DOUGLAS BOMFORD TRUST

Harper Adams University

Field Robot Event Proceedings 2016

Eric – Harper Adams University

- Joseph Allin – Harper Adams University
- Josh Matthews – Harper Adams University
- Ali Taylor – Harper Adams University
- Tom Lindley – Harper Adams University

Harper Adams University, Newport, Shropshire, TF10 8NB

1 Introduction

On the 14th June 2016 agricultural engineers from across the globe congregated in Haßfurt to compete in the annual Field Robotics Event. The robotic event was run in conjunction with the DLG Feldtage event, an annual agricultural show. The robotic event consisted of four individual tasks with varying difficulty:

- Task 1; navigate up a 75cm wide maize row for 15 metres, turn in a 2m wide headland and then navigate down the second row and so on.
- Task 2; was similar to task 1 only a sequence of rows would be provided. For instance, down one row, left turn, miss 4 rows, down the 5th row and so on.
- Task 3; was a demonstration of weed detection and spraying whereby the robots would drive up and down rows as in task 1, only this time with randomly placed pink golf balls (signifying weeds) which must be sprayed.
- Task 4; was the ability to drill seed into a cleared patch of ground with appropriate metering and navigation of the robot.

The aim of the event is to demonstrate the current abilities of modern electronics and sensing equipment to fulfil complex tasks appropriate to agricultural applications. This is in light of an ever growing population and the subsequent need to bring technological efficiency & effectiveness to the agricultural sector. The event therefore highlights a potential avenue to ensure global sustainability through the utilization of modern robotic technology.

This report summarises the design, testing and progress of the Harper Adams University team (of which comprises of the four authors) with their robot, Eric. Firstly the mechanical elements are discussed; vehicle, spraying and drilling. This is followed by a detailed breakdown of the sensing equipment and software used to control and navigate the robot. It should be noted that this buggy shares no resemblance or hardware from either of the previous year's teams, except for the choice of sensor.

The team would like to take the opportunity to thank our sponsor, the Douglas Bomford Trust, for their assistance in travel and accommodation to and from the event.

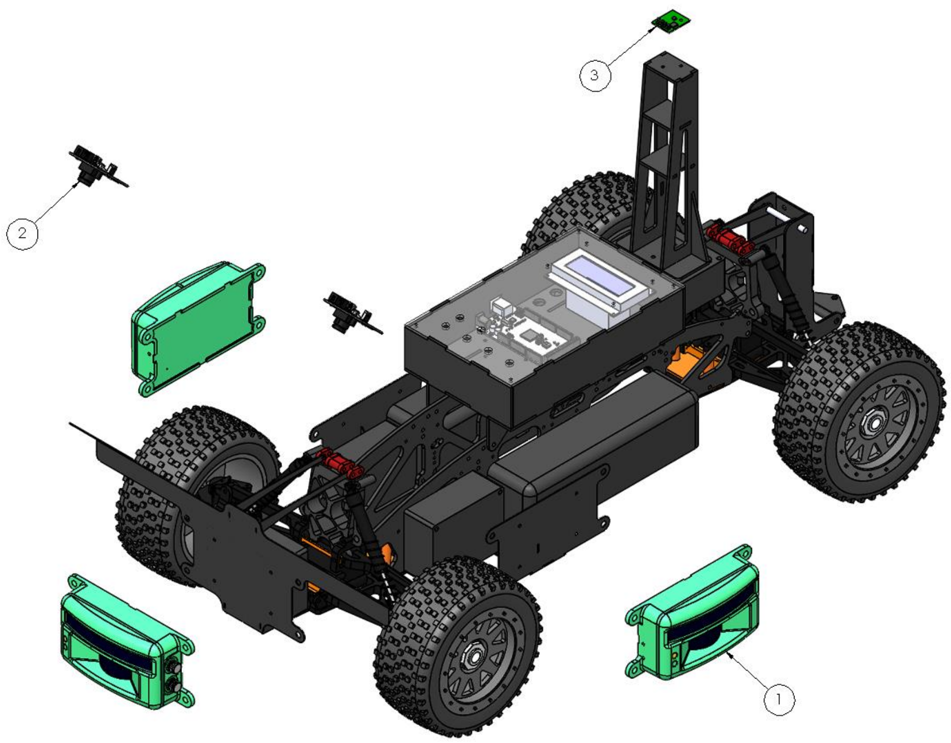
2 Mechanics and Power

The following sections outline the mechanical design and function of the individual elements of the robot; vehicle design, sprayer design and drill design. Throughout the design of Eric a stripped down approach was took in the interest to save money and time as both were budgeted. Therefore, the robot adopted a functional & "naked" appeal as it was designed for the task at hand and nothing more.

2.1 Vehicle

The core of the robot was an "off the shelf" radio controlled (RC) car, this provided a reliable, powerful and functional platform for the rest of the mechatronics to be mounted upon. Some modifications were made; rear axle replaced with a front axle to allow for four wheel steer. The motor was geared down to improve torque and pulling capabilities. The rear suspension was locked out using laser cut plastic to improve the load carrying capability. Apart from these adjustments the mechanical working of the RC car was unchanged. Two 11.1V 3S 3500mAh batteries provided all of the power required; one supplied the high current components (drive motors, sprayer pumps etc.) whilst the other supplied the control and sensing components.

Figure 1 shows an exploded view of the surface mounted sensing equipment on the vehicle.



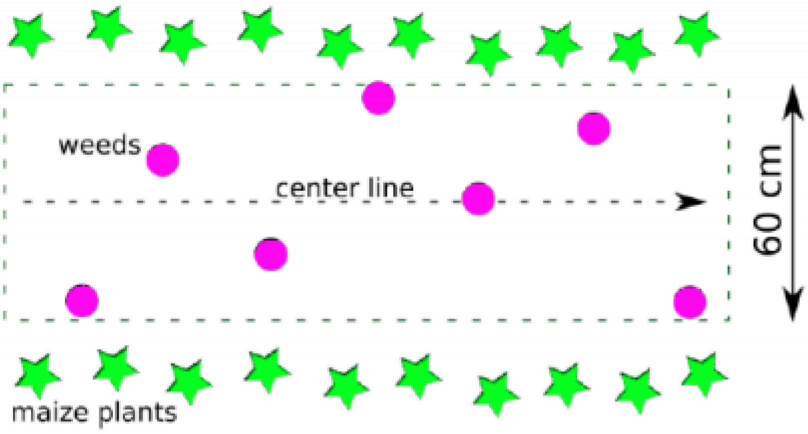
Source: author’s own.

Figure 1 - Exploded vehicle assembly showing sensors fitted

From Figure 1 the LED scanners (1) can be seen. Three of these were used, one in front to guide down rows and two on the side to detect row ends and navigate in the headland. Two digital imaging cameras were mounted to the front (2) which both detect weeds in task 3 and follow the red line in task 4. These were mounted on laser cut steel (1mm) and had polystyrene covers to prevent water ingress. A compass was mounted on a mast towards the rear of the vehicle (3) to indicate vehicle direction. The mast was created with laser cut plastic and lifted the compass away from interference from the primary ECU and high current electrics. The main box on top of the vehicle housed many of the electrical components. It featured a clear lid so that the screen could be read with minimal chance of water ingress throughout use. All parts added to the vehicle were designed, built and assembled at the university and were made to be easily accessible, serviceable and replaceable.

2.2 Sprayer

In the spraying task robots were required to travel up and down the rows (as in task 1) whilst detecting & spraying weeds which were represented by pink golf balls. Figure 2 shows the layout of the course.



