Samyak Autopilot V2 Documentation

Vineet Menon, Prof. Mangal Kothari

August 2023

1 Introduction

Before starting the design of our own FMCW radar

2 Pixhawk Standard Details

Objective of Pixhawk Standards is to provide a defined set of hardware like sensors, MCU and other peripherals that is cross-compatible with PX4 firmware necessary for setting up the flight stack. It also provides protocol (I2C,SPI,etc) and port details (w.r.t. MCU) for each of these devices that is very helpful during Schematic design. Figure 1 provides information on the standards that are available for different subsystems of a UAV.

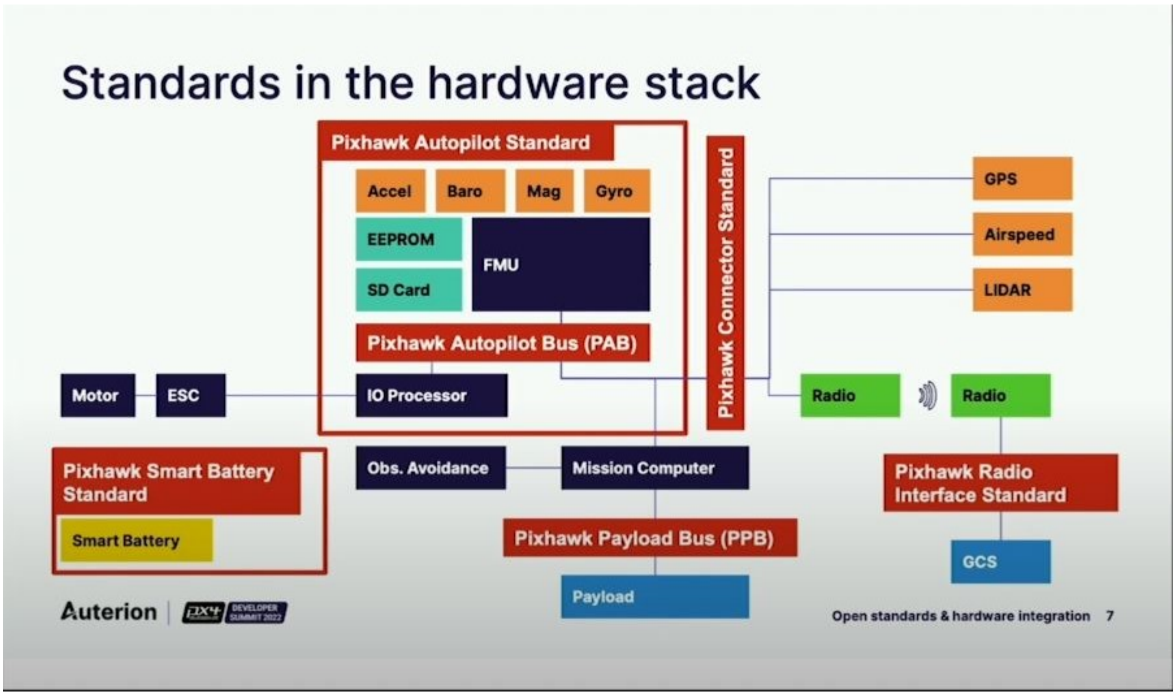

Figure 1: Ecosystem Wise Standards

Samyak V2 will be adhering to the latest Pixhawk v6U standard and below attached are links to a commercially available autopilot from Holybro that follows the same standard.

