MONOCLE

Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

Solar-tracking Radiometry platform (So-Rad)

Build Manual

PML | Plymouth Marine Laboratory

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1. System overview

The purpose of the Solar-tracking Radiometry platform is to maintain optimal viewing angles of radiance sensors recording water-leaving reflectance, in order to avoid sun glint and platform shading, even from moving platforms such as ships or buoys. The system is developed to operate autonomously, with low power consumption, integrating commercially available (ir)radiance sensors and providing remote connectivity.

This construction manual is part of a series of resources documenting the So-Rad:

- Construction manual (this document) with the following appendices:
  - A photographic step-by-step instruction of the controller box layout
  - A series of CAD drawings as templates for electronics
- Deployment Guide: detailing how to use the So-Rad in the field. A summary is included in Ch. 6.
- Software repository (https://github.com/monocle-h2020/so-rad)

The So-Rad system and its main components are shown in Figure 1.

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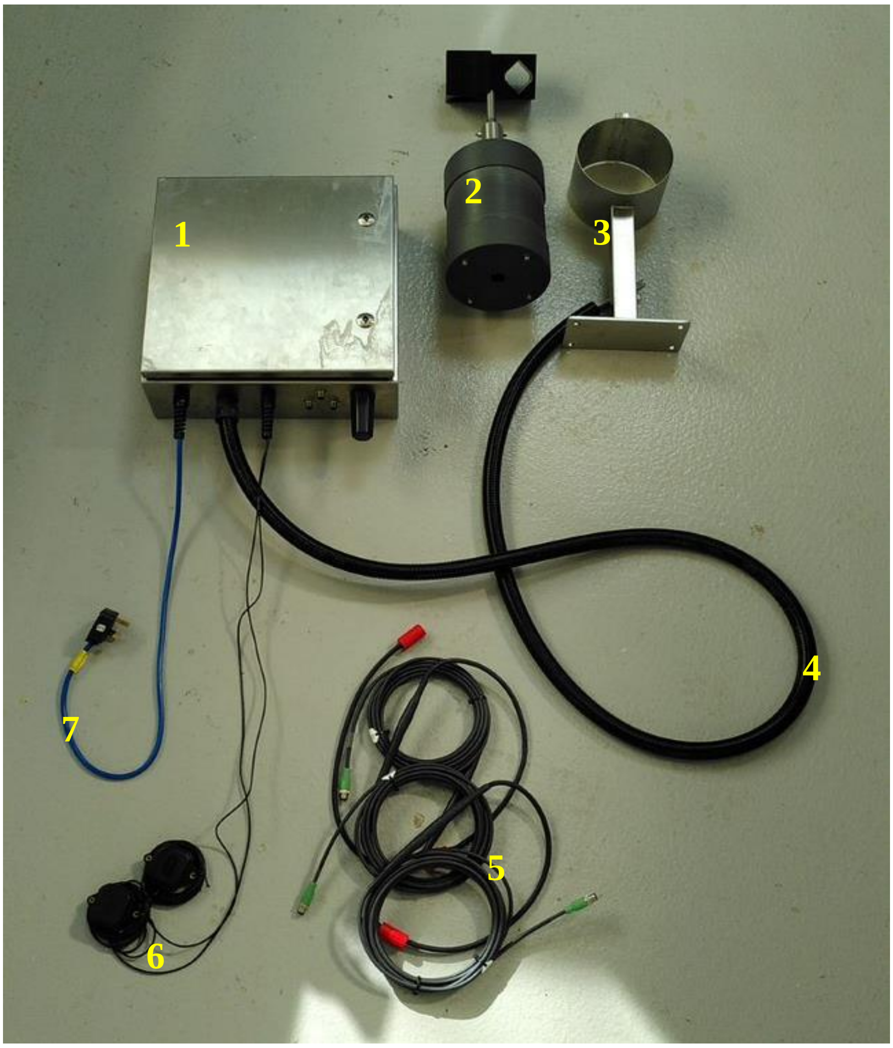

Figure 1. So-Rad unit with (1) Control unit, (2) motor enclosure, (3) mounting bracket, (4) motor cables, (5) sensor cables, (6) GPS receivers and (7) AC mains power cord.

A So-Rad consists of a control unit, a motor enclosure with radiometer brackets, cabling and any mounting hardware to suit the deployment platform. Construction and configuration of the control unit is covered in the following chapters, which includes all electronics work. Construction of the motor enclosure is not described here, but CAD drawings are available as complementary documents.

2. System specifications

2.1. Disclaimer

This document is a guide to building a So-Rad system equivalent to those produced at PML. The quality of the finished build is entirely your own responsibility. PML cannot accept liability of any kind for the information provided in this document and any omissions or errors contained within. Following this guide to build a So-Rad unit does not on its own fulfil any testing requirements that apply to your locale.

We recommend that the equipment is only assembled, installed and maintained by qualified personnel. We further recommend that the equipment is secured from tampering by non-qualified individuals. Any concerns with equipment or operation of equipment should be forwarded to and corrected by qualified personnel only.

2.2. General operating conditions

Intrusion protection: the electronics enclosure has been tested in our laboratory to withstand water intrusion equivalent to IP66. However, the operator should inspect and maintain good seals around cable glands and mounting points, correcting any damage caused by prolonged exposure. The electronics enclosure should always be installed in the correct position to prevent damage to the contained components. This means that the controller box must be mounted with cabling pointing down. It is advised to mount the enclosure in a sheltered location for ease of maintenance.

The motor enclosure has been designed to withstand water intrusion equivalent to IP67. This has been tested with the enclosure submerged without its cable attachments. With cabling attached, we expect that water intrusion protection equivalent to IP66 applies.

All electronics components referred to in this guide are commercially available and bear the CE mark. When included as described in this document, using suitable electrical connections and enclosures, the assembly as such complies with testing regulations for low voltage equipment, provided that all works are carried out by qualified personnel and the assembly is tested for use.

The allowable operating conditions, based on the specifications of the individual components listed in the next section, are a temperature range between 0-50°C, RH: 20-85%, and a pollution degree of 2. Further detail is provided in the next chapter.

In general, observe the following:

- Equipment should only be operated and installed by qualified personnel.

- Operate any component parts within their respective operational limits, both electrically and mechanically.
- Do not overload components with additional mass, voltage or current.
- Ensure installation in appropriate environments with appropriate spacing for units prone to overheating.
- Never access or alter the circuitry or components when power is ON. Always make sure power is OFF before touching ANY component within the unit.
- A fused terminal switch is built into the control unit. An external fused operating switch should be installed by qualified personnel upon installation of the equipment to avoid any need to open the control unit after installation.

2.3. Dimensions and weight

The control unit measures 400 x 400 x 150 mm without cable glands and fixtures. 150 mm bottom clearance is recommended to accommodate cabling. The control unit weighs 13 kg.

The motor enclosure manufactured in ABS plastic, including sensor holders, measures 560 mm in length, 175 mm in diameter and weighs ~6 kg (sensors not included).

Mounting brackets are platform-dependent and not specified here. Use of stainless steel is recommended for marine applications.

2.4. Power consumption

Power consumption is approximately 15W in the default configuration.

2.5. Control unit components

Table 1 lists the component numbers which are consistently used throughout the document (e.g. *"controller box (1)"*. The overview table includes some optional or substitution items which are needed to complete alternative power supply configurations, as explained below the table.

Table 1 Component list for So-Rad control unit construction

Number	Description	Make and model
1	Controller box	RS Pro 304 Stainless Steel Wall box, 400 x 400 x 150 mm
2	Stepping Motor	Oriental Motor AZM46MK-PS36 (higher-torque options available)
3	Motor controller	Oriental Motor AZD-KD
4	Motor cables	Oriental Motor 3 m (CC030VZFB2) – other lengths available
5	24-12V DC/DC converter	Chinfa DRD15-12
6	24-5V DC/DC converter	Chinfa DRD30-05
7	USB Hub	D-link 7-Port Hi-speed USB 2.0 Hub, USB-A – USB-B, with Tracopower DIN rail mounting kit
8	Raspberry Pi and case	Raspberry Pi Model 3B+ and Italtronic Raspberry Pi DIN rail case
9	Real time clock for (8)	Adafruit DS3231 real time clock (RTC)
10	IMU Accelerometer	Adafruit ADXL345 inertial measurement unit (IMU)
11	Temperature and Humidity sensor	Adafruit AM2302: PCB using the DHT22 relative humidity and temperature (RH & T) sensor
12	Cabling for (9-11)	6-way female 2.54mm pitch jumper wires
13	Ribbon cable and Connector for (9-11)	Cable: 40-wire ribbon cable Connector: 20-way IDC socket

14	TH connector for (9-11)	20-way IDC connector plug, through hole (TH) mount
15	SD card	SanDisk (16GB or larger)
16	Solid State Relay (SSR)	Crydom DRA1-CMX60D5 DIN mounted solid-state relay
17	Modem	Teltonika RUT240 Router 4G (WiFi enabled) with RUT 230/240 DIN rail connector accessory
18	LTE Modem antenna	Siretta Tango41 4G LTE Omnidirectional antenna with SMA Jack-Plug cable
19	DIN Rail	35 mm DIN rail
20	Ethernet cable	Network cable cut to length, with RJ45 terminals
21	IDC connector socket	40-way IDC connector socket (Ribbon cable connector)
22	Screw terminal block	DIN rail screw terminal, 5mm, with termination/end clip
23	Triple tier screw terminal	2.5mm Triple level DIN rail screw terminal and blanking plate
24	Earth/Ground terminal	DIN rail Earth terminal, screw clamp connection
25	Cross connectors	Jumper bar/pole connectors for screw terminals
26	End stops	DIN rail screw clamps, rugged end stops
27	Wiring/cabling	1.3mm^2 cabling (Blue)
28	USB - 5V Serial interface	FTDI Chip, 5 V TTL Wire End USB to UART Cable TTL-232R-5V-WE
29	USB - RS232 serial interface	FTDI Chip 1.8m Male USB to Wire-Ended Interface Converter
30	USB - RS485 serial interface	FTDI Chip 1.8m Male USB Black Interface Converter Cable
31	Cable glands	M16 Cable Glands
32	AC/DC converter 220 VAC/24 VDC 5 A	PULS Piano power supply PIC 120.241C (Power configs 1-2)
33	DC/ DC converter 12 V/24 V 4A	PULS Dimension power supply CD5.243 (Power config 3)
34	MCB C6	Schneider electric Easy9 C6 EZ9F66106
35	MCB C10A	Schneider electric C10A
36	220V AC supply socket	DIN rail mounted AC power socket
37	Rechargeable 12 VDC battery	MSC 12V battery GP09 - Rechargeable battery from net supply (Out) 38000mAh (144Wh)
38	GPS Receiver, accurate GPS	SimpleRTK2B power+header
39	GPS + Sensor enclosure	105 x 70 x 40mm, with DIN rail mounting plate
40	GPS dongle	Standard single GPS module (*alternative to (38)*)
41	Solar panel charge controller	Victron charge controller (Power config 3.1)
42	Spectroradiometers	TriOS RAMSES Hyperspectral radiometers are currently supported in the software.
43	SubCONN connectors	SUBCONN micro-5 pin male (spectroradiometer-specific)
44	Micro USB – USB-A cable	Power cable for simpleRTK2B
45	Micro USB - unterminated	Power cable for Raspberry Pi
46	Cable Trunking	Betaduct cable trunking: 40mm H 25mm W
47	Cabling conduit	Plastic Flexible Conduit 25mm (diameter) M25, used for Motor controller cables
48	RJ45 terminals	End terminals for ethernet and RS485 cables
49	Through-hole 8 pin radiometer connector	Unterminated Phoenix contact 8 pin through hole M8 connector
50	LIR1220 rechargeable battery	Rechargeable coin cell battery for use in the RTC charging circuit.

2.6. Alternative power configurations

Power Modification 1 (P1): Mains power (default)

Power is supplied directly from the Mains/Net power via 220-240V AC feed powering the entire control circuit.

Power modification 2 (P2): Mains with battery back-up for critical subsystems

Power is supplied from the Mains/Net source via 220-240V AC which is connected in parallel to a 12V DC rechargeable battery back-up allowing pass-through (simultaneous charging and consumption - battery not included with unit). Mains feed powers the 12V DC battery which supplies power to the 5V control circuit through the 5V DC/DC converter to keep the Raspberry Pi and sensors circuits running during interruptions. The remainder of the control circuit (modem, motor) remains directly powered by the Mains 220V AC feed.

Power modification 3 (P3): External battery

Power is supplied directly from a 12V DC external battery powering the entire control circuit.

Power modification 3.1 (P3.1): External battery with solar panel recharge

Power is supplied from a solar charge controller connected to charging circuitry and a battery unit. The So-Rad is connected as the load of the solar charger. Place the controller and battery in a separate enclosure.

2.7. Component operating conditions

Table 2. Safe operating conditions for key components of the So-Rad controller box as provided by their manufacturers. Conditions marked in red indicate the lowest tolerance in each category.

Number	Component	Degree of Protection	Ambient (operating) Temperature (°C)	Humidity (%) (non condensing)	Pollution degree
1	RS Pro 304 Stainless Steel Wall box	IP66	-	-	-
3	Motor controller (AZD-KD)	**IP10**	**0 - 50**	**<85**	2
5	Chinfa DRD15-12 24-12V DC/DC converter	IP20	-40 - 70	**20-90**	2
6	Chinfa DRD30-05 24-5V DC/DC converter	IP20	-40 - 71	20-90	2
7	D-link 7-Port Hi-speed USB 2.0 Hub	-	0-40	10-90	-
8	Raspberry Pi (3B+) (LAN9512-microchip)	-	0 - 70	-	-
16	Solid State Relay Crydom DRA1-CMX60D5	-	-20 - 80	-	-
17	Teltonika RUT240 Router 4G	-	-40 - 75	10 - 90	-
32	PULS Piano power supply PIC 120.241C	IP20	-10 - 70	5 - 95	2
33	PULS Dimension power supply CD5.243	IP20	-25 - 75	5 - 95	2
34	Schneider electric Easy9 C6 EZ9F66106	IP20	-5 - 60	5 - 95	2
35	Schneider electric C10A (A9F54110)	IP20	-35 - 70	<95	3
38	ZED-F9P ublox, SimpleRTK2B	-	-45 - 80	-	-

2.8. Component safety and warnings

This section provides an overview of the safety warnings, dangers, and cautions involved in operating the components included in this unit. Always refer to individual component manuals for the latest information regarding safe installation, operation, and requirements. The information provided here is only intended to plan your build prior to ordering components.