Source: (Field Robot Event, 2016)

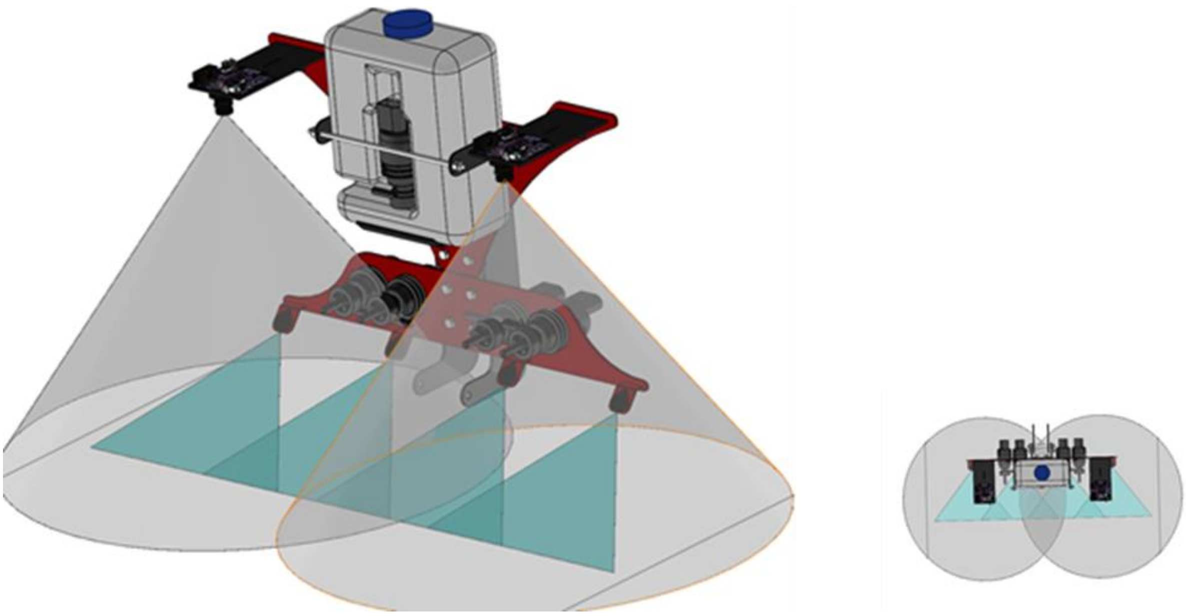
Figure 2 - Task 3 example course layout

As can be seen in Figure 2, golf balls could be positioned in a number of locations within the row of maize plants.

This section describes the design and function of the sprayer unit. A number of spraying methods were considered;

- Pressurised tank – a system requiring one pneumatic pump to pressurise the tank which would then require a valve block to switch flow to individual nozzles. The pneumatic pump could have been manually operated.
- Single pump – a system requiring one pump and a valve unit to switch four individual nozzles.
- Quad pump – four pumps operating individual nozzles.
- Single pump and nozzle – whereby the nozzle moves to suit the positioning of any weed via the camera.

A pressurised tank or single pump with four nozzles would have both needed a complex, expensive and sizable valve system and were therefore not chosen. A single movable pump would have reduced component size and packaging, but would have increased the complexity in programming and required the development of a mobility system of which the camera and nozzle can move. The quad pump option was therefore chosen as it reduced complexity and cost. Four inexpensive pumps were specified along with four nozzles. The number of nozzles (four) was chosen after initial pilot testing whereby the nozzles were held at half the height of the buggy (an estimation made from initial sprayer design concepts) with a 45 degree angle towards the floor. Four were required to achieve an effective spray coverage with slight overlap and spanning the entire 60cm row. The nozzles themselves were also selected from a range of tested nozzles as they gave an optimum spray/mist pattern and did not spray unevenly or in jets. Figure 3 shows the graphical work done to represent the system and ascertain nozzle coverage and height. This was done as time & cost restraints meant that multiple prototypes could not be made. The lines either side signify row width.

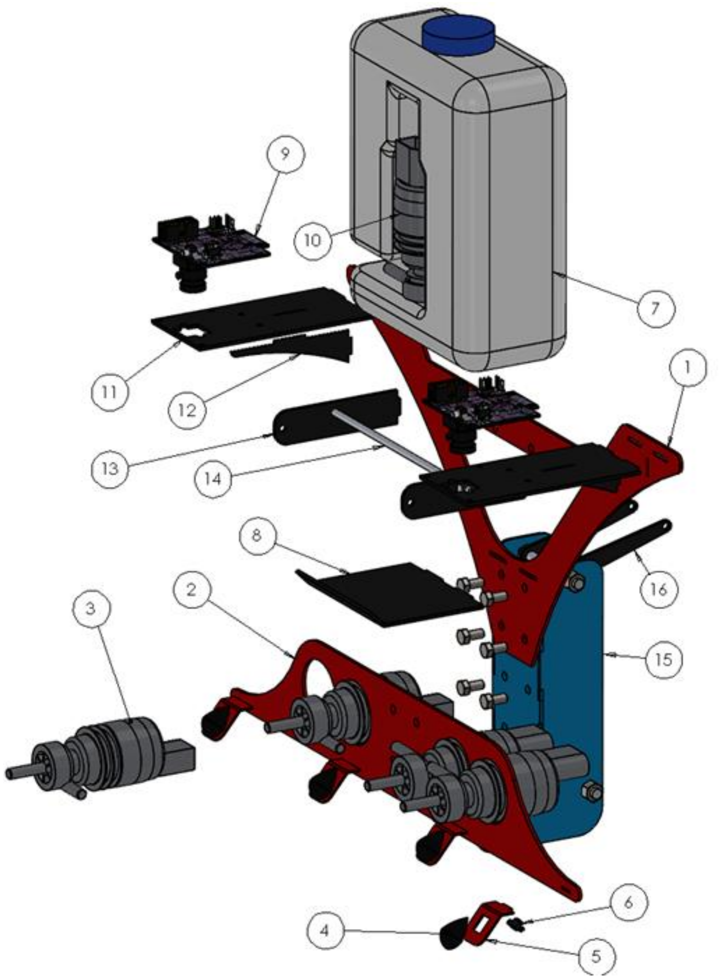


Source: author's own.

Figure 3 - Digital prototyping to determine nozzle and camera position and angle

As seen in Figure 3, the nozzles do not quite reach the far edge of the row. This was corrected by slight angling of the outer nozzles which still allowed for a little overlap. The above view also demonstrates the highly compact design, particularly in depth to ensure significant moments were not induced on the robot due to overhanging weight. The greyed cones in Figure 3 show the viewing areas of the cameras specified by the manufacturer. The cameras were set at just over 300mm from the ground which would provide adequate coverage and were positioned outwards from the rear of the sprayer so that the pump and nozzles would not hinder the view. However, in the final stages of development, the rear cameras were not used as testing proved that the wheel encoder was accurate enough to allow the front sensor to detect the weed and accurately measure the distance to the rear of the vehicle.

The design itself is biased towards simplicity of build, small package size and weight. The downside to this system is the presence of four pumps, however, these were neatly packaged on the boom alongside the nozzles and thus, did not require a great deal of extra space. The control box was attached to the rear of the tank, which is not shown in the model. The two halves of the sprayer (top and bottom) could detach into two pieces, this is to ease assembly, fitting and removal whilst also allowing flexibility in spray height through the various hole-compatibility. Figure 4 shows an exploded view of the sprayer unit along with a bill of materials.



ITEM NO.	Description	QTY.
14	Spray Tank Retaining Bar	1
13	Spray Tank Restraint	2
12	Camera Mount Gusset	2
11	Camera Mount	2
10	Priming Pump	1
9	Imaging Camera	2
8	Spray Tank Mount	1
7	Spray Tank	1
6	Fluid Delivery valve	4
5	Sprayer Nozzle Mount	4
4	Sprayer Nozzle	4
3	Spray Pump	4
2	Lower Mount Plate	1
1	Top Mount Plate	1

Source: author's own.

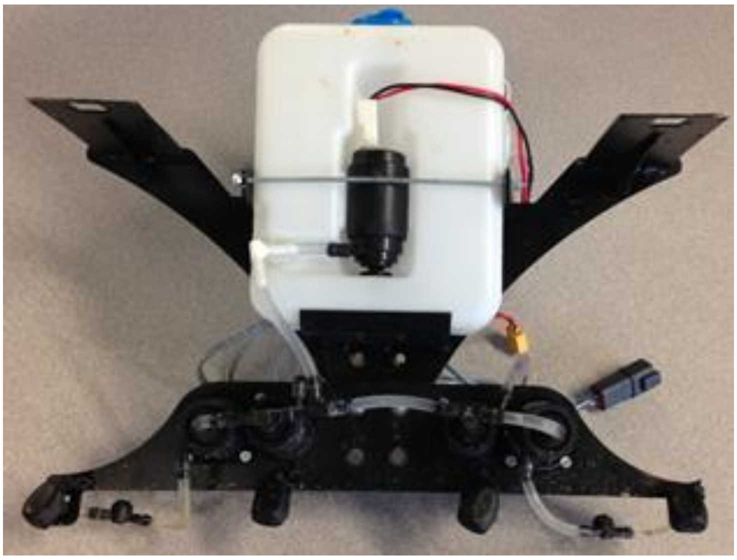
Figure 4 - Exploded diagram of the sprayer unit

Figure 4 highlights the refined design. All welded components were fitted with tabs which made manufacture extremely quick and efficient. Item 15 and 16 in the exploded view are the components of the hitch and not part of the sprayer unit (highlighted in blue).

