

GOVOR® Forest Nursery Trial and Evaluation

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EXECUTIVE SUMMARY

AGOVOR®s Prototype GOVOR® unit, in conjunction with the monitoring evaluation trailer developed by Tui Technology, was able to collect data at three different radiata pine tree seedling or mother tree nurseries. The data collected included how bumpy and off camber the tracks were among the rows of plants, the difficulties the units faced at each site in their current state, and feedback from the nursery site managers. This data, along with pictures from the site visits, is recorded, processed, and then displayed in this report. A summary of the data can be found below.

Summary of Data

Rotorua Forest Nursery Data Summary

The first site visited, Rotorua Forest Nursery, was the only site to use GPS tractors when planting. The rows here were very straight, as to be expected. The tracks were smooth and free of ruts or bogs. The beds were not raised. The track widths, however, were not a consistent width. They seemed to alternate between ~600 mm and ~800 mm. Considering GOVOR®'s width of 600mm, this made it a very tight fit while navigating down the rows. The highest off camber section was only about eight degrees. This was due to a hill in the nursery and not anything to cause issue. There were bumpy areas outside the blocks however, where GOVOR® was driven. While GOVOR® easily navigated these areas, it should be noted that any attachments that GOVOR® will have to pull must also withstand the forces involved. The peak G-force recorded was 3.5.

RFN sees GOVOR®'s potential use in the weeding, monitoring, spraying, and counting functions of their nursery. Because they are among a residential area, they wish to reduce how much they spray and use spot spraying. Also, they are near an airport which means they cannot rely on drones for any of these functions.

ArborGen Tokoroa Data Summary

The next site GOVOR® was able to visit was ArborGen Tokoroa. This site posed more of a challenge, considering they did not use GPS tractors to plant their rows. The block of mother trees that were present had varying width tracks, some too tight for GOVOR® to fit. The tracks that could accommodate GOVOR® were not straight and posed challenging for the GPS based system that GOVOR® uses.

These tracks were also bumpy, peaking at three Gs. In the cutoff rows, the situation was similar in terms of width and straightness issues. The rows also had issues with ruts and soft dirt in some areas. This did cause a problem for GOVOR® and did prevent driving through one spot. The soft dirt in a rutted area caused GOVOR® to get stuck and could not be driven out, even manually.

The ruts also caused some off camber angles, regularly around 10 degrees. The soft dirt was caused from recent undercutting. Another area of potential issue was the amount of available space for GOVOR® to turn around at the end of the rows. During testing, the obstacle avoidance sensors were disabled to help get around some tall grasses and weeds at the ends of the rows that would have otherwise stopped GOVOR®.

The site manager here seemed to be the most interested in using GOVOR® to mow or spray around mother tree blocks. The issue of addressing weeds and grasses in the rows poses a challenge for them. Spraying is an option but not as effective with several types of weeds, and the health of the mother trees to consider. Mowing would be a more ideal solution.

ArborGen Te Teko Data Summary

The last site GOVOR® visited was ArborGen Te Teko. They also do not utilise a GPS tractor when planting. The main issue observed at this site was more of a problem with the public GPS base station nearby in Whakatāne. The issue prevented any precise use of GPS at the site. Here, GOVOR® was only run in their mother tree block using manual mode. The beds were raised, and there were often ruts from the tractors that drove through it. There was one bog hole that was evaluated in as well.

This particularly deep rutted track had collected water and created a small mud pit. GOVOR®, although being driven in manual mode quite slowly, was able to traverse this mud pit. Since the rut was narrower than GOVOR®, however, this did force GOVOR® and the trailer to tilt at a severe angle, maximising at 30 degrees. This wasn't a problem for GOVOR® or the evaluation trailer, but would be a problem for any trailer that utilised arms that extend over the rows for monitoring, counting or spraying.

GOVOR® would be used for counting, weed spraying, or potentially topping their mother trees at this site. They would be interested in being able to get a count of the number of mother trees that have survived. Similar to the Tokoroa site, weeding around mother trees also poses a challenge. It was mentioned that they might like to top their mother trees with GOVOR® as well. Another area of use would be in their containerised plant blocks. Here, they would use it to spray for weeds underneath the trays where they can't easily reach, and to also carry buckets of harvested plants for the workers and bring them back to a waypoint.

Usability in Nurseries

In its current state, the usability of GOVOR® in a nursery setting will be highly dependent on the conditions of the blocks, rows, and tracks at the site. RFN is a notable example of how a site could be set up to best suit GOVOR®. The main conditions for this are the straightness of the rows, the smoothness of the tracks, and the drainage of low spots.

Having straight rows is not necessary but is highly recommended to use GOVOR®'s GPS capabilities, which is its main function. Since it depends on GPS, using a GPS tractor is the best solution to obtain straight rows.

Another mentioned method is a simple string line approach. However, this requires certain conditions, such as a level nursery block, and rows that are not so long that a string would droop too much. If straight rows are not obtainable, then considerably more time is required to set up GOVOR®'s GPS path generation data. Not only does it require placing many more points to begin with, but also there is likely to be more time required to fine tune a path that will work through the block.

The software for GOVOR® does not currently allow for manual tweaks to the generated path on the fly and must instead restart each time after tweaking the path. This means if GOVOR® runs into an issue halfway through executing a block, it will have to be cancelled, adjusted for, and

restarted from the beginning. This adds a lot of time and is why having straight rows to begin with is especially important.

Since this evaluation only examined GOVOR®'s use in forestry nurseries, recommendations can only be made for seedling/clipping blocks and mother tree blocks, which were present at these sites. Between the two types of blocks, mother tree blocks will be more difficult to utilise GOVOR® in. For starters, considering that these mother trees grow to be much larger, the size and shape variation between newly planted ones and mature ones is vast. This causes some problems for GOVOR®.

First, since most of the issues that need to be addressed in mother tree blocks require mowing, it would be difficult to ensure a mowing mechanism doesn't mow newly planted trees, while also getting around the base of mature trees. Meanwhile, the mature mother trees sometimes grow their branches into the trackway, obstructing GOVOR®. This might be able to be navigated around if done manually. However, since the GPS points that GOVOR® follows in auto mode are done soon after planting, this would require constant adjustment to the GPS points, or trimming of the trees. Another approach might be to disable the obstacle avoidance systems and push through the branches, but this is not recommended as they are used for safety reasons.

An area of concern with the current state of GOVOR®, is the GPS systems. At each site visited, the GPS base station server had to be manually restarted by AGOVOR® to start using GPS at that site. Moreover, when the GPS is working properly, it can be a hassle to use. During these site visits, a decent portion of time was taken to plot points, especially when the rows were not straight, and numerous points were plotted for every row. Not only is plotting cumbersome but obtaining an acceptable heading accuracy for GOVOR® does not always happen easily. To get good heading accuracy, GOVOR® must be manually driven in a straight line for some distance. Sometimes it is quick, while other times it takes over 15 minutes. While this must only be done once at a new site, or after GOVOR® has been powered down for a long time, it is still a hindrance to a quick setup.

At ArborGen Te Teko, problems with the public GPS base station could not be resolved. This was due to the shelterbelt around the nursery blocking the view of parts of the sky, required to synchronise with the base station. This problem would be solved with a base station setup on site to match what satellites GOVOR® can see.

The path generating methods used by GOVOR® is adequate for use in these types of nurseries. It does not have as much customisability as might be expected considering the many different use cases that GOVOR® could be used for in a nursery. If GOVOR® is running, it can be used to plot points. This might seem handy, until you realise you need to plot points where the rows are, instead of where the tracks are. GOVOR® can't exactly be driven to where the rows are.

While the path following does what it should, it limits GOVOR® to that one track, meaning there is no on-the-fly adjustments. When GOVOR® is stopped by a tree branch for example, GOVOR® won't attempt to find a way around, or continue until it is manually fixed. If GOVOR® is manually driven around an obstacle, sometimes it will not continue after because it is too far off the path to find its way back.

GOVOR®'s hardware is excellent for the purposes for which it was designed. At the Te Teko site, where GOVOR® drove through a mud bog, there was more than enough torque to push

through. GOVOR®'s size, weight and form factor are all well suited to an automated tractor in a nursery.

While there are some concerns about the internal fusing of the electrical system, there have been improvements made to the next prototype to address this concern. One area of concern relates to when GOVOR® got stuck in soft dirt ruts at Tokoroa. The reason it was stuck was due to a lack of ground clearance. This was mostly due to the rear hitch having a bolt protruding out the bottom quite far.

This bolt being dragged through the dirt caused GOVOR® to get caught up. One other area of concern relating to hardware is its visibility to large vehicles. Both at RFN and Te Teko it was noted that there were large vehicles driving around at times, like forklifts and commercial trucks with limited forward visibility towards the ground.

Most of the problems GOVOR® faced at these sites could be resolved with better site management and maintenance or improvements to the GOVOR® platform. It is a question of whether more resources should be invested into development of GOVOR® to tackle these problems, or into the sites that GOVOR® will be used to mitigate the problems in the first place.

INTRODUCTION

Tui Technologies, in collaboration with Forest Growers Research and AGOVOR®, evaluated the GOVOR® autonomous row-based tractor for use in forest nurseries. The primary goal of this research is to assess the current capabilities of GOVOR® in the forest nursery environment and to develop and test a prototype trailer. This trailer aims to enable future ground-based autonomous tree stock monitoring, including seedling counting, growth tracking, and health assessment.

Current State

As of lending GOVOR® to Tui, GOVOR® appears to be 80-90% complete as a functional platform for navigating nurseries. After a proper setup of the GPS points and site layout, GOVOR® will autonomously drive back and forth between each bed, such that each row gets driven twice, once in each direction.

A trailer can be configured to be pulled behind it, allowing for proper turn radius, or a Smart Trailer can be attached (not yet developed by AGOVOR) and these inputs will be automatically configured. When generating the path, it considers the trailer, the bed width, and its own width to navigate without running into the beds. Roads and waypoints can also be mapped so that GOVOR® can navigate around a nursery between blocks, or back to a charging station for example.

GOVOR® can be controlled manually as well via a smart device (other than Apple products for now), desktop computer, or by a provided PS5 controller connected via Bluetooth. A smart phone is currently the best device for setting up a GOVOR® site.

