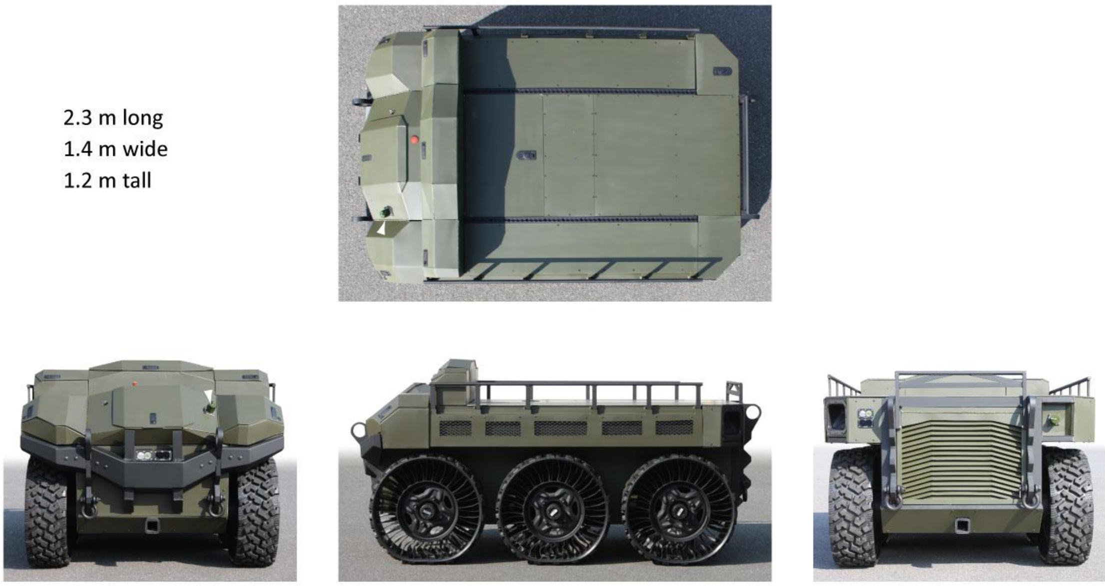

Figure 4: HDT's Drover WOLF unmanned vehicle is about the same size as a large quad bike, but far more powerful and stable.

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.

1.1 Purpose of the Project

The power and autonomous capability of the Drover WOLF make it an attractive option for performing many repetitive tasks in the livestock industry. Two specific areas were investigated in this project:

- Eradication of woody weed infestations on cattle stations
- Improving efficiency of feedlot operations

1.2 Significance for the Australian Livestock Industry

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[1].

[1] 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

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."[2]

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.

Figure 5: Thorns of a Mesquite woody weed.

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.

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[3].

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

Australia's situation is different, because labour costs for feedlots are much higher[5]. Australia's hourly labour cost for feedlot workers is more than twice that of the United States.

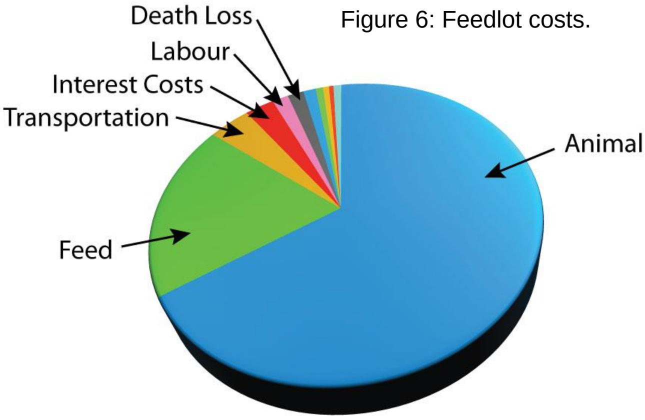

Figure 6: Feedlot costs.

[2] Invasive Plants and Animals Committee 2016, Australian Weeds Strategy 2017 to 2027, Australian Government Department of Agriculture and Water Resources, 1

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

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

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

2 Project objectives

HDT is delivering an autonomous work vehicle for livestock management to Australia under a separate MLA project. This proposed observation phase project is to investigate several additional applications for this vehicle, beyond those already identified. The most important new application is the control of Prickly Acacia and other woody weeds. HDT will travel to a Consolidated Pastoral Company (CPC) cattle station that has problems with Prickly Acacia. HDT will speak with CPC employees and other experts about the current control efforts and visit affected areas. HDT will design an autonomous process for Prickly Acacia control, based on the vehicle they will be delivering to MLA.