Testing of the sprayer quickly highlighted four problems. Firstly, the water would slowly empty itself through the nozzles with the pumps switched off. This problem was solved by the inclusion of pressure-to-open delivery valves which immediately halted leaking. The second issue was the inability of the four boom pumps to begin flow without initial priming. Therefore, the priming pump (found on the bottle) was utilised at the beginning of the spray sequence to prime the entire system with fluid before commencing. This worked extremely effectively and not once did the system stall due to air-locks.

The third issue was found that slightly weaker delivery valves could be opened by the suction of another pump; i.e. when operating nozzle one, the delivery valve would allow some amount of air into the system and therefore causing an air-lock. This was solved through replacement of faulty valves. The final issue was slight fouling of the wheel on the end of the booms which was quickly corrected by a spacer.

All issues were overcome and the sprayer proved to be very effective in testing with good coverage of spray across the row. Figure 5 shows the final physical sprayer after the competition.



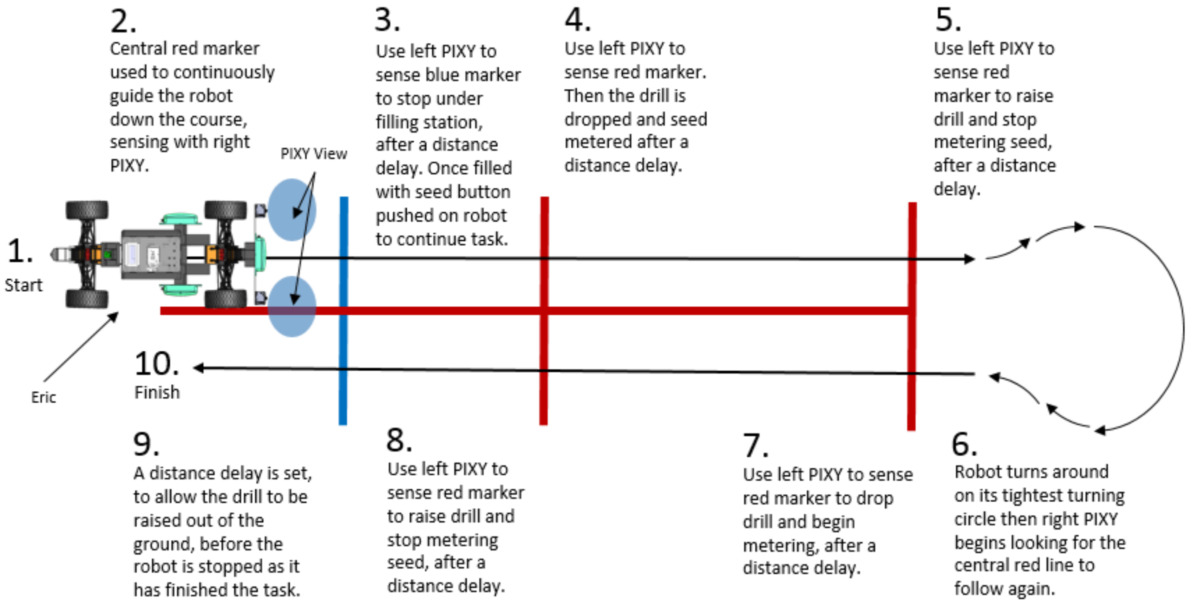
Source: author's own.

Figure 5 - Actual sprayer as used at the competition

The routing of the pipework can be seen in Figure 5 along with the necessary T pieces, right angles and delivery valves. The sprayer proved successful on the day by demonstrating a simple yet well executed solution to the task at hand.

2.3 Drill

Task 4 in the Field Robotics Event 2016 involved a seeding task; where robots had to communicate with a filling station to receive seeds, and then sow them evenly in a 10m^2 area where there were visual ground markers to help the robots navigate. The team decided on a methodology that used the visual markers provided, with the right mounted camera following the central red line to guide the robot up and down the drilling area. The second, left mounted camera, was then free to look for the sequence of blue and red markers needed to step the robot through its seeding mode program. This is shown in Figure 6.



Source: author's own.

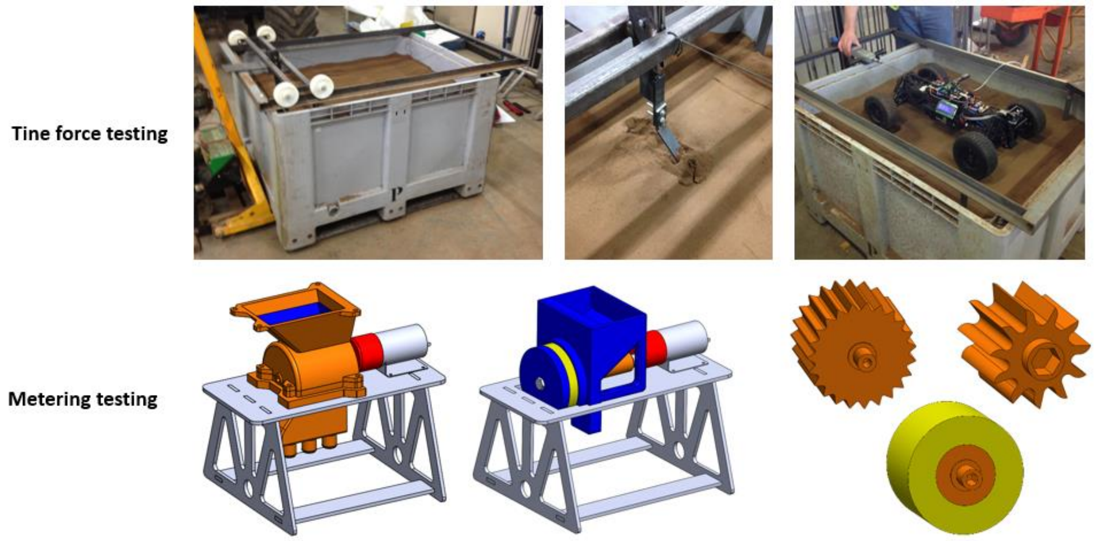
Figure 6 - Layout and sequence of events for task 4

2.3.1 Approach to Drill Design

The methodology chosen by the team outlined two main areas for developing a drill:

- Metering seed from the hopper to 3 coulters equally, with the ability to be turned on and off and be able to match application rate with the robots speed.
- Putting the seed in the soil and covering it back over.

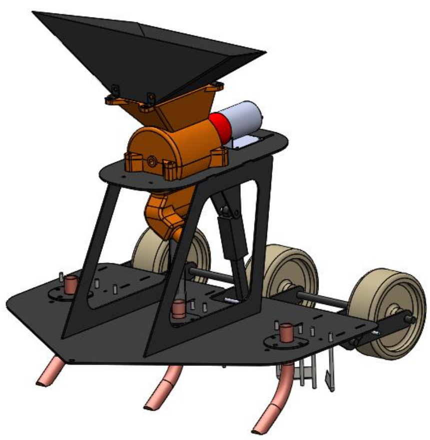
The team did some preliminary testing to help design the drill in both the areas documented. A soil bin was made so that small tine forces could be measured, with different designs of tine tested. This was compared to the tractive capability of the robot being measured, so that it could be understood if Eric was able to pull a drill. In addition, two different metering systems were 3D printed and tested in terms of uniformity during operation. Different rollers for concept 1 were tested to understand if there were benefits from using one roller over another.



Source: author's own.

Figure 7 - Tine force and metering unit subsystem testing

The outcomes of preliminary testing influenced the final design of the drill (Figure 8). The following sections describe the logic behind the design process.

