THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

UMANNED FIREFIGHTING VEHICLE CONTROL SYSTEM CONCEPT REPORT

ENGG1100 Professional Engineering

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EXECUTIVE SUMMARY

The increasing complexity of aircraft, support vehicles and fuel types has increased the hazards and risk of harm for the Australian Aviation Rescue Fire Fighting Service officers. To reduce the risk of harm to officers and civilians an unmanned firefighting vehicle is under consideration. This report evaluates, describes, and presents design options for a control system to operate an unmanned firefighting vehicle. For insight to what the client values outside of the design requirements, the following quote from Airservices Australia's homepage, the parent company of the Australia Aviation Rescue Fire Fighting Service, 'We provide safe, secure, efficient, and environmentally responsible service to the aviation industry and community,' was used. These values became the basis for evaluation design options. An automated and wireless control method were considered.

Through researching design options, the wireless method was found to be an unviable option due to the high precision technical requirements which if slightly miscalibrated. would result in further endangerment of those involved in an incident. The most optimal solution was found to be Bluetooth control over the UFV through an ESP32 development microcontroller. This method allows for a 10m distance between the operator and the UFV during operation and full simultaneous control over the drive and fluid delivery functions. This control solution could be implemented into any small-scale prototype and allow for further additions to the basic functions required for the testing arena.

If further development is greenlit, it is advised that the system will require two additions for full-scale operation. An LTE module to extend the distance between operator and the UFV and a camera to stream footage to the operator. Outside of those additions, the same control subsystem would be viable for full-scale operation.

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1 INTRODUCTION

The Australian Aviation Rescue Fire Fighting Service (ARFF) provide firefighting services at 27 of Australia's largest airports. With over 1,000 operational and support personnel, ARFF can respond to incidents within three minutes of receiving an alert. With the increasing complexity of aircraft, support vehicles and fuel types, the potential risk of harm or death of officers responding to incidents has increased. To reduce the risk of potential harm, an unmanned firefighting vehicle (UFV) is being considered to respond to incidents in place of aviation firefighters.

Proposals for the unmanned firefighting vehicle in the form of a small-scale prototype have been requested for evaluation. This protype must be able to move into and out of a detailed arena using linear forward and backwards drive. The UFV must be capable of aiming to and extinguishing up to six fires within six minutes to be considered as a viable option. In achieving this, the prototype can utilise a maximum of 1L of water and be either algorithmically or remotely controlled in the drive, aim, and delivery of the fluid onto the fires. The fires must be reduced by at least 50℃ to be considered extinguished.

This concept report focuses on the control system for the small-scale prototype of the unmanned firefighting vehicle. The functional decomposition of the UFV was constructed as a team and show below in *Figure 1*. From the decomposition, the design of controlling the arm, the system controllers, and the power will be categorised as the basic control system (BSC). Built upon the BSC will be the method of control with programming dependent on the method of control utilised. The UFV could be controlled in various ways: automated, Bluetooth, radio control, and Wi-Fi as examples. This report will focus on the possibility of using automated or wireless control and the benefits and limitations of each. An algorithm will be outlined in the automated control section. Programming needs will otherwise be stated and investigated deeper as a collaborative effort following the report.

1.1 CONTROL SYSTEMS SCOPE, OBJECTIVES, AND CONSTRAINTS.

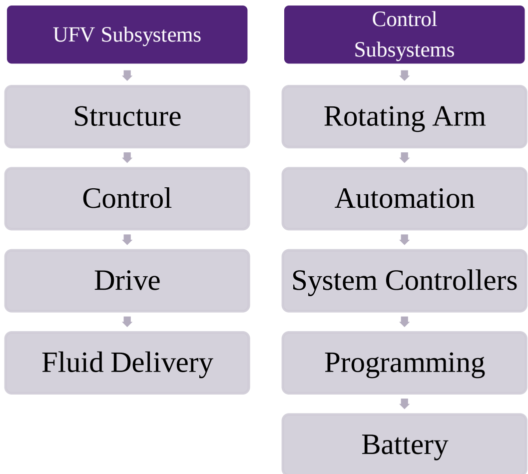

Figure 1. UFV Subsystems and Subsystems of the Control System

Airservices Australia is the government-owned parent organisation of the Australian Aviation Rescue Fire Fighting Service (ARFF). They state a clear message on their homepage:

> *We provide safe, secure, efficient and environmentally responsible services to the aviation industry and community* (Airservices-Australia, 2021).

The objectives and decisions made will be follow the goals of providing a safe, secure, and efficient control system for the UFV that is within the scope shown in *Table 1* and the objectives and constraints are shown in *Table 2*.

Table 1. The Scope of the Control System

In Scope	Out of Scope
• Circuit control systems	• Drive mechanism/s (motor/s, axis, torque)
• Algorithmic/automated approach to control	• Fluid delivery system design (pump, nozzle, direction mechanism/s)
• Embedded programming	• Physical design of the UFV
• Power usage control	• Transformer design
• Remote deployment of fluid.	
• Aiming of fluid delivery nozzle.	