During their time in Australia, HDT will also visit a feedlot and an animal processing facility. At the feedlot, HDT will study the processes for feed distribution, feed trough cleaning, and removal of solid wastes (animal feces). HDT's goal will be to design attachments for autonomously performing these tasks. At the processing facility, we will focus on the loading of processed meat into shipping cartons. HDT produces a line of highly dexterous robotic manipulators, and we will work on how this loading process can be automated.

3 Methodology

Kent Massey, HDT's Director of Advanced Programs, joined with Christian Ruberg, MLA's Program Manager Value Chain Technology, to visit Wrotham Park Station, owned by Consolidated Pastoral Company Pty Ltd (CPC). Jasmine Boxsell, CPC's Commercial Projects Officer, coordinated the visit. Simon and Kirsty Cobb, the CPC Station Managers at Wrotham Park Station, hosted the visit. Wrotham Park Station is in northern Queensland, located about 200 km west of Cairns.

Simon Cobb spent a day with Kent and Christian, showing them current infestations of invasive species, discussing eradications methods that he has used, and showing them the results of those eradication efforts. The Head Stockman at Wrotham Park Station also spent significant time with Kent and Christian, showing them more remote areas of the station that were affected, as well as flying them over some of those areas to photograph the infestations from above.

Kent and Christian stayed at Wrotham Park Station for three days. Most of their time was spent collecting thousands of photos of three different types of plants:

- Chinee Apple
- Rubber Vine
- Native trees

Each of these three different categories of photos was saved to a separate large capacity memory card, which will simplify the preparation of these images for processing by an image recognition algorithm.

Kent and Christian returned to the same areas at different times of day to take photos in different lighting conditions of the same vegetation.

While at Wrotham Park Station, Kent and Christian also began working on a computer model of manual versus autonomous eradication processes (model is described in the next section). Their initial work helped identify areas where more detailed information was needed, while they still had access to subject matter experts at the station.

The following week, Kent visited ACC's Brisbane Valley Feedlot in Buaraba, QLD, located about 60 km west of Brisbane. David Breed, ACC's General Manager – Intensive Production, hosted the visit. Kent and David spent several hours walking through the feedlot and discussing labor-related tasks that might be automated. The following day, Kent met with Paul Gibson, ACC's Manager – Product Development and Research Development, at ACC's Cannon Hill office in the eastern suburbs of Brisbane. Paul provided a larger context for understanding the feedlot operations details that David had discussed the previous day.

At the end of the week, Kent met with Dr. Christopher Lehnert and Dr. Christopher McCool at the Centre of Excellence in Robotic Vision, located at the Queensland University of Technology in Brisbane. The purpose of the meeting was to learn about the Centre's work in using image processing algorithms to distinguish between different types of vegetation.

4 Results

4.1 Woody Weed Eradication

Similar to other woody weeds, Chinee Apple often starts along the banks of watercourses, then spreads to open areas. At present, we believe the steep, broken terrain in riparian areas is too challenging for fully autonomous operations. In a few years, semi-autonomous operations in this difficult terrain may be possible, with one person supervising the work of several autonomous vehicles.

In open, flat terrain, however, safe operations of an unmanned vehicle are achievable with current levels of autonomy. Fortunately this sort of navigable terrain constitutes the vast majority of the valuable pasturage at Wrotham Park Station.

Mechanical removal of woody weeds is not effective. The plants quickly regrow from roots and seeds. For most woody weeds, burning is similarly ineffective. Long-term success requires the use of an herbicide. There are three effective methods that are generally used in applying herbicide:

- Basal bark spraying – a mixture of Access (Triclopyr & Picloram) and diesel fuel (1:60 ratio of herbicide to fuel) applied around the stem of the plant in the autumn when the plant is growing. The spray should be applied from ground level to a height of 40 cm for plants with a stem up to 15 cm in diameter. For larger plants, the height of the spray should be increased, up to as much as a meter above the ground, but the efficacy of this technique is marginal for larger plants.
- Cut stump treatment – the stem of the plant is cut off horizontally, as close to the ground as possible, then a Access/diesel mixture (same as above) must be applied within 15 seconds to the cut stump. This technique is effective on any size plant and at any time of year.
- Soil application – granules of Tebuthiuron (trade names: Tordon, Graslan, Spike, and others) are spread from the main stem out to 30 cm past the drip line of the plant's canopy. The

granules are inactive until rain falls, which dissolves the herbicide into the soil and carries it to the roots.