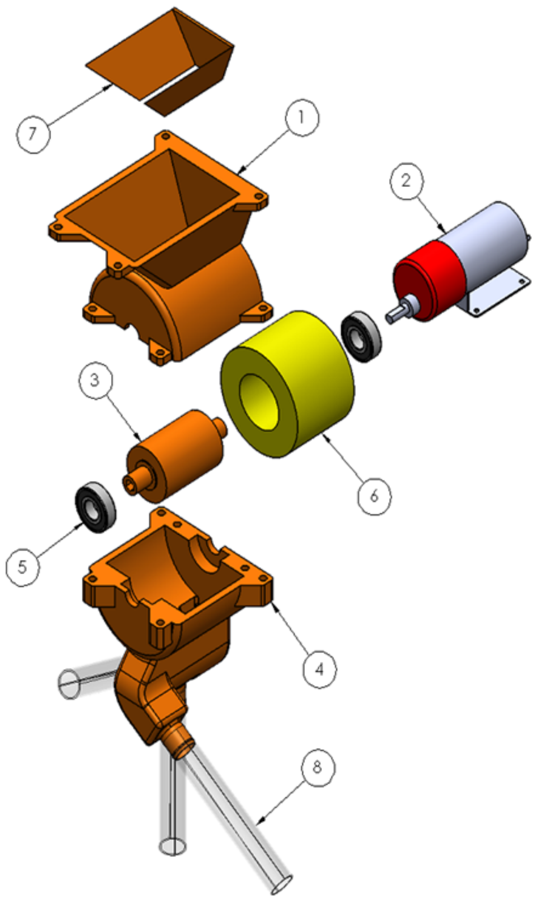


Source: author's own.

Figure 8 - Final digital schematics of the precision drill

2.3.2 Metering System Design

The main aspect of a precision drill is the metering system. Careful planning and many prototypes lead to the final design of the system. It was decided that Harper Adams's 3D printer was a perfect asset in producing a clean and aesthetically pleasing metering system. One issue found in preliminary testing was the jamming of the toothed sprocket when loaded with seeds. This could have been due to the large seeds used during testing compared to the much smaller ones supplied for the competition. However, the sponge roller soon fixed this issue with the ability to compress when put under higher loads. The schematics of the metering system can be seen in Figure 9. The included table highlights each part of the metering system, and the justification for the design.



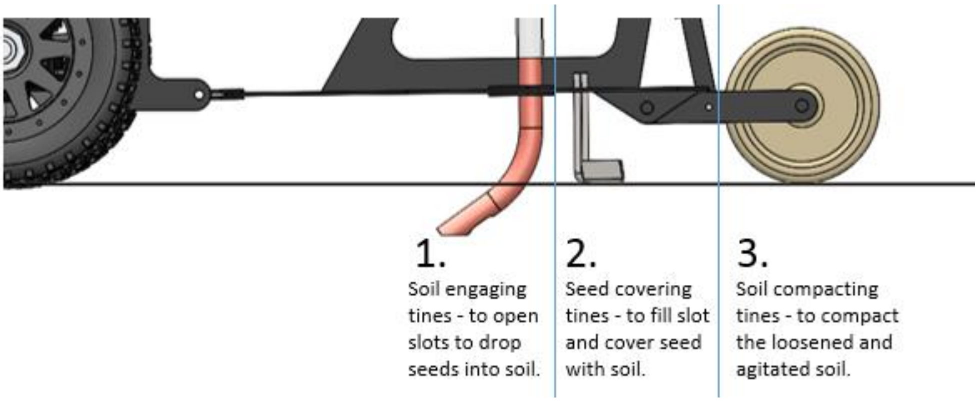
Part Number	Description	Justification
1	Upper Roller Housing	Upper roller housing which incorporated a small seed hopper. 3D printed which increased the aesthetics of the metering system dramatically
2	Geared Motor	This motor provided a wide range of rotational speeds to match the forward speed of the vehicle to the required output. With the use of an electronic speed controller the motor could be controlled simply with an Arduino micro.
3	Roller	After trying a toothed roller and finding problems, it was turned down to incorporate a sponge. It was a good way to transfer the motor drive to the sponge efficiently
4	Lower Roller Housing	This part was also 3D printed. Simple design to split the seed delivery between 3 coulters.
5	Bearing	2 bearings used to prevent the rotation of 2 wearing parts together.
6	Sponge Insert	A sponge was used as it allowed uniform delivery of the seeds to the coulters. The previous sprocket problems were eliminated with the use of a sponge. The sponge was also in keeping with the reduced complexity of the rest of the drill.
7	Hopper Insert	The insert was manufactured to decrease the opening size between the hopper and sponge roller, reducing the severity of seeds being delivered. This helped reduced the seed rate to what was required during task 4.
8	Delivery Hose	Plastic transparent pipe was used to deliver the seeds to the coulters. The pipe was easy to route and fit, and due to it being transparent the uniform delivery of seeds could be seen in case of blockages.

Source: author's own.

Figure 9 - Breakdown of metering system components

2.3.3 Drill Chassis and Soil Engagement Design

Nash and Selles (1995) suggested that it is important for a seed drill to have: means of cutting through the soil to drop seed in, means of re-arranging soil back over the seed to facilitate water movement and compacting the soil so that adequate aeration is achieved for germination.

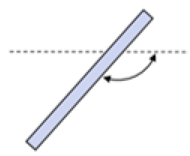
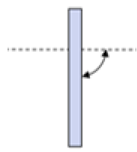
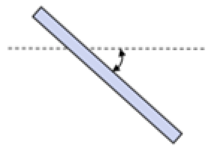


Source: author's own.

Figure 10 - Drill with component functions detailed

Godwin (2007) outlined benefits of different tines, shown in Table 1.

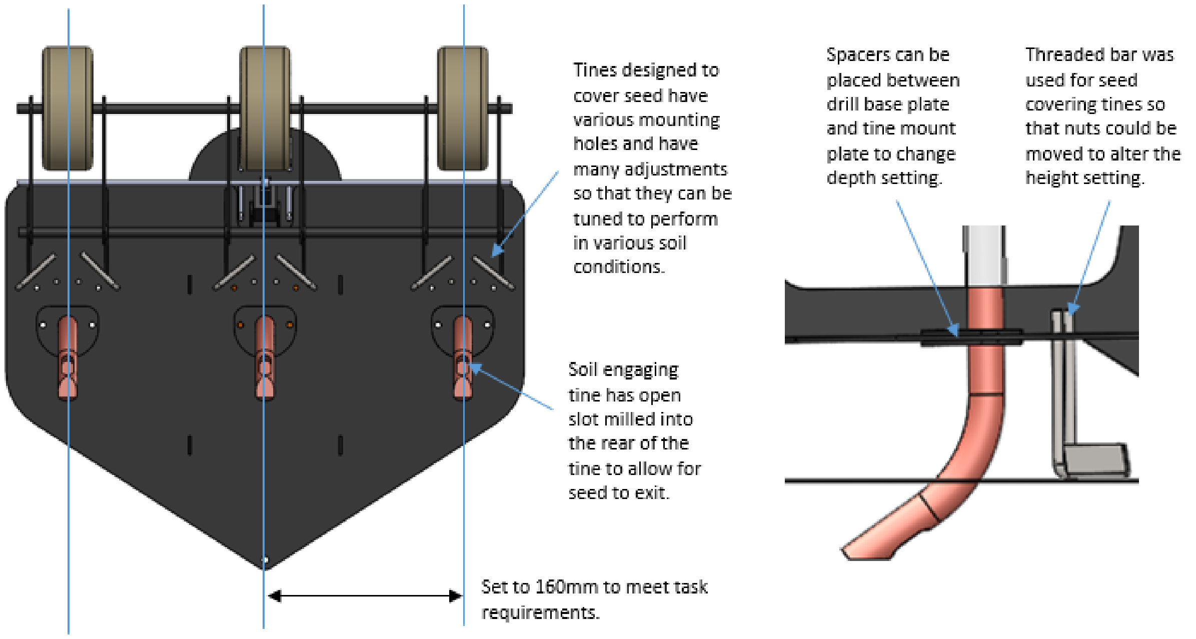
Table 1 - Tine angles and their effect on function

	Rake Angle (Degrees) in respect to direction of travel as →		
			
	>90˚	=90 ˚	<90 ˚
	Rearward Inclined	Vertical	Forward Inclined
Soil Operation	Compacting Disintegrating	Sorting Consolidating Re-arranging	Loosening Cutting Inverting Smoothing

Source: author's own.

Using knowledge from Godwin (2007) and results from preliminary testing various tine types, a forward inclined tine was chosen as the final soil engaging tines as they are good at cutting soil, whilst also generating a downward force. The downward force is required in this application to pull the drill into soil, as the small weight of the implement means that it is otherwise difficult to penetrate the tines into a soil. Copper pipe was used to manufacture the tines as it simplified the overall complexity of the drill and tine design; especially in regards to tine mounting and pipe routing. Soil bin test results showed that using copper pipe tines created a draught force that Eric was able to pull in test soil from the soil hall at Harper Adams University. Actual competition soil properties were not outlined in the task description so the team were unsure if Eric would actually be able to pull the drill in competition conditions.

