MANDELA MINING PRECINCT
MINDS FOR MINES

MILESTONE REPORT

PROGRAMME	Longevity of Current Mining (LoCM)	**WORK PACKAGE**	LoCM21WP3 Remote Charing Unit
MILESTONE	LoCM21WP3-4 Manufacturing and assembly of prototype		

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REF NO:	LoCM21WP3-4 v2

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1 EXECUTIVE SUMMARY

The South African mining industry is experiencing major challenges to sustain its operations since 2008, where the negative impact of a fallen basket price demolished capital availability to expand and replace mineable resources with supporting infrastructure. This has resulted in the majority of workings being located at a far distance from the shaft infrastructure, which limits the face time for workers to complete the production cycle within a shift. As part of the Longevity of Current Mines (LoCM) programme, this project is seeking the opportunity to improve the safety of personnel being exposed in the high-risk areas.

The project will demonstrate the capabilities of the remote charging systems in the underground mining environment which will remove the explosives loading personnel from the high-risk area. This study will demonstrate the remote charging capability with an advanced technological system to optimize the production outcome where no person is entering the unsupported face area whilst charging the blast holes.

The project will be conducted over 17 weeks (starting 1 November 2022 and ending on 28 February 2023) and will cost R 920 700 (excluding VAT). The outcome of this work will be structured such that each work package deliverables are broken down into milestone deliverables. Each milestone comprising of defined deliverables with underground testing of the unit, the evaluation, and the close-out conclusion of the remote charging unit etc.

2 RESEARCH OBJECTIVES AND HYPOTHESIS

The work aims to conduct underground trials of the rugged remote charging unit. The trials are aimed to demonstrate the capability of the unit to load a pre-determined quantity of sensitized bulk explosives into blast holes. The lance will be inserted into a pre-drilled hole and pushed to the toe of the hole. The emulsion will be pumped through the lance into the hole and during the pumping phase, the lance will slowly be retracted. After the set quantity is loaded into the blast hole, the operator will move the unit to the next hole to be charged. The operator will be located at a safe distance under well supported hanging wall and will be able to see the position of the blast hole on a small monitor. The charging of the entire face, using the remote charging unit, should be similar in time compared to the current conventional charging of the face.

3 AIM OF MILESTONE DELIVERABLE

Milestone 4 will aim to discuss the manufacturing and assembly of the RCU prototype 2. The report includes discussions on the procurement of and the types of parts used to construct the new iteration of the RCU. This is discussed for each of the various working components of the RCU (locomotion, actuation, charging lance, electronics and the remote control system)

4 METHODOLOGY

The deliverables for work package 3 are indicated in **Table 1** below. The scope of this report is the deliverables of milestone 4.

Table 1. Milestone deliverables

MS #	Milestone Deliverables	Start Date	End Date	Amount
1	Start-up, and project initiation	2022/04/01	2022/04/15	R56 000
2	Design iteration on original proof of concept	2022/04/16	2022/06/15	R220000
3	Procurement of components and materials	2022/06/16	2022/08/31	R204232
4	Manufacturing and assembly of prototype	2022/09/01	2022/10/30	R296234
5	Testing and demonstration	2022/11/01	2023/01/31	R76234
6	Close-out and approval of final report	2023/01/16	2023/02/28	R68000
TOTAL				**R 920 700,00**

4.1 Procurement of components (planned vs actual)

The motors, gearboxes, chain drives, battery and motor drivers were the most expensive off the shelf components (used to construct the unit) and were procured over a course of two months. These items were expected to have longer lead times due to being procured from international suppliers. Smaller items and consumables were procured locally as needed during the manufacturing process. A detailed description of the internal components used in the unit is shown in **Figure 1**.