Table 2. Objectives and Constraints

Objectives	Constraints
• Direct voltage each system component.	• Batteries can only be 13V each.
• Control the movement of the UFV	• Must use DC power
• An automated design needs to complete the arena in under 6minutes.	• Budget total of $150AUD.

2 DESIGN CRITERIA

2.1 OBJECTIVES OF DESIGN

The objective is to ensure efficient and reliable use of power and water using electronic controls. There are two main methods of achieving this goal: automated and manual. Automated would use a hybrid of algorithmic instructions and sensor data to drive, aim, and delivery the fluid onto the fire. A manual approach would utilise a wireless communication device for an operator to man the Unmanned Firefighting Vehicle (UFV). To assess the viability of either option, criteria based on the design requirements and the needs of the Australian Aviation Rescue Fire Fighting Service must be developed for design option comparison.

2.2 BASIC CONTROL SYSTEM CRITERIA

The basic design of the control system requires a central controller capable of receiving and delivering signals. The delivery will be to three motors and a pump. Receiving the signals can be through programming exact values, receiving and processing data from sensors, or receiving and directing control signals from an operator. Due to stated variations the basic control system will primarily focus on the delivery of signals. Following the *Definition of Design Criteria* in the appendix the criteria in *Table 1* below is developed.

Table 3. Basic Control System Criteria Definitions

Criteria	Definition
C1. Operable	The control board can operate the systems; pump, drive-motor, and both turret motor.
C2. Efficient	The system can operate multiple systems simultaneously.
C3. Adaptable	The system can be reused for various scenarios.
C4. Power Efficient	The system does require a high voltage battery(s) to operate.
C5. Cost	The system is cost efficient.

2.3 WIRELESS CONTROL

There are three main methods of wireless control of the unmanned firefighting vehicle. Radio control, Wi-Fi, and Bluetooth. The two biggest considerations to be made when choosing a wireless controlling method are the reliability and security of the connection. There is also an issue of how strong a wireless connection is within and between various types of smoke and barriers. For this small-scale model, based on the information given about the testing arena, this will be considered out of scope until the full-scale model is designed. The criteria for a wirelessly controlled system can be seen in below in *Table 4*.

Table 4. Wireless Control Criteria Definitions

Criteria	Definition
C1. Secure	Unauthorised connections to the UFV cannot be made.
C2. Adaptable	Establishing a connection to a new controller is simple.
C3. Reliable	There can be a long distance between the operator and the UFV.
C4. Cost	The wireless connection method is cost efficient.

2.4 Automated Control

The unmanned firefighting vehicle, if made autonomous, would utilise a multi-variate closed loop system to operate. A closed-loop system is considered to have five main elements: comparison, control, correction, process, and measurement(Valkenburg et al., 1992). The comparison element compares the variable condition being controlled with the value of what is being achieved, if they do not match an error is produced. The control element decides algorithmically what to do based on the given error. The correction element produces a change in the process to correct or change the controlled condition. The process element is what is being controlled and the measurement element produces a signal on the variable of the controlled process (Bolton, 1996).

The criteria for selecting a sensor based on *Figure 1* below; where x is distance to travel, θ is the turrets horizontal axis, and α is the turrets vertical axis:

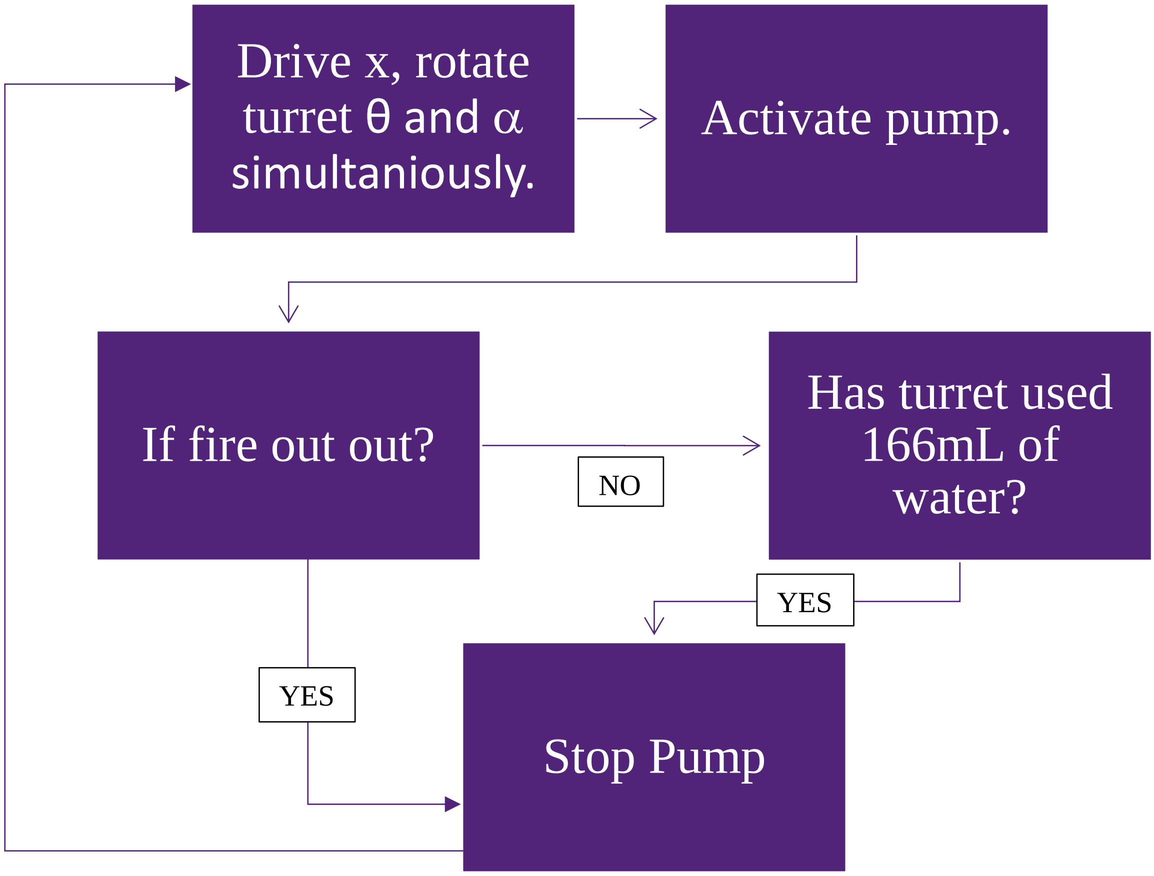

Figure 2. Closed Loop Automatic Control Algorithm Design.

From this algorithm overview the following sensors are needed: water level sensor, sensor to check heat and/or colour, sensor for confirm distance travelled, sensor to confirm alignment. The criteria for selecting a sensor is show in *Table 3* below.

Table 5. Automated System Control Criteria Definitions

Criteria	Definition
C1. Efficient	Sensor can take accurate readings.
C2. Cost	Sensor does not need further support sensors become cost efficient.

The reliability and safety of an autonomous UFV independent of environmental factors are the main criteria to achieve to be considered. The less reliable the readings are of the sensors, the more time it would take to extinguish the fires, jeopardising safety.

3 DESIGN OPTIONS

3.1 BASIC CONTROL SYSTEM

There are three main options for choosing a control system board: Arduino, Raspberry Pi, and an ESP32. Each are designed to be modular development boards for various applications including Internet of Things (IoT) design, network design testing, and mechatronics design (Aufranc, 2020). The ESP32 and Raspberry Pi 4 have faster processing units and volume of random-access memory (RAM) compared to the Arduino UNO (Arduino, 2021; Espressif, 2021; Raspberry-Pi, 2019). The Arduino Uno, however, has a wider-range of low-cost 'shields' (circuit modules) designed for it. The ESP32 has native Wi-Fi and Bluetooth connectivity. It has been combined with the Arduino UNO creating a control board that is highly capable of reliably operating the system.

Table 6. Basic Control System Decision Making Matrix

	Operable		Efficient		Adaptable		Power Efficient		Cost		Sum	Adjusted Weight
	G	x W	G	x W	G	x W	G	x W	G	x W		
A. Arduino Uno	3	0.3	4	0.2	2	0.1	3	0.3	3	0.1	3.1	0.31
B. Raspberry Pi 4	3	0.3	4	0.2	4	0.1	4	0.3	1	0.1	3.4	0.34
C. ESP32	3	0.3	4	0.2	3	0.1	4	0.3	3	0.1	3.5	0.35

By utilising the *BCS Grading Rubric* and the weighting given by *BCS Criteria Piecewise Comparison* in the appendix, in the decision-making matrix in *Table 4* above, the ESP32 is shown to be the best control board. This design can be seen in *Figure 2*. It includes an L298N DC motor driver 'shield' placed on top of the ESP32 (Agnihotri, 2021). This driver can receive up to 18V of additional power to the ESP's 5V to power and control three 6V DV motors simultaneously (Rajguru-Electronics, 2018). Wired to the L298N is the MOSFET module for the water pump. Both the L298N and MOSFET module can be operated by the ESP32 simultaneously. This design achieves all the criteria set out in *Table 1*.

3.2 WIRELESSLY CONTROLLED

In considering a wireless method of control, radio control will not be considered as the minimum cost of a transmitter and receiver is one-third of the budget ($50AUD). Bluetooth and Wi-Fi control can be achieved natively with the ESP32's capabilities. The only benefit of using radio control is the distance between the operator and UFV. As Wi-Fi requires a router for connection between the UFV and the operator, Bluetooth will be utilised for wireless control. It has a connection range of 10m (Bluetooth, 2021). In the development of the full-scale model, 4G telecommunication should be considered in its place to enable a further distance of control over the UFV (DFROBOT, 2021). If implemented, it would bet sandwiched between the ESP32 and the motor driver. The software for the control method would need to be modified for this new method of communication.

Operating the UFV via Bluetooth will be done through *Dabble* developed by STEMpedia (STEMpedia, 2021). In the development of a full-scale model, a platform will be designed and programmed to operate the UFV via a computer. Upon development of a full-scale UFV, a program for computer or a controller will be developed for operators.