2.8.1. AZD-KD motor controller (3) and AZM46MK stepping motor (2).

General advice: The motor controller and stepper motor are connected by three cables combined in a cable conduit, which should be left intact and unaltered to maintain intrusion protection. This cabling should not be disconnected or connected whilst power is ON. The motor controller has been programmed to move at low speed, thereby posing no reasonable danger to operators of the equipment. Cabling to radiometers attached to the So-Rad by the operator should be secured whilst allowing free rotation of the motor. Only designated So-Rad software should be used with this assembly, which will ensure that movement of the motor always passes through the home position thus preventing winding up of external cabling.

Component manufacturer's advice: the following warnings are listed in accordance with those published in the operating manual of Oriental Motors, Stepping Motor and Driver Packages: AZ Series. Source: https://www.orientalmotor.com/products/pdfs/opmanuals/HM-60315-2E.pdf

Failure to handle the product while adhering to the listed "Warnings" may result in serious injury or death.

Failure to handle the product while adhering to the listed "Cautions" may result in injury or damage to property.

Warnings:
Prohibited actions

- Do not use the product in corrosive or explosive environments, in the presence of flammable gases, near combustibles or locations subject to splashing water. This may cause fire, electric shock or injury.
- Do not transport, install the product, perform inspections or form connections to the product when the power is ON. This may cause electric shock or arcing die to high current.
- Do not forcibly bend cable, pull cable, pinch cable. This may cause fire or electric shock.
- Do not touch the driver while power is ON. This may cause fire or electric shock

Compulsory actions

- Installation, wiring, cable connections, operation/controlling, inspecting and troubleshooting should be performed by qualified personnel. Failure to do so may result in fire, electric shock, injury or damage to the equipment.
- Any trigger of the drivers' protective alarm requires removal of the cause and a clear of the protective function. Continued operation without removal of the cause of the alarm may cause malfunction of the equipment, leading to injury or damage of property.
- Install product in an enclosure and such that the product is not at risk of contact with people or ground the product. Failure to do so may result in electric shock.
- In the event of power failure turn the power OFF for the driver. Failure to do so may result in injury or damage to the equipment.
- Keep input power voltage within the specified range. Failure to do so may result in fire or electric shock.

Cautions:
Prohibited

- Do not use the product beyond its specifications. This may cause electric shock, injury or damage to the equipment.

- Keep your fingers and objects clear of any and all openings in the product. Failure to do so may result in fire, electric shock or injury.
- Do not touch the object during operation or immediately after termination. This may cause skin burn(s).
- Keep the surrounding area clear of combustible materials. Failure to do so may cause fire or skin burn(s).
- Keep ventilation regions clear of obstructions. Failure to do so may damage the equipment.
- Do not forcibly bend pull or the cable that was connected to the driver. Doing so may cause damage to the equipment.
- Do not touch terminals during testing (Insulation or dielectric strength test). This may cause electric shock.

Compulsory

- Use only a specified motor and driver combination. Failure to do so may result in fire.
- Take measures against static electricity when operating the switches of the driver. Failure to do so may result in damage to the equipment.
- Use a DC power supply with reinforced insulation on primary and secondary sides to power the driver. Failure to do so may result in electric shock.
- Before supplying power to the driver, turn all input signals to the driver to the OFF position. Failure to do so may result in injury or damage to the equipment.
- Ensure an external emergency stop device or circuit is in place so that the equipment can operate safely in the event of a system malfunction. Failure to so may result in injury.
- When an abnormal operation occurs, immediately cease operation and turn off driver power. Failure to do so may result in injury, fire, or electric shock.
- Dispose of the product correctly in accordance with laws and current government regulations.

Additional precautions

- Always use the accessory cable to connect the motor and driver
- When conduction insulation resistance measurement, be sure to separate the connection between the motor and the driver.
- This equipment is not intended for use in residential environments, nor for use on low voltage public network supplied in residential premises. In these environments the equipment may not provide protection to radio reception interference.
- Do not turn off the power supply during or up to 5 seconds after writing data. Doing so may abort the data and cause an EEPROM error alarm (non-volatile memory can be written ~100,000 times).
- USB communication connector (CN4 connector) is not insulated. When grounding the positive terminal, ensure no equipment is connected where the negative terminal has been ground. This may short or damage the equipment. When connecting, do not ground equipment.
- Install in enclosure with IP54 minimum, with components that do not generate large amounts of heat or noise near the driver. Always install vertically with adequate ventilation such that the ambient temperature of the driver never exceeds 50°C.

2.8.2. PULS AC/DC (Piano) & DC/DC (Dimension) converters (32-33)

These devices may only be installed by qualified personnel and do not contain any serviceable parts. The tripping of an internal fuse is caused by an internal defect. If damage or malfunction occurs during installation immediately power off and return unit to factory.

Mount unit on DIN rail such that output terminals are at the top of the device, ensure sufficient ventilation is available for the unit and DO NOT obstruct ventilation. Ensure the device is installed according to the following clearances between units on DIN rail: 40mm at top, 20mm at base, 15mm on either side (5mm if adjacent unit is not heat producing).

The input must be powered from a SELV source (according to IEC 60950-1), a PELV source (according to IEC 62477-1) or an Isolated Secondary Circuit (according to UL 508).

Warnings:
AC/DC & DC/DC unit

- Turn off power before working on the device. Protect against inadvertent re-powering
- Make sure wiring is correct by following national and local codes
- Do not modify or repair the unit
- Do not open the unit as high voltages may be present inside.
- Use caution to prevent any foreign object entering the housing
- Do not use in wet locations or in areas where moisture and condensation are expected.
- Do not touch during power ON and/or immediately after. This may cause skin burn(s)

DC/DC unit only.

- Do not use the DC/DC converter without proper grounding (protective earth) use the terminal on the input block for the earth protection and not one of the screws for the housing.

Explosion hazard and Hazardous location

- The DC/DC Converter is suitable for use in Class I Division 2 Groups A, B, C, D locations and for use in Group II Category 3 (Zone 2) environments and are evaluated according to EN 60079-0 and EN 60079-7.
- Substitution of components may impair suitability for use in hazardous locations.
- Do not disconnect or operate voltage adjustments unless power has been switched off or the area is known to be non-hazardous. House the unit in a suitable enclosure with a minimum rating of IP54 which adheres to the requirements of the EN 60079-7.

For further reading see Section 10/12-15/17 of the operation manuals for PULS power supply units.

2.8.3. DRD Series DC/DC Converters (Chinfa electronics 30-05, 15-12) (5-6)

Units cool via normal convection ventilation to assist adjacent units must be a minimum of 25mm from the converter. Copper cabling is recommended of gauge 12-26AWG (2.5-0.2mm^2).

Maximum 5 pound/inch torque to be applied during terminal connections using 4-5mm stripping at cable end for DRD 15-12 converter, and 7mm stripping at cable end for DRD 30-05 converter.

2.8.4. Raspberry Pi (8)

To avoid damage to the user and device observe the following.

Warnings

- Only use this equipment in connection with an external power supply rated at 5V DC with a minimum current of 600-1800mA. This must comply with the operating regulations and standards in the country of intended use.
- Do not overclock the device without using the governor as this may overheat certain components
- Operate in a well-ventilated area on a stable, flat, non-conductive surface. Avoid bringing device into contact with conductive items.
- Unapproved devices connected to the GPIO connector may invalidate the warranty and cause damage to the device. Additionally, all peripherals connected to the device must be compliant to operational standards within the country of use. Should peripherals not include cables/connectors the used cable/ connector must provide adequate insulation and operation such that the performance and safety requirements are met.

Instructions for use

Take care while handling the Printed Circuit Board to avoid mechanical or electrical damage. To avoid this, handle the unit when housed in the case.

DO NOT:

- Expose to water moisture or place on a conductive surface.
- Expose to heat from any source, the Raspberry Pi is designed for reliable operation at normal ambient room temperature.
- Power via USB connection, device may malfunction.
- Directly contact the GPIO Pins to avoid static discharge and damage to the unit.

2.8.5. Teltonika RUT240 modem (17)

To avoid personal injuries (Voltage caused traumas) and property damage of the personnel using this device pleas e adhere to the following safety requirements.

Warnings

- The device is intended for supply from a limited power source, of which consumption should not exceed 15VA with a current rating of over current protective device should not exceed 2A
- Voltage within the secondary circuit should not exceed 36V (peak)
- The device used in conjunction with the equipment shall comply with the standard EN 60950-1.
- Do not mount or service the device in a thunderstorm.
- Transport in a damage proof package to avoid mechanical damage.
- Ensure operating LEDs are visible after installation.

2.8.6. Crydom DRA1 CMX60D5 (16)

Danger

Hazard of electric shock, explosion or arc flash, follow the below instructions to mitigate hazards:

- Disconnect all power before installing or working with this equipment
- Verify all connections and replace all covers before turning on power.

Failure to follow these instructions will result in serious injury or death.

Warning

Risk of material damage and hot enclosures when using device failure follow instructions to avoid damage to equipment or serious injury:

- Component can get hot during operation allow product to cool before handling once power is switched off.
- Follow mounting instructions including torque recommendations.
- Do not allow liquids or foreign objects to enter this product.

3. Control unit design and construction

This chapter describes the layout and connection of components contained in the control unit. Follow the detailed instructions in 3.3 Data connections and 3.4 Power connections. The diagrams in this chapter are also included as supplementary CAD files.

3.1. Control unit housing and fixtures

Mark out, on the exterior and interior of the box, the location of drill holes for cable glands and DIN Rail. Drill all holes using a 3.5mm drill bit and a 4mm tapping tool. Use M4 machine screws for fastening. Two holes per fixture is required as a minimum.

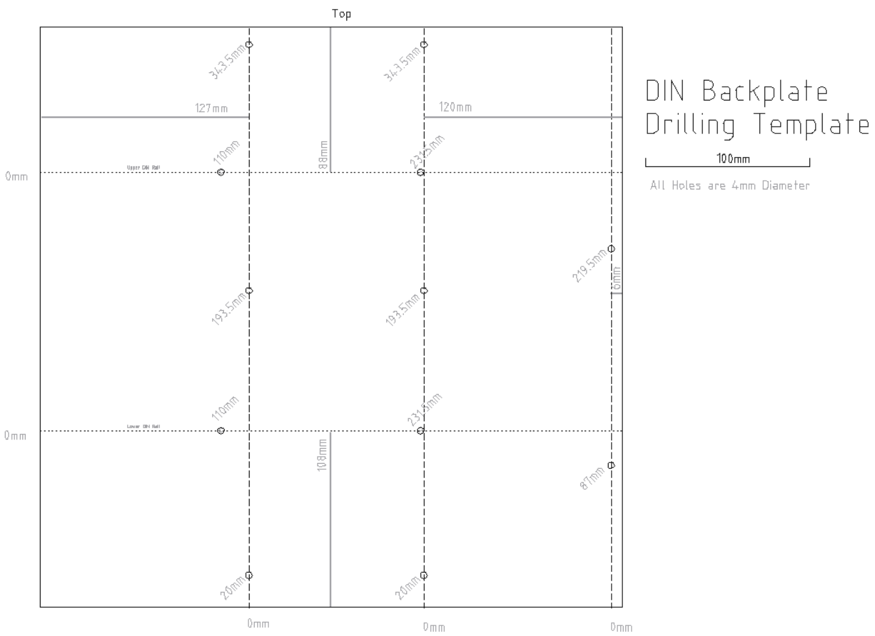

Figure 2. Drilling template of DIN backplate for mounting DIN rail and trunking. All holes marked on the template resemble a 4mm tapped hole. For further detail refer to the CAD files available with this document.

3.1.1. DIN Rail screw locations

Upper DIN rail holes must be drilled 88 mm from the top of the backplate, first hole 110 mm from the left-hand edge and the second 122 mm from the right-hand edge. Figure 2 is a schematic of the locations of the DIN rail and cable trunking holes provided 35mm width DIN rail and 25 mm width cable trunking is being used.

Lower DIN rail holes must be 108 mm from the base of the backplate, 110 mm from the left-hand edge and 122 mm from the right-hand edge.

3.1.2. Cable trunking

Drill top trunk holes 10 mm from the top of the backplate and approximately 127 mm from the left-hand edge and 120 mm from the right, these two locations across the backplate (127 mm-L, 120 mm-R) are repeated in the Centre and Base Trunks.

Drill centre trunk holes 160 mm from the top of the backplate and approximately 127 mm-L and 120mm-R.

Drill base trunk holes 20 mm from the base of the backplate and approximately 127 mm-L and 120 mm-R.

Drill right trunk holes 6mm from the right-hand side of the backplate, approximately 87 mm from the base and 134 mm from the top.

Controller Box Base:

Drill holes through the controller box for the following cables. Figure 3 represents the schematic of the Steel enclosures base were through holes will be cut to allow cables to be into the controller box (1).

- 16mm diameter – **Power cable gland (31)** (65mm from the left edge, 30mm from the top edge of the base of the controller)
- 25mm diameter – **Motor controller cables and conduit (47)** (130mm from the left edge, 50mm from the top edge)
- 16mm diameter – **GPS cable gland (31)** (200mm from the left edge, 30mm from the top edge),
- 3 x 16 mm diameter – **Radiometer sensor cable mounts** (1 - 135 mm from the right edge 60mm from the top edge, 2 - 115mm from the right, 30 mm from the top, 3 - 95 mm from the right, 60mm from the top)
- 16 mm diameter – **LTE Modem antenna (18)** (50 mm from the right, 40 mm from the top).

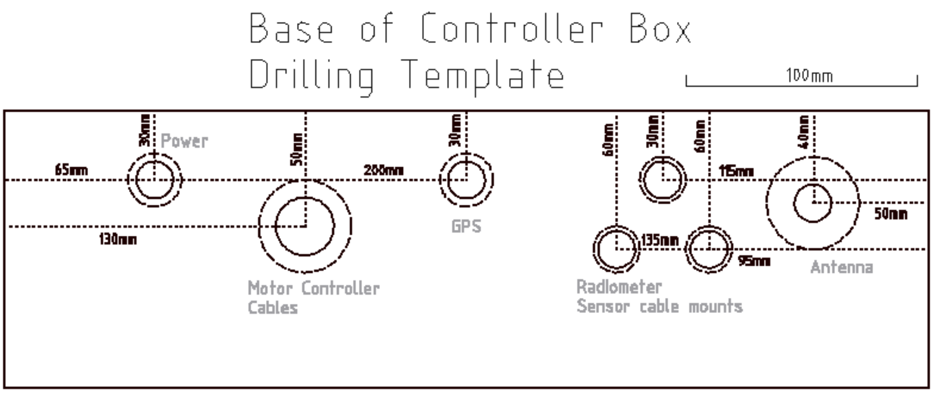

Figure 3. Drilling template for the base of the So-Rad controller box. Solid circles indicate the hole to be drilled. Dashed circles represent the footprint of the respective gland or panel mount. For further detail refer to the CAD files available with this document.