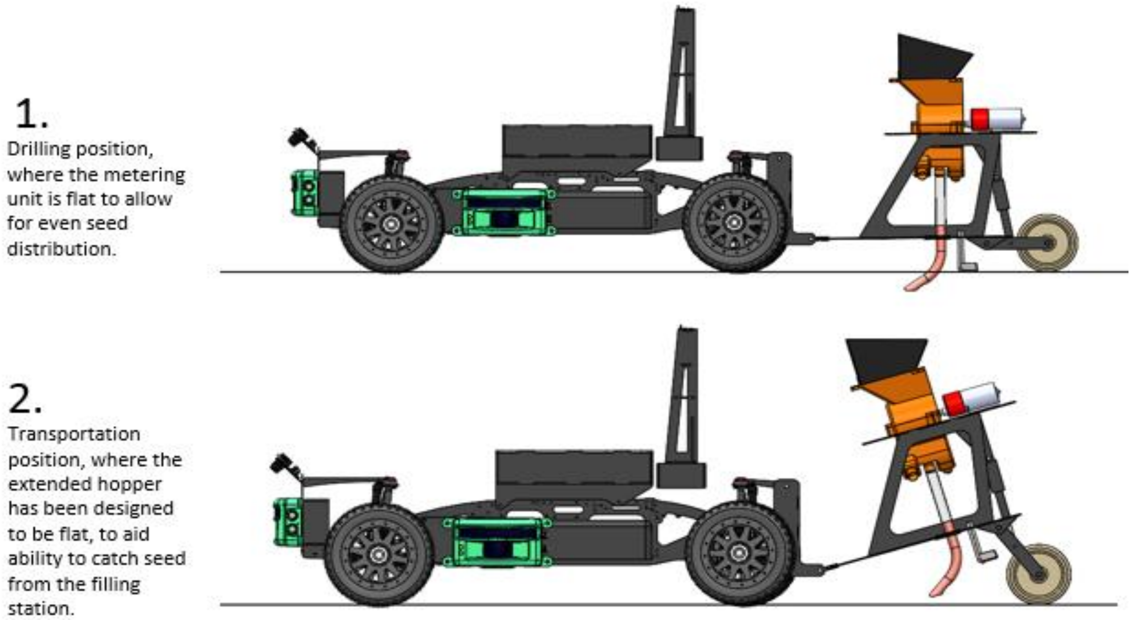
The tines designed to fill the slot/cover seed were designed to have a vertical rake angle, as Godwin (2007) showed that this angle re-arranges soil well. These tines are designed to run at ground level, and have lots of adjustability in type and angle to try and optimise performance in the competition soil conditions. Godwin (2007) showed that a rearward inclined tine is useful to compact soil. Rollers are a rearward inclined tine and in this setup also act as height wheels for the drill, setting the deepest position of the tines. The way the tines were mounted to the drill base plate allowed the depth setting to be adjusted, this is shown in Figure 11.



Source: author's own.

Figure 11 - Justification for tine design (Drill)

The drill was designed to run in two positions: transportation position or drilling positon with a linear actuator providing the movement between the two. Transportation position was the position of the drill when being transported where tines are out of the soil so they don't damage or get caught on task visual markers. The extended hopper has been designed to be flat in this position to benefit catching seed when filling. In drilling position, tines and the seed dispersing slot are under the ground and the metering unit has been designed to be level so that seed does not favour a coulter.



Source: author's own.

Figure 12 - Working and transportation positions for the drill unit

2.3.4 Drill Alterations for Competition

Due to the heavy rain and appalling weather conditions during the competition, the ground preparation for the seeding task could not be carried out. Therefore, what should have been harrowed and rolled with a light garden roller ended up being large clods with much of the course underwater. The decision was made that a layer of wood chip was to be spread over the entire competition plot, and instead of the seed having to be incorporated into the soil it had to be placed on top.

This meant the drill soil engaging tines and roller packer were no longer necessary and so they were removed from the drill assembly. Instead, new hoses to the coulter mountings were cut, which allowed the seed to fall and sit on top of the woodchip. The metering system had to remain level to ensure a uniform distribution to each coulter, therefore this was the main reason for discarding the copper coulters.

In addition the wet mud stuck to the compaction rollers. The seed placed on the ground would stick to the rollers as they passed over and would make the distribution of seed uneven. In order to reduce the risk of any mud stuck to the wheels (whilst practicing at the event or whilst the robot is in parc fermé) changing the distribution of dispersed seed the drill was modified so the three compacting rollers became two transportation wheels between the three seed outlets.

The modified drill used in the competition is shown in Figure 13.

Source: author's own.

Figure 13 - Drill as demonstrated in the competition

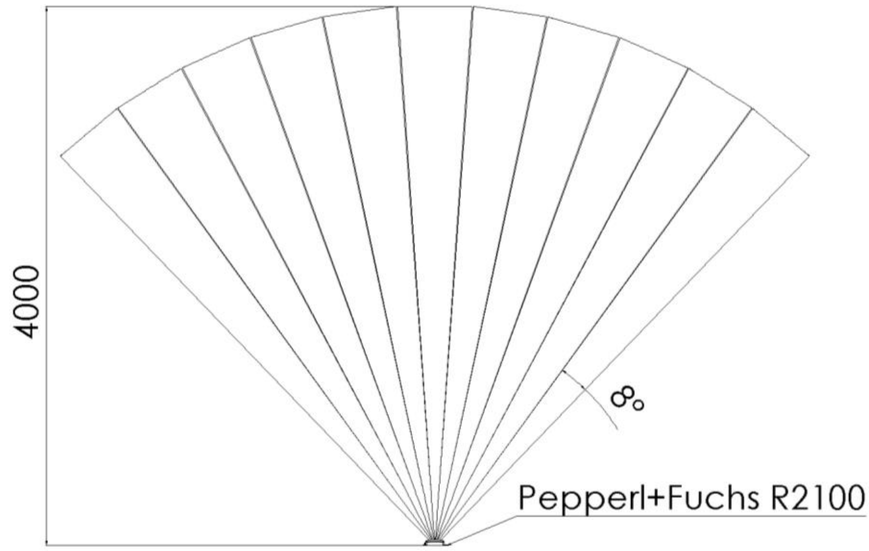
3 Controller Architecture

3.1 Sensors

The sensors used may be placed into three categories based on their purpose: detecting physical objects; detecting colour or navigating the vehicle. These were linked into a distributed control system which communicated via an Inter-Integrated Circuit (i^2c) bus. Finally, vehicle monitoring and control was achieved by a wireless serial link to a laptop displaying a custom human machine interface (HMI).

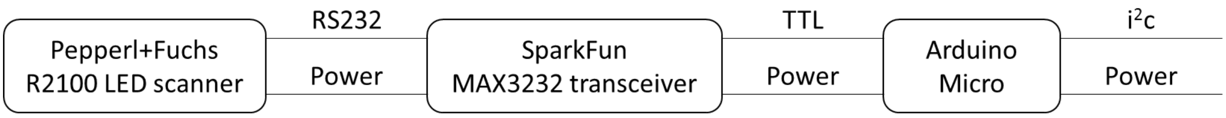
3.1.1 Obstacle distance

In order to determine distance, three Pepperl+Fuchs R2100 multi-ray LED scanners were used. Mounted as shown in Figure 1, they each interfaced with an Arduino Micro via a RS232-TTL transceiver. The R2100 was selected due to its low current consumption; durability (no moving parts as found in a traditional laser scanner); precision and capability to operate in an external environment. This sensor had also been utilised by previous teams – hence its application was proven. The detection envelope can be seen in 14 with the system representation in 15.