3.3 AUTOMATED CONTROL

3.3.1 Reference Values for the Closed-Loop System

For a closed-loop system to function, sensors need to compare data to given references. For the UFV the references are the location of the UFV on the track, the angle required to aim the turret towards each node, the distance between the turret and the UFV, and the distance the UFV needs to travel to get to each location. *Figure 4* shows where the UFV will be placed and the angle it needs to aim the turret at each node. *Table 20* presents the values for *Figure 4*. Where X and Y are the co-ordinates are the location of the vehicle for each node, D is the distance between the turret and the node, and θ is the angle required.

The values are found by first assuming the turret fires from the centre of the UFV and it is at the max dimensions. Place the UFV at the barrier and find the tangent angle. That provides the location and angle needed for the UFV for Nodes 5 through 2. The angles for the following nodes are assumed and entered in *Equation 1* then *Equation 2* to get the exact location and angle needed at all nodes. These values are then tested to node exceed the maximum distance Node 6 when the UFV is at the barrier. They are then refined to reduce rotation needed between each node. After multiple iterations, the most efficient locations and angles were calculated and entered in *Table 20*. The total rotation required by the UFV is 139.24°.

$$Y = \frac{X}{\tan(\theta)} \qquad 1$$

$$D = \sqrt{X^2 + Y^2} \qquad 2$$

3.3.2 Sensors to Support the Closed-Loop System

Three sensors minimum are required to operate the closed-loop automated system: a water-level sensor, a colour sensor, and a distance sensor. A HCSR04 ultrasonic sensor and a GP2Y0A21YK0F infrared sensor are compared in the decision-making matrix below in *Table Name* for a distance sensor (Morgan, 2014; SHARP, 2021). For the colour sensor, a ISL29125 and a TCS230 are compared in the decision-making matrix in *Table Name* below (Renesas, 2017; TAOS, 2008). In the appendix, *Automated Control Sensor Criteria Grading Rubric* defines the grade, G, and *Automated Control Sensor Piecewise Comparison* is W; the weighting.

Table 7. HCSR04 vs GP2Y0A21YK0F Decision Matrix

	C1. Efficient		C2. Cost		Sum	Weighing
	G x W		G x W			
A. HCSR04	4	0.6667	4	0.3333	4	0.5714
B. GP2Y0A21YK0F	3	0.6667	3	0.3333	3	0.4286

Table 8. ISL29125 vs TCS230 Decision Matrix

	C1. Efficient		C2. Cost		Sum	Weighing
	G x W		G x W			
A. ISL29125	3	0.6667	3	0.3333	3	0.5625
B. TCS230	3	0.6667	1	0.3333	2.3334	0.4375

A HCSR04 ultra sonic sensor to detect the water level in the tank. A Sharp GP2Y0A21YK0F infrared sensor to measure the distance travelled and the distance between the UFV and the nodes. And a ISL29125 digital colour sensor to confirm the node is extinguished. In tandem, these sensors would allow the UFV to operate effectively and efficiently within the arena.

4 EVALUATE AND VALIDATE (2 PAGES)

For the UFV to be controlled there are two design choices: wireless Bluetooth control via an operator, and automated control using a closed-loop system. In evaluating control method is preferable, the UFV needs to be considered beyond its small-scale prototype. Limitations, constraints, and variables in a real-world environment that do not exist in the arena need to be considered for the prototype design choice. From this consideration, the assumption that limitations of the small-scale prototype would worsen in a full-scale model implemented, and the *Definition of Design Criteria*, the *Control Method Grading Rubric* in the appendix was developed for the decision making matrix in *Table 7* below. The scores given are weighted against the *Wireless vs Automated Piecewise Comparison* in the appendix.

Table 9. Wireless vs Automated Control Decision Matrix

Criteria	A. Wireless Control		B. Automated Control	
	Grade x Weight		Grade x Weight	
CA. Safe	4	0.1944	2	0.1944
CB. Secure	3	0.0556	4	0.0556
CC. Efficient	4	0.1389	3	0.1389
CD. Cost	4	0.0833	2	0.0833
CE. Weight	4	0.0833	3	0.0833
CF. Power Efficient	3	0.1389	2	0.1389
CG. Adaptable	4	0.0833	3	0.0833
CH. Size	4	0.0556	3	0.0556
CI. Reliable	4	0.1667	3	0.1667

Sum	
A.	B.
34	25
Sum with Weighting	
A.	B.
3.8055	2.639
Total Score	
A.	B.
0.5905	0.4095

As shown in *Table 7*, option A. Wireless Control is the most ideal method of control. Outside of minor security concerns in a full-scale implementation and the requirement of implementing a camera for the operator to see what the drone is doing when their direct line of sight is obfuscated, wireless control fully meets the needs of the Australian Aviation Rescue Fire Fighting Service.