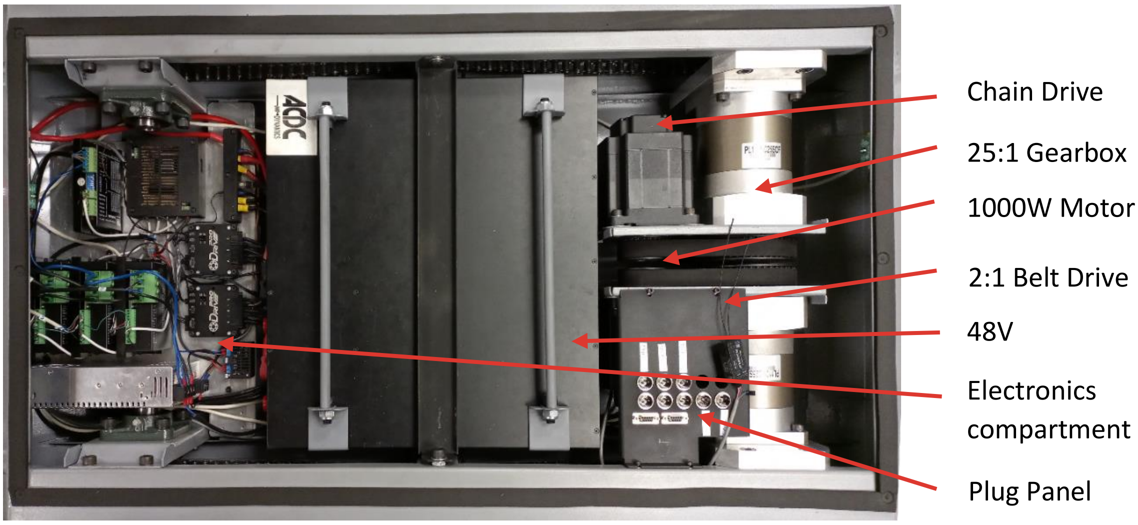

Figure 1. Inner components of the RCU

4.1.1 Locomotion

The mobile unit utilises a skid-steer mechanism for navigation, which involves independently driving the wheels on either side of the unit to adjust its speed and direction of travel. This is accomplished by controlling the speed of two identical drivetrains on either side of the unit, each consisting of a 1000W electric motor connected to a 25:1 planetary gearbox via a 2:1 belt drive reduction, resulting in a total reduction of 50:1 (see **Figure 1**). The output of the gearbox is then connected to one of the rear axles via a flexible coupling. Both the front and rear axles have matching sprockets attached to them, which allows them to be connected by a roller chain.

To enhance the durability of the unit and prevent liquid and dust infiltration through the drivetrain, the axles are secured to the chassis using bearing mounting blocks that include a shaft seal on the outside.

The unit is equipped with 23x7 inch Bearclaw tyres commonly used for all-terrain vehicles, making them sturdy and suitable for rough terrain. The tyres are mounted on 10x5 inch aluminium rims, which are bolted to wheel mounting hubs which are fixed to the end of each axle (**Figure 2**). A list indicating the type and quantity of the components used to construct the locomotion base of the RCU are shown in **Table 2**.

Table 1. List of parts procured to construct the locomotion base RCU

Qty	Description
2	1000W Brushless DC Motor
2	25:1 Planetary Gearbox
2	Pulley, timing belt, taper lock, HTD, 8M pitch, 24 tooth, 20 mm, Fenner.
2	Pulley, timing belt, taper lock, HTD, 8M pitch, 48 tooth, 20 mm, Fenner.
2	Contitech 560 8M 20, Timing Belt, 70 Teeth, 560mm 20mm
2	Coupling, complete, Triflex, 75, 210 Nm, 7200 RPM, Fenner
2	Flex element, Triflex coupling, 75, 210 Nm, 7200 RPM, Fenner
2	Sprocket, taper lock, simplex, 10B, 2012 bush, 30 tooth, Fenner.
2	Sprocket, pilot bore, simplex, 10B, 30 tooth, Fenner
2	Chain, roller, simplex, BS, agricultural, standard duty, steel, 15.875 mm pitch, BTC.
2	Master link, roller, simplex, BS, agricultural, standard duty, steel, 15.875 mm pitch, BTC
2	Half link, roller, simplex, BS, agricultural, standard duty, steel, 15.875 mm pitch, BTC
4	Tyre 23x7-10 Bearklaw
4	10x5inch Aluminium rims
4	Seal, oil, metric, double lip, nitrile, 25 x 52 x 12 mm, TTO
4	Angular contact ball bearing, double row, 2RS, , 25 x 52 x 20.6 mm, NSK.
2	Bearing unit, cast iron, square flange, setscrew type, 4 mount holes, 25 mm, TR

4.1.2 Actuation

Figure 2 depicts a descriptive image of the assembled RCU. The descriptions indicate the specifications of the components that form part of the actuation system of the RCU.