3.2. Circuitry standards

Cabling in this unit adheres to the codes and standards outlined in IEC 60204-1:2016 for UK/EU:

- AC Single phase, Active wire (Black), Neutral (Light blue), Ground (Green & Yellow)
- DC Control circuit, Blue (+/-)
- DC Power circuit, Black (+/-)

Mark the voltage carried through any given cable (3.3V, 5V, 12V, and 24V), for example with numbered cable clips.

Use stranded copper wire cabling for all DC Control circuitry excluding the connections between the DC power supply and AZD-KD Stepping Motor (2), for which solid copper core wire cable is advised.

3.3. Data connections

3.3.1. USB Hub --> GPS receiver (USB-A –> Micro USB)

Components:
7 D-Link 7-Port USB Hub 2.0 DUB-H7
38 SimpleRTK2B+heading board
44 Micro USB - USB-A cable

Connect the simpleRTK2B+heading board to the USB Hub from the power+GPS connector via micro USB (GPS) – USB-A (USB Hub). This board provides high precision location information and relative heading between the receivers, which is required on moving platforms.

Alternatively, If the unit is to be mounted with a fixed, known heading rather than a moving platform, connect a single USB-GPS (40) dongle to the USB Hub.

3.3.2. USB Hub --> Spectroradiometers

Components:
42 Spectroradiometers (3x)
7 D-Link 7-Port USB Hub 2.0 DUB-H7
29 FTDI USB-RS232-WE-1800-BT cable (3x)
16 Crydom DRA1-CMX60D5
22 Screw terminal block
23 Triple tier feedthrough screw terminal block (4x)
43 SubCONN micro-5 pin male connector
25 Cross connector

This section assumes the use of TriOS Ramses spectroradiometers. Please verify the correct power requirements and pinout from the manufacturer to avoid potential damage to the sensors.

The radiometers used in this build will take 12V power supply which is connected in series with the solid-state relay (SSR) and controlled by the Raspberry Pi. USB-RS232-WE-1800-BT interface cables are used for serial UART data connection to each of the radiometers.

Using the triple tier feed through screw terminals connect RX-TX (1st tier), TX-RX (2nd tier) for each USB RS232-WE-1800-BT cable – spectroradiometer cable connection. Using a 4-pole cross connector bridge on the 3rd tier (top), connect the ground cables from each sensor, negative power supply and FTDI USB RS232-WE-1800-BT Ground cables.

The colour coding for the FTDI USB RS232-WE-1800-BT cable is as follows:

- Black – GND (Ground Pin) -> connect to negative pole of 12V supply AND ground of sensor
- Orange – TX (Output), Transmit data -> connect to RX of sensor
- Yellow – RX (Input), Receive data -> connect to TX of sensor
- Brown – CTS (Input), Clear to Send handshake signal -> not used
- Red – Power (Output), Default output 0V -> not used
- Green – RTS (Output), Request to Send handshake signal -> not used

When connecting TriOS Ramses sensors, the pinout of the sensor is as given in Figure 4. Note that while the sensor pinout is as displayed, TriOS have both 5 and 8-pole connectors in use and connectivity tests must be completed to ensure that power pins are not reversed (to avoid damage) and data pins are connected TX-RX and vice versa with the USB interface cable (to avoid disappointment). In the specific case (but check all connections before powering on the sensors) of the panel mount connector for 8-pole cabling, the colour coding is as follows:

1. **Ground (Blue)** -> to neg. pole of 12V AND ground (pin 5 in 9-pin variants) of USB interface
2. **RX (White)** -> to TX (or pin 3) of the USB interface
3. **TX (Brown)** -> to RX (or pin 2) of the USB interface
4. **Power (Pink)** -> to +12V of power supply

Yellow, Red, Grey and Green are not used.

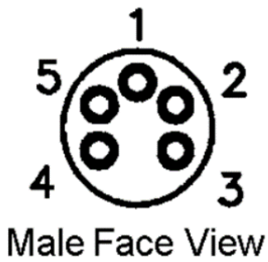

Figure 4 Pinout of TriOS RAMSES

Through a bank of three single tier screw terminals, insert the positive power cable from the spectroradiometers and bridge the bank with a 3-pole cross connector. On the opposing side to the terminal bank attach the 12V positive power supply cable from the solid-state relay.

Through-panel connectors

Fasten the Phoenix contact unterminated M8 8-pole female connectors (49) through the control unit enclosure, seal around connector with a weatherproof sealant for added precaution against water and to prevent movement. Connect the respective colours to the corresponding tiers of the triple tier terminal bank and the single tier terminal bank as outlined above.

3.3.3. USB Hub --> Motor controller

Components
7 D-Link 7-Port USB Hub 2.0 DUB-H7
3 Oriental motors AZD-KD motor controller
30 FTDI USB-RS485-WE-1800-BT serial cable
48 RJ45 connector

Use a standard ethernet connector (RJ45 connector head) with a USB-RS485-WE-1800-BT interface cable (30) for this connection. The RS485 pin out is as follows:

- **Black** – GND (Ground Pin),
- Brown – Terminator 1 (Input), Pin 1 of 120R terminating resistor, only required if the cable is the first or last drop in a multi-drop RS485 system.
- Red – Power (Output), Default output +5V, 0V during suspend
- **Orange** – Data + (A) (Bi-directional), Data + (A) Signal

- Yellow – Data – (B) (Bi-directional), Data – (B) Signal
- Green – Terminator 2 (Input), Pin 2 of 120R terminating resistor, only required if the cable is the first or last drop in a multi-drop RS485 system

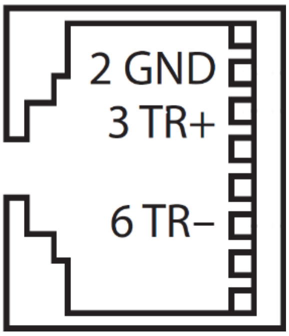

Figure 5. Schematic of AZD-KD motor controller CN6/7 (RJ45 – female) port pins.

CN6/ CN7 on the AZD-KD motor controller unit follow the pin layout. For CN6/7 GND, TR+ are located towards the base of the motor controller.

- Pin 1 – Not connected
- Pin 2 – GND, Ground connection
- Pin 3 – TR+, RS485 communication signal (+)
- Pin 4 – Not connected
- Pin 5 – Not connected
- Pin 6 – TR-, RS485 communication signal (-)
- Pin 7 – Not connected
- Pin 8 – Not connected

Finish the RS485 cable to the motor controller by mounting an ethernet cable connector (Figure 5) to the USB-RS485-WE-1800-BT interface cable:

- Ensure interface cable coloured wire ends are of equal length.
- Inside the ethernet connector align Black wire with the Pin 2 conductor, Orange wire with Pin 3 conductor, and Yellow wire with Pin 6 conductor. When inserting the cables into the connector head (looking from direction the wires are inserted into), the connector release clip should be on the right-hand side and the Ground pin will mate with the connector that is second from bottom.
- Push the wires firmly into the connector head, using a network connector crimping tool crimp the connector and cable. This will form a secure connection.
- Connect the RJ45 terminal into CN6 or CN7 slot on the motor controller and the USB connector to the USB-Hub.

3.3.4. USB Hub --> Raspberry Pi via USB-A - USB-B cable

```
Components:
7      D-Link 7-Port USB Hub 2.0 DUB-H7
8      Raspberry Pi
```

Connect the USB Hub via USB-A port to the Raspberry Pi USB-B port using a USB-A – USB-B cable.

3.3.5. Modem --> Raspberry Pi via Ethernet cable

Components:
17 Teltonika RUT240
8 Raspberry Pi
20 Ethernet cable

Connect LAN port on modem to LAN port on Raspberry Pi using an ethernet cable.

3.4. Power connections

All connections must be made and verified by a suitably qualified person.

Components and tools:
RS Pro ratchet wire stripping tool
RS Pro Bootlace ferrule crimping tool
1.7 mm diameter bootlace ferrules
2 mm diameter bootlace ferrules
Power cabling (27)
3.5 mm precision flathead screwdriver

Follow the connection schematics and instructions in this section for the relevant power modification of the So-Rad configuration.

Unless otherwise specified power cabling should be prepared as follows:

- Using 16AWG (1.3m m2) insulated copper stranded wire.
- Stripped to 7 mm for each terminal connection using an appropriate wire stripping tool.
- Use either 1.7 mm or 2 mm diameter bootlace ferrule crimp to crimp the end of stripped wires. Use a bootlace ferrule ratchet style crimping tool capable of crimping 14-18AWG cable
- At all screw terminals are to be tightened using a 3.5mm precision flathead screwdriver.

3.4.1. Default power configuration: (P1) Mains Power (220 V AC)

Ensure power is disconnected before making changes to any circuitry. All schematics and connection maps can be found in the supplementary material – Technical drawings/Controller box.

The default (P1) power configuration component layout is shown in the below schematic Figure 6, this configuration takes into consideration the minimum spacing required for ventilation of heat prone components. Deviations from the instructions for this power configuration needed to operate on battery (with mains backup) or DC power (e.g. from solar or battery) are detailed in sections 3.4.2 and 0, respectively.

Connections relevant to this power modification are displayed in Figure 7Figure 6. A step by step guide of connections is detailed below.

1. Feed through mains power cable (Light blue) to reach the AC /DC 24V power supply converter (**PULS PIANO 120.241C (32)**). Strip the cable of its insulation to reveal the neutral, live and ground wires.
2. Strip 7mm of the outer sheathing from the ground (Green & Yellow) wire

3. Crimp an insulated bootlace ferrule (2 mm) using a ratchet insulated bootlace ferrule crimping tool.
4. Insert the crimped Ground wire into the AC terminal denoted by the ground symbol with ~1Nm torque using a 3.5mm cross-headed or slotted screwdriver.

Using the same tools and steps as above repeat the process for the Neutral wire (light blue)/ terminal (N) and the Active wire (black)/terminal (L)*.

*The Active or load bearing wire must be run through the MCB C6 (34) fuse before attaching to the load terminal. This is required in the event the circuit becomes overloaded.

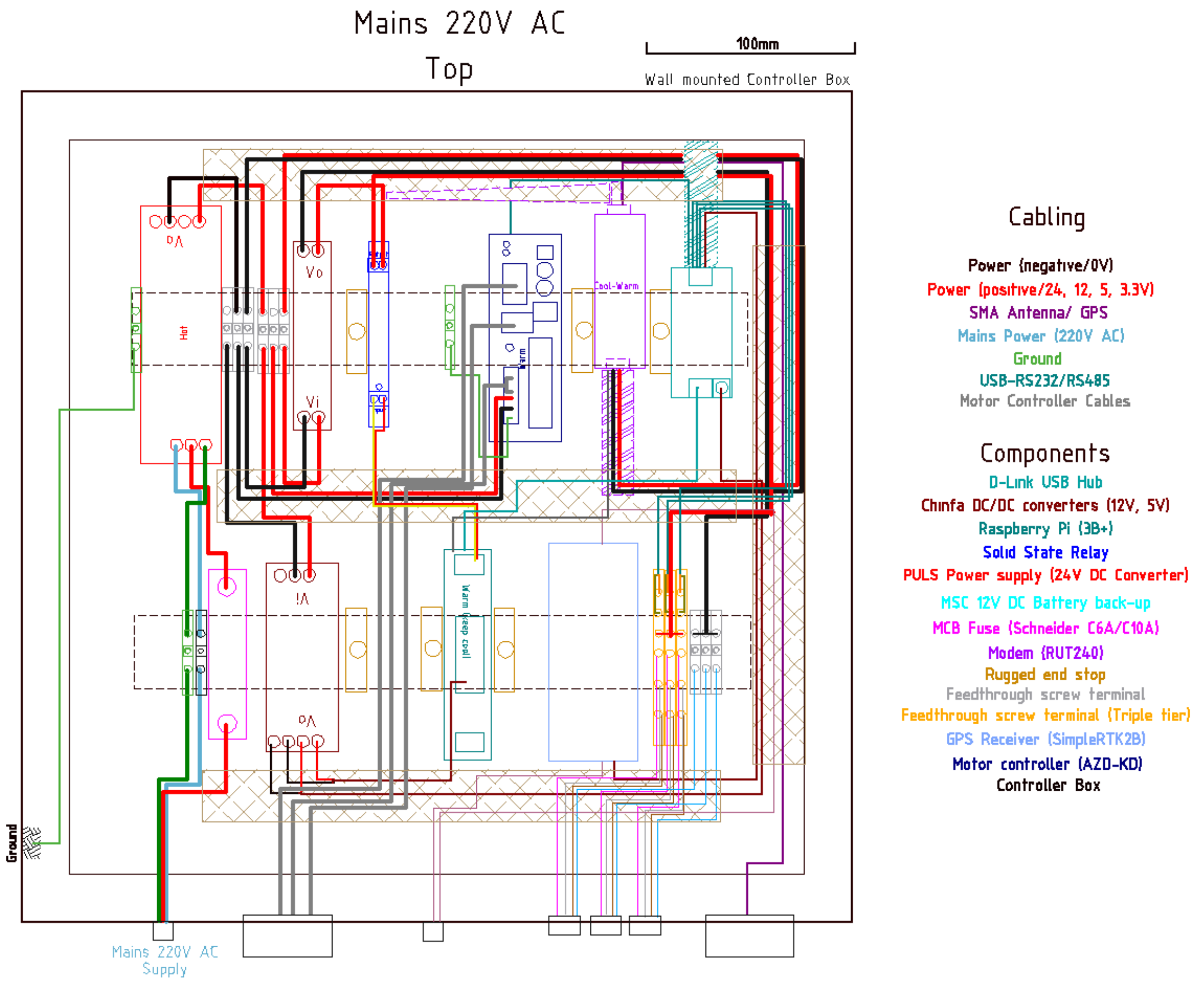

Figure 6. P1 220 V AC, schematic of component layout and cabling configuration of the So-Rad controller box.