4.1 WHY AN AUTONOMOUS SYSTEM IS CURRENTLY UNFEASIBLE

Developing a system for an autonomous UFV are incredibly complex (Martinez & Trevvett, 2010). In January of 2021 Vojtech Spurny and his team developed an Autonomous Micro-scale Unmanned Ariel Vehicle for extinguishing indoor and outdoor fires for the MBZIRC 2020 competition. Their solution required multiple 2D LIDARs, a stereo-camera, a GNSS, and a thermal camera to operate (Spurny et al., 2021). The sensors used in this project require more processing capabilities then the UFV's proposed basic control system can achieve. In a full-scale model, a Nvidia Jetson Nano may be a suitable solution for this (NVIDIA, 2021). Using complementary sensors and prediction models, the UFV could detect various types of fire and people during an emergency situation (Starr & Lattimer, 2013; Treptowa et al., 2006). There are limitations to the effectiveness of sensors and model prediction as shown by the rapid development of self-driving cars.

Self-driving cars have been gaining prominence in private company development since 2014. Tesla, and rideshare companies Lift and Uber have been working independently on software and hardware to produce this product. There are varying levels of automated driving each with their own complications. Alfred Jones (Head of Mechanical Engineering and Manufacturing at Lift's Level-5 Self-Driving Cars Division) gave a keynote presentation at the HackADay *Remoticon 2020* panel. He states the two major difficulties for developing a self-driving car is the latency between the hardware and computer system and the unpredictability of drivers and pedestrians on the road (Szczys, 2020). The consequences of a poor system were seen in March 2018, in two separate accidents, where self-driving cars (Tesla and Uber) killed a cyclist and a driver (Levin, 2018; Wakabayashi, 2018). These accidents show the liability possible for utilising a closed-loop autonomous system for the UFV. Minor mistakes or miscalibration have the potential for devastating consequences. Because of these technical limitations and potential harm, the automated system should not be considered.

5 CONCLUSION

The design shown in *Figure 3* of the Appendix where a Bluetooth method of control is used for the ESP32 based Arduino UNO board achieve the objectives and constraints first outlined in *Table 2* of the concept report. Comparing it to the overall design criteria outlined in *Definition of Design Criteria* in the Appendix, the selected system has achieved almost a perfect score as a method of control fit for the Australian Aviation Rescue Fire Fighting Service's requirements. This small-scale prototype can be effectively scaled up using the similar hardware.

Implemented for the testing arena, this control system theoretically should not cause any issues in maintaining other constraints such as weight, size, and time which require a full-system investigation by the team following finalization of each subsystem's concept reports. The processing power of the ESP32 is more than enough to operate the other subsystems simultaneously. The availability of connection pins allows for adaptability for future revisions of the small-scall prototype before moving forward with the full-scale model.

5.1 RECOMMENDATIONS FOR THE FULL-SCALE MODEL

As mentioned in the wireless design option, there are two major drawbacks to the current wireless communication method. The maximum range between the UFV and operate is roughly 10m and when utilised in a real-world emergency, an operator will need to manoeuvre the UFV out of their line of sight. A SIM7600CE-T is recommended to allow for a further distance between the operator and the UFV during an emergency. This module allows the UFV to be connected to the operator through LTE. A further investigation into this method of connection will be required to ensure there would be no connection issues due to smoke for the walls of an interior the UFV is in. A camera mounted to the UFV can then stream a video feed through to the operator controlling the device.

As shown in *Table 10* below Airservices Australia reported spending 29.7% of their total income in the category of purchase of property, plant, and equipment in their cashflow statement(Airservices-Australia, 2018, 2019, 2020). A 14.78% increase from 2017. If that trend were to continue, the possibility of an autonomous UFV may be possible in the future. Given further advancements of autonomous vehicles and willingness to invest into further research and development.

Table 10. Airservices Australia Yearly Financial Report Figures

	2020	2019	2018	2017
Total Income	$1,021,530	$1,127,076	$1,110,547	$1,076,662
Purchase of Property, Plant, and Equipment	$300,005	$144,561	$129,133	$160,691
Percentage	29.7%	12.83%	11.63%	14.92%