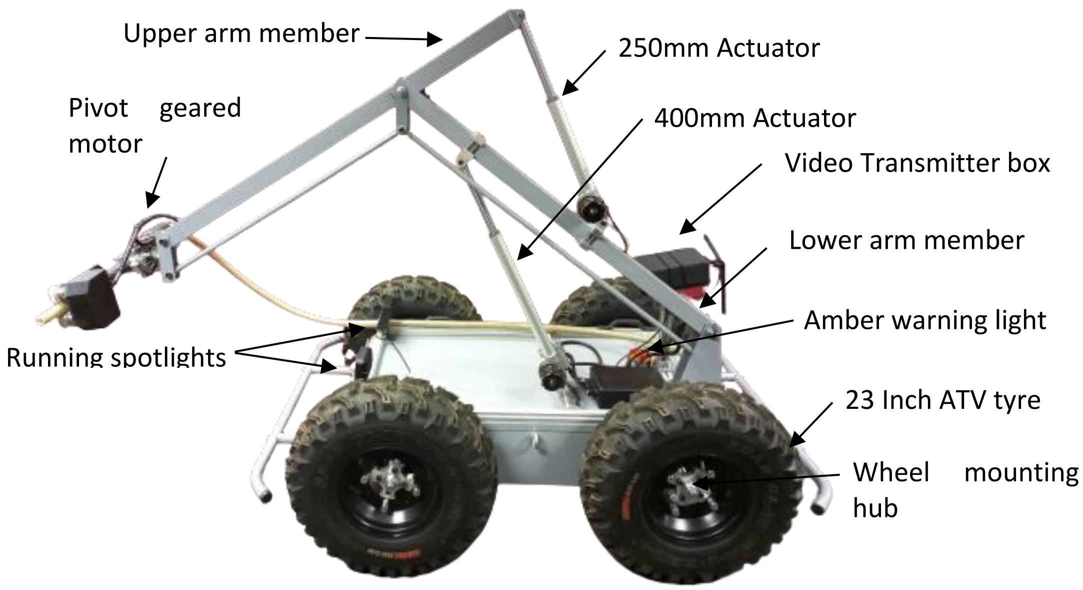

Figure 2. Schematic of the RCU prototype 2

To position an explosive charging implement into a pre-drilled shot hole, the device requires actuation. This is accomplished by a boom arm consisting of two members and three joints. The first joint permits the lower member to pivot around the unit's pitch axis, while the second joint is located at the end of the lower member and forms an elbow in the middle of the arm, enabling it to extend and retract. The final joint is a pivot around the unit's roll axis at the arm's end, which enables the charging mechanism to be tilted for aligning with holes drilled off the horizontal. By utilizing this actuation system, the charging height can be easily adjusted to reach both the maximum and minimum limits of 1500mm and 150mm, respectively.

The position of the first joint is adjusted using a 400 mm linear actuator, while the position of the second joint is controlled by a 250mm linear actuator. The third pivot joint is adjusted using a small worm drive motor gearbox combination.

Table 3 contains the list of the type and quantity of the components used to construct the actuation system of the RCU.