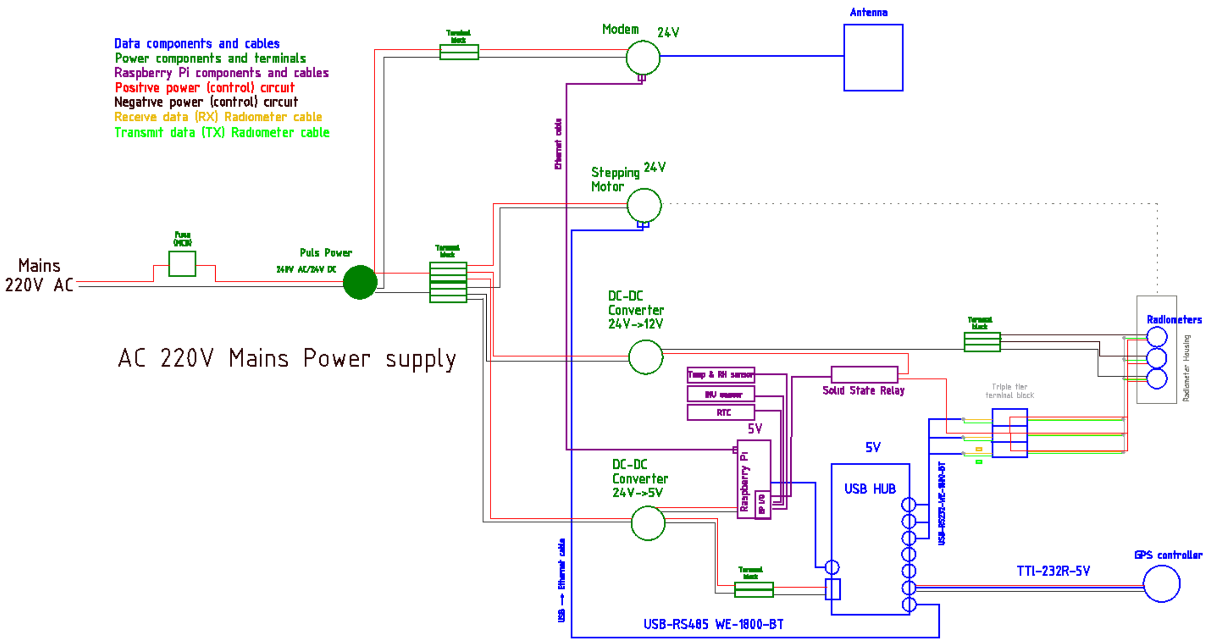

Figure 7. P1 220V AC, power, data and sensor cable connectivity map to complement component schematics for this configuration.

3.4.1.1. **24 V DC circuit**

The 24 V circuit of the P1 220 V AC configuration is outlined by the connectivity map in Figure 8.

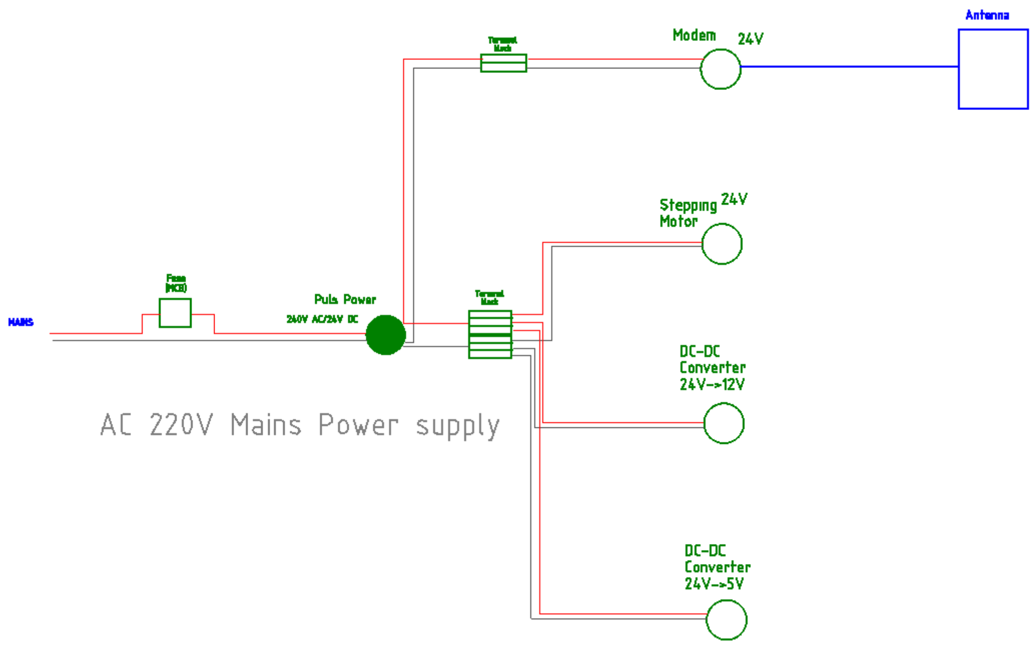

Figure 8. P1 220 V AC, 24 V power cabling connectivity map

3.4.1.1.1. **24 V DC power supply <--> Stepping Motor Controller**

Components:

```
32     AC/DC converter - 24V DC power supply
3      Motor Controller
30     USB-RS485 Serial cable
```

From a DC (+) terminal crimp and connect to the positive socket of the CN1 terminal of the AZD-KD Oriental Motor Controller and tighten the terminal screw with a torque of ~0.25 Nm. Clip on cable markers '2'and '4' to either end of the wire.

Repeat the above process with the DC (-) terminal and negative socket on the CN1 terminal, with a '0' cable marker on either end.

Ground the circuit using the ground socket on the CN1 connected with a ground wire using the same tools and crimps as above to the ground pegs on the controller box.

3.4.1.1.2. 24 V DC power supply --> Screw terminal bank (+) 24 V

```
Components:
32     AC/DC converter - 24V DC power supply
22     Feedthrough screw terminal
```

Clip three 2.5mm single tier feedthrough terminals to the DIN rail, insert a three-pole cross connector into the screw terminal. From the positive (+) 24 V DC power supply feed a single wire to the central terminal of the bank. Tighten the screw with a torque of 0.4 Nm. Clip a '2' and '4' cable ID Markers to denote the voltage.

3.4.1.1.3. Screw terminal bank (-) 0 V --> 24V DC power supply

```
Components:
22     Feedthrough screw terminal
32     AC/DC converter - 24V DC power supply
```

Clip three 2.5mm single tier feedthrough terminals to the DIN rail, insert a three-pole cross connector into the screw terminal. From the negative (-) 24 V DC power supply feed a single wire to the central terminal of the bank. Tighten the screw with a torque of 0.4Nm. Clip a '0' Cable ID Marker to denote the voltage.

3.4.1.1.4. Screw terminal bank (+) 24 V--> Modem --> Screw terminal bank (-) 0 V

```
Components:
22     Feedthrough screw terminal
17     Modem
```

Use the Modem specific power cable with open leads, strip the insulation 10mm. Four wires will be exposed Red: Power, Black: Ground, White: Output and Green: Input.

Strip the power and ground wires to 7 mm, crimp each wire and fasten the 'power' (red) wire into one of the (outgoing) positive screw terminals on the positive (+) screw terminal bank. Repeat this process with the ground (black) wire, instead insert into the negative (-) terminal bank. Clip cable markers '2' , '4' onto the power cable and '0' onto the ground cable at the screw terminals.

Green and White – These wires are external relays (trigger) and do not need to be connected.

3.4.1.1.5. Screw terminal bank (+) 24V --> 5 V DC/DC converter --> Screw terminal bank (-) 0 V

Components:
22 Feedthrough screw terminal
6 24-5 VDC DC/DC converter

From the (+) positive screw terminal bank attach a length of cable circuitry and clip on '2', '4' cable markers. At the alternate end secure the cable to the V_I (+) positive terminal of the converter, tighten the screw using a torque of 0.5 Nm. Repeat this process with another length of circuitry cable connecting the negative (-) screw terminal bank to the V_I (-) negative terminal and denoting wire with cable marker '0' at each end.

3.4.1.1.6. Screw terminal bank (+) 24 V --> 12 V DC/DC converter --> Screw terminal bank (-) 0 V

Components:
22 Feedthrough screw terminal
5 24-12VDC DC/DC converteR

Repeat the process listed above for the 5 V DC/DC converter using the last screw terminals on both the positive (+) and negative (-) screw terminal banks.

3.4.1.2. 12 V Circuit

Important: once components are connected and power is ON, using a multimeter confirm that the voltage under load is 12 V. If not adjust 'adjustment screw' on DC converter – check data sheet for adjustment capability.

The 12 V circuit begins from the 12 V DC/DC converter. The components on this circuit include the hyperspectral radiometers and the Crydom solid state relay, with a bank of three triple tiered feedthrough screw terminals and a bank of three single tiered feedthrough screw terminals seen below in Figure 9.

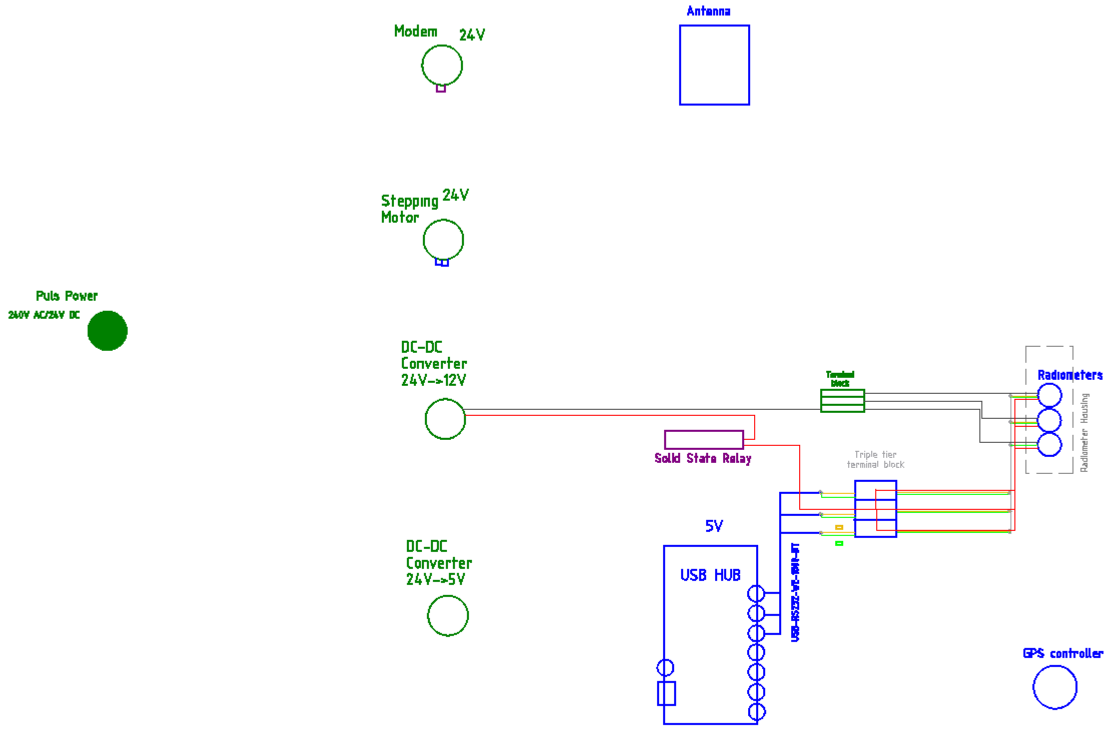

Figure 9. P1 220 V AC, 12 V power cabling connectivity map.

3.4.1.2.1. 12V DC/DC converter --> Solid state relay (SSR)

```
Components:
5      24-12VDC DC/DC converter
16     Solid state relay
```

At the V_o '+' terminal crimp and connect a piece of cable circuitry (16AWG copper stranded wire) stripped between 5-7 mm with a insulated bootlace ferrule (16AWG), clip on '1', '2' cable ID marker to represent voltage. Tighten the screw with 0.5 Nm of torque using a flathead 3.5mm precision screwdriver to ensure good connection. Crimp the opposite end of the cable to the same specifications, insert crimped end into terminal 1 of the SSR and fasten the screw to the same specification.

3.4.1.2.2. Solid state relay (SSR) --> Triple tier screw terminal bank (+)

```
Components:
16     Solid state relay
23     triple tier screw terminal
```

Secure three triple-tiered 2.5 mm feedthrough screw terminals to the DIN rail, screw down a 3-pole cross connector on the top tier. Strip the cable between 5-7 mm, crimp and connect the cable circuitry (16AWG) with a insulated bootlace ferrule to terminal 2 of the SSR, tighten screw using a flathead 3.5 mm precision screwdriver. Feed the opposing end of the cable to the centre terminal of the top tier triple tiered terminal bank (incoming). Crimp and connect via the same process as above and clip a '1' and '2' cable marker to represent the voltage.

3.4.1.2.3. Triple tier screw terminal bank (+) --> Spectroradiometers --> Screw terminal bank (-)

Components:
23 Triple tier screw terminal
42 Spectroradiometers
25 Cross connectors
22 Feedthrough screw terminal
49 Through-hole 8 pin sensor connector

Note that the instructions given here are for spectroradiometers using RS232 communication (TX and RX pins only) and 12 V power supply, sharing a ground pin with the USB to RS232 interfaces. Please always refer to the spectroradiometer manufacturer's instructions for appropriate configuration.

Following the processes of crimping and securing power and data circuitry, as mentioned above, connect the USB-RS232 cables with the unterminated M8 -8 pole female connector as outlined in section 3.3.2 [USB-Spectroradiometers] for correct pin arrangement.

3.4.1.2.4. Screw terminal bank (-) --> 12 V DC/DC Converter

Components:
22 Screw terminal
5 24-12 VDC DC/DC converter
25 Cross connectors

At the single tier screw terminal bank (outgoing terminal) crimp a 5-7 mm stripped cable with a insulated bootlace ferrule (16AWG) and connect to the centre terminal of the bank with a 3.5mm precision flathead screwdriver. Clip a '0' cable marker to represent the voltage, feed the cable through to the Chinfa DRD15-12 V_o (negative) terminal and secure via the same process as above.

Repeat this process, connecting the screw terminal bank to the

3.4.1.3. 5 V Circuit

Important: once components are connected and power is ON, using a multimeter verify that the voltage under load is 5 V. If not adjust the adjustment screw "V_{out} Adj." on DC converter – check data sheet for adjustment capability.