The preferred method at Wrotham Park Station is hand application of Tebuthiuron granules. A group of station hands will walk in ten meter wide lanes through an infected area, throwing measured amounts of granules under the canopies of the plants to be eradicated. The amount of herbicide used depends on the size of the plant.

One drawback of this method is that granules cast on sloped terrain can be washed away by rain, killing any native plant species that may be downslope. Tebuthiuron has been banned in Europe since 2002 for this reason. Another negative factor is that Tebuthiuron is more than three times as expensive as Access/diesel.

Wrotham Park Station does not use Access because the branches of Chinee Apple start at ground level, rather than the higher initial branches of other woody weeds, such as Prickly Acacia. The thorns of Chinee Apple make approaching the stem of the tree very painful. Manual basal bark spraying or cutting is not possible.

Figure 7: The branches of a Chinee Apple (left) extend to the ground. Prickly Acacia (right) has higher branches. Both plants have painful thorns. Accessing the stem of a Prickly Acacia is possible, although it is often unpleasant. Accessing the stem of a Chinee Apple is simply not practical as part of a standard procedure that must be repeated hundreds of times a day by a station hand.

Some cattle stations use a helicopter or unmanned aerial vehicle to spread Tebuthiuron granules. Because this application method is less precise, a larger amount of herbicide must be used, which more than triples the cost per plant eradicated. In addition, native species are more likely to be damaged or destroyed by the widespread application of the herbicide.

Kent Massey (HDT) and Christian Ruberg (MLA) developed a computer model of the following eradication methods:

1. Manual basal bark spraying using Access/diesel
2. Manual casting of Tebuthiuron granules
3. Autonomous casting of Tebuthiuron granules
4. Autonomous cutting and application of Access/diesel to the stump
5. Autonomous basal bark spraying using Access/diesel

The computer model randomly distributes woody weeds across a hectare and then computes an optimum path through this hectare to treat each weed in the minimum amount of time. Parameters used in the model include:

- Woody weeds per hectare
- Stand-off distance to apply treatment
- Time required to apply treatment
- Manoeuvre speed (walking speed for a person or driving speed for an autonomous vehicle)
- Annual salary for a worker
- Working hours per day
- Working days per year
- Type of herbicide used in treatment
    - Grams of that herbicide needed to treat woody weeds of the following sizes:
        - Seedling
        - Small
        - Medium
        - Large
    - Distribution of the weeds by size (percentage of each size)
    - Cost per ton of the herbicide used for treatment
- Cost of an autonomous vehicle
- Useful lifetime of that vehicle
- Amortized annual cost of that vehicle (calculated)
- Cost of diesel fuel
- Fuel consumption of the autonomous vehicle per kilometre

The model calculates the following results for each eradication method:

- Hectares treated per day
- Kilometres travelled per day
- Number of plants treated per day
- Cost of herbicide per day
- Labour cost per day
- Cost of diesel per day
- Amortized cost of the autonomous vehicle per day
- Total cost of treatment per day
- Average cost per plant treated

For applying Access/diesel using an autonomous vehicle, we chose to model the method of cutting down the woody weed and immediately spraying the stump with Access/diesel, rather than basal bark spraying.

As can be seen on the follow page, the computer model clearly shows it is more cost effective to use an autonomous vehicle to eradicate woody weeds than to do this work manually. While the capital cost of the autonomous vehicle is higher than the annual salary of a station hand, the autonomous vehicle can work 24/7. This vehicle can also use a smaller amount of a less expensive and less environmentally toxic herbicide in very precise applications, which lowers costs and greatly reduces the risk of damaging native plants.

