abstract

The project aims to develop an underwater inspection drone that can navigate easily underwater and allow us to vide live video footage underwater. The drone provides following advantages including: Easy to Navigate Underwater, 360 Degree Direction Control, Live Footage Viewing, Dual Motor Propulsion system and anti-rust design for long term usage. The drone uses 2X motors for propulsion and direction control and 4X separate motors for depth control. Both motors are attached with propellers to achieve this task. This mechanism makes use of a unique rudderless mechanism using motor drives to control 360-degree movement of the drone. This mechanism does not make use of ballast tanks to control buoyancy. The drone consists uses the 2 motors to provide front drive as well as for left right direction control. All motors and controller unit are enclosed in a water proof chamber. The drone now uses a camera to capture footages underwater. These footages are transmitted to the unit from there user can connect via Wi-Fi to check the footages. Also, the buoy unit is used to pull out the drone in case it gets stuck or runs out of battery under water.

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# **CHAPTER 1**

# **INTRODUCTION**

## 1.1 INTRODUCTION

Underwater drones, also known as Unmanned Underwater Vehicles (UUVs) or Remotely Operated Vehicles (ROVs), are robotic systems designed to operate beneath the surface of the water. These high-tech devices are used for a variety of tasks ranging from underwater exploration to scientific research, marine inspection, environmental monitoring, and even military operations. Unlike aerial drones, underwater drones must navigate in a much more challenging environment, dealing with pressure, currents, and limited communication due to the nature of water. They can be remotely controlled from the surface.

Under water drone is for spying the marine enemies and attacking them in case of combat times. The underwater drone is capable of diving under the water and it can send the video data to the operator through wireless signals. The drone is also can be controlled wirelessly via transmitter and receivers.

Hence it also can be represented as anti-torpedo missiles. By combining the above mentioned features a small prototype of underwater submarine drone is made. As it is small and narrow it can go into small pores under waters in marine and can be used for taking photographs of sea creatures and can be used in underwater studies.

An underwater drone, also known as an Unmanned Underwater Vehicle (UUV), allowing users to explore and interact with underwater environments from the surface. These drones are typically equipped with high-resolution cameras, lights, and propulsion systems, enabling them to capture stunning footage and navigate through the water with ease.

With a remote-control system, operators can manoeuvre the drone to perform various tasks, such as inspecting underwater infrastructure, exploring shipwrecks, or capturing marine life on film.

Underwater drones are often used for recreational purposes, such as underwater photography and videography, as well as for industrial applications, like inspecting offshore platforms or pipelines. They offer a unique perspective on the underwater world, allowing users to discover and explore the ocean's depths without the need for specialized diving equipment or training.

By providing a safe and efficient way to explore underwater environments, remotely controlled underwater drones are becoming increasingly popular among hobbyists, researchers, and industries alike.

Underwater drones have revolutionized various industries and research fields by providing a safe, efficient, and cost-effective way to explore and work in aquatic environments that are often too dangerous, deep, or inaccessible for human divers.

In essence, underwater drones are the eyes, hands, and data collectors of humanity in the challenging and often mysterious underwater world, opening up new possibilities for exploration, research, and industry.

## 1.2 HISTORY AND FUTURE.

**HISTORY**

**1950s**

Starting in 1957, the first uncrewed underwater vehicle (UUV) was classified as an autonomous underwater vehicle (AUV), and was created in the United States to research the Arctic waters. The Special Purpose Underwater Research Vehicle (SPURV), was used by the University of Washington to collect oceanographic data until 1979 during which the development of SPURV II began to provide better movement performance and better sensing capabilities.

**1970s**

Scientists from the Autonomous and Control Processes Institute took interest in the developments of the AUV “SCAT” which led to the introduction of the UUVs “L1” and “L2” in 1974. “L1” and “L2” are AUV models used for the further development of technology and oceanographic mapping respectively.

**1980s**

Further development of the Remotely operated Vehicle (ROV) brought forth the creation of the Autonomous and Remote-controlled submarine (ARCS) in 1983 by the ISE ltd. company in partnership with the “International Submarine Engineering”. ARCS was also classified as a Remotely controlled underwater vehicle (ROUV) because of its 32-bit Motorola processor which allowed for the remote control it featured. This UUV further served as a testing platform, improving on the battery life, navigational, and communicational systems having its first dive in 1987.

**1990s**

When the Russian Institute of Marine Technology Problems introduced the Solar Autonomous underwater vehicle (SAUV), it was the start of longer-term exploration missions without the need of retrieving the UUV for maintenance. The introduction of solar panels on UUVs began with the SAUV in 1987 and was kept during the making of SAUV II. Solar panels enabled lengthier missions, with the ability to use features such as gaps and high payloads more frequently due to its ease of charge.

Advancements in battery life enabled for the creation of “gliders” in 1995 which would allow for the long-term dives in which the UUVs would remain submerged for weeks or even months at a time.

**2000s**

UUVs begin to be taken into consideration for more than testing tools for other underwater missions due to the increase number of user internationally. There was also an increase in funding for the UUV technology development. The rise in users internationally led to the increase demand for UUV technology outside of government agencies and the commercial sale of UUVs started, expanding the research-based use of the UUV to a more industrial/commercial based use.