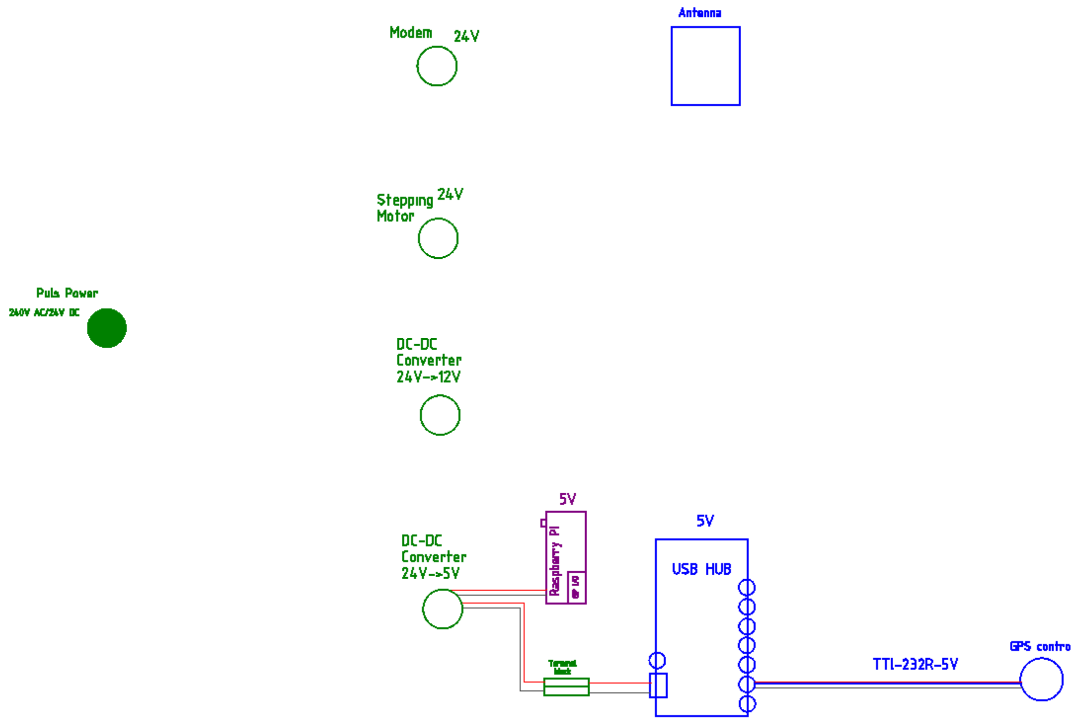

Figure 10. P1 220 V AC, 5 V power cabling diagram

The 5 V circuit begins from the 5 V DC/DC converter. The components of this circuit are the D-Link USB Hub, Raspberry Pi, and SimpleRTK2B GPS controller as seen below in Figure 10.

3.4.1.3.1. 5 V DC/DC converter <--> Raspberry Pi

Components:
6 24-5 VDC DC/DC converter
8 Raspberry Pi
45 Micro USB cable

Cut a Micro USB cable to length and strip the insulation back 10 mm. strip, crimp and connect the red (+) and black (-) cable to the respective positive (+) and negative (-) V_o terminal on the 5V DC converter.

3.4.1.3.2. 5 V DC/DC converter <--> USB Hub

Components:
6 24-5 VDC DC/DC converter
7 USB Hub

With the supplied power cable, remove the socket adapter and strip the cable. Crimp and connect the positive and negative wires inside the power cable to the respective V_o terminals and secure by tightening the screw. Plug the power cable into the rear of the USB Hub via the specified power socket.

3.4.1.3.3. USB Hub --> GPS Receiver

Components:
7 USB Hub

```
38      GPS Receiver (Board)
44      Micro USB cable
```

This connection is made via Micro USB – USB-A cable (Micro USB cable) connected directly to the board (see section 3.3.1).

3.4.2. P2 configuration: mains power (220 V) with battery back-up (12 V)

BEFORE CONNECTIONS ARE MADE Ensure circuitry is not connected to any form of power supply!

This section details the deviations from the default power configuration (P1) needed to operate using Mains power with a battery backup. The P2 power configuration component layout is shown in the below schematic Figure 11. Connections relevant to this power modification are displayed in Figure 12. A step-by-step guide of connections is given below.

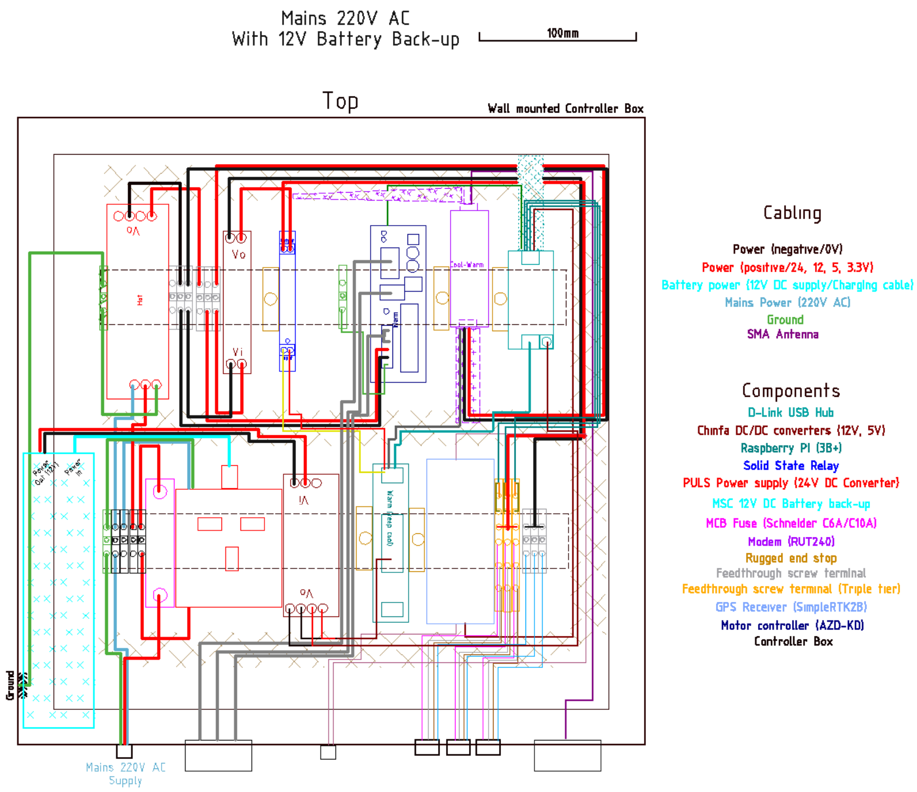

Figure 11. P2 220 V AC + 12 V DC, schematic of component layout and cabling configuration of the So-Rad controller box.

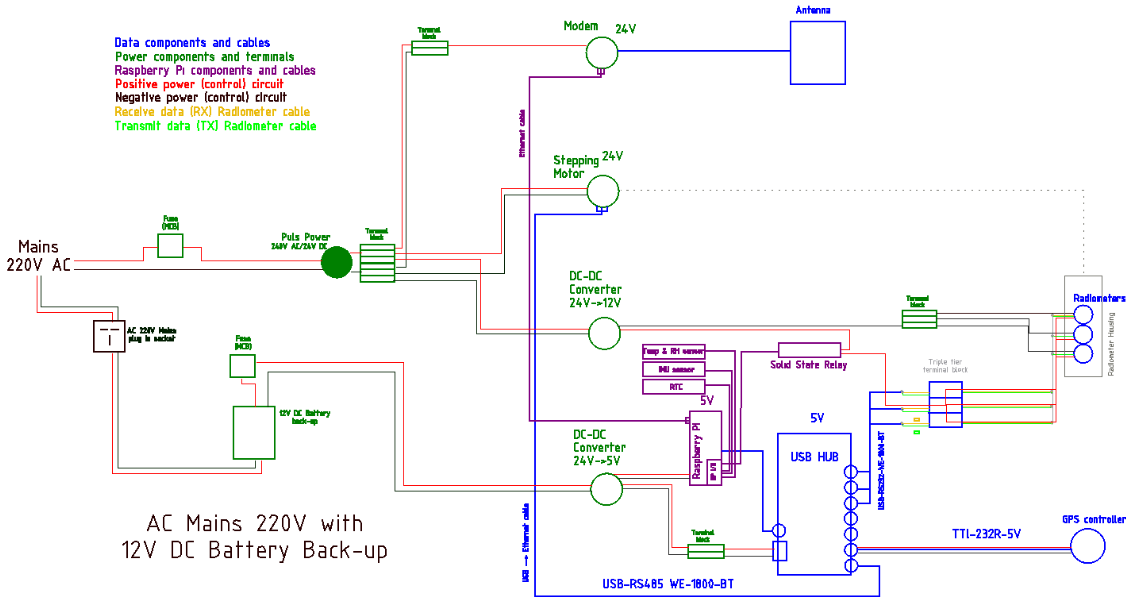

Figure 12. P2 220 V AC + 12 V DC, power, data and sensor cable connectivity map to complement component schematics for this configuration.

This configuration uses a compact 12-V battery to keep certain controller elements powered in case of an interruption in the mains power supply (e.g. ship power switching from engine to shore supply). Only non-mechanical parts will remain powered, whilst components with higher power consumption (motor driver, modem) will be interrupted. **In practise, this means that the 5V circuit will be powered through the battery rather than from the 24V DC circuit.**

A mains power socket is added to the enclosure to allow use of the manufacturer-supplied battery charger, as follows.

3.4.2.1. Mains --> mains power socket --> 12 VDC rechargeable battery

Components:
36 AC power socket
37 12 VDC rechargeable battery

Strip insulation of mains AC 220 V cable to separate, Neutral, Active and Ground cables and connect to the screw terminals at the rear of the power socket. Plug in the 12 V DC Battery charging cable to the power socket and connect to the battery.

Modifications to 24 V DC circuit for P2

The 24 V DC circuit does not require modifications for P2.

Modifications to 12 V DC circuit for P2

Once components are connected and power is ON, using a multimeter confirm that the voltage under load is 12 V.

The connections relevant to this circuit, including the back-up battery, are shown in Figure 13 below.

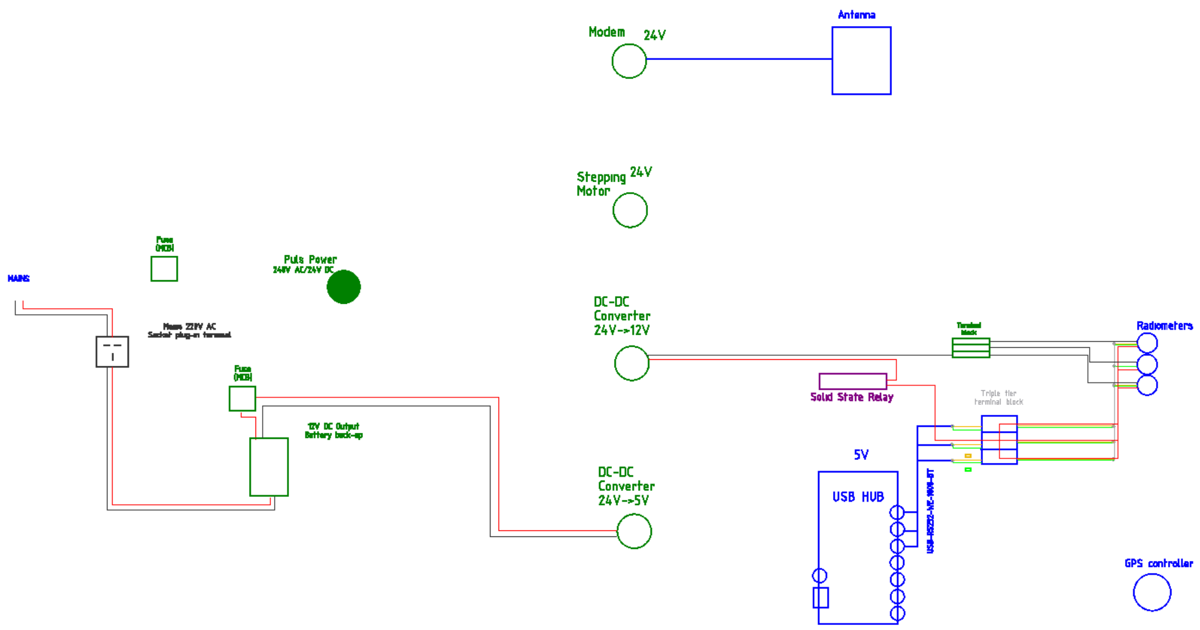

Figure 13. P2 220 V AC + 12 V DC, 12 V power cabling connectivity map.

3.4.2.1.1. 12 VDC rechargeable battery --> Fuse --> 5 V DC/DC converter

An additional fuse between the 5V circuitry and the battery is useful in case the battery has no built-in safety against short-circuiting.

Components:
36 12 VDC rechargeable battery
35 MCB C10A
6 24-5 VDC DC/DC converter
22 Feedthrough screw terminal

From the 12 V DC battery output terminal connect the positive cable to the fuse and the negative cable to a screw terminal clip on cable markers ‘2’ and ‘4’ for the positive cable and ‘0’ for the negative.

From the alternate screw terminal connect a length of circuitry cable to the 5 V DC/DC converter to the V_I (-) negative terminal.

From the fuse connect connect a length of circuitry cable to the 5 V DC/DC converter to the V_I (+) positive terminal.

Modifications to 5 V DC circuit for P2

The 5V DC circuit (now supplied from the battery through the 5 V DC/DC converter) does not require modifications for P2. The 5 V DC/DC converter is capable of using a wide input voltage range so the same component can be used in configuration P1 (24V DC supplied) and P2 (12V DC supplied).

3.4.3. P3 configuration: external battery power (12V)

The P3 configuration is for a DC power supply at 12V. The layout mirrors that shown in section 3.4.1 “Default power configuration: (P1) Mains Power (220 V AC)”, with the main difference the use of a 12-to-24 V DC/DC converter instead of the 220V AC/DC power supply. In addition, if a *Victron* solar charge controller is used to charge the battery (charging circuit not provided here), a data connection can be made using a 5V TTL serial to USB interface between the USB-hub and the solar charge controller serial port, allowing the So-Rad software to read the battery voltage and charging state. These modifications are included in Figure 14.

3.4.3.1. USB Hub → Solar recharge data port via 5V serial cable*

*Only used when solar panel and solar charge controller is employed to recharge the external battery.

```
Components:
7      USB Hub
44     Solar charge controller
28     5V 232R-TTL cable
```

Victron-charge controller adheres to the “Victron VE.Direct” specification. Use the Victron VE.Direct cable connector with the serial data cable using the following pinout.

Pin out of TTL-232R-5V-WE cable:

- Black – GND (Ground Pin),
- Red – Power (Output), Default output +5V, 0V during suspend
- Orange – Data, TXD (Transmit data)
- Yellow – Data, RXD (Receive data)

Providing a serial data stream from solar panel charger indicating whether charger is on/off.

Power is supplied directly from an external battery in series with a (**MCB C10A Schneider**) fuse en-route to (**PULS Dimension supply CD5.243**) 12 V-24 V DC/ DC converter.

3.4.3.2. External Battery Power supply --> Fuse --> 24 V DC/DC Converter

```
Components:
35     MCB C10A
33     DC/DC converter – 24 VDC power supply
22     Feedthrough screw terminal
```

Feed into the controller box the battery supply power cable, strip the sheathing 10mm and crimp both the positive and negative wires.