Table 2. List of parts used for the actuation component of the RCU

Qty	Description
1	Linear actuator, 400mm, 2500N, 25mm/s, Bircraft
1	Linear actuator, 250mm, 2500N, 25mm/s, Bircraft
1	Worm Drive Motor
1	Lower arm member
1	Upper arm member

4.1.3 Hole Charging Mechanism

A descriptive image of the charging lance mechanism of the RCU is shown in **Figure 3** below. The system is designed to move the charging lance in and out of the blast holes. It is made up of two hobbed drive wheels that grip tightly onto the outer surface of the lance and rotate in opposite directions, causing the lance to either extend or retract. These drive wheels are powered by two geared stepper motors that move at the same speed.

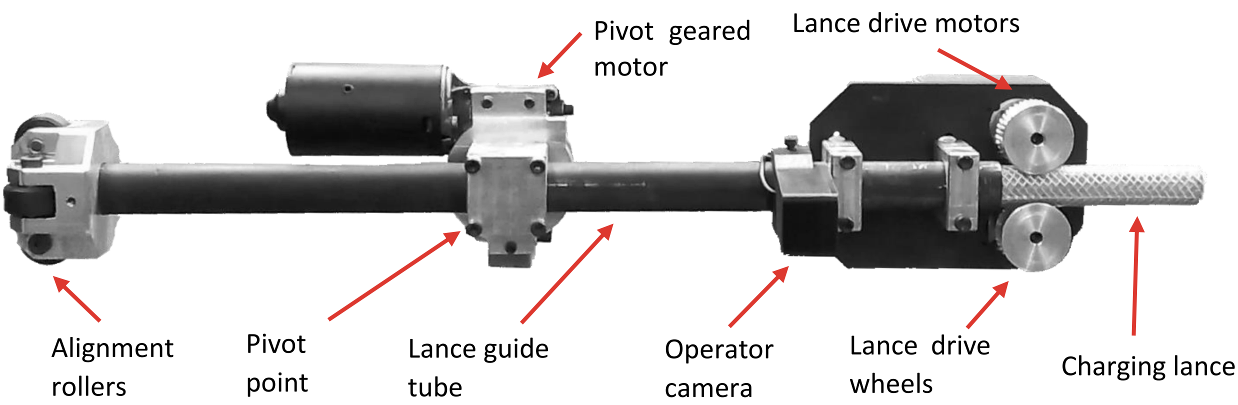

Figure 3. Schematic of the RCU charging lance mechanism

The lance is guided inside a steel tube that is mounted to the central pivot point. The pivot point is driven by a geared motor. At the far end of the pivot guide, a set of rollers are present to align the charging hose with the guide tube. Additionally, an operator camera is mounted near the drive wheels, which enables remote viewing of the charging mechanism's alignment with the hole.

Table 4 contains the list of the various components (type and quantity) used to construct the hole charging lance mechanism of the RCU.

Table 3. List of components used for RCU charging lance mechanism

Qty	Description
4	Alignment Rollers
1	Guide Tube
2	Drive wheels
2	Geared stepper motors 5.25:1 Nema 17
1	Charging lance
1	Remote view camera

4.1.4 Electronics

Power for the unit is all sourced from a 48V 3.2kW/h LiFePO4 battery (**Figure 1**). Which is designed to provide power for up to 8h at a time. The 48V is stepped down to 24V to power the arm actuators and running lights using a dc-dc converter. Finally, there is a further step down to 5V to run the main controller and camera system. The main power is routed through a large lockout switch which can be turned and remove to physically depower the unit.

Commands from the radio receiver are sent (via serial connection) to a central drive controller consisting of ESP32 microcontroller on a custom printed circuit board. The ESP32 interprets the radio control commands and sends appropriate signals to control speed and direction of each motor controller individually. The two 1000W brushless dc motors (used provide tractive power) are controlled by a pair of ODrive 4 motor controllers. These controllers communicate with the ESP32 via a CAN bus which is used to provide speed commands. Three Keya dc speed controllers each take three inputs at 5V, forwards, backwards and speed are used to control the arm actuators and pivot mechanism motors. These drivers also allow for limit switch inputs to keep the actuators from over running their maximum displacements.