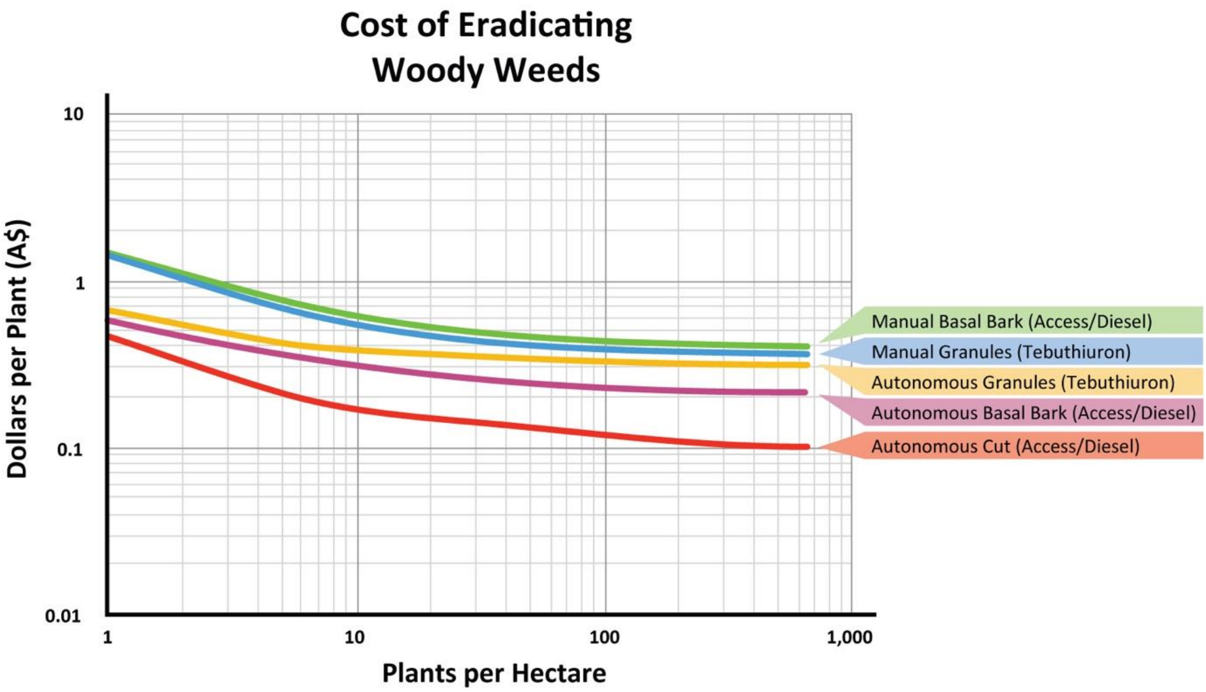

Figure 8: In general, the cost of eradicating each plant drops as the density of plants increases. Manual basal bark spraying and manual application of Tebuthiuron granules are almost the same cost, with the higher labour effort of basal bark spraying almost exactly offsetting the much higher cost of Tebuthiuron.

For low plant densities, autonomous application of Tebuthiuron is about half the cost of manual application, but only about 15% less expensive when the plant density is high. At high densities, the very expensive Tebuthiuron herbicide becomes the predominant cost factor.

Autonomous basal bark spraying is less expensive than autonomous application of Tebuthiuron, because the autonomous operations have similar efficiencies and Access is much cheaper. The most cost-efficient approach is cut-stump treatment with an autonomous vehicle because this method maximizes the benefit of using a robot to do a boring, repetitive task, while also using the smallest amount of the least expensive herbicide. The autonomous vehicle has sufficient power to very efficiently cut down small trees.

While this cost model was developed based on data that is specific to Wrotham Park Station, the results from the model match quite closely to a cost/benefit analysis of woody weed eradication in the Barkly and Victoria River Districts of the Northern Territory[6].

The chart above shows that the cost of eradicating each plant decreases as the density of plants increases. Eradication efficiency is higher when the time spent traveling from one plant to the next is minimized and the time spent treating plants is maximized.

The model shows that the least expensive method is using an autonomous system to cut down plants close to the ground and then apply an Access/diesel mixture to their fresh cut stumps. This method uses a much smaller amount of a less expensive herbicide, which means the cost of the herbicide is a very small part of the total effort. This autonomous method is predicted to be three times cheaper than the best manual method.

[6] Prickly Acacia in the Northern Territory: Costs and Benefits of Eradication, Report prepared for the Northern Territory Department of Environment and Natural Resources, ArGyll Consulting, 2017

Autonomous basal bark spraying and autonomous application of Tebuthiuron granules are also predicted to be less expensive than the manual alternatives, but not as low-cost as cut stump treatment. It will be essential to test the effectiveness of autonomous eradication to validate the cost model's accuracy.

In addition to lower cost, another advantage of these autonomous methods is that they can be used against all types of woody weeds. Some manual methods are not practical against certain woody weeds, such as how the thorns of a Chinee Apple make manual basal bark spraying nearly impossible. Robots, however, are not affected by thorns. The Drover WOLF has non-pneumatic Tweels, rather than tires. Hardy Mesquite thorns can puncture the tread of these Tweels, just as the thorns do with pneumatic tires, but the Tweels will be unaffected. With Chinee Apple trees, the robot can easily penetrate through the tree's lower branches to its main stem. Hundreds of thorns scraping across the vehicle as it pushes into a large Chinee Apple won't slow it down.