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7 APPENDIX

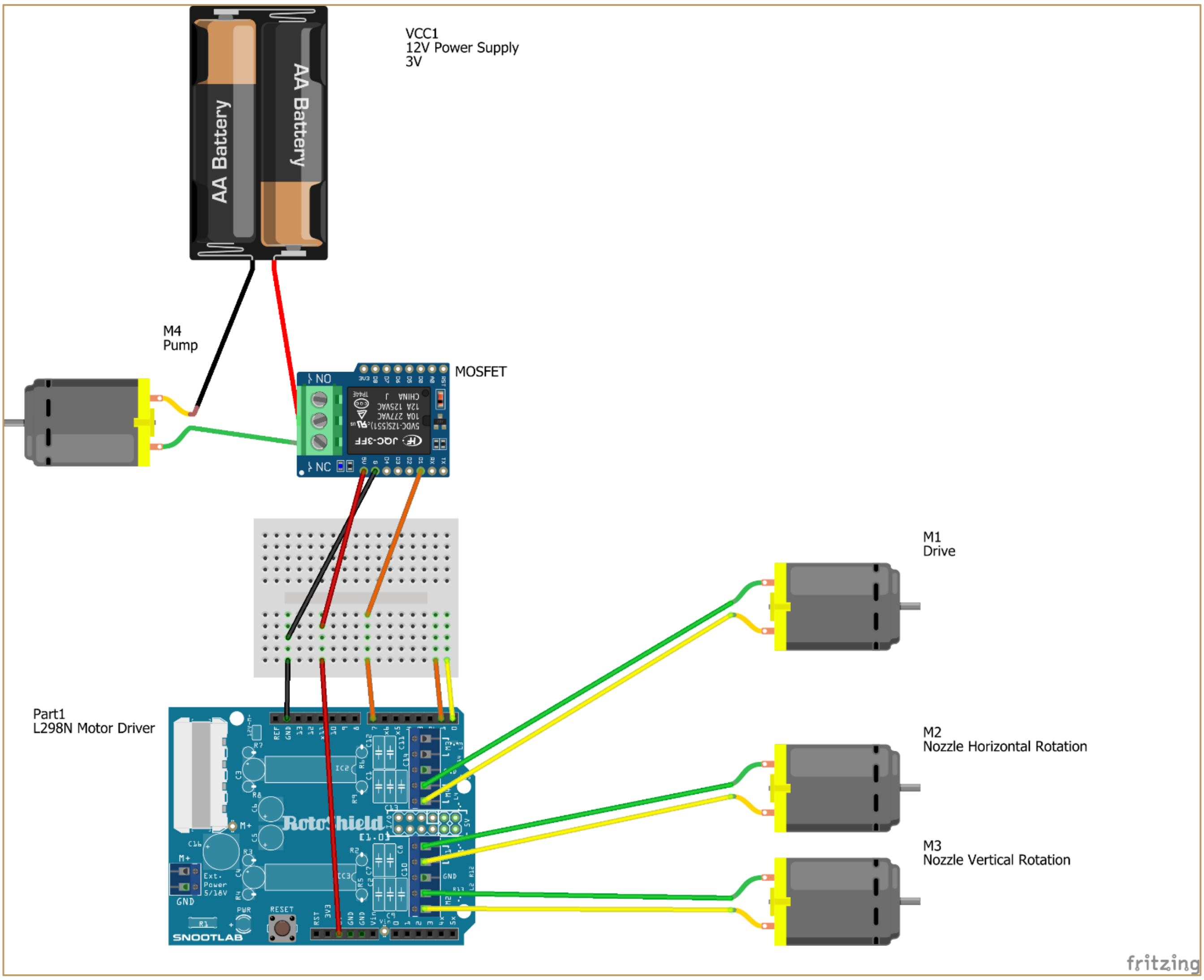

Figure 3. Basic Control System Design. Not to scale.

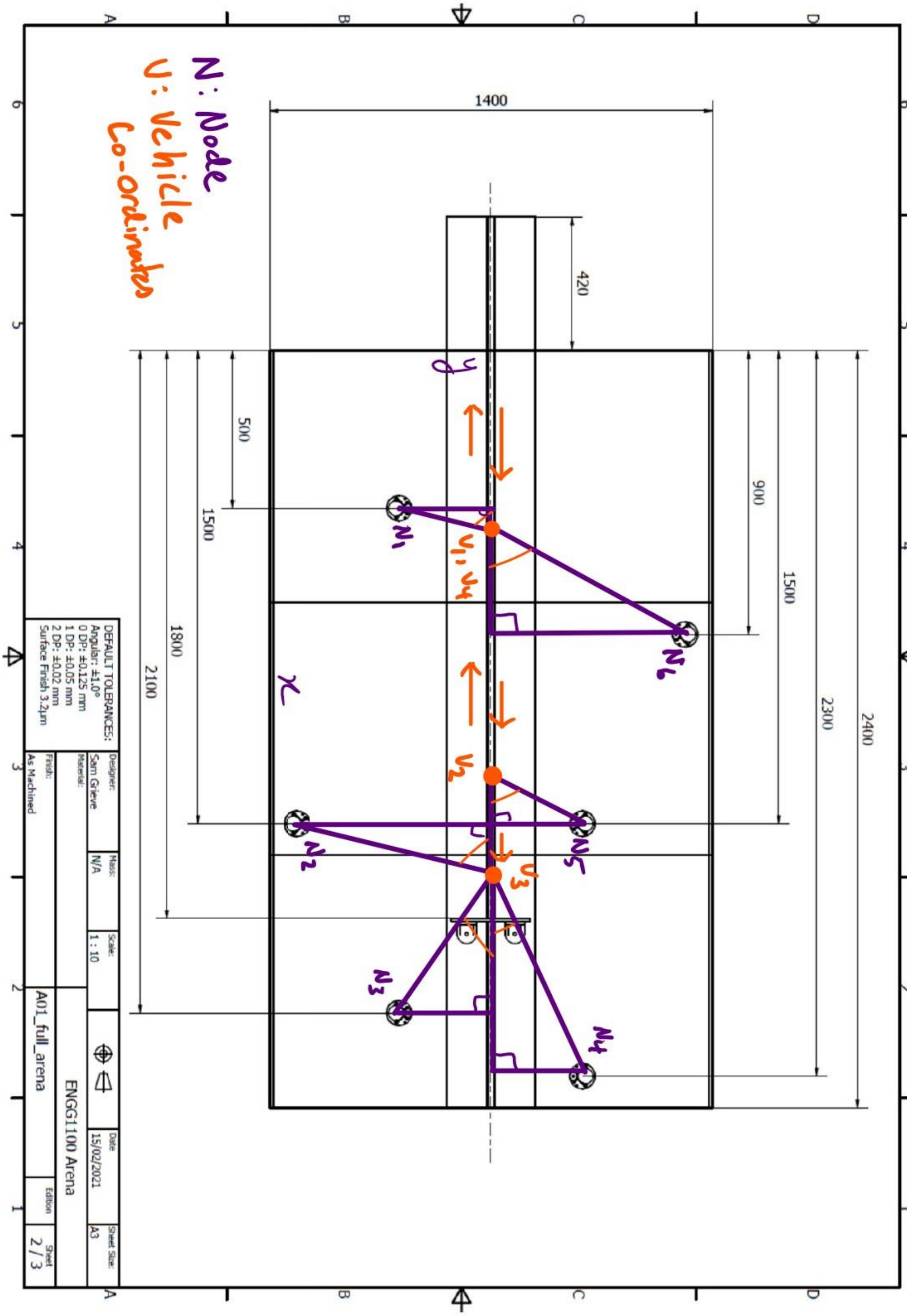

Figure 4. Automated Control Position Diagram

Table 11. Definition of Design Criteria

Criteria	Definition
CA. Safe	The control system components and software are tested to be efficient and reliable for their purpose. The system will not further endanger human life or the environment during operation (Koopman, 2007; Turner, 2009).
CB. Secure	The control system is safeguarded from cyber-attacks. Outside parties cannot easily take control, disable, or misuse the control system through outside software/hardware (Fenrich, 2007).
CC. Efficient	The signals sent and received are precise. The more accurate the signal quality is across the circuit; the less water and time are used. By using less water and time, the design follows Airways Australia's goal of providing an efficient and environmentally responsible service.
CD. Cost	The total cost of the control system and the cost of each part. As the cost lowers, more can be produced.
CE. Weight	The mass of a component. A constraint given by the Australian Aviation Rescue Fire Fighting Service.
CF. Power Efficient	The design uses minimal circuitry and requires minimal power to operate; this excludes power required by the pump and the turret. The more power drawn, the less efficient and environmentally responsible the component is.
CG. Adaptable	How easily can the UFV's circuit be adapted for a different scenario? The more adaptable the circuit is the more environmentally responsible it is as there is less electronic waste. It also makes the design capable of handling real world situations.
CH. Size	The space the component uses. The less space taken internally, the more space for other components.
CI. Reliability	The system is considered reliable when it is not 'stressed'. The components are unlikely to shut down from a lack of supplied power. The central processor of the control system is not made to use more than 85% of its total processing ability. If either case is true, the system is more likely to shut down, and is highly likely if both are true (Goble, 2012).

Table 12. BCS Grading Rubric

Criteria	4	3	2	1
C1. Operable	The control board can operate each system without a supporting module (excluding required MOSFET).	The control board can operate each system with one supporting module.	The control board needs multiple supporting modules to operate each system.	The control board is incapable of operating a system.
C2. Efficient	The control board can operate all systems simultaneously.	The control board can operate three systems simultaneously.	The control board can operate two systems simultaneously.	The control board can operate one system at a time.
C3. Adaptable	The control board has $\geq$40 connection pins.	The control board has $\geq$30 connection pins.	The control board has $\geq$20 connection pins.	The control board has 20< connection pins.
C4. Power Efficient	System requires $\geq$5V to operate.	System requires $\geq$6V to operate.	System requires $\geq$9V to operate.	System requires 9V< to operate.
C5. Cost	Total cost of the system is $\geq$\$10AUD.	Total cost of the system is $\geq$\$20AUD.	Total cost of the system is >\$40AUD.	Total cost of the system is $\leq$\$40AUD.

Table 13. BCS Criteria Piecewise Comparison

	C1. Operable	C2. Efficient	C3. Adaptable	C4. Power Efficient	C5. Cost	Sum	Weighted Total
C1. Operable		C2	C1.	C1.	C1.	3	0.3
C2. Efficient			C2.	C4.	C5.	2	0.2
C3. Adaptable				C3.	C4.	1	0.1
C4. Power Efficient					C4.	3	0.3
C5. Cost						1	0.1

Table 14. Wireless Control Criteria Grading Rubric

Criteria	4	3	2	1
C1. Secure	It is impossible for a cyber-attack to hijack the connection during use.	The connection is difficult to be hijacked in a cyber-attack during use.	It is possible for a cyber-attack hijack to occur during operation.	It is easy for a cyber-attack hijacker to take over the connection during operation.
C2. Adaptable	Connecting a new controller is simplistic.	A multi-step process is required to connect a new controller.	The controller must be of the same make for replacement.	The UFV needs to be rewired and/or programmed to use a new controller.
C3. Reliable	The maximum distance between the UFV and operator is ≥50m.	The maximum distance between the UFV and operator is ≥30m.	The maximum distance between the UFV and operator is ≥10m.	The maximum distance between the UFV and operator is 10m<.
C4. Cost	Total cost of the system is ≥$10AUD.	Total cost of the system is ≥$20AUD.	Total cost of the system is >$40AUD.	Total cost of the system is ≤$40AUD.

Table 15. Wireless Control Criteria Piecewise Comparison

	C1. Secure	C2. Adaptable	C3. Reliable	C4. Cost	Sum	Weighted Total
C1. Secure		C1.	C1.	C1.	3	0.5
C2. Adaptable			C2.	C4.	1	0.1667
C3. Reliable				C3.	1	0.1667
C4. Cost					1	0.1667

Table 16. Automated Control Sensor Criteria Grading Rubric

Criteria	4	3	2	1
C1. Efficient	The sensor readings are ≥90% accurate.	The sensor readings are ≥75% accurate.	The sensor readings are ≥60% accurate.	The sensor readings are 60%< accurate.
C2. Cost	Sensor does not require support for accurate readings.	Sensor requires one additional sensor for accurate readings.	The sensor one additional sensor and a processing algorithm for accurate readings.	The sensor requires multiple additional sensors for accurate readings..

Table 17. Automated Control Sensor Criteria Piecewise Comparison

	C1. Efficient	C2. Cost	Sum	Weighted Total
C1. Efficient		C1	1	0.6667
C2. Cost			0.5	0.3333

Table 18. Automated Control Co-Ordinates and Angles for Turret Operation

Node	X(mm)	Y(mm)	D(mm)	θ
$Node_1$	301	72.26	309.55	76.5
$Node_2$	625	150	642.75	76.5°
$Node_3$	301	450	541.39	33.78°
$Node_4$	301	650	716.31	24.85°
$Node_5$	301	150	336.3	63.51°
$Node_6$	625	350	716.33	60.75°

Table 19. Control Method Grading Rubric

Criteria	4	3	2	1
CA. Safe	The method of control does not create further hazards for human life or the environment.	The method of control reliable for its purpose and unlikely to create further hazards.	The method of control is suitable for specific static environments but could cause more harm in a variable environment.	The method of control is unreliable and would likely create more hazards.
CB. Secure	The method of control could not be taken over by a third-party cyber-attack.	Cyber-attacks on the control method are possible but can be safeguarded against.	Cyber-attacks on the control method are possible and hard to safeguard against.	It is simplistic for an outsider to take unauthorized control of the UFV using this method.
CC. Efficient	The UFV can process control signals with low latency (50ms) and no errors.	The UFV can process control signals with latency(50<300ms), errors may be caused from unaddressed variables.	A high amount of signal processing is required by the UFV to complete each take in a static environment.	The control board of the UFC would need to be redesigned to accommodate for the signal processing.
CD. Cost	The total cost of this implementation (including the control board and excluding the MOSFET) is ≥$30AUD.	The total cost of this implementation (including the control board and excluding the MOSFET) is ≥$40AUD.	The total cost of this implementation (including the control board and excluding the MOSFET) is ≥$50AUD.	The total cost of this implementation (including the control board and excluding the MOSFET) is $50<AUD.
CE. Weight	There is 3≥ components in the control system.	There is 3< 5 ≥ components in the system.	There is 5< 8 ≥ components in the system.	There is 8< components in the system.
CF. Power Efficient	System requires ≥5V to operate.	System requires ≥6V to operate.	System requires ≥9V to operate.	System requires 9V< to operate.
CG. Adaptable	The control board has ≥30 connection pins available for additions.	The control board has ≥20 connection pins available for additions.	The control board has ≥15 connection pins for additions.	The control board has 15< connection pins for additions.
CH. Size	The control method used no more than length, width, and double the height of the basic control board.	The control method needs placements across the body and turret of the UFV to operate.	The control method needs double the width and the height of the control board.	The size required is undefined.
CI. Reliable	The control method does not overload the basic control board.	The control method utilises 50% of the basic control boards processing ability.	The control method utilises 50<% of the basic control boards processing ability.	The control method would overload the basic control boards processing ability.

Table 20. Control Method Piecewise Comparison

	CA. Safe	CB. Secure	CC. Efficient	CD. Cost	CE. Weight	CF. Power Efficient	CG. Adaptable	CH. Size	CI. Reliable	Sum	Weighted Total
CA. Safe		CA.	CA.	CA.	CA.	CA.	CA.	CH.	CA.	7	0.1944
CB. Secure			CC.	CB	CB.	CF.	CG.	CH.	CI.	2	0.0556
CC. Efficient				CC.	CC.	CF.	CC.	CC.	CI.	5	0.1389
CD. Cost					CD.	CD.	CG.	CD.	CI.	3	0.0833
CE. Weight						CE.	CE.	CE.	CI.	3	0.0833
CF. Power Efficient							CF.	CF.	CF.	5	0.1389
CG. Adaptable								CG.	CI.	3	0.0833
CH. Size									CI.	2	0.0556
CI. Reliable										6	0.1667