- Connect the positive cable to the fuse and from the fuse to the (+) positive terminal of the 12 V - 24 V power supply converter.
- Connect the negative cable from the battery to a screw terminal and from there a length of cable circuitry to the (-) negative terminal of the 12 V-24 V power supply converter.
- Clip on cable markers ‘1’, ‘2’ onto the positive cable at the terminal and ‘0’ on the negative cable to denote the respective voltages.

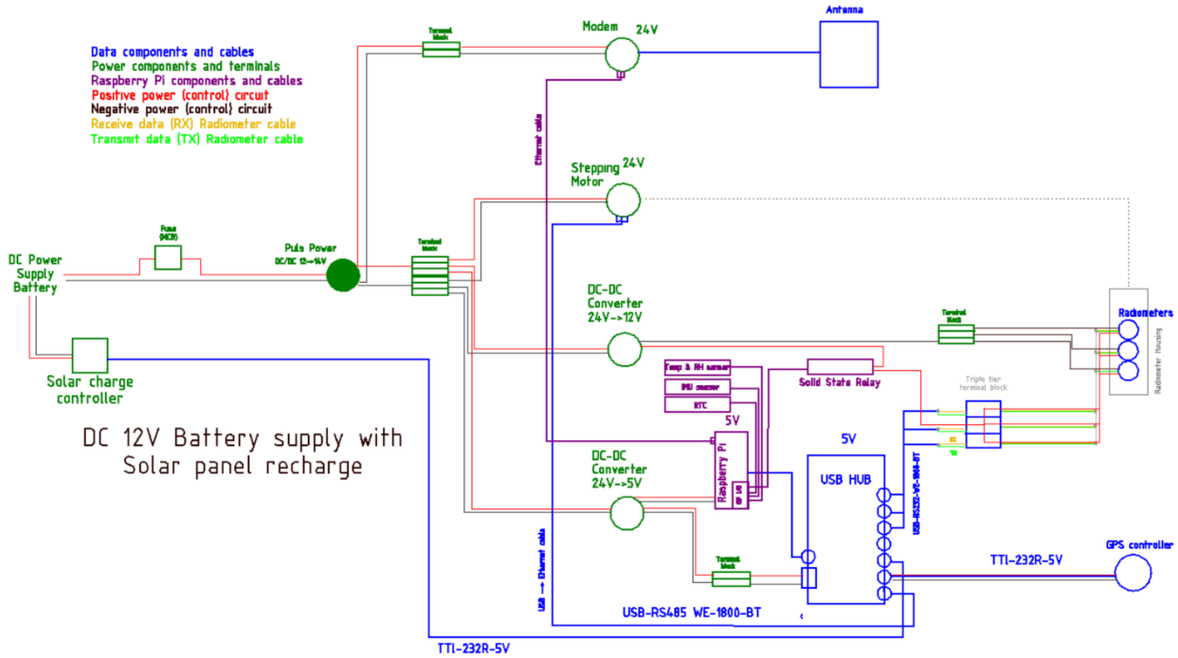

Figure 14. P3 12 V DC + Solar panel recharge, power, data and sensor cable connectivity map for this configuration.

3.5. Connecting peripherals

9 Real Time Clock (RTC) (DS3231) – I2C, GPIO-SDA:SCL
10 Accelerometer (ADXL345) – I2C GPIO-SDA:SCL
11 Temperature and Relative Humidity(DHT22) – Data stream, GPIO-gpio
16 Solid State Relay – Data stream, GPIO-gpio
39 GPS + Sensor enclosure
38 GPS Receiver (Headers)
50 LIR1220 rechargeable battery

3.5.1. Fitting the GPS + sensor enclosure

Ensure the sensor enclosure has holes at its base at the correct position of the GPS receiver. Fasten the GPS receiver board to the enclosure using a self-tapping screw with nylon washers through one of the available fastening holes on the board. Once in position, drill holes through the exterior of the enclosure to align with the GPS receivers power port and the two GPS header ports.

Drill two holes (3.5mm in diameter) parallel with the edge of the enclosure and tap the holes using a 4 mm tapping kit. Secure the IMU accelerometer to the inside of the enclosure with two 4 mm machine screws. Using one of these machine screws secure the Temperature and Relative Humidity sensor to the outside of the enclosure box. Drill a third hole identical to the first two above the power port of the GPS receiver board, using another 4mm machine screw secure the RTC board on the inside of the enclosure. If your RTC has a rechargeable circuit use an LIR 1220 battery for battery back-up, if not use an appropriate battery. Lastly drill a hole of appropriate size (<15mm) in the lid of the enclosure in order to connect the sensor cables.

Sensor cable configuration – female sensor plug

Using the 40-way IDC connector (21) clip 200mm of 20 stranded ribbon cable ensuring position 1 is in the correct location (indicated by the coloured stripe on the ribbon cable). Attach the IDC Socket to the Raspberry pi GPIO pins. On the opposing end of the ribbon cable clip and secure two 20-way IDC sockets (13) to act as the female plug for the sensor cables.

Male sensor plug.
Use two 20 way IDC TH (14) connector plugs and sensor cables (12) to connect the TPR (Tilt Pitch Roll/ IMU/ Accelerometer) sensor, RHT(Relative Humidity and Temperature) sensor, SSR (Solid state Relay and RTC (Real Time Clock) in the configuration shown in Figure 15.

3.5.2. Real-time Clock & Accelerometer

Both components use the I2C protocol and require connection to the SDA and SCL pins on the Raspberry Pi. Each device has a unique address: RTC (0x68) and Accelerometer (0x53). Connect the data pins (SDA – SDA, SCL – SCL) in parallel on an external board/circuit and to the Raspberry Pi Pin 3 (SDA) and Pin 5 (SCL). The pinout for all components as shown in Figure 15 is:

- Pin 2 RTC power (5 V)
- Pin 6 RTC Ground (GND)
- Pin 1 Accelerometer Power (3.3 V)
- Pin 9 Accelerometer Ground (GND)
- Pin 4 RH & T sensor Power (5 V)
- Pin 6 RH & T sensor Ground (Ground)
- Pin 8 RH & T sensor Data (GPIO14)
- Pin 17 SSR Power (3.3 V)
- Pin 15 SSR (GPIO22)

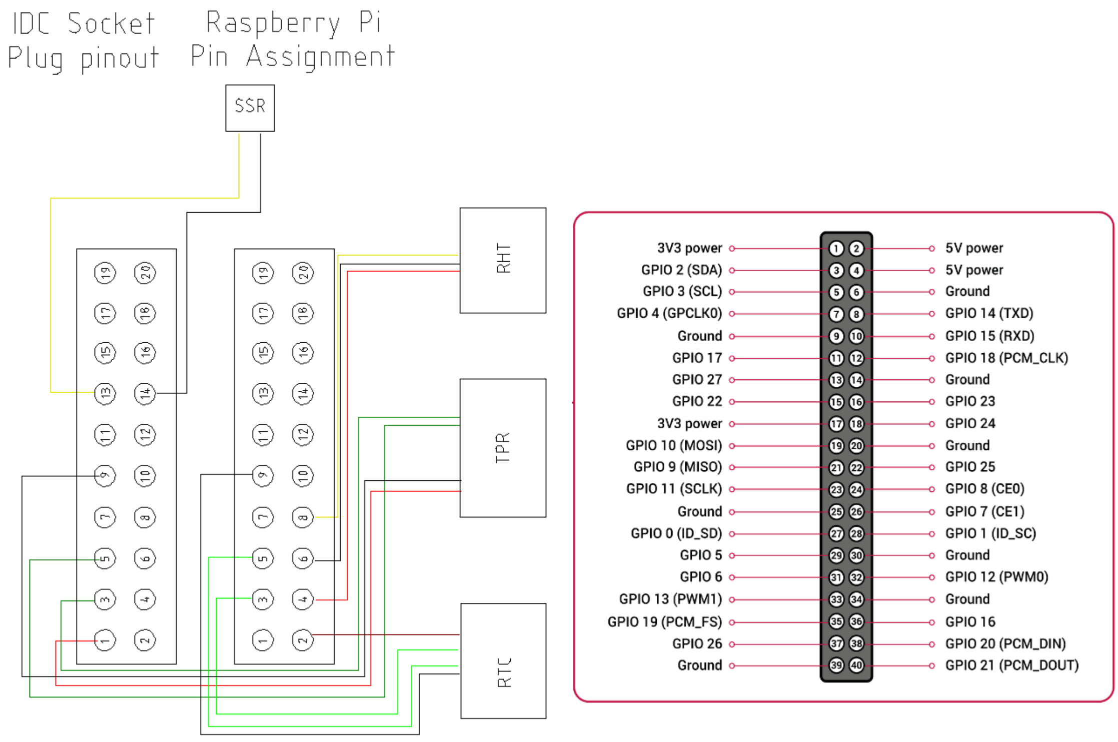

Figure 15. Raspberry Pi pin headers + pinout with relevant connections to sensors and solid-state relay.

4. Stepping motor enclosure

```
Components:
2       Stepping Motor stack
4       Motor connection cables
47      Cable conduit
```

The motor enclosure is designed to translate the motion generated at the AZM46MK-PS36 stepping motor to the sensor holders to provide the optimal measurement position for the spectroradiometers.

Whether gearing of the stepping motor should be considered is dependent on the environment the So-Rad is to be deployed in. Standard type motors (gearless) provide low torque which is preferable as there is less strain on the motor if the rotation becomes blocked. However, geared motors should be considered for high wind environments or situations where the motor must compensate for excessive external forces. If the rotation is blocked for more than 5 seconds (configurable) an overload alarm will be generated by the motor which is monitored by the So-Rad software.

The cabling between the spectroradiometers and controller box is the primary concern regarding obstruction of rotation, these should be installed in such a way to allow for full 360 ° rotation of the sensors. Unlike the sensor cables, motor controller cables (4) must be enclosed within a cable conduit (47) with waterproof connectors at both the lower end cap of the motor enclosure and controller box. **NOTE, Only connect /disconnect the motor controller cables when power is OFF.**

Access to the individual technical drawings of the elements comprising the general assembly, shown in Figure 16, can be found in the supporting material under: Technical drawings/Motor enclosure, along with the relevant CAD designs.

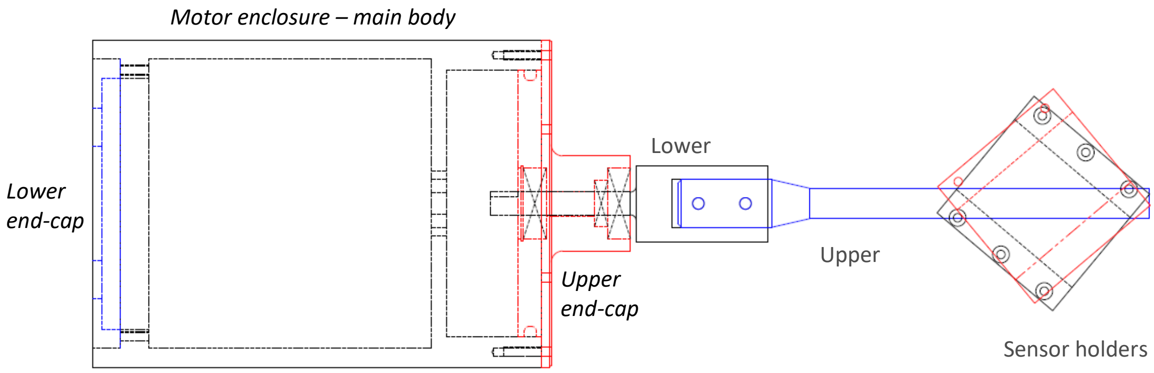

Figure 16. Radiance sensors and stepping motor enclosure general assembly schematic, Individual elements are represented by different colours to the adjoining assembly.

5. Software

5.1. Modem setup

```
Components:
17     Teltonika RUT240 LTE modem (with WiFi antenna)
18     LTE Modem antenna
```

Connect the antennae and connect the power cord to a 24 V supply or use the wall socket adapter.

If available, insert a SIM card in the designated port on the modem. Note the WiFi SSID and password as well as the administration password on the sticker on the side of the modem. If cellular connectivity is not required, the modem can be replaced with a simple network switch or the raspberry Pi can be connected directly to an existing network connection. These options should be straightforward to implement and are not discussed here.

Power on the modem and connect to it from a computer, either using the WiFi network it broadcasts or by plugging a network cable into the LAN port of the modem. If the modem does not connect to the internet using the SIM card, try to run the modem installation wizard and verify the Network Access Point settings of the internet service provider have been loaded correctly under Mobile configuration.

Configure the cabled WAN port to act as secondary LAN port: under Network -> WAN settings select 'Mobile' as the Main WAN port and deselect and WAN failover tick boxes. Click Save. Next, under Network -> LAN settings go to Advanced Settings and select Use WAN port as LAN. Click Save.

You can rename the WiFi SSID and provide an alternative password if desired.

Once the Raspberry Pi is connected to the LAN port (or the WAN port which is now a secondary LAN port) and powered on, note its LAN IP address (Status -> Network -> LAN -> DHCP leases). This can be changed to a static IP assignment to prevent it changing in future.

When changing network settings, it is normal that the connection to the router is lost. Reconnect using the updated configuration settings.

5.2. Stepping Motor driver

```
Components:
Oriental Motor AZD-KD stepper motor driver (3)
USB-to-Modbus cable (USB-RS485-WE-1800-BT) (30)
```

The stepper motor driver is connected to the Raspberry Pi with a USB-to-Modbus cable (see 3.3.3).

The initial setup of the motor controller is as follows.

5.2.1. Switches

- Ensure motor controller is not powered on.
- Set the SW1 switches to
  - 1 OFF - slave address will be in the 0-15 range. OFF is away from the SW1 label.

  - 2 ON - Modbus RTU mode. ON is towards the SW1 label.
  - 3 ON - Termination resistor ON
  - 4 ON - Termination resistor ON
- Set the baudrate switch to 4 (115,200 baud). Note the arrow on the white setting screw.
- Set the ID switch to 1 (slave address 1). Note the arrow on the white setting screw.

5.2.2. Cabling

Connect the motor components to the controller using the appropriate cables (4). Do not power on the motor before connecting motor components.

Connect DC 24V and ground to connector CN1 (alongside the brake wires which are marked MB1/MB2).

5.2.3. Testing and setup of home position

Connect the controller via mini-USB to a PC with the MEXE02 software installed (https://www.orientalmotor.com/downloads/software.html)

Switch on power supply to the motor controller (with motor components attached as instructed above) and start the MEXE02 software. MEXE02 will show a welcome screen (Figure 17).