Using GOVOR®

Transporting

GOVOR® can be transported to/from a site in the back of a vehicle with adequate trunk space, or in the bed of a pickup truck. While GOVOR® does have potential tie down points from its bumpers, it is not necessary to do so, since GOVOR® has considerable mass and won't slide around. If you plan to go on very bumpy roads, then it is advisable to strap it down. GOVOR® weighs approximately 50kg, and subsequently requires at least a two-person lift. The bumpers serve as lift points. Please use caution to not drop or damage GOVOR® or injure any person while performing lifting actions.

Components

On the front of GOVOR®, you will notice the bumper includes a bar, that when pressed will activate a switch. This is used to stop GOVOR® when in automatic mode if it runs into an obstacle. This should rarely, if ever, happen since GOVOR® is also equipped with object detection sensors on the front panel that will stop forward motion before reaching the object. The front panel also includes a camera which can be viewed in the webapp.

On the top of GOVOR®, you will see various components. Starting from the front, there exists two lights to either side. These will flash any time GOVOR® is in auto mode, or while engaged in manual mode. This is to help notify anyone nearby that it is or will be moving.

Between the lights is a kill switch. This disconnects the motors and prevents any movements. To reset the kill switch, just twist it in the direction the arrows point. Behind the kill switch, there are three black modules. These are for the GPS antenna, cellular signal, and Bluetooth connections. Lastly, at the back there are three buttons. They are coloured and can illuminate (sometimes hard to see the colour/light). There is a red, green and blue button.

The red button acts like the kill switch, but only a software kill switch. The green button makes GOVOR® report any relevant information through its speakers if there is any. The blue button means GO or Resume. Under normal operating conditions, none of these buttons need to be used. You can tell GOVOR® to run its path from the webapp, and most information is also available through the webapp.

From the top back of GOVOR® you will see a camera. Like the camera on the front, this can be viewed from the webapp if needed. To the left is the main power switch. This turns GOVOR® on and off. A speaker is in the centre.

As noted above, the speaker can recite information useful to the operator. It can also play music while driving to notify nearby people of its presence. On the right you will see four plugs. These have caps on them to protect against the elements. The lower two plugs can be used for charging, while the upper two are currently reserves. At the bottom, you will see the bumper and hitch. The hitch is a standard towing hitch ball.



Rear Side of GOVOR®

Charging

AGOVOR® will provide a charger for recharging GOVOR®. Connect the charging cable to a wall outlet, and then connect the other end into one of the two lower receptacles on the rear of GOVOR®. Since Tui has had GOVOR®, we have not needed to recharge GOVOR® since it has quite a large battery capacity.

Power On

On the back of GOVOR®, a large cutoff knob is used to power GOVOR® on and off. When turning on GOVOR®, it will take a moment to power up. While it powers on, the three buttons on top will illuminate. When it is finished, it will recite some words through its speaker.

GROUND BASED MONITORING EVALUATION TRAILER

Tui Technology has developed a small trailer attachment for GOVOR®. This trailer can collect motion and GPS data while being pulled behind GOVOR® in a nursery setting. It is slightly narrower than GOVOR® and attaches with a normal trailer hitch. This setup makes it easy for GOVOR® to navigate with.



GOVOR® Evaluation Trailer Attachment

Purpose of the Trailer

This trailer is intended to collect the motion and GPS data so we can assess what, if any, hardware requirements may be required for future developments of GOVOR® trailer attachments. This hardware might include such things as trailer suspension, gimbals, vibration damping, or other mechanical stability systems. After collecting the data across multiple sites, a good baseline can be determined for typical conditions these attachments may be operating in, and the required hardware can then be determined.

Use of the Trailer

To use the trailer, hook the hitch to GOVOR® and power on the electronics. Currently, a 12V battery is used inside the trailer box to power the electronics. Where the battery connects to the fuse, you should be able to shut the fuse to connect the power. This will be replaced in the future with a direct connection to GOVOR®.

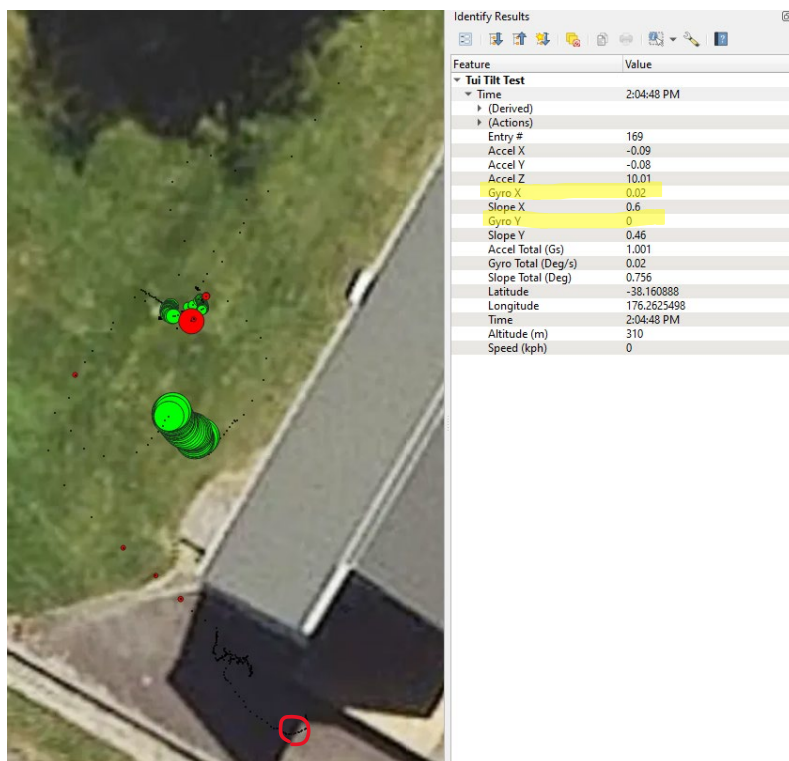
Once powered on, lights on the front of the TDC will turn on, indicating it is starting up. Eventually, the lights will go into a slow flashing mode. This means the TDC has started. Next, it should be noted that a light on the inclinometre should be solid green. If it is flashing, you may need to wait until it is solid green to continue. After the TDC starts, the red light on the front of the trailer box should illuminate (these lights on the front can be very dim). This means that the GPS has not yet connected. Wait until the red light turns off.

Now we are ready to start collecting data. Turn the switch on the front of the trailer box to on, and the green light should illuminate. If it doesn't, and the red is on instead, this means there was an error writing to the USB stick. If the green light is on, it is recording to the USB stick. With the Tui USB stick (1.87 GB), it should last more than 10 days straight, assuming the battery doesn't die first.

Mapped Data Results

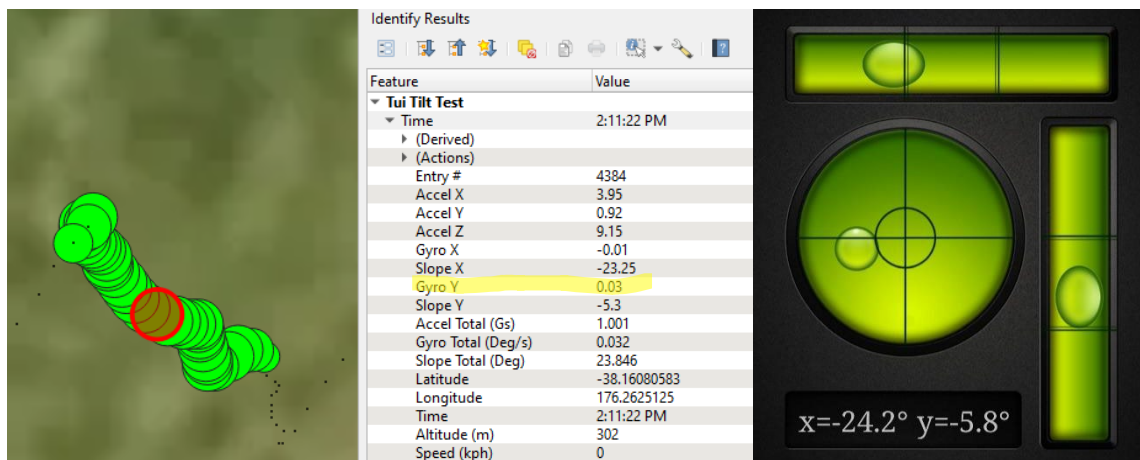
Tilt Test

First, we did a tilt test with the trailer outside the Tui office. This was to ensure the readings we got out of the TDC were correct. We used a level app on a smart phone to compare against. We started at completely level and then moved on to different angles and obstacles. The pictures below demonstrate this.



Starting point (0 degrees)

As you can see in the right panel, slope X and slope Y are close to 0 degrees. This point was grabbed from the start of the run, circled in red. The slopes were not perfectly 0 degrees, which is understandable considering we are using a phone's gyroscope to compare against. It is not high precision by any means.



High Angle (-24 degrees)

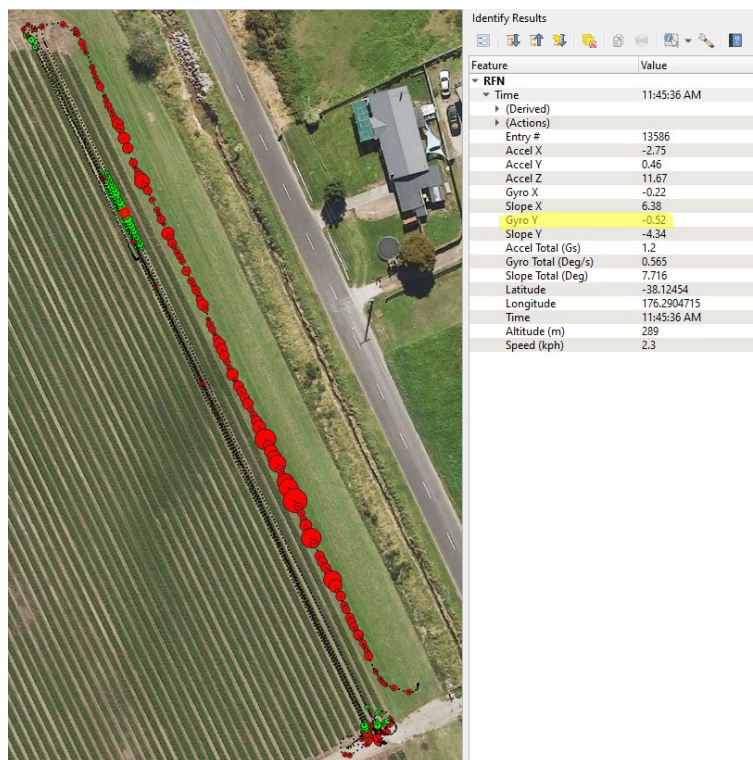
Here the map is zoomed in on the high angle portion of the data. The trailer was propped up so that one wheel was on a concrete pad outside the office. A screenshot was taken of the level app when in this position and can be seen on the right above.