The curves in the graph on the previous page end at 650 plants per hectare, because at that point the area is fully saturated and the pasturage is no longer useable. The densest area Kent and Christian measured at Wrotham Park Station had about 200 plants per hectare. If left untreated, woody weeds spread so quickly that these paddocks are only a couple years away from being completely saturated, which is why Simon Cobb is aggressively working on eradication efforts.

Overhead photography can be used to identify areas where infestations are, or are beginning. These photos can be indexed to a geographic grid, so GPS can be used for navigation.

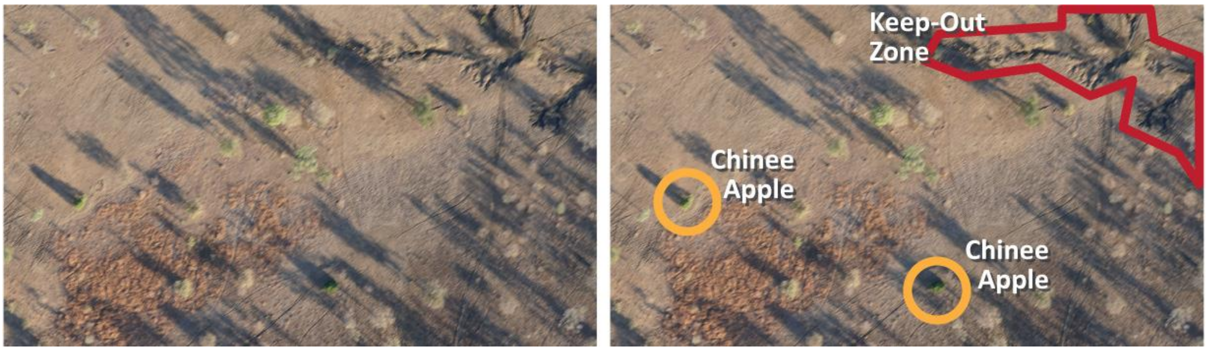

Figure 9: Overhead image (raw photo on left, annotate version on right) taken from a small aircraft operated by Wrotham Park Station. These photos can be used to identify new infestations and also to create keep-out zones that help the autonomous vehicle avoid difficult terrain.

In addition to spotting new infestations of woody weeds, as shown above, overhead imagery can also be used to establish "keep out" zones for autonomous vehicles. All current sensing systems for autonomous vehicles have difficulty reliably detecting sharp drop-offs in terrain. (These drop-offs are called "negative obstacles" in the jargon of autonomy). A station hand can use a point-and-click interface with the computer imagery to "geo-fence" areas where the robot should not go.

One further advantage to using an autonomous vehicle to eradicate woody weeds is that a successful eradication program requires repeated visits to every location where a plant was treated to look for regrowth or new seedlings. Robots can record the GPS location of every single plant that was treated and revisit that location every six months until it is clear the treatment was completely effective. For larger cut trees, the vehicle can be equipped with a mulcher on these repeat visits.

Grinding up the dead tree will speed up the pasture's recovery process by breaking down dry, thorny brush that would otherwise be an obstacle to cattle and would also be a fire hazard.

4.2 Feedlot Automation

Because so little has been done to automate workflow in feedlots, there are many straightforward opportunities to improve efficiency. The potential savings extend well beyond direct labour offsets achieved by tasks being performed with machines instead of people.

The most significant opportunity appears to be in distributing feed to the cattle. Currently, the animals are fed once a day. Their feed is very energy-dense, which is what allows the cattle to gain weight so quickly. Because cattle have a ruminant digestive system, great care must be taken to not overwhelm the animal's ability to process a high-energy diet. With once-a-day feeding, cattle tend to gorge on feed, due to competition for space at the feed bunk and also because they are very hungry following the previous 23 hours of feed deprivation[7]. The result of eating too large a meal can be acidosis and death.[8]

Any feed that is not consumed in the first rush will tend to remain in the bunk for many hours before the cattle are sufficiently hungry to return. In the heat of summer, molasses and other components of the feed can ferment during that time, causing the feed to be undesirable. During the rainy season, any unconsumed feed will become saturated with water, which also makes this feed undesirable. All the uneaten feed needs to be manually cleared from the bunks with shovels before any new feed can be added.