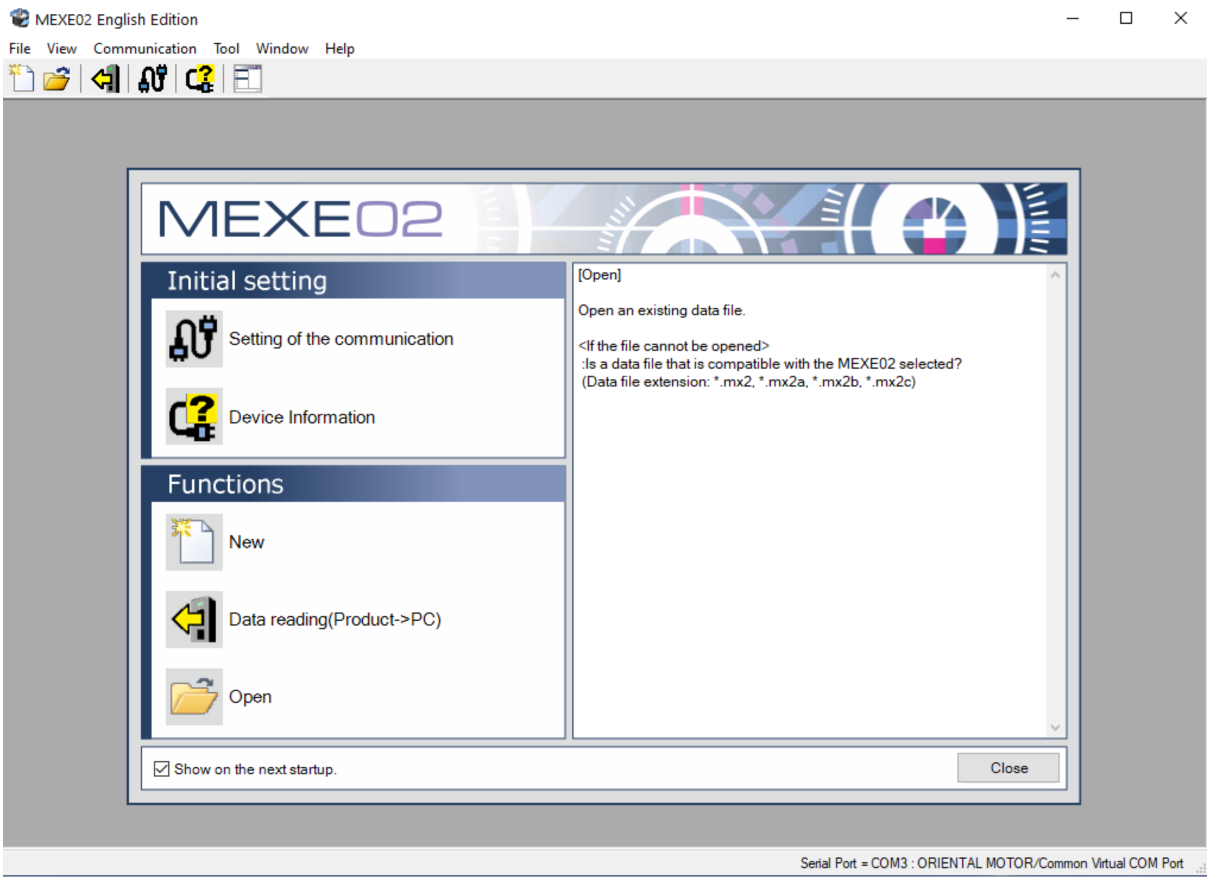

Figure 17. MEXE02 Welcome screen for visual walkthrough.

Connect the motor by selecting it through 'Setting of the communication'

Select Data reading (Product -> PC) to start remote operation

Open the 'Teaching, remote operation' window and activate it by clicking the box in the top-left corner (Figure 18). Use the + and - icons to move the motor to its intended home position. The recommended home position aligns the flat edge of the motor axle to be parallel to the side with the cable connections. Click the 'Position Preset' button to fix the home position to the desired location. This position can be changed by following these steps again.

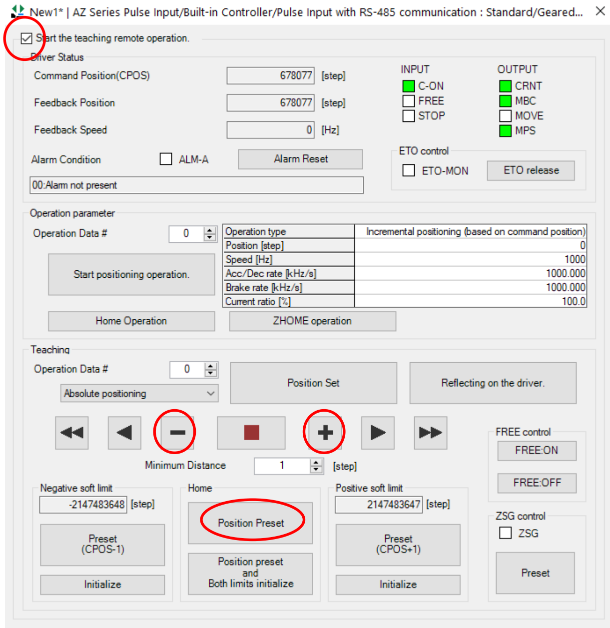

Figure 18. MEXE02 Teaching and remote operation window. Red circles indicate the required tick box, motor control and pre-set button.

Close the "teaching, remote operation" and select the "System of Units Customize Wizard" to set the following:

- Mechanism select: motor only
- Mechanism information: Next
- Gear/pulley reduction rate: next
- Minimum distance setting: 0.0360°

  Important: note the value for "Resolution per one round of output axis" as this will need to be entered into the config.ini file of the unit.

- Position: step/speed (Hz)
- Acceleration: kHz/s
- Click "finish"

Now click on the 'Data writing (PC > Product)" icon (white arrow pointing right) (Figure 19), allow configuration to be written. Exit the program.

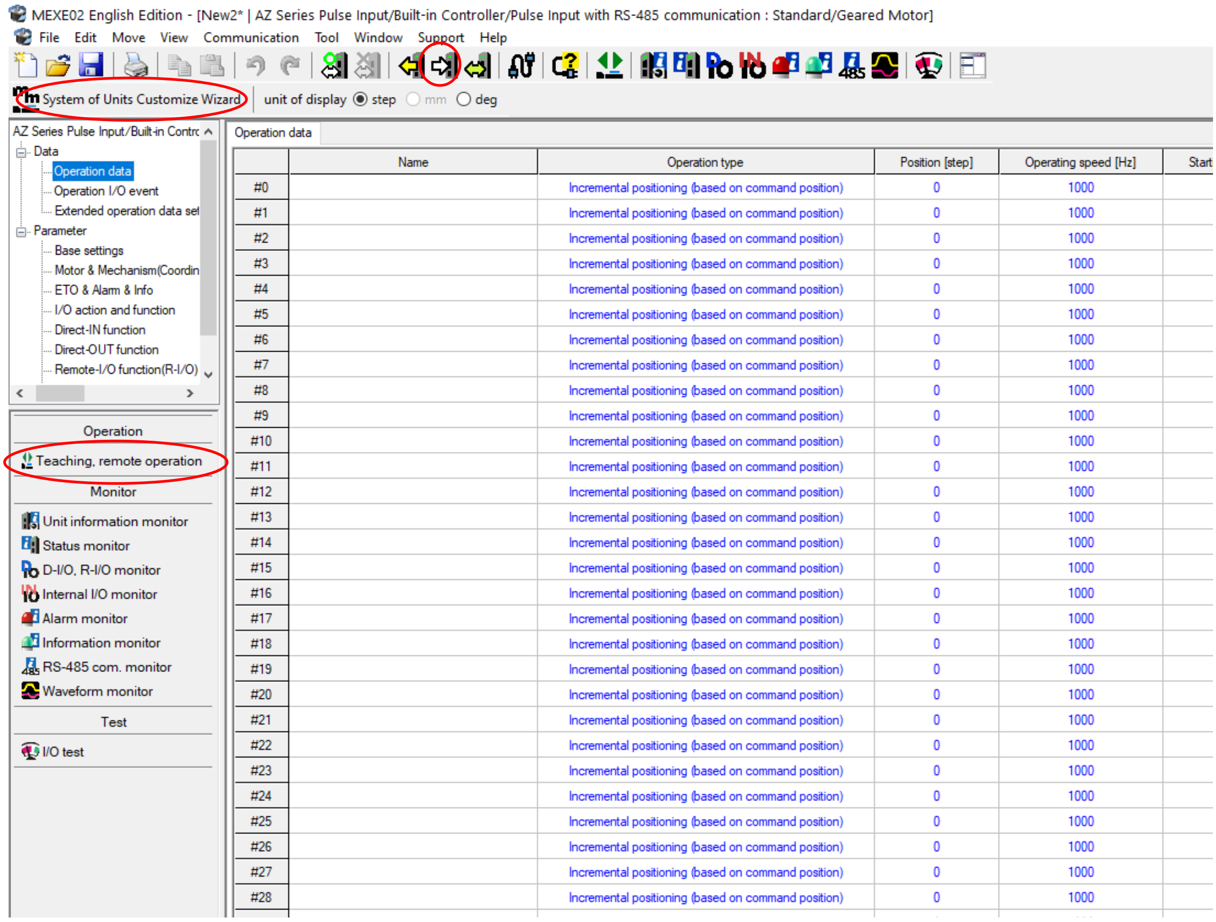

Figure 19. MEXE02 setup screen for motor controller. Red circles indicate the data writing button, customization wizard and teaching mode.

5.3. Raspberry Pi - software configuration

This section describes how to set up a Raspberry Pi to control the So-Rad.

These instructions have been tested with a Raspberry Pi 3B+. Newer models will also work but may need to have additional cooling measures installed - heatsinks and fans are available.

These instructions are based on Raspbian Buster Lite (version 4.19, February 2020). Download it from https://www.raspberrypi.org/downloads/raspbian/ and install it from a PC with an SD card slot.

5.3.1. Headless setup [optional]

The easiest way to configure the system is by connecting a keyboard and monitor to the Raspberry Pi. Setup can also be done headless by connecting to the Pi over ssh, after connecting the Pi to a network. For a headless setup from a Windows PC over a WiFi connection follow these steps to gain ssh access to the Raspberry Pi after installing the Raspbian disk image:

- Insert the SD card into a PC
- Locate the boot partition of the SD card (the only one visible to Windows)
- Add an empty file named `ssh`
- Using a text editor that supports **Linux-style line endings**, create the file `wpa_supplicant.conf` with the following content and move to SD card root folder:

```
country=GB
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1
network={
    ssid="NETWORK NAME"
    psk="PASSWORD"
}
```

Substitute the country code (GB, see https://en.wikipedia.org/wiki/ISO_3166-1) and the Network name and Password for the WiFi network you wish to continue setting up the Pi on.

- Eject the SD card and insert it into the Pi
- Power up the Pi and give it a few minutes to connect to the WiFi network
- Look up the IP address for the Pi from the network router, or use software to scan IP addresses for a new host named raspberrypi
- open an SSH connection to the PI and logon using the default user name (default `pi`) and password (default `raspberry`)
- Continue with step 2 in the next section.

5.3.2. Operating system configuration

If you are using the default raspbian distribution, run the following command once:

```
sudo raspi-config
```

Choose the following menu options (sequential menu item selections in bold):

1 Change the password for the default user (`pi`) and store it somewhere safe.
2 >N1: Set the hostname (e.g. `sorad-myname)` or any name you prefer
3 >B1 > B2: Configure the pi to auto logon as user `pi` using only command prompt, i.e. without starting the desktop environment to conserve system resources.
5 > P5 > Yes: Enable the I2C interface

Exit the configuration tool (you can choose to reboot immediately or later).

Reboot the Pi: `sudo shutdown -r` and establish a new ssh connection (if you used the IP address to connect it should still be the same, but the hostname will have changed in the previous step).

Depending on your linux distribution you may need to give the user permissions to communicate with serial devices:

```
sudo adduser pi dialout
```

5.3.3. Software dependencies

Make python v3 the default python version if needed:

```
ls -l /usr/bin/python
```

if this does not point to python3, use

```
sudo rm /usr/bin/python
```

followed by,

```
sudo ln -s /usr/bin/python3 /usr/bin/python
```

Install software dependencies as follows:

- First update the package lists using

```
sudo apt-get update
```

- update to the latest software using

```
sudo apt-get upgrade
```

- To prevent a potential conflict with the pre-installed serial library:

```
sudo pip uninstall serial
```

- Install the python package manager pip, git and other dependencies:

```
sudo apt-get install python3-pip git libatlas-base-dev
```

- Install the following python packages using `pip`

```
sudo pip install RPi.GPIO libscrc ephem numpy serial flask adafruit-circuitpython-adxl34x Adafruit_DHT
```

- Optionally install uWSGI and nginx to set up the So-Rad webservice, which is recommended for remote system monitoring:

```
sudo apt-get install nginx
sudo pip install uWSGI
```

In the home directory (`/home/pi`) issue the following command to clone the So-Rad code repository into a new folder:

```
git clone https://github.com/monocle-h2020/so-rad.git sorad-code
```

Important: record the location of the local code repository as you will need it to set up the services to automate the script on startup.

Connect all USB devices (GPS and RS232/RS485 interface cables - the motor and spectroradiometers do not need to be connected)) and type:

```
python
```

In the python terminal issue the following commands

```
>>> import serial.tools.list_ports as lp
>>> ports = lp.comports()
>>> for port,desc,hwid in sorted(ports):
        print(port, desc, hwid)
```

Which will output a list similar to:

```
/dev/ttyACM0 u-blox GNSS receiver USB VID:PID=1546:01A9 LOCATION=1-1.1.2.1:1.0
/dev/ttyAMA0 ttyAMA0 3f201000.serial
/dev/ttyUSB0 USB-RS485 Cable USB VID:PID=0403:6001 SER=FT2URZ5N LOCATION=1-1.1.2.2
/dev/ttyUSB1 USB-RS232 Cable USB VID:PID=0403:6001 SER=FT2ILQ7Q LOCATION=1-1.1.2.3
/dev/ttyUSB2 USB-RS232 Cable USB VID:PID=0403:6001 SER=FT2IM7HB LOCATION=1-1.1.2.4.1
/dev/ttyUSB3 USB-RS232 Cable USB VID:PID=0403:6001 SER=FT2ILPYC LOCATION=1-1.1.2.4.2
```

This is a list of the serial devices currently connected to the pi, stating the port they are connected to, their description and their hardware ID. Take note the description of the GPS sensors and the cables connecting the radiometers and motor controller to the Pi.