The slope X reported in QGIS is within a degree of the level app X reporting, and similarly with the slope Y. This confirms our data and processing are correct. It should be noted that, even on flat ground, the trailer sits at a slope Y of -2.5 degrees. This is only because the trailer axle is slightly higher than the hitch, and so angles down. It should also be noted that the GPS used by the TDC does drift some over time.

As you can see in the above photo, the large green circles are spread across the map, while in reality, all these data points were taken at the same position. This drifting is most apparent when the trailer is stopped, but still happens when it is moving.

Rotorua Forest Nursery

The trailer was taken to Rotorua Forest Nursery (RFN), and some runs up and down their rows were made. Below are the results of this test.



Test Run at RFN

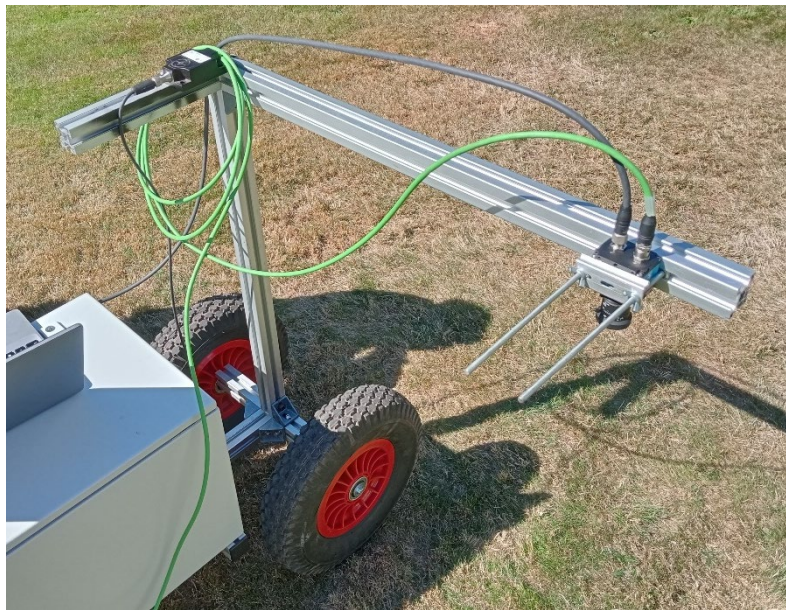
The runs through the rows are mostly clear of high acceleration data points but do show signs of an area with high slope. One point in this green zone (highlighted in red) was selected and its information is shown on the right. It has a high slope X, in the left to right direction of the trailer, at 6+ degrees.

Another area of concern is the area outside the rows. There is excessive acceleration on the path that is furthest to the north-east. It was observed that this was particularly bumpy terrain when GOVOR® drove on it. This shows that the acceleration values are good indicators of how bumpy the tracks are. This will also be useful to know for future designs of GOVOR® attachments.

Other areas of interest are the turn around areas at the end of the rows. These were also observed to be bumpy and sometimes off kilter. This can be seen in the data as well.

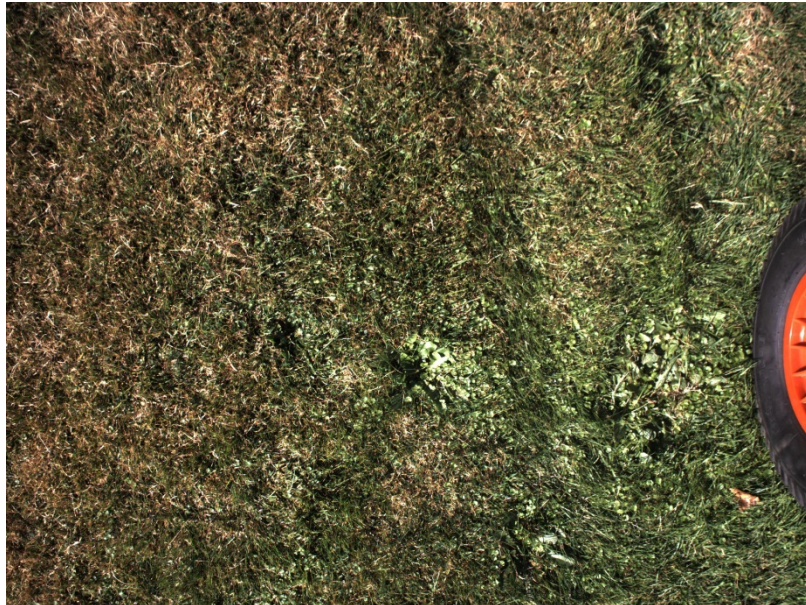
Tui Pole Test

Later, it was decided to fit the trailer with a pole and camera to simulate using the trailer for machine vision type procedures. The inclinometre was moved to the top of the pole and an arm was fitted with a camera to see how usable a camera would be on the trailer. The camera used is one that our software team often uses for their camera related projects and is a good representation of such a camera that would be used for machine vision.



Trailer with Pole and Camera Arm

While it was confirmed that the motion and bumpiness of the trailer shouldn't cause problems with smudged or blurry images, there might be more of a problem with lighting. Some example photos are shown below showing pictures of grass to demonstrate clarity.



Moving in Sunlight

First, photos were taken while the ground was completely illuminated by the sun. A good photo can be taken after the shutter speed and aperture are dialed in.



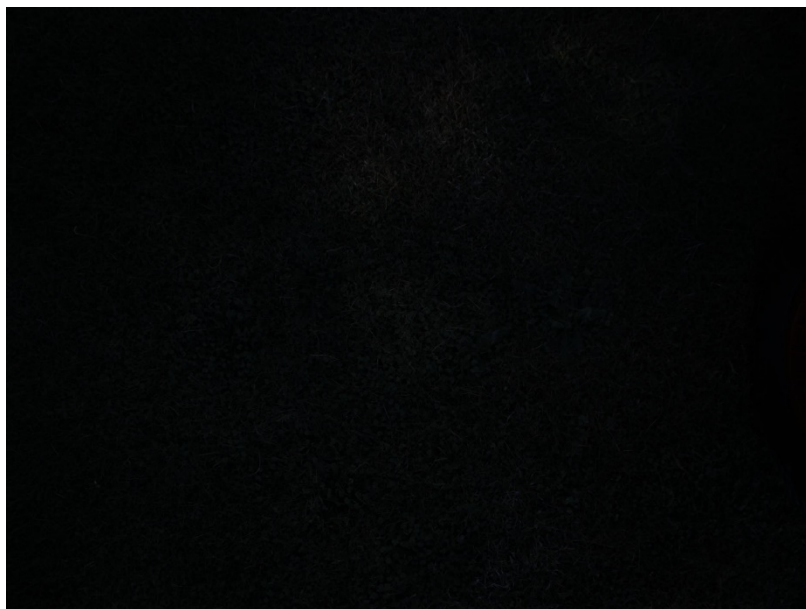
Moving with Partial Shadow

Next, it was noted that any shadows that appeared in the camera view will pose a problem. They are much too dark to use in any sort of application.



Moving Over a Bright Patch of Grass

A particularly bright/dead patch of grass was observed to also start to blow out the image. This could be adjusted for by reducing the shutter speed, but then this would only serve to increase the problem with shadows.



Moving in Complete Shade

The completely black image above was captured when the trailer drove into the shade of a tree. The shutter speed and aperture were not adjusted from before. This is a very unusable photo.



Moving in Complete Shade with Adjusted Shutter Speed

Lastly, we adjusted the aperture to collect as much light as possible, but still had to adjust the shutter speed to compensate for the shade. Because the shutter speed was increased, this induces motion blur in the image as can be seen above.

While collecting these pictures, the trailer was also collecting data. A block with rows were set up in the field outside the Tui office and a path was generated to run the rows. While GOVOR® drove in auto mode, the pictures were taken. Often GOVOR® was stopped to adjust things or check the camera. The results of the data collection can be seen below.



Tui Pole Test Data

The data shows that there was little acceleration or slope issues. It was observed that if GOVOR® was commanded to pause the auto mode, it would stop quite abruptly. This seems to correlate with the few red spots in the data.

The point highlighted, toward the bottom right of the map, shows that there is excessive acceleration in the Y direction (forward). Again, this is likely from the abrupt stops observed in testing. Going forward, we will be using this pole setup, although without the camera or arm, in our testing at sites. This should better simulate the forces that any equipment will need to endure in future designs.