In their natural state, cattle graze slowly over time. In the summer, they often graze more during the cooler night than during the heat of the day. In feedlots, however, the labour cost of distributing feed multiple times a day is too high to be practical. Distributing feed at night is also not a realistic option because it is very difficult to hire and supervise people who work at night.

Autonomous systems, of course, do not care if it is day or night. Distributing feed frequently throughout the day is actually more efficient for an autonomous vehicle, because that vehicle can be sized to carry smaller amounts continuously, rather than having to be large enough to carry a large load, but only for a small fraction of the day.

Frequent distribution of feed should reduce cattle's morbidity and mortality due to acidosis. The animals' rush to the feed bunks (due to once-a-day feeding) will be reduced, which will give shy feeders a better opportunity to feed and increase their weight gain.

By balancing the frequency of feed supply with the animals' natural consumption patterns, there should be less spoilage of unconsumed feed. Reducing spoilage will lower feed costs as well as reduce the need to clean feed bunks.

Since the risk of acidosis from gorging on a single large meal will be reduced, it may be possible to actually increase the total amount of feed cattle consume each day, which will accelerate their

[7] Cattle Disease Guide: Rumen Acidosis, 2014, http://www.thecattlesite.com/diseaseinfo/193/rumen-acidosis/ (accessed August 3, 2018)
[8] Peter Watts, Mairead Luttrell, and Orla Keane, Feedlot Design and Construction: Feeding Systems, 3

weight gain and reduce the number of days animals need to be in the feedlot. A faster turnover of cattle will reduce interest and depreciation costs.

As can be seen from this discussion, using an autonomous vehicle to distribute feed does not just save labour cost, it can also:

- reduce feed costs, due to less spoilage
- reduce cattle mortality costs by eliminating acidosis due to gorging
- reduce interest and depreciation costs due to faster weight gain
- increase revenue due to better weight gain by shy feeders and also by animals that would otherwise acquire subacute acidosis from once-a-day feeding

There are similar synergistic gains an autonomous vehicle can achieve in handling the waste produced by cattle. Each animal produces over 100 kg of manure every month. A significant portion of that manure is water and volatile organic compounds, which dissipate over time, but even after that dissipation, about 10 tons of manure accumulate in a pen that holds 200 cattle every month.

If this manure is not removed on a regular basis, it can build up and cause problems. "Weight gains can be reduced by 30–40% and feed conversion rates increased by 20–35% when cattle are kept on deep manure. Wet, muddy conditions also adversely affect animal health, with increased incidence of foot problems such as foot abscesses.[9]"

Figure 10: In heavy rain, accumulated manure can liquefy.

Manure can cake onto an animal's hide, forming clotted masses of hair and dung that are nearly impossible to remove. As much as 20 kg can collect on a single animal, which causes difficulty in assessing a correct weight when selling the animal for slaughter and presents a significant challenge for infection control once the animal enters the abattoir.

The advantage to using an autonomous vehicle to clear manure from pens is that the vehicle does not need a very high load capacity. There is no labour cost, so an autonomous vehicle can work slowly and steadily, keeping the pen clean. Existing small-scale laser graders and tractor-drawn box scrapers can be adapted for autonomous operations.

[9] Robyn Tucker, Stephen McDonald, Michael O'Keefe, Tony Craddock, and Justin Galloway, Beef Cattle Feedlots: Waste Management and Utilization, Meat and Livestock Australia, 2015, 2

Figure 11: Small scale equipment can be automated to slowly and precisely remove manure from pens.

HDT could also develop a combination grader/scraper kit for its current Drover WOLF autonomous vehicle. When the scraper bowl fills up, the vehicle would drive to the fence next to the stock lane, lift the scrapper bowl over the fence (similar to a front loader), and dump the manure into a trailer. This kit would only have a capacity of about 0.25 cubic meters, but since speed is not a cost factor, a small and manoeuvrable vehicle is a good solution, despite its limited capacity.

For feedlots that use composted manure in their own cropping operations, autonomous manure spreading will reduce labour costs. Because autonomous vehicles operate 24/7, a small capacity is generally an advantage. Small systems are less expensive and easier to maintain. Using several small systems rather than one large system also means that if one small system fails, only a portion of the total productive capacity is affected.

Figure 12: Small scale manure spreader.

Autonomous vehicles record the GPS locations of all their movements, so manure can be precisely and evenly applied to a large field over a period of several days.