Edit the `config.ini` file in the SO-RAD repo:

- Set the correct USB descriptions for the GPS sensor, spectroradiometers and motor serial interface cabling. When using TriOS spectroradiometers, it does not matter which sensor is plugged into which interface, but to use the periodic Ed sampling function the serial number of the Ed sensor should be specified (4-character hexadecimal code printed on the sensor) so that the software can identify which channel this specific sensor is connected to. If specific serial properties are provided by any of the manufacturers of your interfaces, change these too.
- Enter the `step_limit` set during motor configuration (5.2)
- Set the clockwise and counter-clockwise limits (in degrees) from the motor home position. These limits determine how far the motor is allowed to rotate in either direction to avoid pointing the sensors at any obstructions (such as the ship)
- There are many other system settings that can be altered but are not strictly required for the initial system test. Please refer to the annotations in the configuration file to optimise your specific configuration.

Note: the `config.ini` will be overwritten when the firmware is updated from the gitlab respository. To prevent losing settings that apply to a specific so-rad platform, they can be entered in the `config-local.ini` file. Any settings configured in the latter file will substitute the defaults given in config.ini. However, a firmware update will not add any new functionality to `config-local.ini`, so these need to be maintained by the operator.

5.3.4. Setting up the Real Time Clock [RTC DS3231]

Detect the address of the RTC device: when first set up the DS3231 should be at address 0x68 and will read “68”. Once setup is complete address 0x68 will read “UU”:

```
sudo i2cdetect -y 1
```

Load RTC module through the kernel:

```
sudo nano /etc/modules
```

To the bottom of the list add:

```
rtc-ds1307
```

Edit the root user startup script:

```
sudo nano /etc/rc.local
```

Add the following two lines before the exit code:

```
echo ds1307 0x68 > /sys/class/i2c-adapter/i2c-1/new_device
hwclock -s
```

Reboot the system to activate the changes

```
sudo reboot
```

Write system time to RTC:

```
sudo hwclock -w OR sudo hwclock –systohc
```

If system time is not accurate, manually set system date and time:

```
sudo date -s "08 DEC 2020 13:00:00"
```

(insert date as string in format: "DD MMM YYYY hh:mm:ss")

```
sudo hwclock -w
```

5.3.5. Set up the So-Rad software as an automated service

This section describes how to set the So-Rad software up for automated execution. The first set of instructions describe how to set the software up as a service, followed by how to set up a web service for easy monitoring of the status of the So-Rad, either locally or remotely.

Create a systemd service file in `/lib/systemd/system:`

```
sudo nano /lib/systemd/system/so-rad.service
```

Add the following contents to the file. Alter any paths and user/group names if you are not following the defaults described above.

```
[Unit]
Description=so-rad service
After=multi-user.target

[Service]
Type=idle
WorkingDirectory=/home/pi/sorad-code/bin
Environment="DISPLAY=:0"
ExecStart=/usr/bin/python /home/pi/sorad-code/bin/main_app.py -c
/home/pi/sorad-code/bin/config.ini -l /home/pi/sorad-code/bin/config-
local.ini

Restart=always
#StandardOutput=syslog
#StandardError=syslog
SyslogIdentifier=so-rad
User=pi
Group=pi
KillSignal=SIGINT

[Install]
WantedBy=multi-user.target
```

Once written and saved check that everything seems in order by typing:

```
sudo service so-rad status
```

To set the service to auto-start on boot, in the terminal type:

```
sudo systemctl enable so-rad
```

The `so-rad` service is now set up so that it starts on boot of the Raspberry Pi. The following commands are useful to control the service.

To check the status of the service:
```
sudo service so-rad status
```

To start the service (if not running already):
```
sudo service so-rad start
```

To stop the service (if it's currently running):
```
sudo service so-rad stop
```

To restart the service:
```
sudo service so-rad restart
```

To kill the service:
```
sudo systemctl kill so-rad
```

If you manually started the service for the first time here, it is possible that the root user created the intial log files and database. To ensure that user pi can write to these when the service starts automatically, run the following commands:

```
sudo chown -R pi:pi /home/pi/sorad-logs
sudo chown pi:pi /home/pi/sorad-data/sorad_database.db
```

Because So-Rad is not an embedded system but consists of several connected off-the-shelf components, a possibility always exists where a component stops working without the software being able to independently diagnose this. Restarting the programme is normally very quick (seconds) and should solve most connectivity issues. This also ensures that initialisation checks are carried out periodically. It is therefore advisable to build in an automated restart at set intervals, to keep data collection going.

Edit the root crontab using:

```
sudo crontab -e
```

Then add (include line feed at the end):

```
15 * * * * service so-rad restart >> /home/pi/sorad-logs/cron.log 2>&1
```

This will restart the service once every hour at x:15h

5.3.6. Set up the So-Rad for remote monitoring

A web service showing a status page and the latest logs is provided in the code repository and can be set up as a service so that it runs automatically when the system starts

The folder `/home/pi/sorad-code/bin/webservice` already contains most of the pre-configured webservice. All we need to do is configure the `uwsgi / nginx` stack to point at the pages generated by the flaskws.py script in this folder.

Create the following file

```
sudo nano /etc/nginx/sites-available/sorad-flask
```

with the following contents:

```
server {
    listen 80;
    server_name _;

    location / {
        include uwsgi_params;
        uwsgi_pass unix:/tmp/flaskws.sock;
    }
}
```

Link this file into the list of enables site:

```
sudo ln -s /etc/nginx/sites-available/sorad-flask /etc/nginx/sites-enabled/
```

and remove the default website from the enabled sites list:

```
sudo rm /etc/nginx/sites-enabled/default
```

Next, create the service file:

```
sudo nano /etc/systemd/system/sorad-flask.service
```

with the following contents:

```
[Unit]
Description=uWSGI instance to serve so-rad flask web service
After=network.target

[Service]
User=pi
Group=www-data
WorkingDirectory=/home/pi/sorad-code/bin/webservice
Environment="PATH=/home/pi/sorad-code/bin"
ExecStart=/usr/local/bin/uwsgi --ini /home/pi/sorad-code/bin/webservice/flaskws.ini

[Install]
WantedBy=multi-user.target
```

Now start the uwsgi and nginx services and enable them to run on startup

```
sudo systemctl start sorad-flask
sudo systemctl enable sorad-flask
sudo systemctl start nginx
sudo systemctl enable nginx
```

You should now be able to reach the So-Rad status page by pointing a web browser (from any device on the same network) to the local IP address of the Pi. The web service first shows a status page with the last 10 entries into the local database, and has links to open the most recent 100 lines of the log file, or the log file in full (which can take a while to load).

If you cannot access the webservice immediately, **first try to reboot the Raspberry pi** (`sudo reboot`). The following log files may be of use to see whether external requests are reaching the web server:

```
/var/log/nginx/error.log
/var/log/nginx/access.log
```

And similarly, the status of the services:

```
systemctl status sorad-flask
systemctl status nginx
```

5.3.7. Remote monitoring of the webservice

To access the status page from a remote location, we need to be able access the Pi over the internet. In the configuration described in this build guide the Pi is secure behind a modem which does not forward internet traffic to the Pi. If you expose the Pi directly to the internet, you will need to take additional steps to secure the system, such as by enabling a firewall. This process is not described here (but look up the `ufw` package if you want to learn more).

We will assume here that the Pi is connected through an LTE (cellular 3g/4g network) modem. If, instead, the Pi is connected to a local network connection there may already be additional security measures in place that could block traffic and you may need to seek assistance from the network administrator to make the following work, although it is likely to work in most situations.

Another consideration to how you reach the Pi remotely is that internet service providers increasingly use network translation to bundle many connections under one public IP address. It is often possible to pay for an individual, static IP address. In that case, you should ensure that the router which the Pi is connected to is set up with appropriate security measures to block incoming traffic except your own. Here we will assume that the Pi cannot be reached over a static IP address.

The solution to a volatile IP address is to set up a reverse-tunnel: rather than connecting remotely to the Pi, we make the Pi connect to a remote server with a registered address. Here, we use an existing service named Dataplicity, because it is almost entirely designed around our use case where a Pi is somewhere at a remote location. It is of course worthwhile to explore the options available to you, and it is entirely possible to set up a similar service on a server you own.

Using Dataplicity you will be granted one free connection per registered user (email address).
Go to www.dataplicity.com. Select "Sign in" or "Create account".

Select 'add new device' and a command will be provided like the following excerpt, but containing a unique code:

```
curl https://www.dataplicity.com/********.py | sudo python
```

Paste and execute this code in a terminal on the RPi. It will automatically download all files and create a daemon and connect to the account used to log in. Whenever the RPi boots up, the dataplicity daemon will run, allowing the Pi to connect to the dataplicity server to offer a reverse-connection. As the operator, you will go to www.dataplicity.com to create a terminal session in your web browser. It will create this session as the 'dataplicity' user. To access the So-Rad system and processes, we will need to work as the 'pi' user, by entering `su pi` in the terminal and entering the password.

Dataplicity can allow the flask web app to be accessible as well as the terminal. To use this, turn on the toggle for "Wormhole" which you see once you have selected your device on dataplicity.com. This will show a unique URL through which the web service will then be exposed. This address can be accessed by anyone who has the URL!

Once enabled, the link provided by wormhole will now show the web service which we had already exposed on port 80 of localhost in the previous section.

6. Deployment guide

The following instructions assume installation on ship.

Tools required: Set of Allen keys and spanners

1. Install the motor enclosure near the forward bow or along the front-side of the ship, thus providing the largest unobstructed view of the water surface while avoiding the wake of the ship.

2. Attach the radiance sensors to the motor platform. The sensor brackets point at 40 degrees forward angles, either up or down. Align the 'home' position of the motor (marked on the motor housing) with the ship bow-stern axis so that sensors point in the forward direction when the motor is in the home position. A rotational offset to the home position can also be configured in the software, should this need correcting later. Secure cables to the ship to ensure sufficient rotational movement of the sensors, but keep cable loops tight enough to prevent them catching and getting stuck. The motor torque (for the default model) is low enough to prevent damage to caught cables. Getting the mechanism stuck will result in an error message and an interruption to normal operation, as a safety precaution.

3. Install the irradiance sensor at a high point on the ship where it is free from shading by any ship structure. This sensor must point straight up. The sensors and their cabling are interchangeable: any radiometer can be connected to any of the three cables.

4. Mount the controller box and optional solar / battery box vertically so that all cable connections are at the bottom.

5. Mount the GPS receivers along the long axis of the ship. The GPS sensors marked 'FRONT' should be positioned several meters ahead of the sensor marked 'REAR'. It is best if both receivers have an unobstructed view of the sky. The further the receivers are placed apart, the higher the accuracy of the ship heading and location. Avoid placing the receivers within 2m of each other.

6. Mount any additional items, such as solar panel and communications antenna, at suitable locations.

7. Connect all data / communication cables but not the power cables.

8. Open the control unit (only in dry conditions) and ensure the mains fused terminal switch is in the OFF position. Close the control unit.

9. Connect power cables in the following order, as applicable: connect controller box to mains or battery box. If using solar, connect solar panel to battery box last. Always be aware that solar panels hold a voltage when exposed to light.

10. Secure all cables to ship structure using cable ties.

Only open the control unit when it is safe to do so, given that there are electric terminals inside. Switch the mains terminal fuse to the ON position

11. Ensure that indicator lights on the DC 24V, DC 12V and DC 5V supplies, motor controller, Raspberry Pi and USB hub and Modem are all ON. After approximately one minute the solid-state relay will switch on (indicating the So-Rad software has started) and the motor will move to its home position. If other conditions (specified in the configuration file) are met, the motor will rotate the sensors to the optimal measurement position.

12. Close and lock the controller enclosure.

13. Connect to the So-Rad WiFi (as configured in Section 5.1) from a mobile device and point an internet browser to the IP address of the Raspberry Pi. Verify that the log files indicate normal operation.

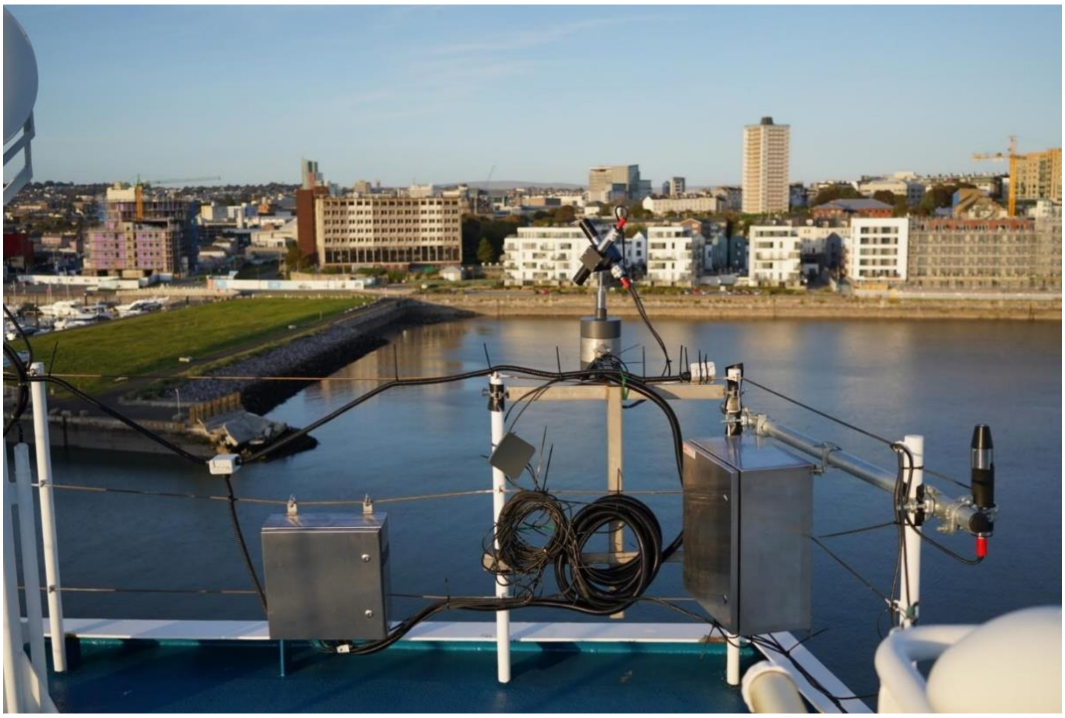

Figure 20 So-Rad installed on the passenger ferry *Armorique* traversing the English Channel between Plymouth (UK) and Roscoff (France). This configuration includes a battery and solar power charger (enclosure on the right).