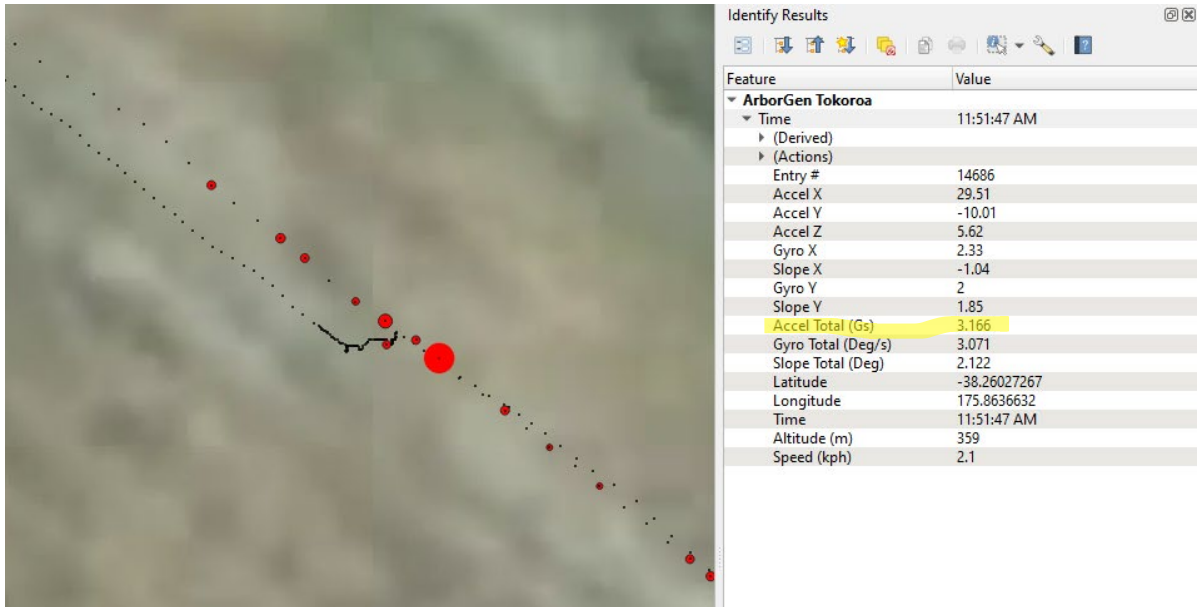
ArborGen Tokoroa

A site visit to ArborGen Tokoroa was made to collect more data. First, we drove down a row of mother trees, as shown by the longer run on the map. Despite plotting more points along these rows, GOVOR® still had problems in auto mode, running into the trees. We decided to control it manually instead. Next, we drove it manually through a short section of their seedling rows. We intentionally chose a row that looked to be the most difficult to drive.



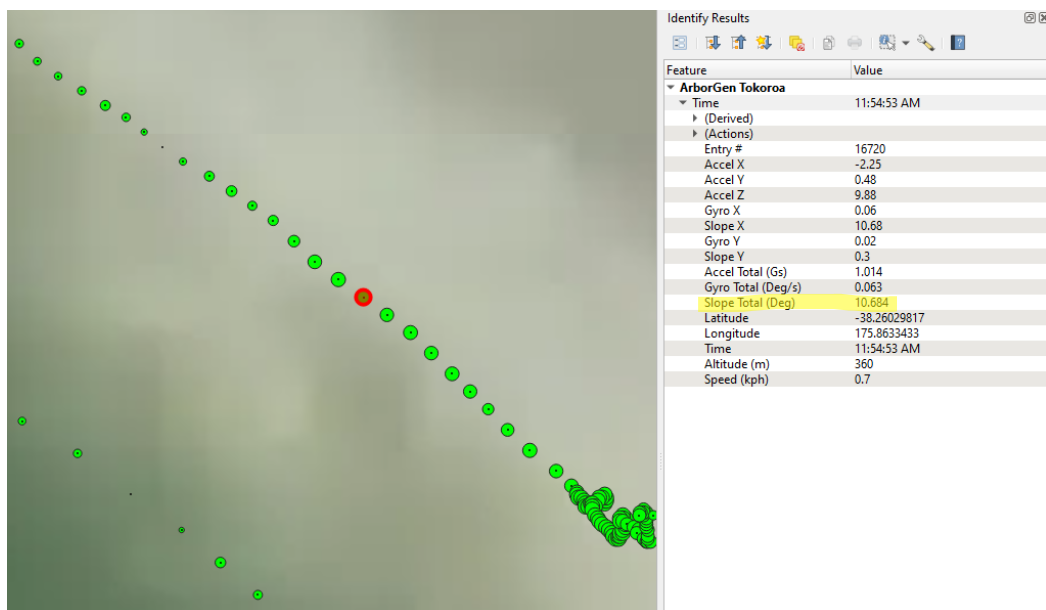
Mapped Points at ArborGen Tokoroa

Below, the maximum total acceleration point within the rows was highlighted. This can be seen to read as 3.166 Gs.



ArborGen Tokoroa Max Total Acceleration in the Rows

The highest total slope was selected and can be seen below. It reads as 10.6 degrees. This was due to some degree of dishing of the track which GOVOR® couldn't fit inside.



ArborGen Tokoroa Max Total Slope in the Rows

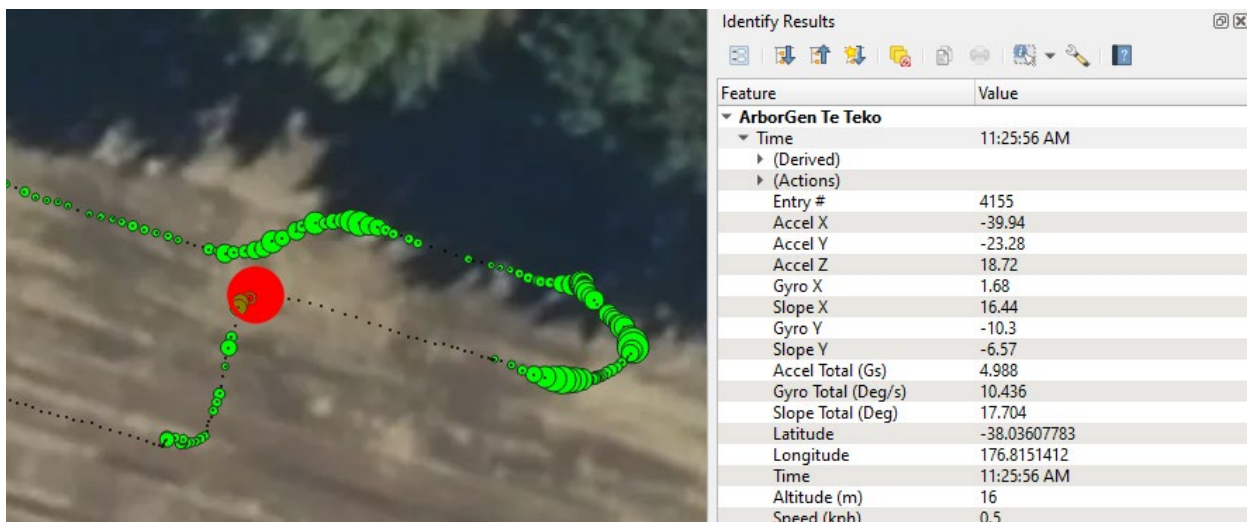
ArborGen Te Teko

The next site visit was to ArborGen Te Teko. Here, we ran in their mother tree block only. We encountered issues syncing with the Whakatāne base station at this site, so we could only drive in manual mode here. First, we chose a row to drive to see how it performs in a typical row. At the end of the row, we crossed over to a row that had particularly bad weeds, as tall as 1.5m in some spots. We demonstrated that GOVOR® had the capabilities, if the obstacle avoidance was deactivated, to drive through/over even larger weeds. Then we crossed over to a different row chosen because it looked difficult to traverse and drove back to the start of the rows.



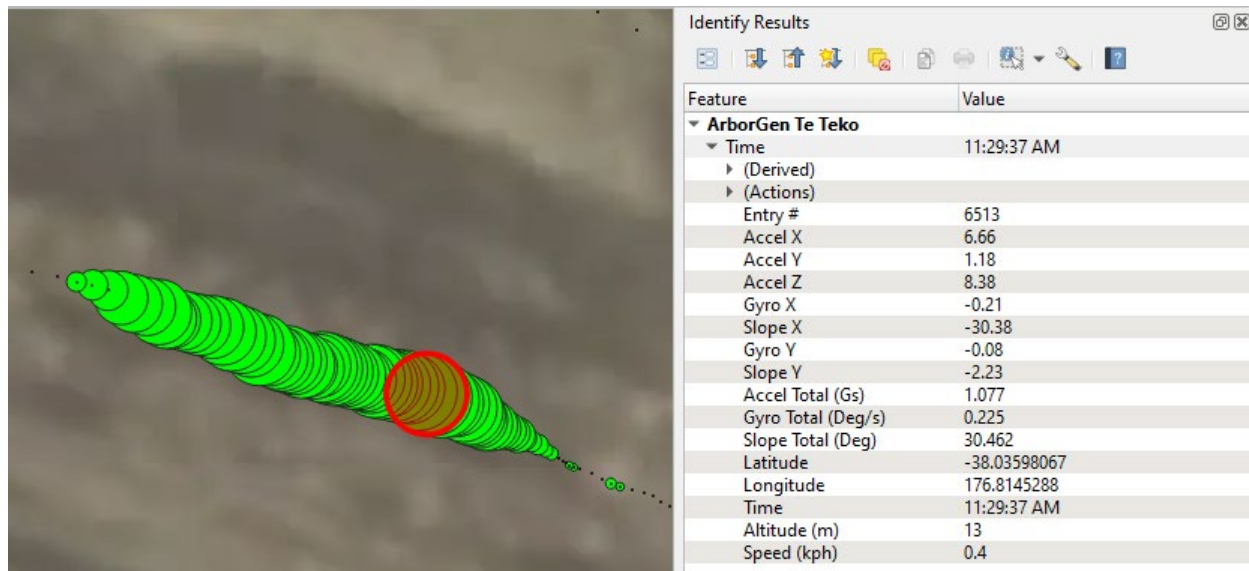
ArborGen Te Teko Mapped Data Points

Among the data points, one point had exceedingly high total acceleration at almost 5 Gs. This point coincides with a moment when the trailer had to be manually picked up, moved, and dropped to navigate around a tight corner that GOVOR® wouldn't normally be navigating.



ArborGen Te Teko Max Total Acceleration

One area of interest is the below pictured zone of exceptionally high slope. It consistently had a slope above 25 degrees and maxed at 30.5 degrees. This was due to a particularly deep rut that put GOVOR® and the trailer at a fairly sever angle to the right. This rut also prevented GOVOR® from driving out of it while attempting to get both wheels on top of it. Since this was done manually, it was taken very slowly. If it had been in auto mode, it likely would've gotten itself stuck and wildly thrown the trailer around.