A stepper motor driver is used to control the lance drive wheel position. Kill switches were placed on the front and back of the unit to shutoff all motor power in the extremely unlikely event that the unit were to somehow lose remote control. The controller was designed so that it has some additional inputs and outputs in the event that more hardware needs to be controlled (such as switching a charging pump on and off). A list of all the electronic components used is shown in **Table 5**.

Table 4. List of components used for RCU electronics system

Qty	Description
1	48V 3.5KWH LiFePo4 Battery US3000C
1	Mean Well DC-DC Converter, 24V dc/ 8.4A Output, 36 → 72 V dc Input, 200W
1	Main power lockout switch
1	Esp32 Microcontroller development Board
2	Odrive Brushless DC Motor Controller
3	Brushed DC motor speed controller, DC12/48RT50BL-XW, Keya
1	Stepper motor driver HY-DIV268-5a
1	Amber Flashing Beacon Light, 18-30 V, Xenon Bulb, IP67, Moflash X80 Series
2	15W LED Spot, 9-32VDC, IP67, ACDC

4.1.5 Remote Control System

The remote control system (**Figure 4**) consists of a commercial 2.4GHz radio control transmitter (FrSky Taranis x9D Plus 2019) and a receiver (FrSky X8R). The system utilizes frequency hopping to avoid interference from other 2.4GHz sources like Wi-Fi. The system can communicate over a distance exceeding 100m with line of sight. The transmitter is powered by a lithium-ion battery, and the receiver is powered by the 5V supply from the main control board.