5 Discussion

This project provided clear data that autonomous vehicles can eradicate woody weeds in open, flat areas at a significantly lower cost and likely with a higher level of effectiveness. Eradicating woody weeds in riparian areas is more challenging because current sensor systems for autonomous vehicles are not able to reliably navigate steep, difficult terrain. Over the next couple of years, supervised semi-autonomous operations in riparian terrain may be possible. Fully autonomous operations in this sort of challenging terrain is probably a decade or more away.

Autonomous vehicles can also greatly benefit feedlot operations. These benefits extend beyond simply offsetting labour costs. Distributing smaller amounts of feed more frequently, including during the night in hot weather, will reduce morbidity and mortality, improve weight gain, and reduce wastage due to spoilt feed.

Autonomous vehicles can also reduce costs and improve animal health by more frequently removing smaller amounts of manure from pens. If the feedlot uses composted manure in cropping operations, these autonomous vehicle can also spread the manure on fields in a consistent, cost-effective process.

6 Conclusions/recommendations

This project identified the clear potential for autonomous vehicles to reduce the cost and improve the performance of both woody weed eradication and feedlot operations.

6.1 Woody Weed Eradication

HDT recommends the following next steps for woody weed eradication:

1. Process the thousands of photos that were taken of two different invasive species and native trees through Google's *AutoML Vision* software to determine the accuracy of image recognition in discriminating between invasive species for eradication and native species to be preserved.
2. Develop attachments for the Drover WOLF autonomous vehicle to:
    a. Cut down woody weeds and immediately spray the stump with Access/diesel (expected to be the primary path)
    b. Basal bark spray or distribute Tebuthiuron granules around woody weeds (these are secondary paths in the event that technical issues reduce the effectiveness of the cutting attachment)
3. Create prototype software to:
    a. Navigate a paddock with vegetation
    b. Identify woody weeds among the vegetation
    c. Manoeuver the vehicle to a woody weed
    d. Treat the plant
    e. Repeat the process until all woody weeds in the paddock have been treated
4. Test the attachments and software at one or more cattle stations in Australia
    a. Initial testing will be supervised
    b. Primary focus of the initial testing will be proof of concept
    c. Goal of testing is to evaluate which attachment is more effective, improve the design of the attachment, validate cost model, and better understand operational integration issues with overall station workflow
5. Define the infrastructure needs and develop a system architecture for a larger, integrated system

HDT will prepare a proposal for performing these next steps. If this proposal is funded and the development/testing is successful, then a follow-on effort would be required to correct any design problems revealed during testing and to develop a fully integrated system that can be commercially sold for autonomously eradicating woody weeds.

6.2 Feedlot Automation

HDT recommends a more gradual development process for feedlot automation. If automation proves successful in feedlots, the scope of changes required for feedlot infrastructure and operations will be wide-ranging and profound. These sorts of changes cannot be accomplished in a single step.

Each of the key autonomous system components needs to be developed and tested to demonstrate/evaluate its technical capabilities. This process will almost certainly require one or two rounds of iteration to achieve reliable and efficient performance.

These technical capabilities, however, are not useful without a clear understanding of how the feedlot's infrastructure and operations will need to be modified to integrate the autonomous technology. In the earlier stages of development, only a rough plan is needed for understanding these infrastructure and operational issues. There is little sense in spending too much money or effort on these larger issues until it is clear that the technology can deliver sufficient cost savings and performance benefits to justify the larger investment in modifying infrastructure.

If the technology is able to demonstrate reliable performance that can consistently generate cost savings, then it will be appropriate to select a site for prototype integration of modified infrastructure, autonomous technology, and new operational procedures.

The overall process will likely take four or five years, although each phase of development will only take a year or 18 months. HDT will prepare a detailed proposal for the first phase, along with a general plan for follow-on phases. The first phase will focus on demonstrating/evaluating the technical capabilities of autonomous systems in performing the following tasks:

1. Feed delivery
    a. Develop a mixer/trailer to be pulled by an autonomous vehicle
    b. Develop software accurately positioning the trailer and controlling feed delivery
    c. Conduct multi-week testing at a feedlot in Australia
    d. Get data on effect of increasing the frequency of feeding on animal health and weight gain
2. Feed bunk cleaning
    a. Develop a spinning wire brush attachment to clean feed bunks
    b. Develop software accurately positioning and controlling the cleaning attachment
    c. Test attachment in Australia
3. Pen cleaning
    a. Adapt existing small graders and scrapers for autonomous operations
    b. Develop a combined grader/scraper kit for the current Drover WOLF vehicle
    c. Develop software accurately controlling the grading/scraping depth and for manoeuvring the vehicles within a pen

    d. Test these systems in Australia
4. Manure spreader
    a. Develop a loader attachment for Drover WOLF
    b. Modify a manure spreader trailer for autonomous operations while being pulled by a Drover WOLF
    c. Develop software to load the trailer with manure and accurately control delivering to crop fields
    d. Test these systems in Australia

At the end of this first phase, HDT will also work with the feedlot to develop an initial plan for the infrastructure and operational changes that would be needed to incorporate these autonomous systems.