ArborGen Te Teko Max Total Slope in the Rows

USABILITY IN A NURSERY SETTING

GOVOR® has potential to be used in nursery settings. While there were many complications at some of the sites, some of these should be mitigated with small improvements to the software or hardware of GOVOR®, while other issues would be best resolved with better site management on the nurseries' end. Keep in mind that the sites visited were all forestry regrowing related nurseries, and not entirely representative of the intended use cases that GOVOR® was designed for.

At each site, feedback from the site managers showed there was a clear idea of what each site would use GOVOR® for. The most common requirement for GOVOR® is to help manage weeds in either seedling/cutoff rows or among mother tree blocks. Each site presented unique challenges to GOVOR® and are relayed in the following sections. GOVOR® also had varying degrees of performance in these conditions.

Rotorua Forest Nursery

RFN grows Radiata pine tree seedlings for planting stock in the north island of New Zealand. They utilise GPS tractors when planting and have short bed heights. RFN has a couple of blocks that are situated next to residential area's and would like to explore opportunities to reduce chemical usage in these area's through improved monitoring / spot spraying. Another

reason RFN would be interested in GOVOR® was due to their proximity to an airport. This makes it difficult to use drones in that area for any aerial monitoring purposes.



RFN Rows

Site Requirements for GOVOR®

They envision GOVOR® being able to do monitoring for counting, monitoring to catch terminal crook early on, and spot spraying for terminal crook and weeds. GOVOR® would pull a trailer that would have machine vision capabilities to allow it to count the number of seedlings, or to map out areas that are being affected by terminal crook and weeds. It may also, on the fly, be able to spot spray for those weeds or terminal crook.



RFN Example Area to Monitor

Site Specific Challenges

While their blocks were quite nice, compared to other nurseries, there were issues with row/track width consistency. It seemed to alternate between ~800mm wide to ~600mm wide tracks. Because GOVOR® is 600mm wide, the tight tracks had zero margins for error. The track spacing is very tight and there were minor row straightness issues. It was observed to be extra bumpy outside rows/tracks (i.e. along the roads or sides of the nursery).



RFN Tight Track

Operating Performance

Plotting points and setup of blocks and rows was easy. GOVOR® follows in the tracks very well, when properly configured. The only issue was due to how tight the track was and a slightly skewed row end causing GOVOR® to drift into a row and running over a short section of trees along the edge.



RFN Slightly Askew Row

Nursery Feedback/Comments

They were interested in seeing what GOVOR® would be able to do for them. Along with the above-mentioned site requirements, there was discussion of using point cloud data collected from a drone, which they would only have to do once, in a script that would automatically plot the rows/paths for GOVOR®, instead of doing it manually with the survey pole.

Operator Feedback and Comments

It was noted that on the particularly tight tracks, GOVOR® would scrub against the seedlings. With the way the tyres are moving, this would sometimes pull seedlings down and run them over. One potential easy fix for this would be to have a skirt bar that ran from the front bumper to the rear, just above the ground and just clear of the outside of the tyres. This would function

to push the seedlings out of the way before the tyres could run them over. The bar would have to be close to the tyres however, since width constraints are already an area of concern.

ArborGen Tokoroa

The ArborGen Tokoroa nursery site grows planting trees from seedlings and from cuttings taken from mother trees at their site. They do not use GPS tractors and have power line towers in their blocks. The beds are slightly taller than at RFN.

Site Requirements for GOVOR®

ArborGen Tokoroa thought GOVOR® would be best served mowing around their mother trees. They have a comparable situation, where they currently spray for the grass and weeds but there are some complications with that method. It was mentioned that they have many distinct types of weeds along with the grass they wish to get rid of, however the chemicals required to kill certain types of weeds affect or kill the mother trees. They would be more interested in mowing with GOVOR®.

The grass and weed removal is wanted for a few reasons. First, it makes worker access easier during the cutting period. Another reason is that some of the weeds that grow taller compete with the mother trees. Lastly, some of the weeds emit seeds that stick to the workers, which spread them around to other areas they do not desire to have weeds.

Along with mowing around the mother trees, it was said they would be potentially interested in topping their mother trees. The goal is to keep them around 30-40 cm tall, which would require a trailer that can reach over the rows from between the rows, or to straddle over the top of the rows.

Site Specific Challenges

This site did pose some challenges, which RFN did not, First was the row straightness. They did not use GPS tractors when planting their rows and instead followed the irrigation lines that already exist there.



ArborGen Tokoroa Rows Not Very Straight

Next was the issue of row tightness. Much like RFN, some rows were tighter than others. This did not appear to be as regular, or alternating, like at RFN, but rather more randomised. The tightest of rows just barely allowed GOVOR® to fit through. The site manager had mentioned that GOVOR®, at ~60 Kg, should not do damage to the plants if ran over.



ArborGen Tokoroa Tight Rows

Another issue was the rutted tracks between rows. The track was recently ploughed and very soft.



ArborGen Tokoroa Rutted/Ploughed Track

Operating Performance

Syncing with the GPS base station at this site was more difficult. A call to AGOVOR® to help sort out the issue was made and after their server was restarted, GPS tasks were able to be performed.

At this site we plotted many points along the rows of mother trees, since they were not perfectly straight. A total of 12 points were plotted on each row. This did take more time to plot as opposed to just plotting the end points like at RFN.

The next issue arose when the heading accuracy needed to be dialed in before a path could be generated for GOVOR® to follow. The usual procedure of running it in a straight line manually was not working initially. A restart of GOVOR® and another quick straight-line drive ended up solving this issue, but it did waste a lot of time. Once everything was set up and GOVOR® was able to generate a path, we attempted a run in auto mode.

Unfortunately, another problem arose. Despite adjusting the row offset when generating the path, GOVOR® continued to hit the beginning of the first row. A large adjustment had to be made in order to allow it to enter the row without hitting, but this quickly caused another problem. As it continued down this row it tended towards hugging the opposite side of the row and eventually running into mother trees. From this point on, GOVOR® was driven in manual mode.



ArborGen Tokoroa Row Offset Issue

That issue aside, GOVOR® was easily able to navigate these mother tree rows, where they were not too tight. When it came to the rows of cutoffs, it was more difficult to traverse. Because of the raised beds, GOVOR® did tend to tip to one side as can be seen in the mapped data and the picture below. While this doesn't pose any problem, it will be worth noting for any future trailer designs that have arms that extend to the side.



ArborGen Tokoroa Track Tilt

The major performance issue was related to the soft rutted dirt in some tracks. GOVOR® managed to get itself stuck in a track. Even in manual mode, it was not able to get unstuck on its own. Some physical pulling was required to release GOVOR® from the predicament. It had managed to bottom out on the hitch preventing the drive wheels from getting enough traction to move forward or backward.



GOVOR® stuck in a row at ArborGen Tokoroa

Nursery Feedback/Comments

The site manager showed some interest in the possibilities that GOVOR® could provide to their operations. While they were only initially interested in its weeding capabilities around their

mother trees, they mentioned it would be potentially useful for weeding among the cutoff rows if it could be proven to reliably detect and spray weeds.

Operator Feedback and Comments

Because we compensated at the beginning of the mother tree row, we then in turn went too far over for the rest of the row. This would indicate that the points at the end of the rows were not placed correctly, similar to the drifting issue we saw at RFN. However, because we plotted many more points to account for this, it would indicate the methodology of marking rows does not work well, if at all, if the rows are not perfectly straight.

It might be better to instead mark where GOVOR® can drive within the block of rows, rather than where it can't. Then plotting points would be much easier and more dependable. We would instead mark the middle of the tracks which is easy to access/reach instead of to the middle of the row which is not.

Additionally, since GOVOR® itself can be used to plot points, it would make sense to manually drive it where it can go and mark points with it. It could also be easier if it could plot points every half metre or so as you drive it down the row.

Using the PS5 controller, it is quite easy to drive GOVOR® nicely down a row, even if it is tight and bendy. A new system of marking out blocks and rows would have to be implemented, such as marking a zone GOVOR® can't enter unless it follows a path that you marked out by manually driving it through it.

ArborGen Te Teko

The ArborGen Te Teko nursery site grows mother trees from their genetics lab. They do not use GPS tractors but do appear to have a very experienced tractor operator who makes fairly straight rows. The beds are level with the track, but occasionally the tracks are rutted from tractors driving on them or boggy spots.

Site Requirements for GOVOR®

ArborGen Te Teko is mostly interested in counting and topping their mother trees. The counting of mother trees through machine vision would be beneficial to better predict how many they will have available. While it should be known how many they plant, not all of them survive. Certain areas may be too wet for example.

It is important to be able to count the number of trees and not the branches or other features that might be difficult for a computerised system to differentiate. They also wish to be able to top the mother plants to keep them at consistent heights. It was mentioned that cuttings from lower on the trees tend to grow better, so keeping them short will help produce more of this type of cutting.



ArborGen Te Teko Dead Tree Example

There was an interest in spraying for weeds as well, both in their mother tree blocks and potentially underneath the trays in their containerised plants. Their current method of spraying around the containerised plants involves carrying around an herbicide sprayer and manually spraying the weeds underneath the trays. If GOVOR® could run underneath the trays and spray, this would be much more efficient.



ArborGen Te Teko GOVOR® Just Fitting Under Plant Tray

Site Specific Challenges

The GPS base station was a problem at Te Teko. While we were able to connect to it, it appeared to not be able to synchronise properly. Even after multiple server restarts on AGOVOR®s end, and restarts of GOVOR®, the GPS remained in a float state instead of a

fixed state that is required. This made it so we could not get the heading accuracy of GOVOR® to be within the allowable threshold. While we were closer to the base station used at this site than at Tokoroa, this issue may have been caused by the shelterbelt around the nursery.



ArborGen Te Teko Shelterbelt

Another area of concern was the particularly tall weeds they had along their native mother tree rows. As they had not managed weeds at all in this area, some of the weeds were over 1m tall. It is not obvious, even while there in person, that these are rows that they wish to be driven by GOVOR®. This type of situation might be best served using a mover instead of spraying. The only issue would be needing to disable the obstacle avoidance system.



ArborGen Te Teko Tall Weeds Mixed with Native Mother Tree

Another area of concern was a particularly deep rut that had collected some water in it. This deep rut was also not wide enough for GOVOR® to fit inside.



ArborGen Te Teko Deep Rut with Water

Operating Performance

Similar to the problems at Tokoroa, there were issues using the public base stations for GPS. This problem disallowed us from using any auto mode driving of GOVOR®. As described above, this is likely due to the shelterbelt around the nursery.

We were able to successfully drive GOVOR® through the rows in manual mode. Since the obstacle avoidance systems are disabled in manual mode, we were also able to briefly drive GOVOR® in the overgrown weeded rows along the native mother tree block. It was strong enough and had enough traction to easily push over the taller weeds.



GOVOR® Driving Among Large Weeds at ArborGen Te Teko

One area of concern, although ultimately wasn't an issue, was a particularly deep rut with water collected in the bottom. Because GOVOR® couldn't fit in the row, it was forced to put one tire into the rut. Once it had dropped into the rut, the wheel could not be pulled out through driving and remained in the rut until its end. This did put both GOVOR® and the trailer at a severe angle, and the front bumper of GOVOR® was being pushed through the mud. GOVOR® was able to be driven through without external intervention, so auto mode may have been able to navigate this obstacle.



GOVOR® navigating a deep rut at ArborGen Te Teko

After the rut was driven through, there was considerable mud on both GOVOR®'s and the trailer's wheels, along with GOVOR®'s front bumper. A quick drive over to an available hose off

area allowed a rinse down. The mud was not a hindrance to performance but is something to note if you need to keep certain areas on a site clean.

Nursery Feedback/Comments

The main interest from Te Teko was GOVOR®'s potential for operations in their mother tree blocks. These would be the most technically demanding tasks that they wish to see, but also expressed it would be interesting to use as a mule to carry a load around their site. When they harvest the plants in their containerised block, they put the plants into buckets of water and carry them to a different location. If instead, they loaded the buckets onto a trailer that GOVOR® was pulling, and had GOVOR® drive back to a waypoint, this would reduce the required amount of effort and time the workers exert in the harvesting process.



ArborGen Te Teko Containerized Plants

Operator Feedback and Comments

This site does appear to have many areas that GOVOR® could potentially be used. Since the containerised plant blocks do appear to have a very straight grid, this area would be perfect for using GPS with points placed at the corners/ends of the tray racks. The “pack mule” functionality is something GOVOR® can already do using the manual mode with the controller and simple waypoints. As for the rows of mother trees, there may be some obstacles that may need to be addressed by site management, but otherwise is a good contender for GOVOR®.

AREAS FOR IMPROVEMENT

While using GOVOR®, it was noted that there was one main category of improvement. That category would be improvements to GOVOR®'s hardware.

Hardware

Regarding hardware improvements, there are not many. GOVOR®'s hardware platform is already very solid and promising. That being said, there is always room for improvement. The first being its waterproofing or lack thereof. While GOVOR® can be driven through a bog, as demonstrated at ArborGen Te Teko, it must be done slowly. GOVOR® is not currently waterproof, although it has been mentioned it will be in the future. It would make it easy to clean if it could be blasted with a hose.

Another suggestion, to help address visibility to taller or larger vehicles, is to add a tall flag onto GOVOR®. The simplest solution would be to obtain fiberglass whip flagpole that is often used with desert off road vehicles. These come in various lengths, but for this application, it would be advisable to be 1.5 to 2m high.



Example Fiberglass Whip Flagpole

In conjunction with the higher quality camera stream recommended earlier, it would be desirable to also equip GOVOR® with a wider-angle camera. While driving with the cameras, it felt as if there were large blind corners to both sides. This would be solved with a wide-angle camera.

One small issue is the single front wheel. Since the front wheel is in the centre of the track and the rear wheels are on the sides, if there is a rut, the front drops in while the rear sits on top. This causes GOVOR® to tilt forward in the rows. Again, this isn't so much a problem, but just an observation. This could be solved with two front wheels in line with the rear wheels. AGOVOR® has already considered this idea but seem to be testing out different variations. The last and potentially largest alteration to GOVOR®'s hardware is a recommendation to enable GOVOR® to drive over the top of a row rather than between them. This would involve some type of modular system to attach lifted legs that give GOVOR® a wider stance and much higher ground clearance.

The benefit of such a system would be to allow operations that happen over a row to be executed more easily, allow for better navigational abilities through rough and difficult tracks, prevent severe tilting from rutted tracks, and potentially take over more functions from a traditional tractor such as topping. This would be a rather big alteration to GOVOR®, which is why it might be best to make it an extension, or modular type system.

Depending on the implementation and design, this could solve many of the problems faced while navigating tracks. This would also allow a customer to be able to use GOVOR® for a wider range of tasks as well as expand the potential customer base. Of course this would also require changes to the software as well, to manage the different navigation method. This sort of system is something that might be best to plan for modularity, waiting until more feedback can be collected on this concept from users.

CONCLUSION

In conclusion, the evaluation of AGOVOR®s Prototype GOVOR® unit presents a promising outlook for its integration into nursery operations, offering significant potential benefits in tasks ranging from weeding to monitoring and spraying. The data collected from various nursery sites, alongside feedback from site managers, underscores its value in enhancing efficiency and productivity.

Despite its evident strengths, particularly in well-maintained and GPS-equipped sites like the Rotorua Forest Nursery, several key challenges and areas for improvement have been identified. Issues such as track variability, obstacles, and limitations in GPS functionality pose significant hurdles to seamless operation. Furthermore, software glitches and hardware limitations, including waterproofing and maneuverability concerns, necessitate attention for optimal performance.

However, it's crucial to recognise that these challenges are not insurmountable obstacles but rather opportunities for refinement and innovation. By addressing the identified shortcomings through targeted software enhancements and hardware modifications, GOVOR® can further enhance its adaptability and effectiveness in diverse nursery environments.

While there are areas for improvement, the evaluation underscores GOVOR®'s significant potential to revolutionise nursery management practices. With concerted efforts to address identified areas of improvement and capitalise on its strengths, GOVOR® stands poised to become an invaluable asset in the pursuit of enhanced efficiency, sustainability, and productivity in nursery operations.

APPENDICIES

Data Collection System

The data collection system consists of three main components: a data collection unit, the GPS module, and the inclinometre.

TDC-E200R6 Overview

For the data collection unit, a SICK TDC-E200R6 (Telematic Data Collector) was used. This is a purpose-built data collection and processing unit intended for mobile use. It comes with various Inputs and Outputs (IO): a magnetic GPS antenna as an input, and CANopen, Cellular, Ethernet, Wi-Fi, Serial, USB, and General-Purpose Input Output (GPIO) pins are used for both inputs and outputs.

For this project, CANopen is used to communicate with the inclinometre, USB is used to save the data to a USB stick, and some GPIO is used to indicate states with LEDs and take input from a switch to control when to collect data.

The TDC takes 9V-36V to run. Once given power, it takes a couple of minutes to start up. To program the TDC, connect with a laptop or PC via the ethernet port closest to the 20-pin connector.

You will have to configure your Ethernet IPV4 IP address to 192.168.0.XXX. Choose any number that is not 100 for XXX. Then open a browser (chromium-based browsers worked in testing such as Chrome) and go to <http://192.168.0.100:9000>. There, it will ask for login information. Use the following to login.

Username: developer

Password: tdceDeveloper

The TDC runs Linux using docker containers. Docker containers are similar to how virtual machines work, but they run a program instead of an entire OS. They are an environment that has everything the program needs to run but is isolated from everything else so they can't interfere with each other in any way.

On the dashboard, you will see five boxes. These are the dockers that are on the TDC. For this setup, only three of the five are running: Node-Red, HWManager, and Portainer.

Portainer is the interface you are currently looking at. It manages the other dockers, users for the device, and many settings we will run through in the next section. HWManager, or Hardware Manager, is used to interface with all the IO. It tells you how to access the data that comes in from the various IO methods, or how to write to them.

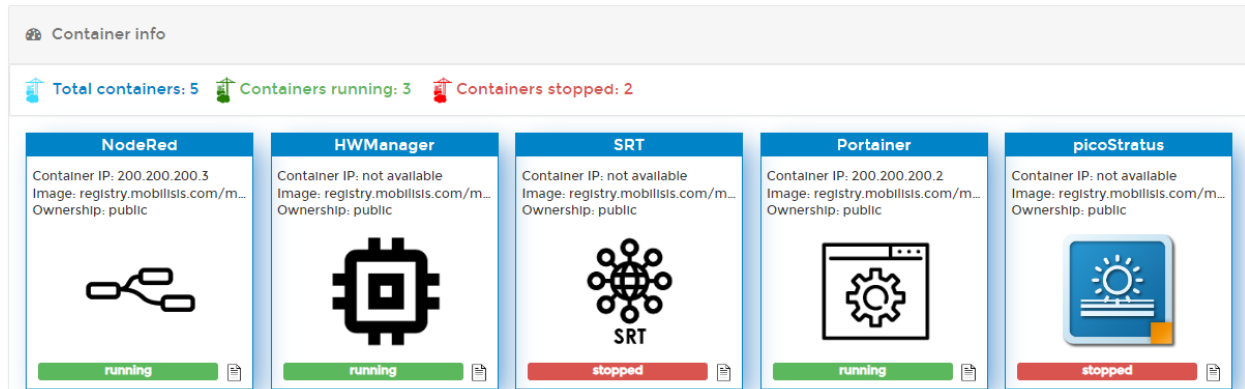
Node-Red is where the actual programming happens. It can read and write from/to the IO, process and manage the data and perform various other functions. It uses a user-friendly graphical block programming interface. The Node-Red "code" for this project will be copied below.

Portainer Settings

On the left of the screen, you will see a menu with many sections. Below we will run through any relevant sections for this project.

Dashboard

The dashboard shows you the docker containers you have running, and this is where you will access those other dockers as well. Clicking on the image inside the docker box will take you to that docker program if it is running.



The screenshot shows a 'Container info' dashboard with the following summary: Total containers: 5, Containers running: 3, Containers stopped: 2. Below the summary are five container cards:

Container Name	Status	Image	Ownership
NodeRed	running	registry.mobilisis.com/m...	public
HWManager	running	registry.mobilisis.com/m...	public
SRT	stopped	registry.mobilisis.com/m...	public
Portainer	running	registry.mobilisis.com/m...	public
picoStratus	stopped	registry.mobilisis.com/m...	public

TDC Dashboard

Applications

This lets you enable or disable different dockers. Portainer and HWManager are not able to be turned off. Here, SRT and picoStratus are disabled while Node-Red is enabled.

Security

Here, the only setting that should be changed from factory is WebSocket API > Status should be enabled.

Power

Here, you can reboot the device without having to do a power cycle if necessary.

Data

Here, we can download or restore TDC-E Configuration files. A file with the configurations for this project will accompany this report. It is in a tdcfg file format.

LAN

Here, under Eth0 Adapter Info, you can change the IPV4 address to suit your needs. This will change the address used to access the device. Change this if you need to meet IP restrictions on your network if you intend to use it on a network instead of directly connecting to it.

IO Devices

Here is where we can configure the GPIO of the device. We will only use the first section, Digital IO pin management. Here you will see DIO_A through DIO_F and DO_5V. They should be configured as follows:

⚙️ Digital I/O pin management		
DIO_A	Direction: <input type="text" value="in"/>	State: 0
DIO_B	Direction: <input type="text" value="out"/>	State: <input type="text" value="0"/>
DIO_C	Direction: <input type="text" value="out"/>	State: <input type="text" value="0"/>
DIO_D	Direction: <input type="text" value="out"/>	State: <input type="text" value="0"/>
DIO_E	Direction: <input type="text" value="in"/>	State: 0
DIO_F	Direction: <input type="text" value="in"/>	State: 0
DO_5V	Direction: <input type="text" value="out"/>	State: <input type="text" value="0"/>

Digital I/O Mapping

CAN

There are two CAN channels: A and B. For the connection to the Inclinometre, we use Channel A. under CAN A info, it should be enabled, with a baud rate set to 125000 bps. If you would like to see the data the inclinometre is sending to Node-Red, you can click on “Connect to websocket”. This isn’t particularly useful since it is in hex byte format, but at least you can see that it is working.

USB Storage

Here we can see if a USB stick is connected to the TDC. This will only update when the TDC starts. This means that the USB stick must be inserted before starting the TDC to work properly. This will be mentioned in the Use of the Trailer section below. When connected, it shows the path to the USB folder location which Node-Red will write to. If it is not connected properly, the TDC will not log any data.

GPS

Here we can see that the connected GPS is enabled and see what it is reporting. Without this enabled, the TDC will not log any data.

Node-Red code

To access the Node-Red interface, go to the dashboard and click on the image inside the Node-Red container box.



Node-Red Docker Image

It will ask you to login. The login information is the same as the TDC login listed in the TDC-E200R6 Overview section above. On the left you see available “nodes”.

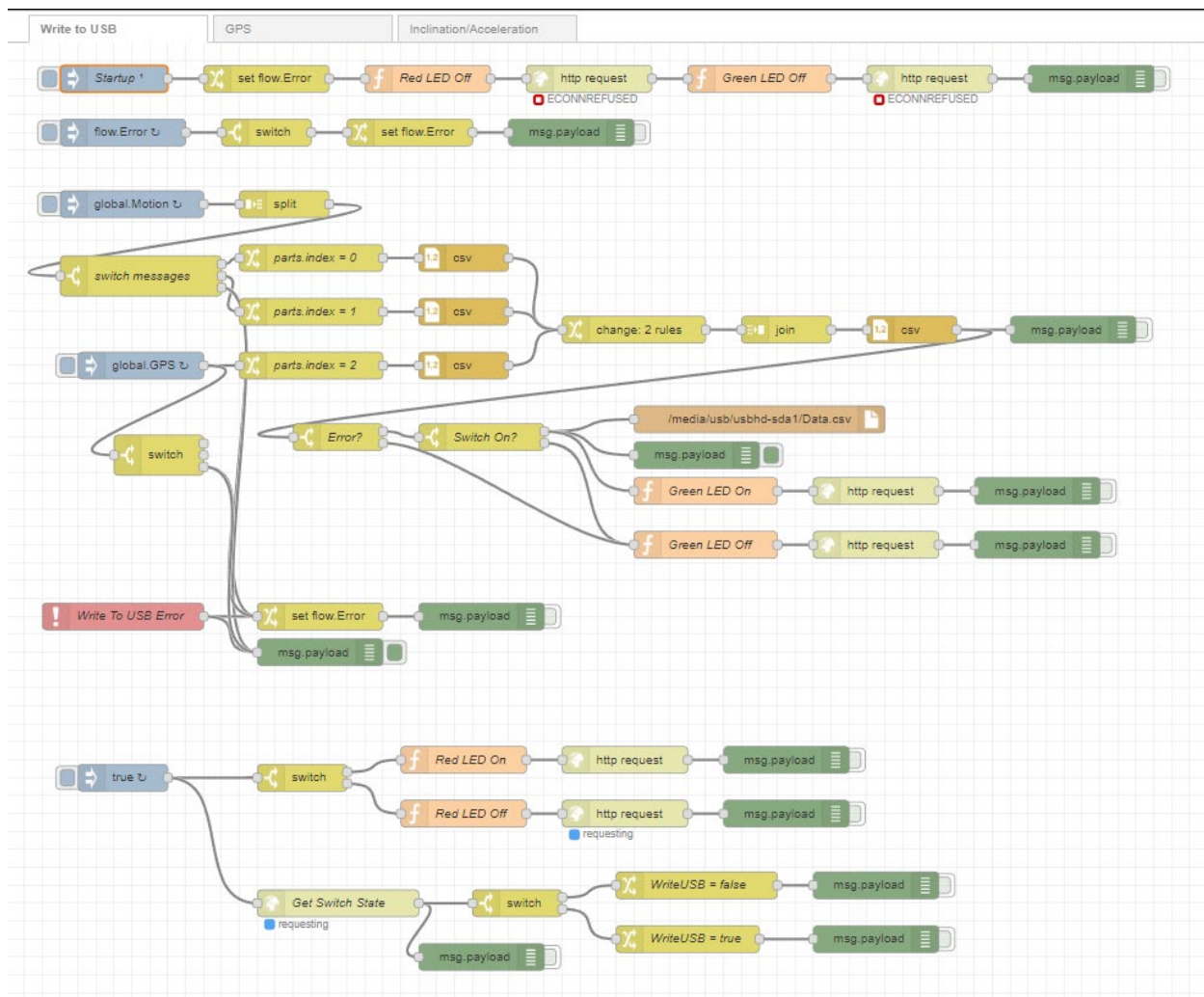
If you wish to change or write Node-Red “code”, you can drag and place nodes from there. The middle is where you see your “flows”. Each tab is a flow. For this project we have three flows: Write to USB, GPS, and Inclination/Acceleration.

On the right you can see info, debug, and dashboard tabs. We won’t be using the dashboard tab for this project. The info tab shows information about the node you have selected, and the debug tab spits out messages that we want to be shown or errors in the code. If you want to configure a node, double click on it.

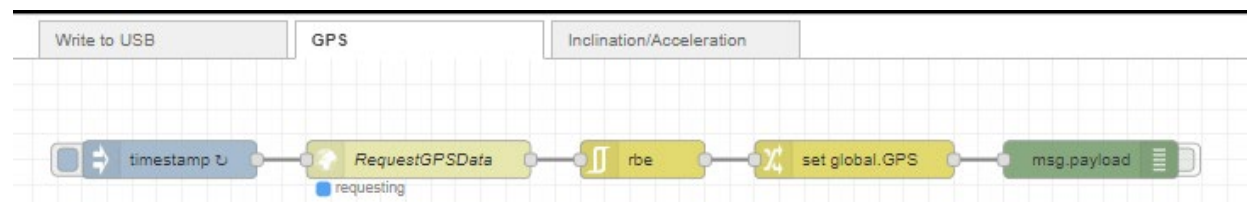
The networks of nodes you see in each flow can be exported into a long string which can later be imported by anyone with Node-Red. To export all the flows to your clipboard, click on the Menu icon on the top right of the screen > Export > Clipboard. This will open a popup where you can choose between “selected nodes”, “current flow”, and “all flows”. Here we want “all flows”.

Click “Export to clipboard”. This will save the long string to your clipboard. You will want to paste it somewhere to save it, in a text file for example. The string export for this project will be in a txt file that will accompany this report.

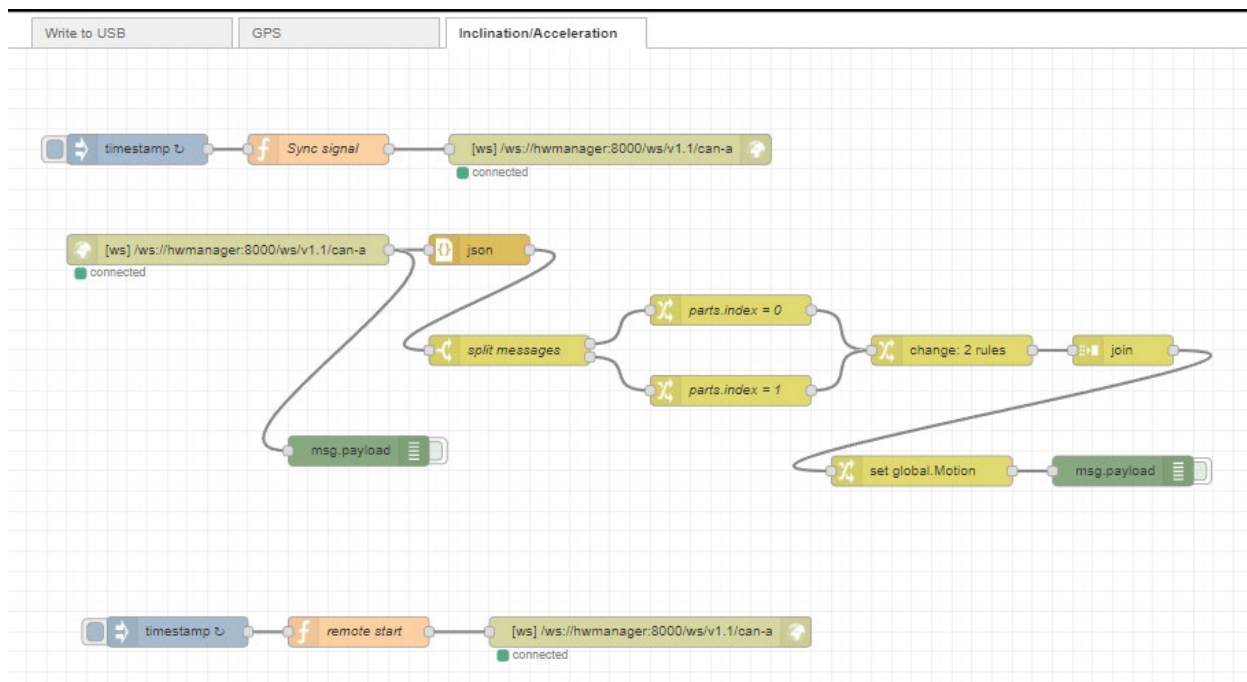
To import the string, open the txt file, select all, and copy it. In Node-Red, go to the Menu on the top right > Import > Clipboard. A popup will appear where you paste the string into the text box and click “Import”.



"Write to USB" Node-Red Flow



"GPS" Node-Red Flow



"Inclination/Acceleration" Node-Red Flow

Inclinometre

The Inclinometre used was an IFM JD2110. This sensor is capable of collecting and transmitting acceleration in three axes, pitch and roll angles, and angular acceleration in two axes. These are reported over the CANopen protocol which the TDC can receive.

Results

How to Replicate the Results

Processing

The data is stored in a CSV file inside the USB stick, called Data.csv. Make a copy of this file onto your computer and rename it to something that can identify what process the data is from (eg. "Data Tui Field Test.csv"). To process the data, an excel sheet was made with a macro to automate the process.

Open the "TDC-E Data Processing.xlsm" file in excel. If you have macros enabled, it should automatically ask you to select a CSV file. If not, then make sure macros are enabled and hit CTRL+L. Select the CSV file you copied off the USB stick.

Hit OK when the next prompt pops up. It will take a moment to process and then show another popup notifying you it is done.

Here, the important sheet to be looking at is the "Table" sheet. This is the data collected from the trailer. Since this is not yet very readable, we can export this table to be used in a map data visualisation program called QGIS.

First, save this excel sheet with the new data in it. To export this for QGIS, just hit the close button on the window. It will stop you and ask if you want to export for QGIS. Hit yes. It will then ask you where to save it. Please select a different name than the imported data csv (ex. "QGIS Tui Field Test.csv").

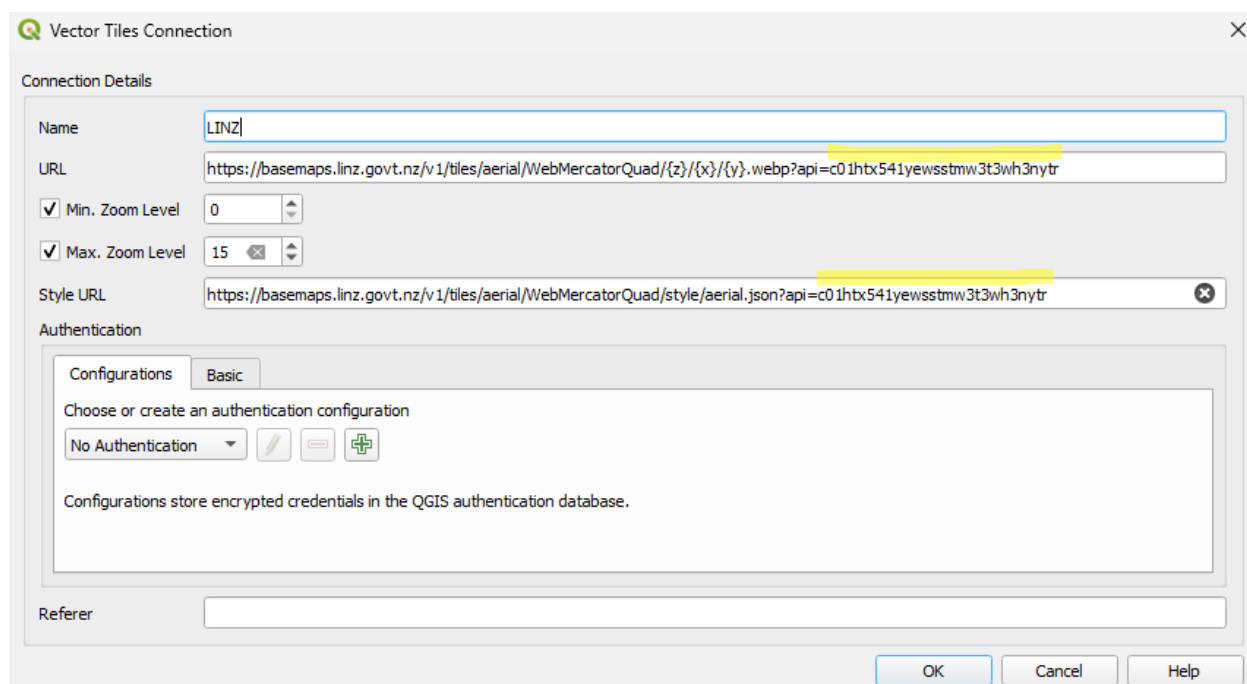
Mapping

Next, we will import it into QGIS. If you don't yet have QGIS, please download and install it. It is free. Open QGIS Desktop [version]. Once it loads, you will first have to import a base layer for the satellite image data. To do this, we will use LINZ basemaps.

Go to <https://www.linz.govt.nz/guidance/data-service/linz-basemaps-guide/how-use-linz-basemaps-apis> and scroll down until you see "Example request: Retrieve vector tiles for use in QGIS".

Follow the instructions there for getting the base layer setup. However, for the URLs given, use the ones in the picture below. The last part after ?api= will be different, however. To get the "API Key", go to this site and copy it from the menu on the top right:

<https://basemaps.linz.govt.nz/>



LINZ Basemap Setup

Now, on the left of the screen, you should see LINZ in the drop down under "Vector Tiles". Right click LINZ and select "Add Layer to Project". You should see a map appear in the centre area.

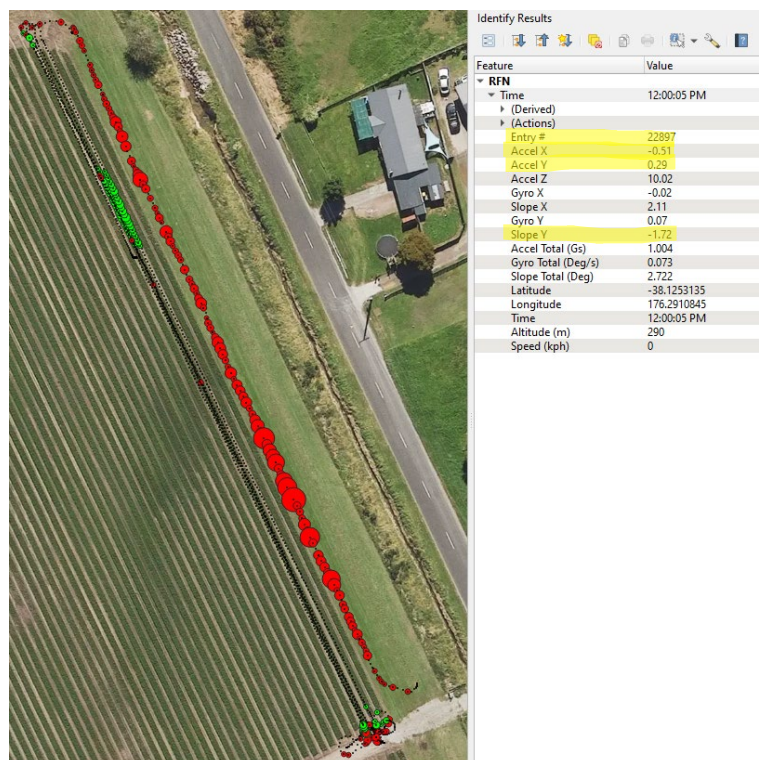
To add the data, go to "Layer" at the top, then "Add Layer" > "Add Delimited Text Layer". On the popup, select the three dots button on the top right and open the csv file exported for QGIS. You will see the "Sample Data" will populate.

Under the “Record and Fields Options” drop down, put one into “Number of header lines to discard”. Make sure to check both “First record has field names” and “Detect field types”. Now hit “Add” at the bottom of the popup. You will notice that points should appear on the map where the data was collected.


Next, we need to change how the data looks. With this report, there should be an accompanying file named “Accel and Slope Style.qml”. Copy that file to somewhere you can find easily. Now in QGIS, you should see the layer appeared on the bottom left area of the screen.

Right click the data layer (not LINZ) and select properties. On the left of the popup, go to “Symbology”. At the bottom, open the “Style” drop down menu and select load style. Hit the three-dot button and find the “Accel and Slope Style.qml” file. Now select “Load Style”. Then hit OK. The plotted data should now appear to be black dots with red or green circles around some of them.

The green represents excessive slope, and the red represents excessive acceleration. The larger the circle, the larger the value. This project should be saved if you would like to see the map later to edit or add more data.



Example Map Data Visualization QGIS

It is possible to see the data at each point. First click on the Identify Features tool () at the top of the screen. When you click on a point, or highlight a box around points, the right panel will populate with information about the point(s) as can be seen in the above picture. This shows all the data we passed in with the CSV file.

For example, the above picture shows data from the last point on the lower right of the map. It shows the entry # used in the table in excel, acceleration in the X, Y and Z directions (10ths of a G), angular acceleration (Gyro, degrees/sec) and slope in X and Y (degrees), total acceleration (Gs), total gyro (degrees/sec), total slope (degrees), latitude, longitude, time, altitude (m) and finally speed (kph).

Since the above selected data point was taken while at a standstill, the X and Y acceleration are near to 0, while the Z acceleration is close to 10, or one G. This shows that it is correctly reading gravity pulling in the Z direction. The total acceleration also indicates that it is experiencing nearly 1 G of force from gravity as expected. The red and green circles on the map are controlled by the total acceleration and total slope, respectively.