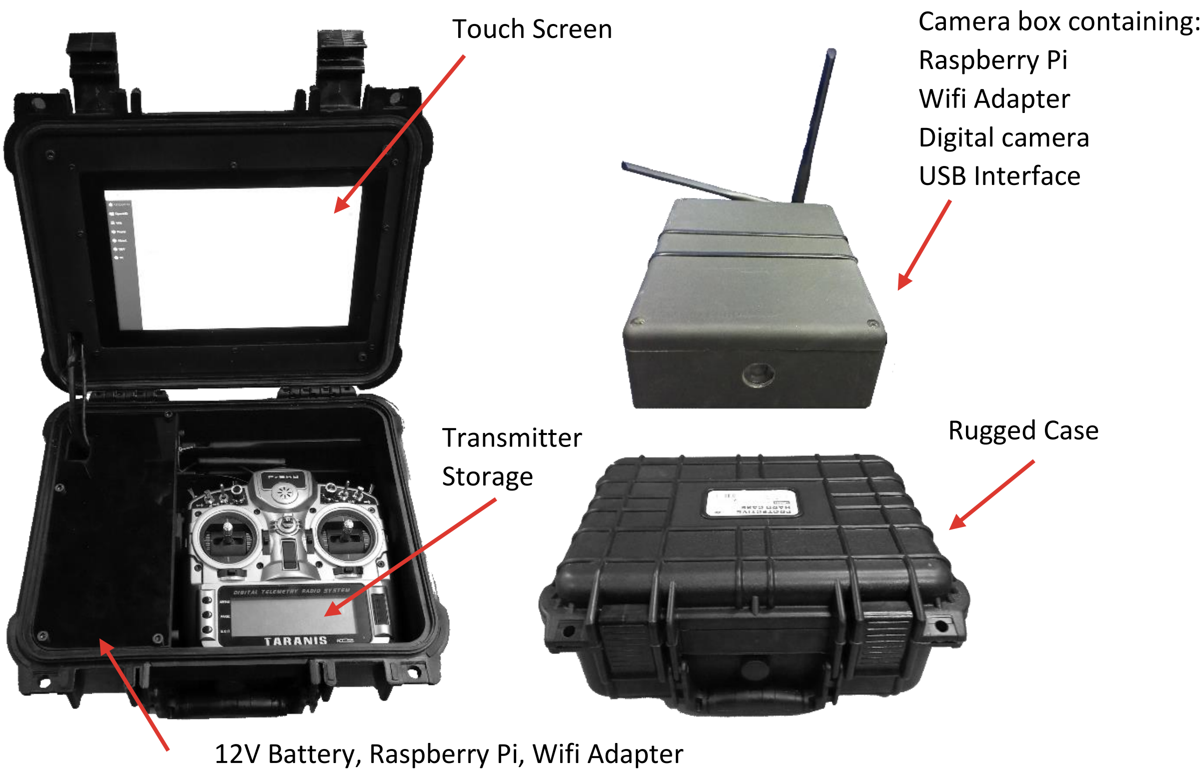

Figure 4. RCU remote control system components

The mobile unit is mounted with a box that contains a Raspberry Pi, a Wi-Fi adapter, and a digital camera. The camera is used to provide the operator with a view ahead while manoeuvring the mobile unit. The computer also has a secondary USB camera that captures the view from the charging mechanism. The video is streamed from this computer to a second Raspberry Pi computer using a 5.8GHz communication link.

The second Raspberry Pi and Wi-Fi adapter are packaged in a ruggedized case, which also contains a touchscreen display. The display shows the video feed from both cameras, and the case provides storage for the handheld remote controller.

4.2 Manufacturing of RCU prototype 2

The upgraded version of the remote charging unit was designed to achieve significantly improved performance and greater durability compared to the original prototype. In order to meet these design goals, the chassis was engineered using bent and welded sheet steel, resulting in a sturdy and secure tub-like structure that could be completely sealed with a single-piece lid and sealing strips. To prevent water and dirt infiltration, all holes that penetrated the chassis, such as those required for mounting the axles, utilized appropriate sealing techniques.

Other components which needed to be manufactured included:

- Motor mount brackets
- Motor to gearbox mounts
- Battery retention hardware
- Boom arm members
- Boom arm mounting brackets
- Charging lance guide tube
- Guide tube mounting systems
- Lance alignment rollers
- Electronics mounting plate
- Electronics boxes required to house the camera system
- Wireless video feedback system and rugged carry case

4.3 Assembly of RCU prototype 2

After manufacturing most of the components, the mechanical systems were assembled for the first time to identify any fitment issues. This process lasted for about two weeks as small design oversights and details emerged during the assembly process. For example, welding caused warping and brackets didn't fit as originally designed.

Once the main mechanical system was assembled, the main drive electronics were installed and tested. This process took about two weeks as everything needed to be carefully checked because of the system's high power rating. Although the initial tests with the main drive motors were successful, the main drive controllers stopped working and couldn't be reset. After some investigation, it was discovered that one of the motor drive control circuits had failed, and due to the international chip shortage, a replacement couldn't be found. To fix the problem, two complete new motor drivers were ordered from ODrive Robotics in the US and shipped with highest priority to the lab. However, this caused a significant delay to the project as it took two weeks for them to arrive.

Once the new main drivers were installed, calibration and testing of the motor control could commence. This took about a week to get the main drives producing adequate torque while ensuring that there were no unforeseen electrical issues that could cause damage.

After the main motors were working, the rest of the electronics were installed and tested. This process took approximately two weeks because of the complex wiring and the need for the unit to be rugged. Great care was taken to ensure that there was no possibility of a short circuit or loose wire inside the unit.

Next, the entire unit was disassembled, and final welding and painting were done both inside and out using enamel metal paint to provide rust protection and durability. The painting process took about a week, and reassembly took another four days. After this the unit was reassembled progressively as indicated by the figures below (**Figure 5**, **Figure 6** and **Figure 7**). The fully assembled unit can be seen in **Figure 2**. Assembly of the camera system took about a week as the enclosures had to be designed from scratch and housed in rugged containers.