7 Appendix

7.1 Data Sheets

7.1.1 Drover WOLF

Drover WOLF
Autonomous vehicle for Livestock and Agricultrue

HDT GLOBAL

Based on the Hunter WOLF unmanned vehicle that HDT developed for the US military, Drover WOLF is an autonomous vehicle for livestock and agricultural uses. This civilian version was created as part of a joint project with Meat & Livestock Australia. Drover WOLF can perform repetitive and boring tasks, such as checking on water bores and refilling feed troughs, which frees up labor to work on higher value tasks.

This unmanned system was developed for the US military over a period of seven years, with more than $10 million in funding and a dozen field evaluations by the US Army. Drover WOLF is rugged and dependable. The vehicle can carry 500 kg and tow more than 2,000 kg for hundreds of kilometers. The vehicle can operate 24 hours a day, seven days a week.

With its tethered quadrotor airborne drone, Drover WOLF can conduct livestock counts, analyze pasture health, and detect pest animals.

In crop agriculture, Drover WOLF can pull farm implements, such as seeders. It can also autonomously fertilize and spray crops. Its small size, light weight, and low cost makes Drover WOLF an attractive alternative to large, heavy, expensive farm equipment in situations where the scale of operations is smaller, or where wet conditions make low ground pressure essential.

KEY FEATURES

- Hybrid diesel/electric drive.
- 20 kW diesel generator.
- 6 kWhr storage battery.
- 100 kW electric drive motors.
- System weighs 2,500 kg.
- Carries 500 kg
- Tows over 2,000 kg.
- 6x6 drive with non-pneumatic Tweels.
- +60 to -40 C operating temperatures.

Drover WOLF

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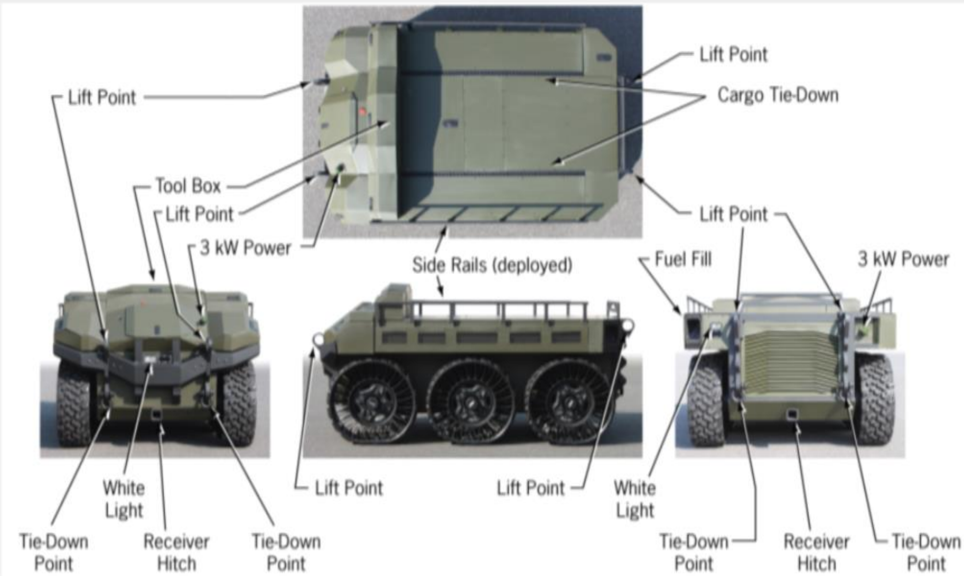
VEHICLE OVERVIEW



TETHERED QUADROTOR AIRBORNE DRONE

Drover WOLF can autonomously fly a tethered quadrotor to count livestock, assess pasture health, or detect pest animals.

Thermal imager from quadrotor of a dingo tracking a steer.

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