Source: adapted from (Pepperl+Fuchs, 2015)

Figure 14 - Pepperl+Fuchs R2100 Field of View



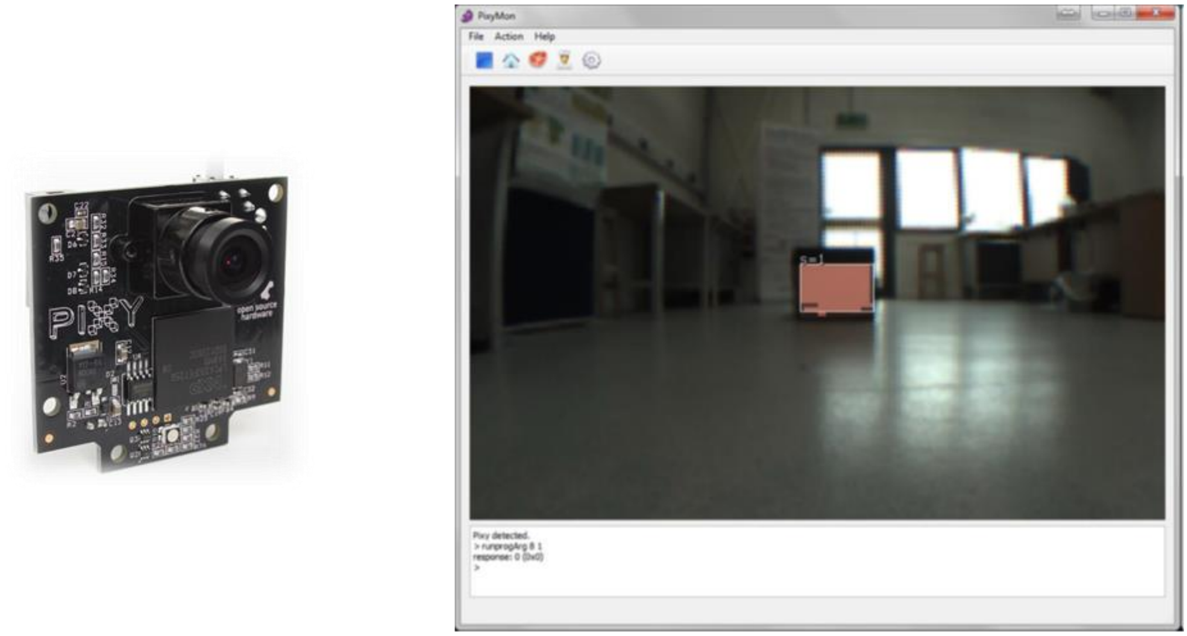
Source: author's own.

Figure 15 - Distance sensor system representation

The control hardware for each LED scanner was mounted onto a custom designed PCB, an example of which is shown later. This was designed such that most components were socketed, allowing for quick replacement in the case of a malfunction. Each PCB was kept separate, allowing the system as a whole to be replicated or replaced.

3.1.2 Colour

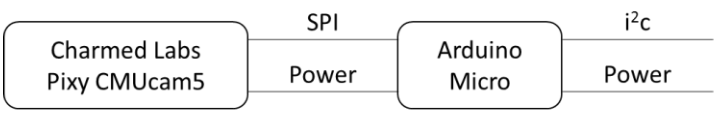
To complete tasks 3 and 4 a sensor capable of detecting colour was required. As the controllers selected did not have the power to process live video, a sensor which completed this was required. Two Pixy CMUcam5s were utilised, mounted on the front of the vehicle. They were selected for their low cost; small packaging size and ease of communication. 16 shows the sensor itself and an example detection of a coloured target.



Source: adapted from Charmed Labs (2011) and author's own.

Figure 16 - Pixy CMUcam5 and example detection image

As seen in Figure 1, they were mounted to the front of the vehicle, facing forward at 45°. This allowed two to cover the entire width of the vehicle and were suitably mounted for both tasks. Communication was over SPI, to the controllers mounted on each side of the vehicle.



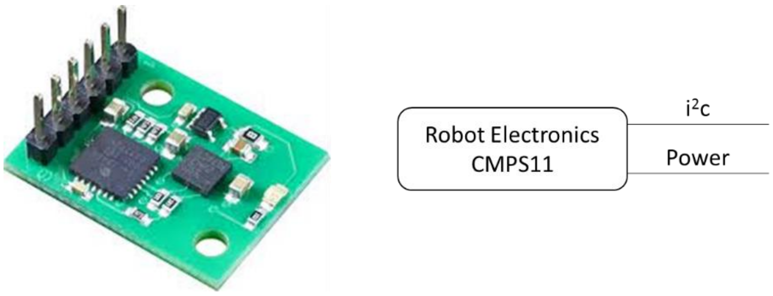
Source: author's own.

Figure 17 - Vision sensor system representation

Serial, i^2c and analogue communication was also available, yet SPI offered the fastest communication rate and easiest integration.

3.1.3 Vehicle navigation

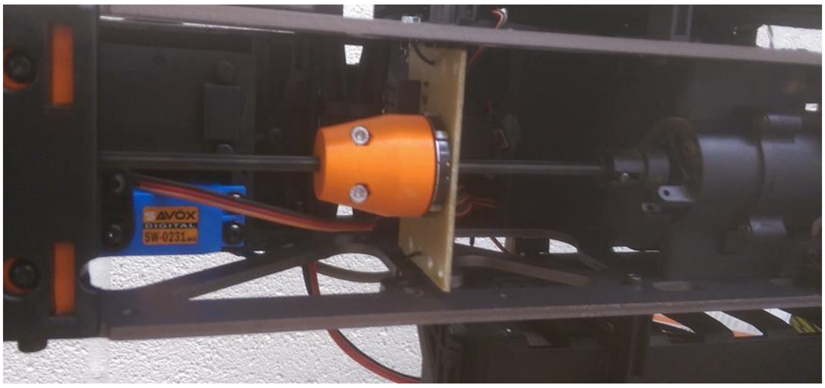
The final category of sensors used were those which provided navigational feedback and included a compass and a rotary encoder. The compass, a tilt compensated CMPS11, was mounted high on the vehicle. This ensured interference from the high current electrical systems was minimised. It was chosen for its ability to communicate over i^2c and the integrated tilt compensation, of which the tilt angle could also be read. It communicated directly with the system controller through the bus.



Source: adapted from Robot Electronics (not dated).

Figure 18 - CMPS11 and system representation

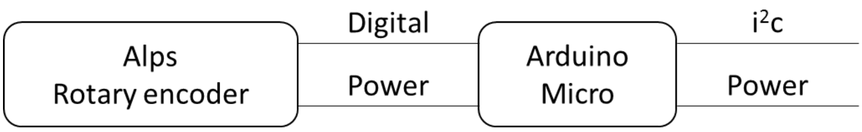
As both the Pixy CMUcam5 and the CMPS11 were vulnerable to the environment, splash-proof covers were employed to provide a level of protection. The final sensor was an Alps 16 pulse incremental rotary encoder. The encoder's through-hole design allowed fitment to the driveline and also provided 16 pulses per revolution with direction. Due to the gear ratios of the differential, this provided approximately one pulse per 10mm of vehicle travel. It was fitted onto a 3D printed custom mounting flange which clamped around the driveshaft, which is shown in figure 19.



Source: author's own.

Figure 19 - Rotary encoder mounting flange and mounting position

This encoder was chosen for its physical dimensions, mounting method and cost. Although it is not very durable, the mounting was designed such that it and its mounting PCB could be replaced easily. Its lack of durability was also offset by the cost. The digital signals from this were interpreted by the chassis node, as shown in figure 20.



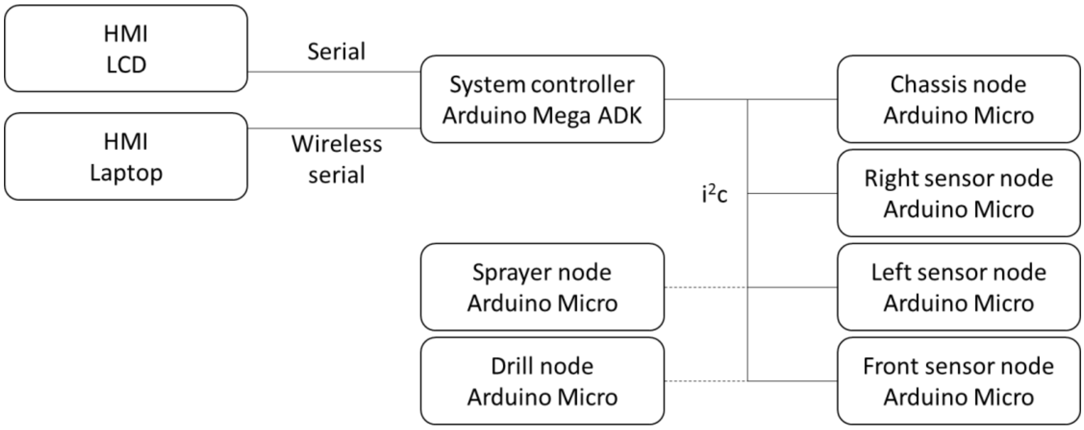
Source: author's own.

Figure 20 - Rotary encoder system representation

The two digital signals allowed the controller to determine the rotation, based on a phase difference in their switch timing.

3.2 Computer and other Hardware

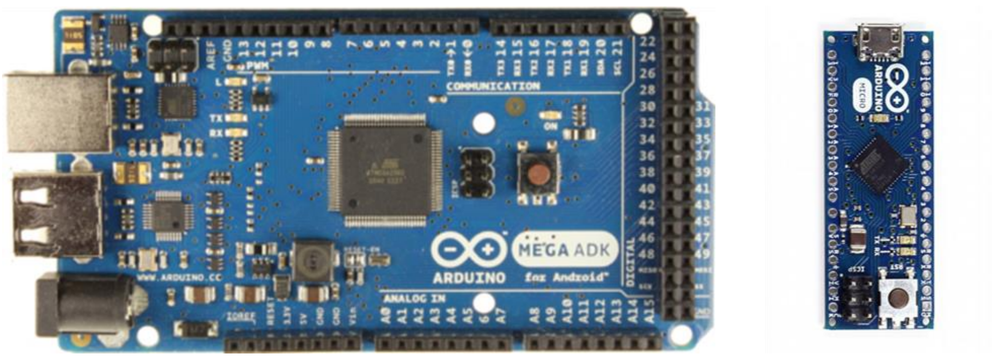
As stated above, a system of distributed control was used. This allowed each controller to take care of time critical sensing (such as reading of the encoder) and then pass data on request to the system controller. This was implemented so that a lower level of controller could be used – microcontrollers in place of an embedded computer. For this application, benefits such as a lower cost; lower software complexity and easier hardware interfacing could be achieved. Controller communication occurred over an i^2c bus with the system controller as the master. Figure 21 details the controllers used on the robot and their connections.



Source: author's own.

Figure 21 - Complete controller system representation

Power, at a level of 11.1V, was provided to all on-board controllers (omitted from figure 21 for clarity). Figure 22 shows the Arduino Mega ADK used as the system controller and the Arduino Micro used for each of the nodes.



Source: adapted from Arduino (not dated)

Figure 22 - Arduino Mega ADK (L) and Arduino Micro (R) vehicle controllers

The Mega ADK was selected based on its processing power, program memory size and number of serial ports (4). As it would be storing the program for all four tasks, a large memory was required. The serial ports, as seen in figure 21, were required in order to communicate with the HMI elements. Processing power was not as critical as first imagined as many time critical functions had been moved. Instead, it was important for the Micro. As the code was smaller the memory size required was not as great, and physical size took greater importance. Cost for both of these types of controllers was also one, if not two, orders of magnitude less in comparison to an embedded computer.

3.2.1 Base Station

A major new requirement for this year was the ability to control start/stop from outside the test area. In order to do this, a wireless serial link was created between the robot and a laptop using a set of XBee Pro 10mW 2.4GHz RF modules. Matched with a 200mm aerial, these modules were chosen as they are capable of transmitting over a distance of 1.6km outdoors. Although over-specified for the current application, these will hopefully provide a resilient link for future applications.

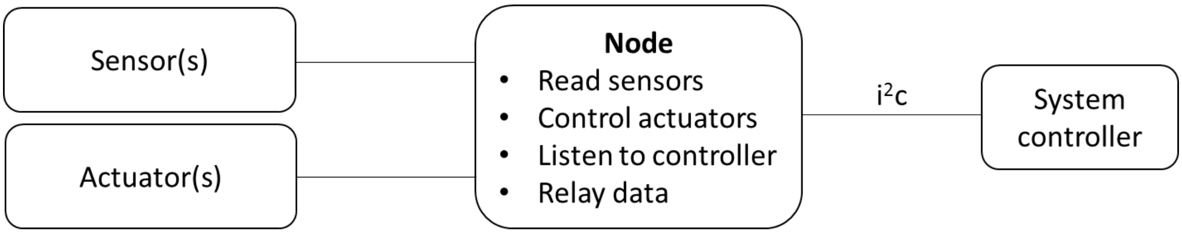
Through a USB-serial convertor board, data could then be exchanged with the robot. A Dell Latitude XT2 tablet/ laptop ran the HMI, allowing inputs via mouse, touch or an Xbox 360 handheld controller.

3.3 Software and Strategy

In the same way that the controllers can be split, so too can the software and strategy used for the nodes and the main controller.

3.3.1 Nodes

Although the nodes completed differing tasks, the overall strategy was the same for each (figure 23).



Source: author's own.

Figure 23 - Node control strategy

By completing all interfacing with the sensors and actuators and only providing the system controller with the required data, processing power and program space required was minimised. Tasks such as pulse width modulation (PWM) control of the servos and detection of the rotary encoder pulses could be maintained with a greater timing accuracy. As an example, the chassis node received four bytes of data (desired speed; desired steer angle; steer mode and speed mode) and returned three bytes (distance (two bytes) and velocity). From this, the steering servos and speed controller were set and data was returned.

3.3.2 Main controller

The main controller completed various functions using data from the other nodes. These functions either ran continuously or when the mode was selected and the robot was in go.

These programs, detailed below, completed communication, HMI update and diagnostics tasks along with the individual mode functions.

Table 2 - Program details and functionality

Program name	Call frequency	Function	Hardware interacted with
ReadFrontNode	Every loop	Request data from the node. Check the node is available.	Front node
ReadChassisNode	Every loop	Request data from the node. Send commands to the node. Check the node is available.	Chassis node
ReadLeftNode	Every loop	Request data from the node. Check the node is available.	Left node
ReadRightNode	Every loop	Request data from the node. Check the node is available.	Right node
ReadCompass	Every loop	Request data from the node. Check the node is available.	Compass
ReadDrill	Every loop	Send commands to the node. Check the node is available.	Drill
ReadSprayer	Every loop	Send commands to the node. Check the node is available.	Sprayer
SerialDisplay	10Hz	Send data to the dash. Parse data from the dash when available.	Dash
LCDDisplay	Every loop	Display data on the LCD, modified depending on current mode and error state of node communications	Vehicle mounted LCD
LidHardware	Every loop	Read switches to perform various functions. Set LED states dependent on error state of node communications and *Go.*	Vehicle mounted PTM switches and LEDs
Mode_RC	Every loop when *Mode* = 3 and *Go*	Take *RCSpeed* and *RCSteer* from the dash and pass to *Speed* and *Steer* commands	-
Mode_4	Every loop when *Mode* = 4 or 6 and *Go*	Use an array to determine required state. Call *DownRow* for row following or *HeadlandTurn* for a headland turn. Use *RowEndDetection* to detect row ends.	-

Mode_5	Every loop when *Mode* = 5 and *Go*	Use a case statement to step through the sequence. Call *FollowLine* for line following.	-
Mode_6	Every loop when *Mode* = 6 and *Go*	Call *SprayerControl* when the spray function is required	-
DownRow	Every loop of *Mode_4* when the *M4sequence* array [x][2] = 0	Use the left and right distances to the rows (if within limits) to determine the value of *Steer*. Use the front distance to stop in the case of an obstacle.	-
HeadlandTurn	Every loop of *Mode_4* when the *M4sequence* array [x][2] = 1	Perform a three point turn in the requested direction (from *M4sequence* array) using feedback from the compass and distance travelled.	-
RowEndDetection	Every loop of *Mode_4* when in the row	Looks at the distances to both rows, if both have not been seen for a set distance then return *true*.	
FollowLine	Every loop of *Mode_5* when required	Uses the line position from the right camera to set the *Steer* command.	-
SprayerControl	Every loop of *Mode_6* when required	When a weed is detected fill a line in an array with its position and sensed distance, and sound the sounder. When the set distance has elapsed since detection start spraying, after another set distance stop.	-
CompassSteer	Every loop when required	Set the *Steer* command based on the difference between the desired heading and actual.	-

Source: author's own.