- Pixhawk 6C autopilot
- Pixhawk 6C documentation
- Reference Schematics
- Pixhawk Debug Adapter

3 Autopilot Block Diagram

To start selecting the appropriate SMD components for our own FMCW radar design, we need to follow the below procedure sequentially -

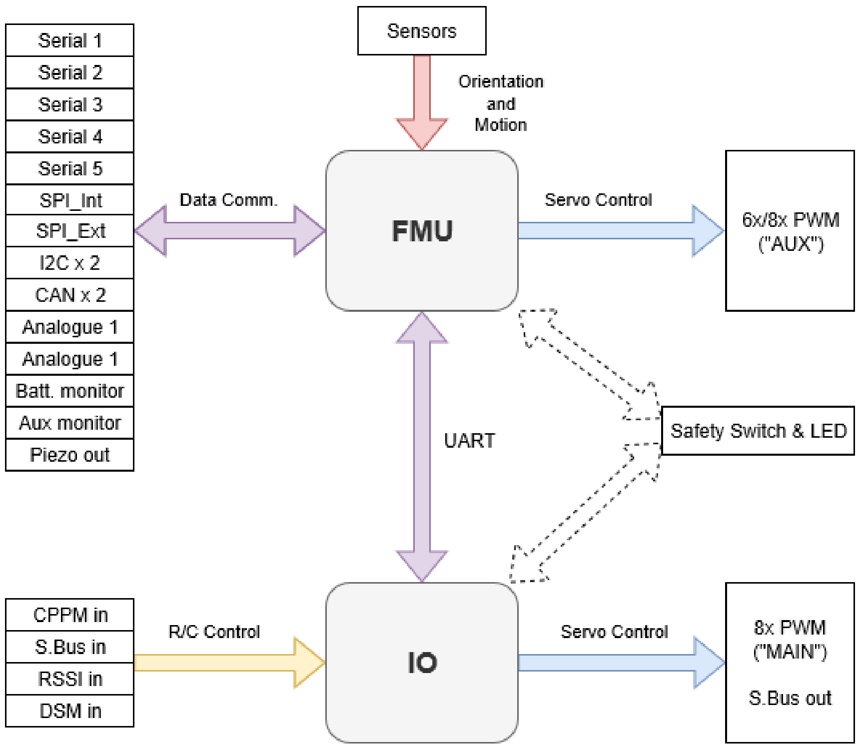

Figure 2: FMU and IO functional diagram

4 Hardware Components

This section will cover all the components selected for the design of autopilot. They will be classified based on their subsystem.

4.1 MCU

- FMU (Primary)- STM32H743VI
  This will be the main FMU (Flight Management Unit) of the autopilot whose functionality was described in previous section. The key features of the MCU are-
  - 32-bit ARM Cortex-M7 core with FPU
  - Up to 2 Mb of flash memory and up to 1 Mb of RAM
  - 4× I2Cs; 4× USARTs/4x UARTs; 6× SPIs
  - 2× CAN controllers; 2× USB OTG interfaces
  - IC Package: 100 LQFP
- IO (Secondary)- STM32F103C8
  This is selected as the secondary IO (Input Output) MCU of the autopilot. The key features of the MCU are-
  - 32-bit ARM Cortex-M3 core
  - 128 Kb of Flash memory and 20 Kb of SRAM
  - 2 x I2C; 3 USARTs; 2 SPIs
  - IC Package: 36 LQFP

4.2 Internal Sensors

- IMU1- BMI088
  One of the 6-DoF IMU whose values are used by autopilot for state estimation. Key features include
  - Accelerometer selectable params-
    * Acceleration ranges- ± (3/6/12/24) g
    * Output data rate- 12-1600 Hz
  - Gyroscope selectable params-
    * Angular ranges- (125/250/500/1000/2000) °/sec
    * Output data rate- 100-2000 Hz
  - Two seperate DRDY (data-ready) pins (for accl and gyro separate)
  - SPI protocol, +3.3V
- IMU2- ICM-42688-P
  The other 6-DoF IMU whose values are used by autopilot for state estimation. Key features include
  - Accelerometer selectable params-
    * Acceleration ranges- ± (2/4/8/16) g
    * Output data rate- 12-32000 Hz

- Gyroscope selectable params-
    - Angular ranges- (15.625/31.25/62.5/125/250/500/1000/2000) °/sec
    - Output data rate- 12-32000 Hz
  - Single DRDY pins (for accl and gyro combined)
  - SPI protocol, +3.3V

- MAG1- IST8310
  The 3-DoF Magnetometer that uses earth's magnetic field to determine heading angle along all three axes. Key features include
  - Dynamic ranges- ± 1600 uT (X, Y axis)
  - Dynamic ranges- ± 2500 uT (Z axis)
  - Output data rate- 1-200 Hz
  - I2C protocol, +3.3V

- BARO1- MS5611
  The barometer is used to determine height at which the UAV is present based on the atmospheric pressure the sensor measures. Following are the key features of the selected barometer-
  - Operating range: 10 to 1200 mbar
  - High resolution module (10 cm)
  - I2C protocol, +3.3V

4.3 Critical Peripherals

- FRAM- FM25V02A-G
  The external FRAM is used to store configuration parameters of the craft (dependant on the type of UAV like quadrotor, fixed-wing, etc.) and following are its key features:
  - 256Kb memory organised as 32Kx8
  - SPI protocol, +3.3V

- EEPROM- 24LC64
  The external EEPROM is used for storing calibration values of onboard sensors that in-turn helps in eliminating inaccuracies that include varying signals and temperature. Following are its key features:
  - 64Kb Electrically Erasable PROM as a single block of 8K x 8-bit memory
  - I2C protocol, +3.3V

- CAN Trans-receiver- TJA1051
  This high speed CAN transceiver is used to create an interface between the controller and the two-wire CAN line.

4.4 Power

- **TPS563211** is a synchronous 3A buck converter that is used to supply reliable +3.3V supply mainly to both the FMU and IO MCUs. Other subsystems that will be power through this supply include SD card, FRAM, EEPROM and both CAN transceivers.
- **TPS563211** is a low-noise LDO that sources dedicated 300mA to all analog components that include INS sensors like both IMUs, Mag and Barometer at +3.3V.
- **INA186A2** is an analog Current Sense Amplifier (CSA) that is used to determine specifically the current consumed by the autopilot in real time. The gain of the selected amplifier is 50 and will be utilised to measure current in the range of 10mA to 1A unidirectionally.

4.5 Other peripherals

- ESD suppressors- Four channel ESD protection diodes for all 3.3V compatible signal lines.
- SD card has 6 data lines connected and all lines are protected via a serial RC pi filter that not only attenuates noise but also acts as ESD suppressor.
- All resistors except sense resistor are of 0402 form factor. Decoupling capacitors are 0603 or higher, some other capacitors in use are of 0402 though.

5 Autopilot Pinouts

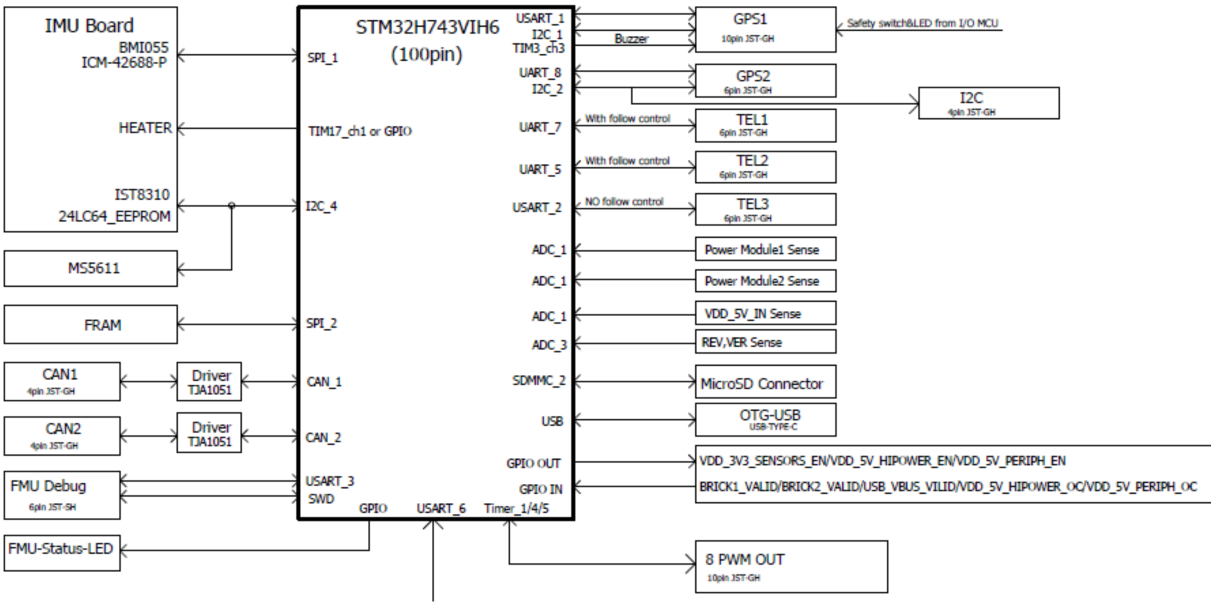

Figure 3: STM32H743(FMU) System Block Diagram

Figure 3 shows all the subsystems that are connected to the FMU. Also listed below is the detailed list of pin-outs in accordance to connected subsystems. The format of nomenclature is- Format - (Port name and number) (MCU Signal)

5.1 FMU pinouts

- IMU1(BMI088) and IMU2(ICM42688P) [SPI1]
  - PA5 SPI1_SCLK
  - PA6 SPI1_MISO
  - PA7 SPI1_MOSI

  - PC14 CS2_BMI_GYRO
  - PC15 CS1_BMI_ACC
  - PC13 CS3_ICM

  - PE4 SPI1_DRDY1_BMI_ACC
  - PE5 SPI1_DRDY2_BMI_GYRO
  - PE6 SPI1_DRDY3_ICM

- MAG1(IST8310); BARO1(MS5611) and EEPROM(24LC64) [I2C4]
  - PD12 I2C4_SCLK
  - PD13 I2C4_SDA

- FRAM(FM25V02A) [SPI2]
  - PC2 SPI2_MISO
  - PC3 SPI2_MOSI
  - PD3 SPI2_SCLK
  - PD4 CS_FRAM
- MICRO-SD
  - PD6 SDMMC2_CK
  - PD7 SDMMC2_CMD
  - PB14 SDMMC2_D0
  - PB15 SDMMC2_D1
  - PB3 SDMMC2_D2
  - PB4 SDMMC2_D3
- CAN connectors (x2)
  - PD0 CAN1_RX
  - PD1 CAN1_TX
  - PB13 CAN2_TX
  - PB5 CAN2_RX
- TELEM connector (x3)
  - PE7 UART7_RX
  - PE8 UART7_TX
  - PE9 UART7_RTS
  - PE10 UART7_CTS

  - PD2 UART5_RX
  - PC12 UART5_TX
  - PC8 UART5_RTS
  - PC9 UART5_CTS

  - PA3 USART2_RX
  - PD5 USART2_TX
- I2C
  - PB10 I2C2_SCLK
  - PB11 I2C2_SDA

- GPS1
  - PA10 USART1_RX
  - PB6 USART1_TX
  - PB7 I2C1_SDA
  - PB8 I2C1_SCLK
- GPS2
  - PE0 UART8_RX
  - PE1 UART8_TX
- USB C
  - PA9 USB_OTG_FS_VBUS
  - PA11 USB_OTG_FS_DM
  - PA12 USB_OTG_FS_DP
- FMU PWM out (AUX)
  - PA8 TIM1_CH1
  - PE11 TIM1_CH2
  - PE13 TIM1_CH3
  - PE14 TIM1_CH4

  - PD14 TIM4_CH3
  - PA15 TIM4_CH4
  - PA0 TIM5_CH1
  - PA1 TIM5_CH2
- FMU debug
  - PD8 USART3_TX
  - PD9 USART3_RX
  - PA13 SWDIO
  - PA14 SWCLK
- Analog power
  - PA2 FMU_BAT2_I
  - PB1 FMU_BAT2_V
  - PC4 FMU_BAT1_I
  - PC5 FMU_BAT1_V

- Powerpath control signals
  - PC10 VDD_5V_HIPOWER_nEN
  - PC11 VDD_5V_HIPOWER_nOC
  - PE2 VDD_5V_PERIPH_nEN
  - PE3 VDD_5V_PERIPH_nOC
  - PB2 VDD_3V3_SENSORS_EN
- Indication LED
  - PD10 LED_nRED
  - PD11 LED_nBLUE
- Voltage Sense
  - PA4 FMU_SCALED_V5
  - PD11 Add 3V3 pin
- Other signals
  - PB0 TIM3_CH3
  - PC6 USART6_TX
  - PC7 USART6_RX

5.2 IO pinouts

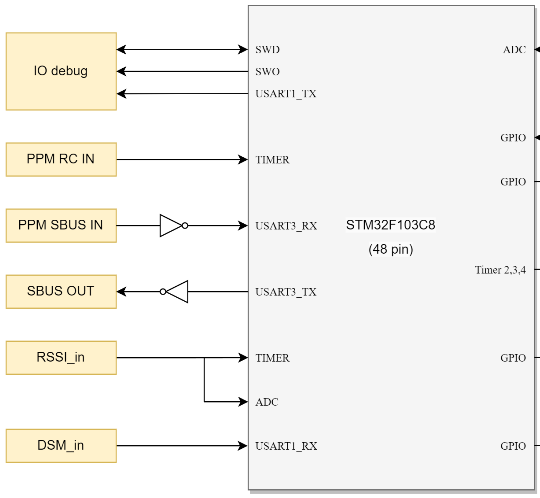

Figure 4: STM32F103 System Block Diagram

Figure 4 shows all the subsystems that are connected to the IO MCU. Also listed below is the detailed list of pin-outs in accordance to connected subsystems. The format of nomenclature is-

Format - (Port name and number) (MCU Signal)

- SBUS connections
  - PB10 IO_SBUS_OUT
  - PB11 IO_SBUS_IN

- Other Digital Signals
  - PA8 IO_PPM_IN
  - PA5, PA12 IO_RSSI_IN

- IO PWM out (MAIN)
  - PA0 IO_CH1
  - PA1 IO_CH2
  - PB8 IO_CH3
  - PB9 IO_CH4

  - PA6 IO_CH5
  - PA7 IO_CH6
  - PB0 IO_CH7
  - PB1 IO_CH8

- FMU connections
  - PA2 USART6_RX_from_IO
  - PA3 USART6_TX_to_IO
- Safety Switch connections
  - PB5 IO_SAFETY_SWITCH_IN
  - PB13 IO_nSAFETY_SWITCH_LED_OUT
- LED and Sense signals
  - PB14 nIO_LED_BLUE
  - PB15 nIO_LED_RED
  - PA4 IO_VDD_SERVO
- IO Debug
  - PA9 IO_USART1_TX
  - PA10 IO_USART1_RX
  - PA13 IO_SWDIO
  - PA14 IO_SWCLK
  - PB6 IO_Spare_GPIO1
  - PB7 IO_Spare_GPIO2

Important points (include changes made to original FMUv6C std). Main reference design PIX32 schematics. Other important points-

- SBUS signals are inverted and both inverter buffers are always enabled. nSBUS_OUT_EN is disabled in this design.
- SPEKTRUM Power is not added in current design.
- BUZZER and safety switch are intended to be used discretely from GPS1.

6 Subsystem brief details

Now that we have completed the process of individual part selection and provided details like pinout as highlighted in the Pixhawk standard, this section will provide details on section-wise parts of the design for simpler understanding. This is the same grouping even followed while designing Schematics on Altium. The primary reference for our design is drawn out of the Holybro Pix32 v6 autopilot whose schematics have been made public [1]. It also maintains system compatibility with Pixhawk V6C that we're following.

6.1 FMU section

This section includes the main STM32H7 connections along with some other peripherals. Some of the critical parts include components like 16MHz crystal oscillator with 18pF load capacitors, seperate decoupling caps for analog and digital power pins and Coin cell power for RTC running after primary power's lost. It also includes USB C port connection directly connected to the MCU. Other connections included are three resistor divider networks, status LEDs and Debugger port connections.

6.2 IO section

This section includes the secondary STM32F103 connections along with some other peripherals. Some of the critical parts include components like 24MHz crystal oscillator with 10pF load capacitors and seperate decoupling caps for analog and digital power pins. It also includes the dual channel inverting buffer IC 74LVC2G240DC used to invert voltage logic of SBUS signals. Other connections included are one resistor divider network, status LEDs, buzzer connections and Debugger port connections.

6.3 Sensors section

This section includes the major sensor connections like both IMUs, magnetometer and barometer. Their communication is either based on SPI or I2C protocol. It also includes both the FRAM and EEPROM circuits and two 2.2K ohm pull-up resistors are used on the I2C clock and data lines. It also includes the two CAN transceiver IC connections and the SD card connections which has 100K ohm pull-up resistors on all data lines and also a multi channel pi filter along all data and clk lines.

6.4 Connectors section

This section includes the main connections to the two Dsub connectors and also the power supply components required to supply reliable and stable 3.3V to all the autopilot internal components. Details of both these sections will be provided below-

6.4.1 Power

The autopilot can be powered using either the USB voltage (+VBUS) or the voltage supplied by an external source (+VBAT). In case both the sources of power are connected at any given time, the ORing diode configuration ensure that the source with the higher voltage is selected. Like voltage monitoring, it is even critical to measure and log the real-time current consumption of the autopilot as a stand-alone module. For the purpose, an analog current sense amplifier (CSA) is used between the cathodes of the ORing diodes and inputs to the regulators which is capable of measuring 10mA to 1A of input current. The analog equivalent voltage value of the

measured current is sent to the FMU.
A 3A ultra low noise buck converter is used to supply constant 3.3V to both the MCUs and all the other digital peripherals. A separate 300mA LDO regulator is used to supply dedicated 3.3V to the sensors. This is to ensure that noise generated from digital components during switching is not coupled with the power supply of analog sensors.

6.4.2 Connectors

All connections from the autopilot will be through two D-sub connectors and the connections are grouped as follows:

- GROUP A
  - TELEM1 (UART7)
  - TELEM2 (UART5)
  - GPS1 (USART1 & I2C1)
  - GPS2 (UART8 & I2C2)
  - I2C and TELEM3 (USART2)
  - BUZZER
  - CAN1 and CAN2
  - 9x GND (1 per subsystem)
- GROUP B
  - FMU PWM ports (x8)
  - IO PWM ports (x8)
  - RC ports (SBUS_IN; SBUS_OUT; RSSI_IN; PPM_IN)
  - Safety Switch
  - POWER1
  - 8x GND (1 per subsystem)

Apart from these connections, there will be two JST 6-pin connectors for debugger connections of FMU and IO. This would be compliant to the Pixhawk Debug Mini connector in accordance to the Pixhawk Connector Standard[2]. It includes both SWD pins and the System Console (dedicated USART ports).

The two Dsub PCB Headers used is D37P33E4GV00LF as shown in Figure 5. It is a two row 37-pin male connector with pcb board lock.

Figure 5: Two Row 37-pin Plug Header

The mating connector for the PCB Header is DC37S064TLF as shown in Figure 6. It is a two row 37-pin female connector that needs external UNC4-40 screw to interlock with its mating header.

Figure 6: Two Row 37-pin Receptacle Connector

7 Connector pinout for wire loom

Next and one of the most important steps remaining is preparing the wiring loom that's compatible with the autopilot. The mating connector used for the selected Dsub pcb header has solder cups as termination. Since this is a prototype design, we have selected solder cup instead of a crimp-type connector for ease of operation during interfacing.

The first image below illustrates pinout diagram of GROUP A connector wherein 26 AWG wires need to be soldered onto the cups. Note that reference point of the connector's image is from the rear part, i.e. the solder cup section.

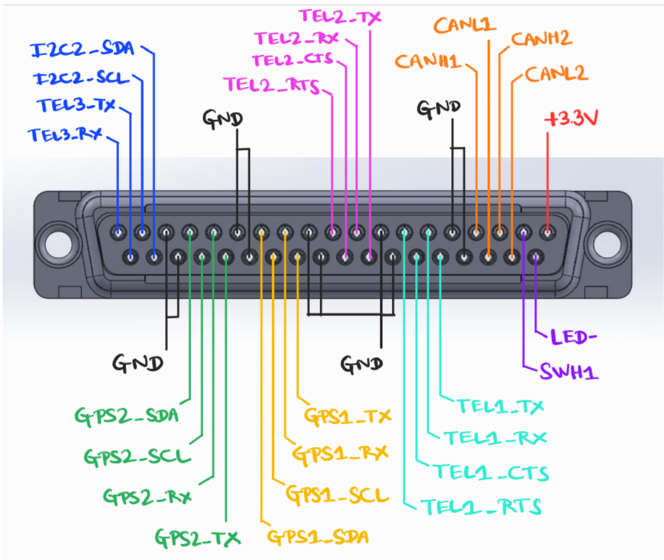

Figure 7: GRP A Dsub pinout

The next image illustrates pinout diagram of GROUP B connector wherein 26 AWG wires need to be soldered onto the cups. Note that here to the reference point of the connector's image is from the rear part, i.e. the solder cup section.

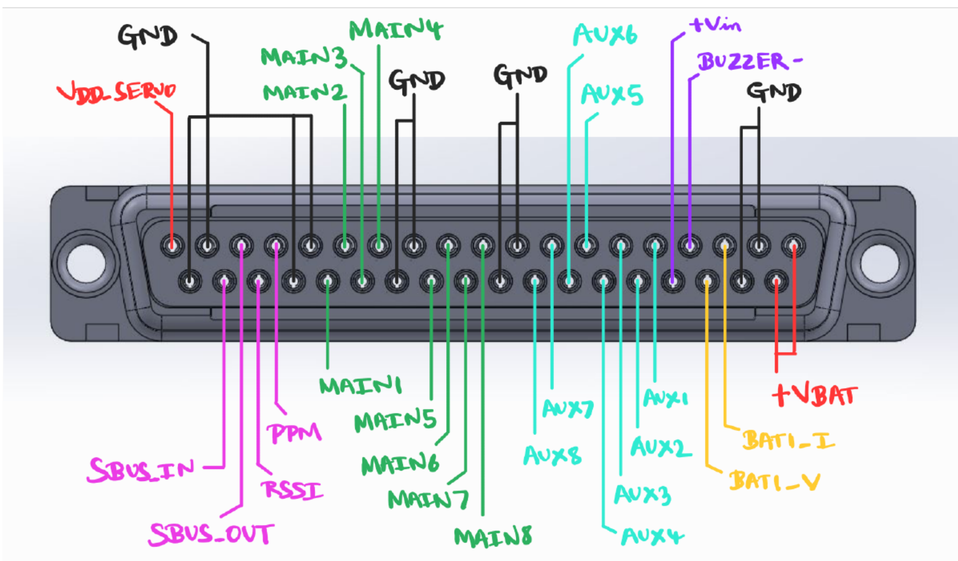

Figure 8: GRP B Dsub pinout

The other end of each of the respective wires as per label given (eg. gps, telem, etc.) has to be connected to relevant device. For example, GPS1 I2C and UART connections will be made with GPS modules from holybro, HERE2 and others.

Note that in this particular configuration power for each device like gps modeule, telemetry and servo motor has to be delivered seperately with care that the ground of power modules output is shared with autopilot's ground.

References

[1] Holybro. *Pix32 v6 Design Resources*. URL: https://docs.holybro.com/autopilot/pix32-v6/download. (accessed: 03.10.2023).

[2] PX4. *SWD Debug Port*. URL: https://docs.px4.io/main/en/debug/swd_debug.html. (accessed: 31.08.2023).