Figure 5. Assembly of RCU inner components

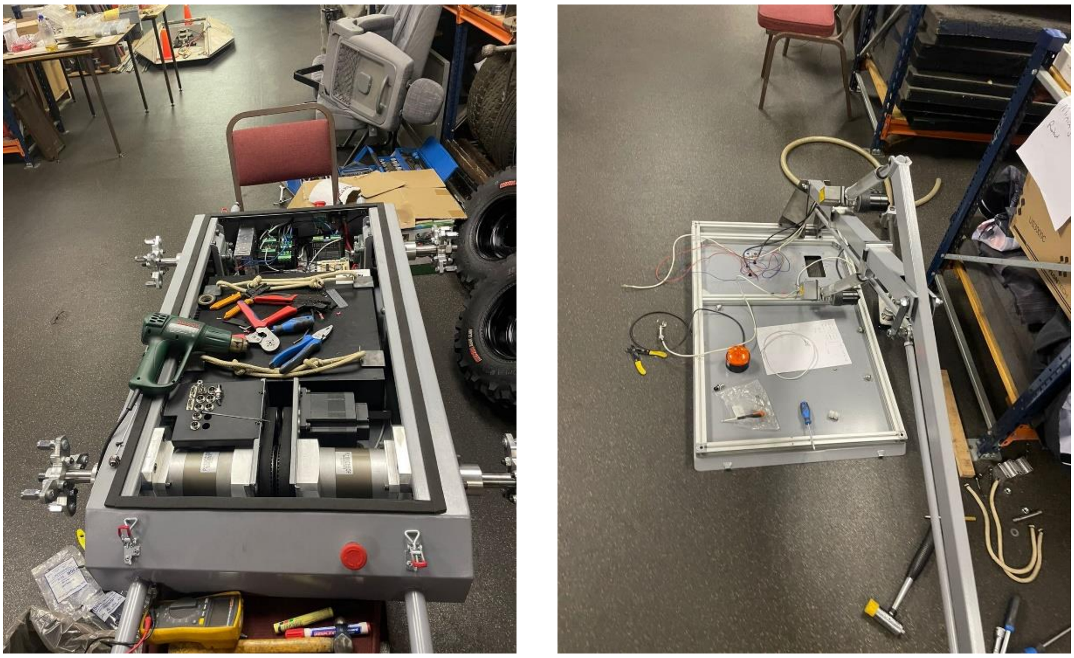

Figure 6. Assembly of RCU base (left) and robotic arm sections (right) near completion

Figure 7. Fully assembled base unit of RCU

5 CONCLUSIONS

There were several challenges experienced during the procurement, manufacturing and assembly stages of the RCU that added to the two month delay in completing the assembly of the unit.

Delays due to international shipping and chip shortages had a significant influence on the initial manufacturing and assembly timeline. This was highlighted again when the main drive controllers stopped working due to the motor drive control circuits failing, and due to the international chip shortage, a replacement couldn't be found. Two completely new motor drivers were ordered from ODrive Robotics in the US and shipped with highest priority to the lab. However, this still caused a significant delay to the project as it took two weeks for them to arrive.

The manufacturing process proceeded smoothly and was generally in line with the planned schedule of two months, with a few exceptions, such as the camera and video feedback systems, which could not be finished until the unit was fully assembled and mobile.

Overall, the assembly process took two months longer than expected due to the system's complexity and the care needed in the wiring and system layout to fulfil the ruggedness requirement. This process revealed that the team had severely underestimated the time required for the system integration step when designing a prototype of this complexity.

6 RECOMMENDATIONS

The challenges experienced during the procurement, manufacturing and assembly stages revealed that the initial timeline was severely underestimated. It is therefore recommended that these timelines be estimated with more care for the procurement, manufacturing and assembly stages of future prototypes.

7 WAY FORWARD

The manufacturing and assembly of the new prototype remote charging unit was completed and the following milestone, “Testing and demonstration”(LoCM21WP3.5) will commence.

8 QUALITY ASSURANCE

8.1 Internal Sign-off

The signature below verifies that this document meets the necessary quality assurance standards. The signatures below also provide assurance to the Mandela Mining Precinct that the work presented in the report has been quality checked, verified, validated for technical correctness and has not been plagiarised and is the original work of the team as submitted

The signatories below also note that any publication of material in this report in any form (presentation or written) will be vetted by the Mandela Mining Precinct management and the appropriate Technical Steering Committee through a written request before publication.

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2) Supervisor/Manager	Hein Barnard		9 March 2023
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Programme Manager	M Pretorius		22/03/2023