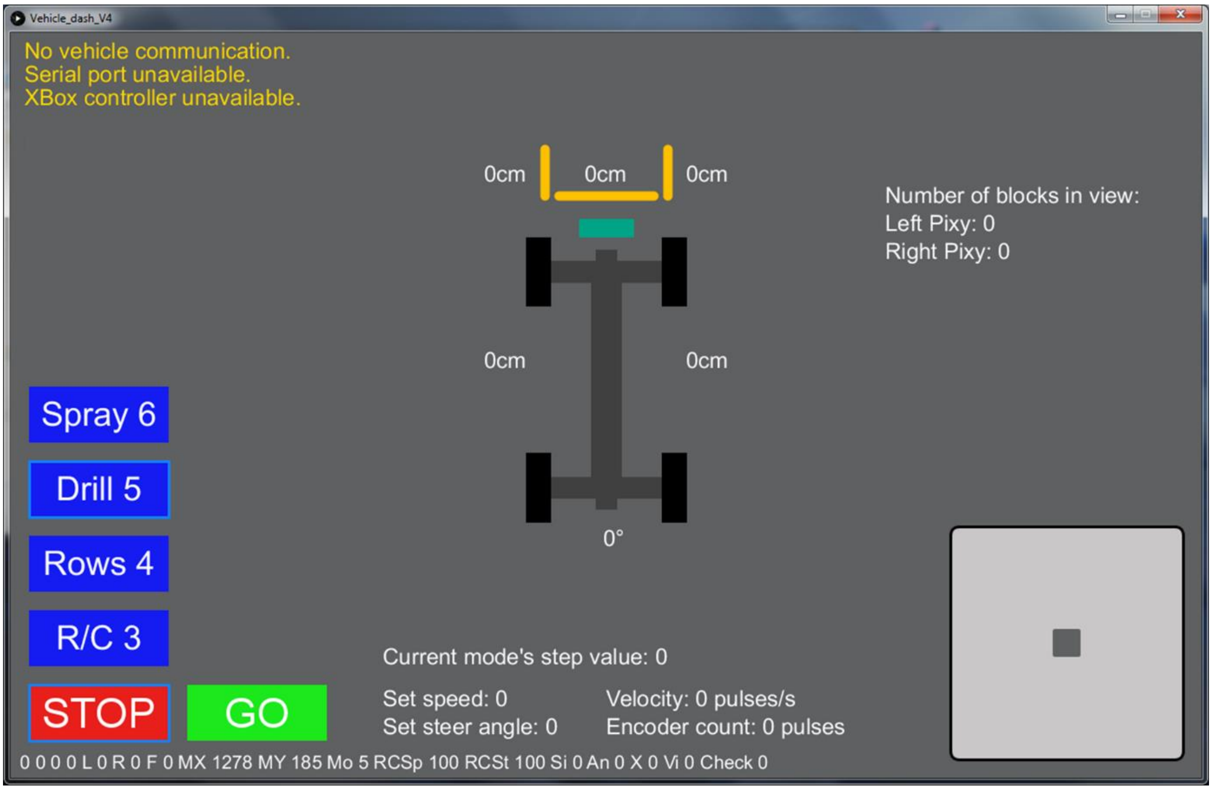
In addition to the explanation given in Table 2, some aspects of the program require further explanation. One of these is the link to the dash. By monitoring the time elapsed since the last message was received (on both ends), each can detect when the other is lost. This may be for a variety of reasons, but most commonly power off of the robot. As this state can be detected, the dash is able to inform the operator and the robot is able to modify its behaviour. The required mode and stop/ go state were the most important pieces of data transmitted – to ensure their integrity a checksum was calculated on each end and the data was only accepted if it matched.

Another aspect of note was the diagnostics capability of the robot. As noted in Table 2, if any of the nodes were unavailable (and should be attached in the case of the drill and sprayer), then an LED was lit and the operator was informed textually. This allowed for quick diagnosis of issues and prevented inadvertently starting a task without the required hardware available.

Finally, the method in which the modes were implemented ensured that the robot could be paused and restarted, and would return to its previous task. As the individual mode programs were not run when in stop, all variables and program position was maintained until either autonomous running was resumed or the mode was changed.

3.3.3 HMI (Dash)

As mentioned, the final part of the autonomous system was the user interface. Programmed in Processing 3, it received the serial data from the robot and displayed it for the user. Input via touch; mouse or an Xbox 360 controller was sanitised and then data was also sent to the robot, including stop/ start and mode commands.



Source: author's own.

Figure 24 - HMI (Dash) as seen whilst unconnected

The box in the lower right corner provided an alternative to the Xbox 360 controller for RC navigation, by touching and dragging the small grey square, the speed and steer angle could be controlled. The mode and start/ stop was controlled and indicated by the buttons in the lower left corner, whilst error messages were displayed in the upper right. The centre displays various data from the robot, including various sensor values. Finally, information such as that from the cameras (on the right) was only displayed when in the correct mode.

4 Recommendations

Following the robot performance within testing and the competition, various shortcomings were identified. Although they did not prevent vehicle operation, implementation of solutions should ensure a higher level of performance.

For the vehicle itself, one of the major shortcomings was the turning circle. Eric was one of only two robots which required a multipoint turn on the row ends, however the longer chassis did provide stability and load capacity unmatched by the other chassis' available to the team. A reduction in turning circle, to an outside measurement of 1.5m, would allow for single row end turns. Other issues with the vehicle were a lack of ingress protection beyond splash-proof; a lack of closed loop speed control; no ground speed sensing; and a slight lack of power in some conditions. By ensuring all components were rated to IP67 and driveline modifications were introduced two of these could be solved relatively quickly. Closed loop speed control, using the rotary encoder fitted, is only a matter of programming and testing to implement (a task which the team did not have time to complete). This would identify a stall condition and be able to apply power as required. Ground speed sensing, in order to identify conditions of slip, was not as important, however in differing soil types it could quite quickly become an issue. One method of providing this feedback is an un-driven ground wheel and encoder; or the fitment of a ground speed radar.

For this application, the control system worked adequately. However, greater programming power may allow for greater amounts of data to be processed, such as a rotating laser or further vision processing. Other improvements would be the addition of wireless programming, which would also allow ingress ratings to be maintained during testing. A degree of lag in the remote control system was also identified. This may be removed by prioritisation of the required signals or a dedicated transmitter/ receiver pair fitted.

For the drill unit, a few observations were made. The use of a parallel linkage or a change in the orientation of the metering unit would allow metering accuracy to be increased by keeping it level at all times. Driven wheels on the rear of the drill and greater lifting power (by addition of another actuator) would allow for greater draught forces to be produced and a quicker transition time between transport and work positions. Finally, a clevis hitch or ball joint for the connection would allow a greater degree of rotation around the direction of travel, an element found to be limited.

For the sprayer unit, only observations for possible improvements were made. Joining the two mounting plates would allow for easier mounting, along with a quicker method of attachment. Modification to the linkage would also allow for better positioning of the nozzles whilst bringing the tank further toward the centre of the vehicle, improving the centre of gravity. During the competition and testing it was also noted that the number of nozzles could be reduced to three, reducing complexity and cost whilst still covering the required width to the required accuracy. Cost could also be removed by changing the specification of pump which would allow for the removal of the priming pump. Finally, the package size may also be improved by fitting the boom to the underneath of the vehicle, bringing it closer to the sensing unit and protecting it from collision whilst turning.

5 Conclusion

This report has explained the robots functions with justifications for hardware, software, systems and methodologies, sensors selected and the mechanics of the robot. The team placed 2nd overall at the competition, with a 4th in task 1, 7th in task 2, 2nd in task 3 and 1st in task 4. The team hope that the future recommendations given will help any future teams to enter the Field Robot Event and compete for first place overall.

6 Sponsorship

The team would like to thank the Douglas Bomford Trust for their financial support with travel and accommodation for the Field Robot Event 2016.

7 References

Arduino. not dated. *Arduino.* [Online]. Available at: https://www.arduino.cc/ [Accessed 20th June 2016].

Charmed Labs. 2011. *CMUcam5 Pixy.* [Online]. Available at: http://www.cmucam.org/ [Accessed 20th June 2016].

Field Robot Event. 2016. *Program Booklet.* [Online]. Available at: http://www.fieldrobot.com/event/wp-content/uploads/2016/06/Booklet_2016_complete_v5-with-cover.pdf [Accessed 21st June 2016].

Godwin, R. J. 2007. A review of the effect of implement geometry on soil failure and implement forces. *Soil and Tillage Research,* 97(2), pp. 331-340.

Nash, H. M. and Selles, F. 1995. Seedling emergence as influenced by aggregate size, bulk density, and penetration resistance of the seedbed. *Soil and Tillage Research,* 34(1), pp. 61-76.

Pepperl+Fuchs. 2015. *R2100 LED Diffuse Scanner.* [Online]. Available at: http://www.pepperl-fuchs.us/usa/en/25229.htm [Accessed 20th June 2016].

Robot Electronics. not dated. *CMPS11 - Tilt Compensated Compass Module.* [Online]. Available at: https://www.robot-electronics.co.uk/htm/cmps11doc.htm [Accessed 20th June 2016].