**2016 incident**

On December 16, 2016, a Chinese warship in [South China Sea](https://en.wikipedia.org/wiki/South_China_Sea) seized an underwater drone that was in the process of being retrieved by the [U.S. Navy](https://en.wikipedia.org/wiki/U.S._Navy) [survey ship](https://en.wikipedia.org/wiki/Survey_ship) [*USNS Bowditch*](https://en.wikipedia.org/wiki/USNS_Bowditch_(T-AGS-62)). A day later, the [Chinese Defence Ministry](https://en.wikipedia.org/wiki/Ministry_of_National_Defense_of_the_People%27s_Republic_of_China) said it will return the drone to the United States. [The Pentagon](https://en.wikipedia.org/wiki/The_Pentagon) confirmed that and says the drone, used for gathering weather and temperature data, is not armed. The drone was returned several days later.

**2020s**

In early 2023, following successful [military use](https://en.wikipedia.org/wiki/Unmanned_surface_vehicle#Use_in_combat) of uncrewed surface vehicles (USV) by [Ukraine](https://en.wikipedia.org/wiki/Navy_of_Ukraine) in the [Black Sea](https://en.wikipedia.org/wiki/Black_Sea) in October and November 2022, the Ukrainian Navy began to employ an uncrewed underwater vehicle (UUV), a maritime drone, called the Tolosa TLK-150. A small robotic submarine, the TLK-150 is 2.5 m (8 ft 2 in) long, with twin thrusters mounted on wing-like stabilizers. Although "smaller than previous Ukrainian maritime drones [and with a] much shorter range and slower speed, [it] should make up for that by being more stealthy and more survivable. An advanced version has a range of 2000 kilometres and a payload approaching 5000 kg of explosives and has been effective in destroying vessels and infrastructure such as the [Kerch Bridge](https://en.wikipedia.org/wiki/Crimean_Bridge).

TLK-150 is developed by [Brave1](https://en.wikipedia.org/wiki/Brave1), which has designs for two larger UUVs. The TLK-400 is longer at 4–6 m (13–20 ft) and "has a much larger diameter body inferring greater range and payload. The TLK-1000 would be much larger again, up to 12 meters (40 feet) in length and with four thrusters."

In April 2024, Ukraine has announced that it was testing an “uncrewed submarine” that can be fitted with a warhead, stealth features and sensors, carry up to 10 divers, carry six torpedoes or missiles and has an endurance of 54 hours/1000 kms, with a speed of up to 50 kms/h underwater.

In May 2024, [Northrop Grumman](https://en.wikipedia.org/wiki/Northrop_Grumman) unveiled an underwater drone named the Manta Ray, developed for the Defence Advanced Research Projects Agency ([DARPA](https://en.wikipedia.org/wiki/DARPA)). Modelled after the manta ray, this drone underwent four years of development to mimic the movements of this oceanic creature. The product is engineered for extended-duration and long-range military operations with minimal human intervention. Additionally, it features the capability to harness energy from the ocean. Manta Ray successfully completed full-scale at-sea trials off the coast of Southern California in February and March 2024. According to DARPA, Manta Ray demonstrates a first-of-its-kind capability for an extra-large UUV due to its "cross-country modular transportation, in-field assembly, and subsequent deployment."

In April 2025, [Anduril Industries](https://en.wikipedia.org/wiki/Anduril_Industries) announced their [Copperhead(UUV)](https://en.wikipedia.org/wiki/Copperhead_(UUV)) family of autonomous unmanned underwater vehicles, which includes a loitering munition.

**FUTURE**

The future of underwater drones is promising, with advancements expected in autonomy, stealth, and operational capabilities. They will likely play a vital role in naval warfare, marine research, and ocean exploration. Increased integration of AI, improved energy solutions, and enhanced sensor systems will enable these drones to perform more complex tasks with minimal human intervention. We can envision swarms of underwater drones working collaboratively, mimicking the behaviour of marine life, and becoming more difficult to detect. Additionally, the development of autonomous decision-making capabilities will shift the balance of power in naval warfare, allowing for faster and more efficient responses to threats. The underwater drone market is also expected to grow significantly, with projections indicating a value of USD 9.34 billion by 2033.This growth is fuelled by increasing demand for these versatile tools in various applications, including sea farming, underwater infrastructure inspection, and environmental monitoring.

In scientific research, these drones will play a crucial role in ocean exploration, climate monitoring, and marine biodiversity studies, reaching areas previously inaccessible to humans. In the defence sector, underwater drones are becoming essential tools for surveillance, mine detection, and unmanned combat missions, with militaries investing in stealthier, more capable UUVs. Industrial applications, particularly in oil, gas, and underwater infrastructure, will benefit from AI-driven inspection and maintenance capabilities, reducing the need for human divers in hazardous environments. Additionally, consumer interest in recreational underwater drones for activities like diving and photography is growing, supported by compact designs and improved user interfaces. Despite challenges like limited underwater communication and navigation without GPS, ongoing technological innovation promises a future where underwater drones are more autonomous, intelligent, and widely used across both commercial and public sectors.

# **CHAPTER 2**

# **BLOCK DIAGRAM**

TX/RX

FLIGHT CONTROLLER

MCU

ESC

CAMERA

BRUSHLESS MOTOR

INPUT&OUTPUT

TX/RX

MCU

USER

VIDEO MONITOR

Fig. 2 Block Diagram of Underwater Drone with visual output

# **CHAPTER 3**

# **DIFFERENCE BETWEEN UNDERWATER DRONE AND AERIAL DRONE**

The fundamental difference between an underwater drone and an aerial drone lies in the medium they operate in and the physics that govern their movement and communication. While both are unmanned vehicles used for remote sensing and operations, their design, capabilities, and applications diverge significantly due to the vastly different properties of water versus air.

Here's a brief overview of their key differences:

**1. Operating Environment:**

* **Underwater Drone:** Operates in water (freshwater or saltwater).
* **Challenges:** High pressure, poor visibility (turbidity), cold temperatures, strong currents, highly corrosive environment, limited light penetration, no GPS signal, significant signal attenuation.
* **Aerial Drone:** Operates in air.
* **Challenges:** Wind, weather phenomena (rain, snow, lightning), air traffic regulations, battery life for sustained flight.

**2. Propulsion and Manoeuvrability:**

* **Underwater Drone:** Primarily uses thrusters (propellers) for movement in multiple directions (forward, backward, up, down, sideways, yaw). Designs are often streamlined to reduce drag in water. Buoyancy control (using ballast tanks or foam) is also crucial.
* **Aerial Drone:** Primarily uses propellers (rotors) for lift and thrust. Quadcopters, hexacopters, and octocopters are common, providing vertical lift and precise hovering. Fixed-wing drones are also used for longer endurance.

**3. Communication:**

* **Underwater Drone**:
* **Tethered (ROVs):** Most common for real-time control and high-bandwidth data, as radio waves (like Wi-Fi) don't penetrate water well. The tether provides power and data.
* **Acoustic Modems (AUVs/tether less):** For wireless communication, but data rates are very slow, and latency is high.
* **No GPS:** GPS signals cannot penetrate water, so underwater navigation relies on INS (Inertial Navigation Systems), Doppler Velocity Logs (DVLs), acoustic positioning systems (USBL, LBL), and dead reckoning.
* **Aerial Drone:**
* **Radio Frequencies (RF):** Uses Wi-Fi, Bluetooth, or proprietary radio protocols for control and data transmission. These work well in air.
* **GPS:** Relies heavily on GPS for accurate positioning and navigation.

**4. Sensors and Payloads:**

* **Underwater Drone:** Equipped with sensors designed for the aquatic environment:
* **Sonar (Sides can, Multibeam):** Essential for mapping and object detection due to poor visibility.
* **Depth Sensors**: Crucial for maintaining desired depth.
* **Water Quality Sensors:** For salinity, temperature, turbidity, dissolved oxygen, etc.
* **Hydrophones:** For listening to underwater sounds.
* **Powerful Lights:** To illuminate dark environments.
* **Manipulator Arms:** For grabbing or interacting with objects.
* **Aerial Drone:** Equipped with sensors for aerial perspectives:
* **High-Resolution Cameras (RGB, Multispectral, Hyperspectral):** For visual inspection, mapping, and agricultural analysis.
* **Lidar:** For 3D mapping and terrain modelling.
* **Thermal Cameras:** For heat signatures and inspections.
* **Gas Detectors:** For air quality monitoring.

**5. Power Source and Endurance:**

* **Underwater Drone:** Often limited by battery capacity for untethered operations, or by the length/capacity of the tether for ROVs. Battery life can be significantly impacted by drag and current.
* **Aerial Drone:** Limited by battery capacity (typically 20-40 minutes for consumer drones) or fuel (for gas-powered drones). Higher power consumption due to fighting gravity.

**6. Applications:**

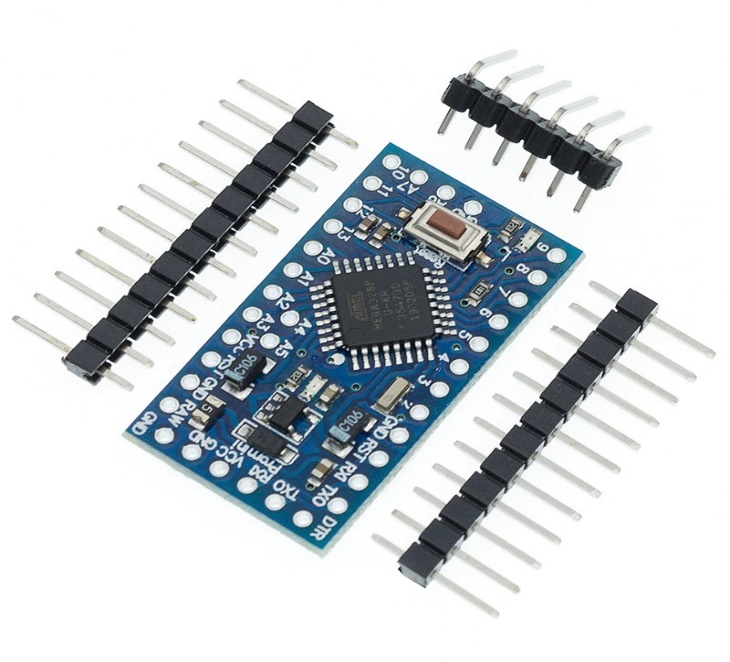
* **Underwater Drone:**
* Oceanographic research, marine biology.
* Offshore oil and gas inspection and maintenance.
* Search and recovery of submerged objects.
* Infrastructure inspection (dams, bridges, pipelines).
* Salvage operations.
* Aquaculture monitoring.
* Défense and security (mine countermeasures).
* **Aerial Drone:**
* Aerial photography and videography.
* Mapping and surveying (agriculture, construction, urban planning).
* Inspection of buildings, power lines, cell towers.
* Delivery services.
* Surveillance and security.
* Search and rescue (SAR) on land.
* Precision agriculture.

In essence, while both types of drones extend human capabilities into inaccessible or hazardous environments, they are fundamentally tailored to the unique physics and challenges of their respective domains, leading to distinct designs, operational procedures, and applications.

# **CHAPTER 4**

# **DESCRIPTION OF COMPONENTS**

## 4.1 Arduino Pro mini



**Figure 4.1.1 Arduino Pro Mini**

The Arduino Pro Mini is a microcontroller board based on the [ATmega328P](http://www.atmel.com/Images/Atmel-8271-8-bit-AVR-Microcontroller-ATmega48A-48PA-88A-88PA-168A-168PA-328-328P_datasheet.pdf).

It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogy inputs, an on-board resonator, a reset button, and holes for mounting pin headers.

A six-pin header can be connected to an FTDI cable or Spark fun breakout board to provide USB power and communication to the board.

The Arduino Pro Mini is intended for semi-permanent installation in objects or exhibitions. The board comes without pre-mounted headers, allowing the use of various types of connectors or direct soldering of wires. The pin layout is compatible with the Arduino Mini.

There are two version of the Pro Mini. One runs at 3.3V and 8 MHz, the other at 5V and 16 MHz

The Arduino Pro Mini was designed and is manufactured by Spark Fun Electronics.

**POWER**

The Arduino Pro Mini can be powered with an FTDI cable or breakout board connected to its six-pin header, or with a regulated 3.3V or 5V supply (depending on the model) on the Vic pin. There is a voltage regulator on board so it can accept voltage up to 12VDC.

If you're supplying unregulated power to the board, be sure to connect to the "RAW" pin on not VCC. The power pins are as follows RAW For supplying a raw voltage to the board. VCC The regulated 3.3- or 5-volt supply. GND Ground pins.

**MEMORY**

The ATmega328P has 32 kB of flash memory for storing code (of which 0.5kB is used for the bootloader). It has 2 kB of SRAM and 1kBs of EEPROM

**INPUT AND OUTPUT**

Each of the 14 digital pins on the Pro Mini can be used as an input or output, using [pin Mode](https://www.arduino.cc/reference/en/language/functions/digital-io/pinmode/) ,[digital Write](https://www.arduino.cc/reference/en/language/functions/digital-io/digitalwrite/), and [digital Read](https://www.arduino.cc/reference/en/language/functions/digital-io/digitalread/) functions. They operate at 3.3 or 5 volts (depending on the model). Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 Kiloohms. In addition, some pins have specialized functions:

* Serial: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the TX-0 and RX-1 pins of the six-pin header.
* External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the [attach Interrupt](https://www.arduino.cc/reference/en/language/functions/external-interrupts/attachinterrupt/) function for details.
* PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the [analogy Write](https://www.arduino.cc/reference/en/language/functions/analog-io/analogwrite/) function.
* SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.
* LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
* The Pro Mini has 8 analogy inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). Four of them are on the headers on the edge of the board; two (inputs 4 and 5) on holes in the interior of the board. The analogy inputs measure from ground to VCC. Additionally, some pins have specialized functionality:
* I2C: A4 (SDA) and A5 (SCL). Support I2C (TWI) communication using the [Wire library](https://www.arduino.cc/reference/en/language/functions/communication/wire/).
* There is another pin on the board:
* Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

**COMMUNICATION**

The Arduino Pro Mini has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328P provides UART TTL serial communication, which is available on digital pins 0 (RX) and 1 (TX). The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board via a USB connection.

A [Software Serial library](http://www.arduino.cc/en/Reference/SoftwareSerial) allows for serial communication on any of the Pro Mini's digital pins.

The ATmega328P also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the [reference](https://www.arduino.cc/reference/en/language/functions/communication/wire/) for details. To use the SPI communication, please see the ATmega328P datasheet.

**PROGRAMMING**

The Arduino Pro Mini can be programmed with the Arduino software [download](https://www.arduino.cc/en/software). For details, see the [reference](https://www.arduino.cc/reference/en/) and [tutorials](https://docs.arduino.cc/tutorials/).

The ATmega328P on the Arduino Pro Mini comes pre-burned with a [bootloader](https://docs.arduino.cc/hacking/software/Bootloader) that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol [reference](http://www.atmel.com/dyn/resources/prod_documents/doc2525.pdf), [C header files](http://www.atmel.com/dyn/resources/prod_documents/avr061.zip).

You can also bypass the bootloader and program the ATmega328P with an external programmer; see [these instructions](https://docs.arduino.cc/hacking/software/Programmer) for details.

**AUTOMATIC (SOFTWARE) RESET**

Rather than requiring a physical press of the reset button before an upload, the Arduino Pro Mini is designed in a way that allows it to be reset by software running on a connected computer. One of the pins on the six-pin header is connected to the reset line of the ATmega328P via a 100-mph capacitor. This pin connects to one of the hardware flow control lines of the USB-to-serial converter connected to the header: RTS when using an FTDI cable, DTR when using the Spark fun breakout board. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of the reset line can be well-coordinated with the start of the upload.

This setup has other implications. When the Pro Mini is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Pro. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

**Table 1 : Arduino Pro Mini Technical Specifications**

|  |  |
| --- | --- |
| Microcontroller | ATmega328P |
| Board Power Supply | 3.35-12v (3.3v model) or 5-12v (5v model) |
| Circuit Operating Voltage | 3.3v or 5v (Depending on the model) |
| Digital I/O Pins | 14 |
| PWM Pins | 6 |
| UART | 1 |
| SPI | 1 |
| I2C | 1 |
| Analog Input Pins | 6 |
| External Interrupts | 2 |
| DC Current Per I/O Pin | 40mA |
| Flash Memory | 32KB of which 2KB used by bootloader |
| SRAM | 2KB\* |
| EEPROM | 1KB\* |
| Clock Speed | 8MHz (3.3v version) or 16MHz (5v version) |

**PIN Configuration**

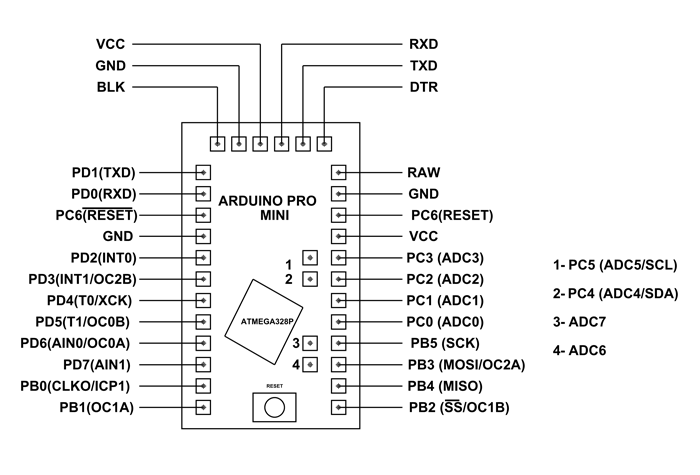


Fig. 4.1.2 Arduino pro mini pin diagram

ARDUINO PRO MINI board is one of the application boards. Since it is an application board, it does not have an in-built programmer. USB port and other connectors are also removed. Because once it is placed in an application, programmer and connectors are basically useless.

ARDUINO PRO MINI is of two types; they are differentiated based on CONTROLLER working voltage. One is +3.3V and another is +5V. Choose the appropriate board based on application.

**Table 2 : ARDUINO PRO MINI Pinout Configuration**

|  |  |  |
| --- | --- | --- |
| PIN GROUP | PIN NAME | DESCRIPTION |
| POWER SOURCE | VCC, GND, and RAW | VCC - Connected to +5V or +3.3V  GND – Connected to GROUND  RAW – Connected to Unregulated power supply 5+V to +12V |
| COMMUNICATION INTERFACE | UART Interface (RXD, TXD)  SPI Interface (MOSI, MISO, SCK, SS)  TWI Interface (SDA, SCL) | UART (Universal Asynchronous Receiver Transmitter) Interface can be used to program PRO MINI  SPI (Serial Peripheral Interface) Interface ban be used to program PRO MINI  TWI (Two Wire Interface) Interface can be used to connect peripherals. |
| INPUT OUTPUT PINS | PD0 to PD7 (8 pins of PORTD)  PB0 to PB5 (6 pins of PORTB)  PC0 to PC6 (7 pins of PORTC)  ADC6 and ADC7(2 additional pins) | Although these 23 pins have many functions, they can be considered as data I/O pins. |
| ANALOG to DIGITAL CONVERTER | ADC0, ADC1, ADC2, ADC7 | These channels can be used to input Analog signals. There are of 10bit resolution. |
| PWM | OC0A, OC0B, OC1A, OC1B, OC2A, OC2B | These six channels can provide PWM (Pulse Width Modulation) outputs. They are of 8-bit resolution. |
| RESET | RESET | Resets the controller. |
| EXTERNAL INTERRUPTS | T0 and T1 | These two pins are specially designed hardware interrupts. |
| ANALOG COMPARATOR | AIN0 and AIN1 | These two pins are connected to an internal comparator. |

The [Arduino Pro Mini](https://store.arduino.cc/arduino-pro-mini) is intended for advanced users who require flexibility, low-cost, and small size. It comes with the minimum of components (no on-board USB or pin headers) to keep the cost down. It's a good choice for a board you want to leave embedded in a project. Please note that there are two versions of the board: one that operates at 5V (like most Arduino boards), and one that operates at 3.3V. Be sure to provide the correct power and use components whose operating voltage matches that of the board.

## 4.2 BLDC Motors

Brushless DC electric motors also known as electronically commutated motors (ECMs, EC motors).



Fig. 4.2.1 BLDC Motor

A brushless DC electric motor (BLDC), also known as an electronically commutated motor, is a [synchronous motor](https://en.wikipedia.org/wiki/Synchronous_motor) using a [direct current](https://en.wikipedia.org/wiki/Direct_current) (DC) [electric](https://en.wikipedia.org/wiki/Electric) power supply. It uses an electronic [controller](https://en.wikipedia.org/wiki/Control_system) to switch DC currents to the motor [windings](https://en.wikipedia.org/wiki/Windings), producing magnetic fields that effectively rotate in space and which the permanent magnet rotor follows. The controller adjusts the phase and amplitude of the current pulses that control the [speed](https://en.wikipedia.org/wiki/Speed) and [torque](https://en.wikipedia.org/wiki/Torque) of the motor. It is an improvement on the mechanical [commutator](https://en.wikipedia.org/wiki/Commutator_(electric)) (brushes) used in many conventional electric motors.

Primary efficiency is a most important feature for BLDC motors. Because the rotor is the sole bearer of the magnets and it doesn't require any power. i.e. no connections, no commutator and no brushes. In place of these, the motor employs control circuitry. To detect where the rotor is at certain times, BLDC motors employ along with controllers, rotary encoders or a Hall sensor.

**Construction of Brushless DC motor**

The construction of a brushless motor system is typically similar to a [permanent magnet synchronous motor](https://en.wikipedia.org/wiki/Permanent_magnet_synchronous_motor) (PMSM), but can also be a [switched reluctance motor](https://en.wikipedia.org/wiki/Switched_reluctance_motor), or an [induction (asynchronous) motor](https://en.wikipedia.org/wiki/Induction_motor). They may also use [neodymium magnets](https://en.wikipedia.org/wiki/Neodymium_magnets) and be [outrunners](https://en.wikipedia.org/wiki/Outrunner) (the [stator](https://en.wikipedia.org/wiki/Stator) is surrounded by the rotor), [in-runners](https://en.wikipedia.org/wiki/Inrunner) (the rotor is surrounded by the stator), or [axial](https://en.wikipedia.org/wiki/Axial_flux_motor) (the rotor and stator are flat and parallel).

In this motor, the permanent magnets attach to the rotor. The current-carrying conductors or [armature windings](https://www.electrical4u.com/armature-winding-pole-pitch-coil-span-commutator-pitch/) are located on the stator. They use electrical commutation to convert electrical energy into mechanical energy.

The main design difference between a brushed and brushless motors is the replacement of mechanical commutator with an electric switch circuit.  A BLDC Motor is a type of synchronous motor in the sense that the magnetic field generated by the stator and the rotor revolve at the same frequency.

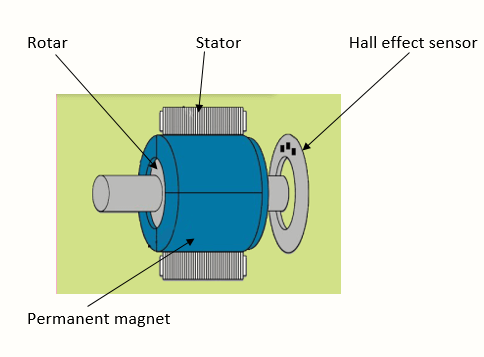


Fig. 4.2.2 Parts of BLDC Motor

Brushless motor does not have any current carrying [commutators](https://en.wikipedia.org/wiki/Commutator_(electric)). The field inside a brushless motor is switched through an amplifier which is triggered by the commutating device like an optical encoder.

The layout of a DC brushless motor can vary depending on whether it is in “Out runner” style or “In-runner” style.

* **Outrunner –** The field magnet is a drum rotor which rotates around the stator. This style is preferred for applications that require high torque and where high rpm isn’t a requirement.
* **In runner –**The stator is a fixed drum in which the field magnet rotates. This motor is known for producing less torque than the out-runner style, but is capable of spinning at very high rpm.

**Working Principle of Brushless DC motor**

BLDC motor works on the principle similar to that of a[Brushed DC motor](https://robu.in/product-category/motors-drivers-actuators/dc-motor/). The Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In the BLDC motor, the current carrying conductor is stationary and the permanent magnet is moving.

A Brushless DC (BLDC) motor works by using an electronic controller to switch the current in the stator windings, creating a rotating magnetic field that interacts with the permanent magnets on the rotor. This interaction generates torque, causing the rotor to rotate. The electronic controller uses feedback from sensors, like Hall effect sensors, to determine the rotor's position and adjust the current flow to maintain continuous and smooth rotation.

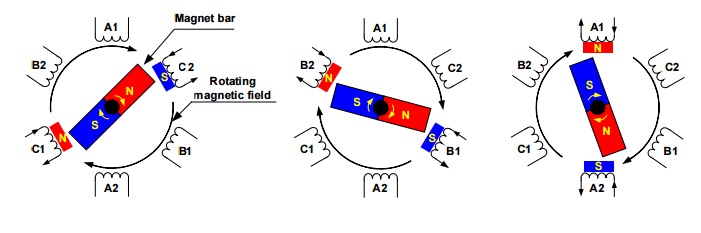


Fig. 4.2.3 Working of BLDC Motor

When the stator coils get a supply from source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

With the switching of windings as High and Low signals, corresponding winding energized as North and South poles. The permanent magnet rotor with North and South poles aligns with stator poles which causes the motor to rotate.

1. Stator and Rotor Interaction:

* The stator has windings that, when energized, create a magnetic field.
* The rotor consists of permanent magnets that are aligned with the stator's magnetic field.

2. Electronic Commutation:

* An electronic controller (like a motor driver) sequentially energizes the stator windings, creating a rotating magnetic field.
* This rotating field interacts with the rotor's permanent magnets, causing the rotor to rotate.

3. Rotor Position Sensing:

* Hall effect sensors are typically used to determine the position of the rotor.
* These sensors send signals to the electronic controller, which then adjusts the current flow to maintain the alignment of the magnetic fields.

4. Continuous Rotation:

* The electronic controller continuously energizes the stator windings in a specific sequence based on the rotor's position, ensuring smooth and continuous rotation.

In essence, the BLDC motor uses electronic switching to create a rotating magnetic field that drives the rotor, eliminating the need for brushes and a commutator like in traditional brushed DC motors.

**Advantages of Brushless DC motor**

* Less overall maintenance due to absence of brushes
* Reduced size with far superior thermal characteristics
* It has no mechanical commutator and associated problems
* High efficiency and high output power to size ratio due to the use of permanent magnet rotor
* High speed of operation even in loaded and unloaded conditions due to the absence of brushes that limits the speed
* Smaller motor geometry and lighter in weight than both brushed type DC and induction AC motors.
* Long life as no inspection and maintenance are required for commutator system
* Higher dynamic response due to low inertia and carrying windings in the stator
* Less electromagnetic interference
* Low noise due to absence of brushes

**A2212 1000KV BLDC Motor for RC Drone**

This A2212 1000KV Brushless Motor for Drones designed for quadcopters and multi-rotors. It has exceptional performance, superpower, and efficiency. These motors are ideal for medium-sized quadcopters with propellers ranging from 8 to 10 inches in diameter. Build powerful and efficient quadcopters with this.

This BLDC Motor comes with an integrated prop adaptor for use with a variety of prop styles, including a 4mm shaft and adaptor sleeves for 5mm/6mm props. It also includes an aluminium mount for quick and simple installation on your quadcopter frame. The 1000Kv Brushless Quadcopter Motors kit includes mounting bolts, prop adapters, and power leads. Brushless DC motors also known as electronically commutated motors, are available (ECMs, EC motors). Primary efficiency is a critical feature of brushless motors. Because the rotor is the sole magnet bearer and does not require any power.

That is, there are no connections, no commutator, and no brushes. Instead, the motor makes use of control circuitry. Brushless DC motors use controllers, rotary encoders, or a Hall sensor to detect where the rotor is at any given time.

**Table 3 : BLDC Motor Specifications**

|  |  |
| --- | --- |
| Model | A2212 |
| Motor KV (RPM/V) | 1000 |
| Compatible Lippo Batteries | 2S ~ 3S |
| Shaft Diameter (mm) | 3.17 |
| Max. Efficiency Current (A) | 4 ~ 10 |
| Maximum Power (W) | 150 |
| No-Load Current (mA) | 500 |
| Internal Resistance(me) | 90 |
| Maximum Efficiency | 80% |
| Poles | 14 |
| Length (mm) | 27.5 |
| Width (mm) | 27 |
| Weight (gm) | 64 |
| Model | XT60 |
| Bullet connector | 3.5mm |

**Features:**

* The steel construction can resist the demands of competition.
* They are appropriate for a variety of Quadcopter and Hexacopter Frames due to their lightweight construction.
* Small size.
* Provides excellent performance and value.

## 4.3 ESC (Electronic Speed Controller)

An ESC or an Electronic Speed Controller controls the brushless motor movement or speed by activating the appropriate MOSFETs to create the rotating magnetic field so that the motor rotates. The higher the frequency or the quicker the ESC goes through the 6 intervals, the higher the speed of the motor will be.

You may have heard them called motor controllers, or even plain old inverters. An Electronic Speed Controller (ESC) is a purpose-built device designed for controlling the speed of an electric motor. Using a specialised combination of hardware and firmware, ESCs drive motors to a commanded speed. They maintain motor speed under various circumstances, such as the dynamic load of a propeller.



Fig. 4.3.1 Electronic Speed Controller

While different ESC types exist for different motor types, the focus here is on Brushless DC (BLDC) motors. BLDC ESCs convert power from a DC supply into a dynamic voltage to drive BLDC motors. This conversion process is flexible, varying the voltage to increase or decrease the motor speed.

The input supply can take the form of a battery or power supply. Using a centralised control system, inputs from a user or an autopilot system are mapped into throttle setpoints for each connected ESC.

An ESC can track the motor's real-time position and speed using one of two methods. The first is using external sensors attached to the motor (censored systems). The second is by taking voltage measurements from the motor itself (sensor less systems).

APD ESCs are typically sensor less, which improves reliability by removing the sensor as a potential failure point. Other advantages include higher maximum RPMs, and compatibility with most off-the-shelf powertrains. A downside to using the motor as the sensor is without any RPM, starting a large load (like a traction application), is very difficult due to lack of signals from the motor.

**Working of ESC (Electronic Speed Controller)**

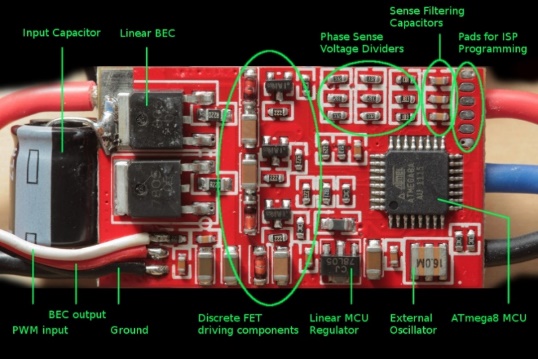


Fig. 4.3.2 Circuit Components of ESC

The role of the ESC is to act as the regulating middleman between the battery and the electric motor. It controls the rotation of the motor by delivering timed electric signals that are translated into changes in speed. It uses the direct current from the battery coupled with a switch system to achieve an alternating three-phase current that is sent to the motor.

The vehicle’s flight controller is used to vary the speed of the motor, whether it be an electric car, plane or drone. Increasing the throttle increases the output power, which modifies the rate at which the switches open and close in the ESC’s circuit.

There are several signal delivery protocols that are used to convey throttle information from the remote controller to the ESC. Each protocol has a slightly different performance, the most common ones being PWM, One-shot, Multishift and Shot.

The most important difference between them is the frequency of the signals they deliver. Shorter frequencies allow a faster signal and a quicker drone reaction time. Furthermore, the Shot protocol is different from the others because it sends a digital signal instead of an analogy signal. This makes the signal more reliable since it is less sensitive to electrical noise and is more precise with its higher resolution. We will cover this in more detail later in this article.

**ESC Components**

Within the ESC there are a number of important components, including the microcontroller, gate driver and MOSFETs, as well as the battery eliminator circuit and device manager adapter in some cases.

**Microcontroller (MCU)**

The microcontroller plays three key roles in the ESC’s operation: 1) housing the firmware that interprets the signal from the controller and feeds it in a control loop, 2) keeping track of the motor’s position in order to ensure smooth acceleration, 3) sending pulses to the gate driver to achieve the desired command.

The microcontroller also determines the motor’s position through a censored or sensor less system. Censored systems use electronic sensors in the motor to track the rotor’s position, which is great for low speed, high torque applications such as ground vehicles. The more popular sensor less systems use back EMF to determine the location of the rotor relative to the stator. This works great at high speeds, though when the motor is turning at lower speeds with less back EMF, the sensor less system does not work as well. This is generally not an issue when driving a propeller. Overall, for highspeed applications, the sensor less system is more efficient, cheaper and more reliable.

**Gate driver**

The gate driver’s job is to act as the middleman between the controller and the gate of the MOSFETs. Upon receiving a low-voltage signal from the microcontroller, the gate driver amplifies the signal and delivers a high-voltage signal to the MOSFETs.

The driver has lower resistance than the microcontroller so can deliver higher current, which also amplifies the speed of the signal. This allows for faster switching and lower heat production. Some ESCs have insulation optical chips between the low voltage microcontroller and the high voltage transistors. Manufacturers may call those ESCs Opto-ESCs.

**MOSFET**

The Metal Oxide Semiconductor Field Effect Transistors or MOSFETs are the switches that strategically deliver power to the motor. The ESC has six of these transistors and each wire from the motor is connected to two of them. The MOSFETs receive signals from the microcontroller then deliver power to the motor so that each of its coils is in one of three phases: high voltage, low voltage, or off/ grounded

As the motor rotates, the signals from the MOSFETs switch the phases of the coils so the rotor keeps spinning. The ESC uses direct current coupled with the switch system to achieve an alternate three-phase current. The higher the throttle input, the faster the switching frequency, leading to a higher RPM in the motor. There are several signal delivery protocols that control this process, each with a different performance and signal frequency.

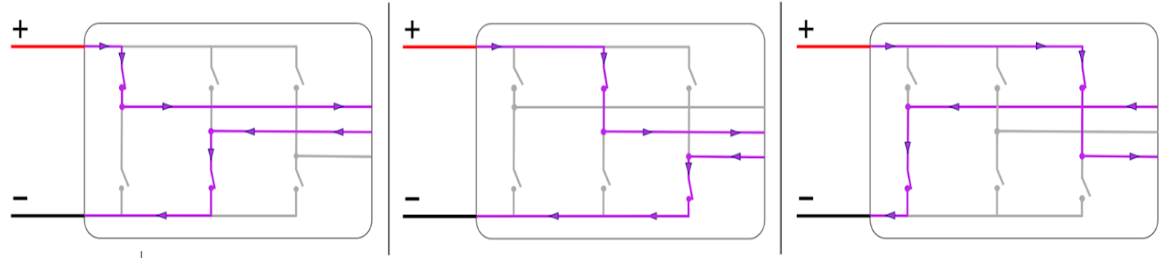


Fig. 4.3.3 Opening and closing of switches in an ESC circuit

**Battery Eliminator Circuit**

ESCs often have a built-in battery eliminator circuit (BEC), which doesn't eliminate the need for a battery, but acts as a voltage regulator to eliminate the need for a separate battery for on-board electronics. The power going through the BEC is dropped to a lower voltage, usually 5 V, which safely powers the throttle receiver and any other devices on board.

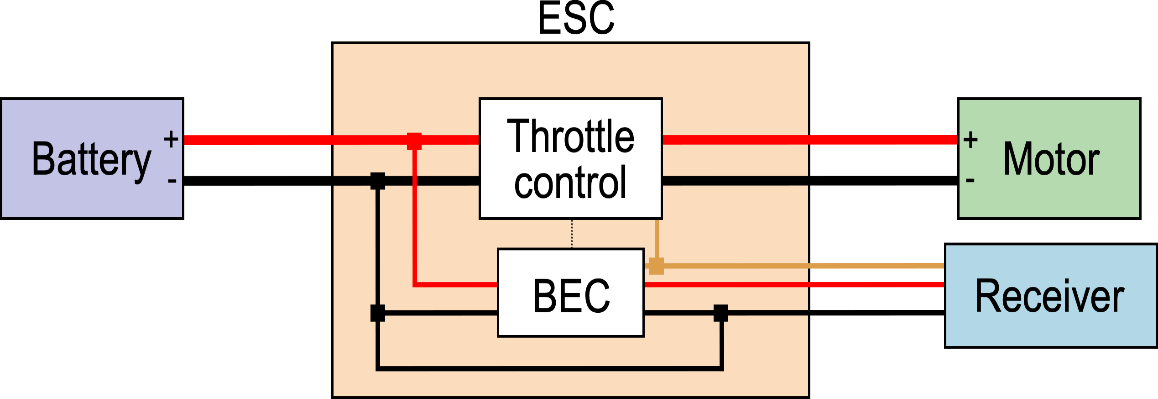


Fig. 4.3.4 Electric propulsion system wiring including an ESC and BEC

Device Manager Adapter (DMA), Programmer, Configurator, Program boxes

The programmer allows the user to connect their ESC to their computer to download firmware updates and use advanced programming options to customize their device. This keeps the ESC up to date and allows for control of advanced settings such as voltage cut-off, throttle calibration mode, and motor direction.

This component is generally brand-specific and is not available for all ESCs.

Simon 30A BLDC ESC Electronic Speed Controller with Connectors is specifically made for quadcopters and multirotor and provides faster and better motor speed control giving better flight performance compared to other available ESCs. It can drive motors which consume up to 30A current. It works on 2S-3S LiPo batteries. It has an on board BEC which provides regulated 5V (2A max draw) to power the flight controller and other on board modules. This particular ESC is recommended with A2212 brushless motor (1000kv, 1400kv, 1800kv, 2200kv).

**Table 4 : ESC Connections**

|  |  |  |
| --- | --- | --- |
| Connection Type | Wire Colour | Function |
| Power | Red | 7.4 to 14.8V |
|  | Black | Ground |
|  |  |  |
| BLDC Motor Connections | Three Blue Wires | BLDC ESC Connections |
|  |  |  |
| Servo Connector | White | Throttle Input |
|  | Red | 5V, 2A Output |
|  | Black | Ground |

**Features:**

* High-quality MOSFETs for BLDC motor drive.
* Backward-polarity protection and protection on the 5V receiver line.
* High-performance microcontroller for best compatibility with all types of motors at greater efficiency.
* