Introduction to Autonomous Mowing Robots

AMR

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Introduction

The intention of this website is to introduce to the public and investors the proto-type mowers that AMR has designed, built and is currently field testing.

AMR-100 Current Form (Cutting deck removed)

AMR-100 Production model conceptual drawing

Early form with Gasoline Mower attached

Early Form with electric mowing deck attached

AMR-200 Stripped down,

Fully autonomous Zero-Turn Mower. Mowing deck removed

AMR is a private company. It has developed equipment to allow large areas of grasslands to be mowed completely autonomously. The heart of the system is the AMR-NCP. The NCP is a navigation and controls package that can be retrofitted to almost every ride on mowers. It converts a manual operated mower to a fully autonomous self-driving mower. To test the AMR-NCP, AMR has also built
three fully functioning autonomous mowing robots. Two of the prototypes are currently being field tested. The family of AMR products include

The AMR-PHD is a independent GPS unit that output position and heading. Magnetic and ferrous materials do not affect it

The AMR-NCP includes the PHD and all other equipment to make a service robot vehicle autonomous.

The AMR-100 is an all-electric differential drive mower with a 24” mowing deck for areas up to 1 acre or 4,000 m² on one charge. With additional batteries it can mow still larger areas

The AMR-200 is a much larger gasoline powered differential drive mower that has a 50” mowing deck for areas up to 10 acres on a single tank of gasoline.

The AMR-300 is a conventional ride on mower. It runs on gasoline and has a 36” mowing deck. This mower differs from the previous mowers in that it has Ackerman type steering, whereas the others are differential drive steering robots. Field testing of this ubiquitous type of mower will commence after the completion of the field test of the AMR-100 and AMR-200 mowers.

The AMR-1000 is a variant of the NCP that can be retrofitted to agricultural tractors to make them fully autonomous. Using open source software and hardware we can make your tractor fully autonomous for between $3000 and $7500 depending on the options selected. We believe that this is a large market waiting to retrofit cheaper equipment than what is available from the named brands.

It is AMR’s initial intention to offer to the public the PHD and NCP plus one of the prototype mowers that we are field testing. Once support for the project develops AMR will widen the range on offer to include the remaining prototypical types. Developing the AMR-1000 will take place in parallel.

As part of this introduction we are going to focus on what we think are the key subject areas that you will be interested in. We are interested in your feedback so if there are other areas that we need to cover do not hesitate to let us know. The key area’s include, the mowing market, mowing accuracy, safety, the ease of operation of all of AMR’s mowers and what comes next. Included with this introduction on the AMR website are other downloadable documents in which we take the statements made in this introduction and we provide information to substantiate those statements.

**The Market for AMR robots**

Imagine that you have some grassland up to 10 acres that you want to keep mowed. This means you need a mower ($4000 to $20,000 for these larger tracts) and if you are lucky you will have someone else to do the repetitive work of operating the mower to cut the grass.

Let us take my case as we own a ranch in Texas. To keep the place looking good we need to mow an area of 10 areas around the house. It takes at least 10 hours to mow this area and on average we mow the same area 10 times per year. Now, if I charged myself or employ some casual labour it going to cost at least $20 /hour to do the work. This is a $2,000 per year cost as long as you want the mowing to take place. If you used a mowing service, I think the reoccurring costs would be significantly higher.

**By the way other than using livestock this is currently your only choice as there is not an autonomous mowing machine on the market that can handle this size of mowing task.**

If your area was a quarter to half acre, then no problem you do have some choice. You can buy one of the small electric, all plastic mowers that you have seen on the market for the last 5 years. These
mowers are basically grass maintainers. They typically have 8” cutting decks and mow at random. They have limited functionality, nor are they long lasting, powerful mowing machines. For the area they cover they are expensive. They range in cost from $1500 to $5000 for a machine that can do the job and in most cases, they cut less than half an acre. These mowers will cost between $3000 to $10000 per cut acre, whereas the AMR-200 costs $800 per cut acre. Lastly, they generally mow in a random pattern. As you can imagine they are not very energy efficient as they repeat cut the same area over and over before they finally cut 100% of the area.

At the other end of the market you could buy a fully autonomous tractor, however, that will cost $100,000 and they are not designed to mow in a “garden” type environment.

AMR has identified this need and has developed a range of autonomous mowers to reliably carry out your mowing needs from any sized area up to 10 acres. If you refill the gas tank you can mow even larger areas.

Potential customers can be found in the following user groups. Lawn Care companies, Schools, all sporting venues, air stripe operators, large gardens and ranches, municipalities with park lands the list is endless. During the pre-production phase we will undertake a full market analysis and will identify and approach potential customers. It will be our goal to fill an order book for 10 chassis before committing to production

**We are not just a mowing company we are a navigation and controls company**

The core of AMR is navigation and control of mobile robots. We are initially focussing on the mowing market as we think it is ready to be exploited. However, there are many other markets that can be easily exploited with the addition of some off the shelf equipment to AMR’s accurately positioned robotic bases. These include the addition of cameras for inspection, security, and military usage. The addition for sprayers, fertilization, and soil sampling equipment for small scale agricultural work. The addition of drags to level the surface of arenas. Even in their current state, all the AMR chassis can record geometric survey data of position and elevation to the cm level over its operational area. Obtaining real time cheap survey data for all types of construction projects would be invaluable. With the addition of readily available indoor navigation equipment the AMR electric chassis can be further utilized for indoor tasks.

**We hope that you will agree that the market for accurately positioned mobile robots has without doubt arrived. It just needs a company to fulfil the need with a reliable, accurate, safe and easy to use product.**

**Accuracy**

For any autonomous mower to be worth buying it first and foremost we must mow accurately and not waste energy. What ever mowing patter is chosen the mower should move in straight lines between the path waypoints. The straighter the mower moves on its path then the overlap between adjacent lanes can be minimized. Minimizing the overlap reduces the distance mowed.

To accurately quantify this goal of “straightness” we record continuously the distance the mower has moved off the desired lane location. We call this the Cross-Track Error (CTE). From our mowing trials we have determined that an average CTE of less than 5 cm +/- is required to look good and to be of acceptable efficiency for a commercial mowing product. As of the time of writing the AMR mowers are typically averaging a CTE of 9 cm +/- . The GPS that we use for navigation is accurate to
within 2cm so we are confident that with some further work and sensor tuning we will make the 5cm+/- goal.

The chart posted below plots the record of CTE for a mowing mission. By eye you can see that most of the data is below 20cm and with some statistical analysis we determined that the average CTE for this data set is 9cm+/- . We record this data for every mission and use it to drive further improvements.

The bottom left chart shows the actual mowers trajectory in relation to the actual desired path and CTE. The dots are heat coloured so the error is obvious. Green dots good, Orange ok and red out of specification.

The bottom right chart informs us of the area that was mowed vs missed. The absence of white uncut areas visually shows the vast majority of the area. After doing some maths it is calculated that 98% of the desired area was mowed. Both charts are used to visualize the mowers performance and to let us know when we are making improvements.

This outstanding accuracy is made possible by using a GPS system that utilizes what is known as "Real Time Kinematics” or RTK GPS. RTK GPS, out of the box is accurate to within 2cm. When this GPS system is combined with other sensors like an IMU and wheel encoder the accuracy can be further improved.

**Safety**

The AMR autonomous mowers have been designed from the ground up with safety being the highest priority. The system includes many safety features to ensure that your mower is always under our control. It includes the following safety features.
• An autonomous mission cannot be started unless an entry code is input and the “start” button on the data display screen has been pressed.
• The mower has two ways to be controlled. Manually by using a radio-controlled transmitter and the second is in AUTO mode in which the mower is driven by the system computers. At any time, you can switch from AUTO mode to Manual mode and drive or stop the mower via the RC Transmitter.
• Mounted on the mower in a convenient location there is a physical engine kill switch.
• A remote engine kill switch is also assigned to one switch on the RC transmitter. This has a range of several kilometres.
• We have devised a handheld remote kill switch, called the PIK. The PIK continually receives status reports from the mower. These status reports can include the following being stuck, not moving, low fuel or low battery voltage, poor GPS and so on. Once the state is received you can take the appropriate action including killing the motors. This unit was designed so that you do not need to carry around the bulkier RC transmitter.
• All permanent obstacles like trees can be pre-programmed and then avoided when the mission goes live. On the production versions we will also include a sensor to avoid more transient obstacles.
• As part of the mission planning process a virtual fence is set up around your mowing area. If the mower attempts to drive outside of the mowing virtual fence the mower will immediately stop and send the state to the PIK.
• The system also includes a GPS quality test. If the quality of the GPS signal falls below a predetermined value, the mower will stop until the quality of the GPS signal returns to specification.
• The mower can be monitored via your PC on a mission map via radio. If the mission develops a fault condition you can take corrective action via the RC transmitter.
• The above-mentioned monitoring can be extended to other locations via the internet.

Ease of Operation

When you buy one of our systems you need to carry out some pre mowing set up tasks. These include setting up the GPS base station and loading software onto your laptop. We will be on hand to walk you through the process. We will have pre programmed your first mowing mission before the mower leaves the factory. We will include in the production website text and video material plus an extensive operator’s manual.

As the rover has wireless connectivity, so after taking your permission, we can gain access to your mower via Wifi and undertake most of the location specific set up actions remotely. This feature is useful as we can review all of your settings to verify that your mower is correctly set up for mower operations.

Setting up the base station involves recording a static location for one hour in order to determine the exact location of your base station. This base position information then needs to be entered into the base GPS receiver and then you are good to go.

It only takes a few minutes to prepare your mower for a mowing mission. This includes switching on your base station, manually driving the Mower out of the garage. Waiting a few seconds until the
GPS is fixed. Press Start on the main display screen and then move the transmitter switch from Manual at to the Auto position, then the mower is self-driving.

At first, we suggest to closely monitor your mower in case of some unexpected situation. As you build confidence with your mowing areas you can progressively rely more on the remote monitoring tools rather than physically being present.

**What’s Next**

After reaching the CTE 5cm+/– accuracy goal it will be time to raise funds to undertake all of the necessary pre-production activities required to commercialize AMR’s products. Broadly these activities will include:

- Contracting robotic hardware and software engineer to further develop the AMR Navigation Control Package to ensure durability of all components and finalize designs of in-house mowing chassis.
- Undertake detailed Marketing studies to determine the best markets and pricing.
- Actively develop the market via website, industry events.
- Reaching out to high net-worth individuals to secure funding.
- Incorporating AMR and securing its Intellectual Property rights. Setting up minimal administration functions.

So how much do we think this is going to cost you? Current estimates for the NCP is around $5,000. This is in addition to the cost of your mower. This would represent about 2.5 years of mowing cost which you would have anyway if you do not buy our products.

So, if you have any interest in investing in the company or purchasing one of the first autonomous mowers on the market then place contact us at info@autonomousmowingrobots.com.
PART II

AMR Supporting Material to Investment Case

In these pages we go into more detail in the following key areas

1. Accuracy
2. What is RTK GPS
3. Operational Details
4. Specifications of each Mower

1. Accuracy of the Mowing System

To develop an accurately positioned self-driving robotic mower we need to obtain in real time extremely accurate position and heading data. Until recently obtaining data with this level of accuracy was economically not justified. To understand what we need let’s break the subject into two parts, position and heading.

The problem with traditional GPS that is little known nor understood is that the locations published by the GPS are distorted due to effects within the atmosphere. Typically, a position taken over a period of time from a fixed location will vary around a fixed location by anything up to 8 meters. This means that we only know our position to within 8 m from that central location. That means we could be anywhere within a 50 m² circular area around the central point. This is perfectly ok, when walking in the hills or sailing your ship across the Atlantic or even flying a plane. Some more modern systems receive correction data with the satellite data that allow the location to correct for the error and reduce the uncertainty in position down to 1-2 meters. This would be a location within an area of 3 m². This accuracy yet again is fine for some applications but not for precise mowing. To get to 2cm of uncertainty we need to add a local base station to the system and to use the RTK acquisition technique. At 2cm our error circle is 3.1cm². This is less than a square inch.

Regarding heading, have you ever tried using a compass to guide you? It wobbles all over the place. OK to know roughly where north is, but no good to us. We need accuracies of 1 degree to be able to drive along straight lanes. Well the modern equivalent of a compass is called an IMU. This electronic device combines 3 separate sensors in a small package to deliver heading, roll and pitch. Unfortunately, the heading can easily be distorted by any iron or magnetic materials brought near to the unit. This distortion can be 10’s of degrees and will throw us off course. So we can not rely on an IMU for our heading estimate.

RTK GPS also can provide a solution to this as well. By using 2 GPS’s on the rover separated by 1 meter we can work out a heading between the 2 GPS antennas. This heading estimate is not adversely affected by any metals at all and it is very accurate.

What level of accuracy can we expect?

“State of the Art” Dual frequency Real-Time Kinematics (RTK) GPS is used to guide the mower. This is the most accurate GPS on the market. It is typically accurate to within 2cm. Unfortunately, just because the GPS is accurate to 2cm does not necessarily follow that the mower can follow a path to within 2cm. This is because the mower has play between the motors and wheels, delays between gathering data and issuing move commands, we also mow on challenging sloping ground and a raft
of other reasons as well. The skill is to reduce the mismatch in desired position determined by our mowing plan and our actual position as determined by the GPS mounted on the mower.

Ideally, for efficiency reasons the mower should drive as straight lanes between a start and end points as possible. The straighter the line the less overlap required between adjacent lanes. Any deviation from the desired path we call the Cross Track Error (CTE). We recorded the CTE continuously and currently we average a CTE of less than +/- 9cm from the centre of the desired path. We are working on improvements to this parameter and early signs indicate that prior to commencing the pre-production phase we will achieve a CTE of +/-5cm or less. This level of accuracy is important because with it the lanes are straighter and with straight lanes, we can minimize the need to have larger overlaps between mowing lanes. This in turn saves time, energy and wear and tear on the mowers.

For each mission we record all sensor and command data. After the mission is completed the mission report file is automatically emailed for analysis of the mission. All mowing missions are then analysed to derive key performance indicators that help to further improve the efficiency of the mowing process.

The images below are generated from data recorded during the mission. Each coloured dot represents a position of the mower during the mission. The grey dots represent the desired paths. The distance between the two is the CTE and it has been heat mapped to better show the error.

**Fig Heat Map of Rover’s actual position (coloured) vs desired/planned position (gray)**

The second chart is the log of the absolute CTE with time of the mission. The average of the current CTE is 9cm. This will be reduced to 5 in due course.
The actual area mowed...

The last chart is a plot that shows any area that the mower did not cut i.e. a missed area will show up as a white area. Currently we are cutting 98% of the mowed area.

2. What is (RTK) GPS?

The GPS system that we use for positioning is called a dual frequency Rover-Base RTK GPS system. It involves a GPS receiver and antenna on the rover and one on the base station. To derive a heading we use an additional third GPS receiver and antenna located 1m from the position GPS in a Moving Base configuration. By working out the position of the two rover GPS relative to each other we get a heading.
The base station is surveyed for some time (on one occasion) so the base GPS knows its exact location down to a few centimetres. During operations the base is receiving continuously its location (plus its positional error) from the satellites. The Base GPS calculates the error between the known position and newly acquired position. The Base then sends via conventional radio this error to the rover, where it is used to correct the position of the rover.

This system updates the position and heading 5 times a second. So for the AMR-100 traveling at 0.5 ms\(^{-1}\) we get a new very accurate data set at every 10cm. If we merge this data with wheel encoders we can get faster update rates.

If you have researched this new technology, then you may have come across Ntrip. Without detailing it here, this is a way to reduce the cost of the GPS equipment and to obtain the error corrections due to the atmosphere from a cell phone via a Ntrip server.

3. Operational Details

All the normal activities that relate to conventional mowing, like mowing machine maintenance, mowing deck height, speed of your mowing operation all remain the same for autonomous mowing so they are ignored here. We should point out that as an operator is not required the machine can be driven slower. Although the mission takes longer it is gentler on the grass surface and the machine. This is better when you are mowing in more fragile grasslands environments.

AMR has developed proprietary software to help you plan and analysis mowing missions. We did this to ensure that the customer has the flexibility to fully utilize all the benefits of autonomous mowing.

We normally think that mowing should be done in parallel lanes. However, this is only one of many ways you can carry out a mission. We include software to generate clockwise, counter-clockwise, and parallel lanes mowing missions. In addition, we include a hybrid method that is a combination of clockwise for the outside and parallel lanes for the interior of the mowing area. At first you may not see the advantage of one system over the others. We can say that the circular missions involve less turning and therefore they are faster and cause less wear and tare on the machines.

In addition to mowing in different styles we can also join individual mission from different zones in to one larger mowing mission. Lastly if we so desire we can mow and area in one direction today and then in another direction when it is next mowed. Apparently changing the mowing direction is better for the grass.
Creating a mowing mission

To create a mowing mission, you need to download and install the open source software called Mission Planner.

Then locate the area you want to mow within mission planner. You then outline the area you want to mow with a simple polygon. This is a simple matter of clicking on the satellite image of your mowing area. Save this polygon and then open AMR proprietary software called Mow Plan that will turn the polygon into a mowing mission in seconds. You will need to provide some basic information like the mower deck width etc. You need to choose the type of mission you want to create ie clockwise, counter-clockwise or parallel lanes. You then select the input and output files and the associated parameters like cutting direction. Press execute and the software produces the mowing file.

Load the file created by Mow Plan back into Mission Planner to make sure that it is what you want.

And then finally create the references to the mowing files in the configGeneral file and then you are good to go. With a little practice you can make a mowing mission and loaded it onto the mower in 3 to 5 minutes.

Our program allows you to merge any number of mowing missions. It also allows you to identify obstacles to be avoided like trees.
For now, we should point out that you can select from any or all of the missions that have been programmed. So if today you want to mow east west and tomorrow north south you can change between the two stores missions. It takes a few seconds.

**Normal Operations to undertake a mowing mission**

Now that a mission has been created what do we need to do to run the mission?

For normal operations turn on the base station, prepare your mower, drive the mower out of your garage, obtain the RTK GPS fix from the base station and then your mower will do the rest. You will be mowing your garden within 3 to 5 minutes.

**4. Specifications of AMR prototype Mowers**

**AMR-NCP (Navigation and Control Package)**

The AMR-NCP is the heart and brains of the control system. It can be retrofitted to any mower to make it fully autonomous. The package consists of the system electronics, the RTK GPS equipment required for positioning and heading plus either two linear actuators or a motor controller for the electric models. Depending on requirements it also can include additional sensors like IMU, wheel encoders and avoidance hardware.

**AMR-100**

The AMR-100 is a total mowing solution, built by AMR, it comprises of a custom chassis designed to hold either a 17 to 21 inch petrol engine mower (see left) or a 24 inch cut all electric mower (see right). The AMR-100 comes in 2 varieties.
**AMR-100RC** In this version the mower is set up to be completely controlled by Radio Control only. So this means that you need to be driving the mower at all times. This is quite useful for cutting area that you do not want to push a conventional mower.

**AMR-100AC** This version has the full GPS NCP fitted so it can operate in RC mode and Auto mode and be totally autonomous. The mower is capable of mowing for 60 minutes before requiring the battery to be recharged.

The AMR-100 is designed for small to medium size gardens. It is capable of mowing 0.8 acre in an hour.

**AMR-100 Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total system battery capacity</td>
<td>72.8 lipo amp/hours</td>
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<tr>
<td>Current consumption of system</td>
<td>5 amp.</td>
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<tr>
<td>Endurance of batteries</td>
<td>4 hour++ Batteries can be added to augment this</td>
</tr>
<tr>
<td>Area mowed per hour</td>
<td>1,000m²</td>
</tr>
<tr>
<td>Area mowed on 1 charge</td>
<td>4,000m²</td>
</tr>
<tr>
<td>Speed of mower</td>
<td>0.5 meters/second</td>
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<tr>
<td>Mowing Zones</td>
<td>Multiple no limit</td>
</tr>
<tr>
<td>Weight</td>
<td>58 kg</td>
</tr>
<tr>
<td>Dimensions</td>
<td>115(L)X 75(W)x 50(H) cm</td>
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<tr>
<td>Mowing deck width</td>
<td>60 cm</td>
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<tr>
<td>Suggested Mowing lane gap</td>
<td>30 cm</td>
</tr>
<tr>
<td>Mowing accuracy mowing system</td>
<td>9 cm +/-</td>
</tr>
<tr>
<td>Accuracy of positioning system</td>
<td>2 cm +/-</td>
</tr>
<tr>
<td>Expected Mowing coverage</td>
<td>98% (uncut area therefore is 2%)</td>
</tr>
</tbody>
</table>

**AMR-200**

With the NCP fitted, the mower travelling at 1.5 m/s it will cut approximately 1.3 acres per hour at current accuracy tolerances. With a 5 gallon tank of gasoline this mower currently consumes 1 gallon of fuel per hour and therefore will cut 6.5 acres on a single tank of fuel. The mission will take 5 hours.
With future improvements in accuracy it is expected to mow 2 acres per hour. Also we expect the fuel consumption to drop due to engine downsizing and therefore we expect to cut 13 acres and on one tank of fuel. The mission will take 6.6 hours. If the fuel tank is increased to 8 gallons the mower could cut 24 acres in on one tank of fuel.

**AMR-200 Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total system battery capacity</td>
<td>amp-hours</td>
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<tr>
<td>Current consumption of system</td>
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<tr>
<td>Endurance of batteries</td>
<td>Batteries charges by engine charging system</td>
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<tr>
<td>Area mowed per hour</td>
<td>5,000 m² currently 1.3 acres per hour</td>
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<td>Area mowed on 1 tank of fuel</td>
<td>25,000 m² per hour</td>
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<tr>
<td>Average size garden in the UK/USA</td>
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<tr>
<td>Speed of mower</td>
<td>1.5 meters/second</td>
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<tr>
<td>Mowing Zones</td>
<td>Multiple no limit</td>
</tr>
<tr>
<td>Weight</td>
<td>kg</td>
</tr>
<tr>
<td>Dimensions (L)X (W)x (H) cm</td>
<td></td>
</tr>
<tr>
<td>Mowing deck width</td>
<td>1.27 cm / 50 inches</td>
</tr>
<tr>
<td>Suggested Mowing lane gap</td>
<td>1 m</td>
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</table>
Mowing accuracy mowing system 12 cm +/-
Accuracy of positioning system 2 cm +/-
Expected Mowing coverage 98% (uncut area therefore is 2%)

**AMR-300**

The AMR-300 is based on a conventional ride on mower. We have streamlined the mower by removed everything that is not required for mowing. Using two linear actuators we have made this 36 inch cutting mower fully autonomous.

Due to the different style of steering, this project is still in its early stages of development. Currently it is in the assembly stage. No mowing trials have yet taken place. Having said the above once we finalize the steering algorithm for this style of mower it will take very little time to reach a fully working prototype.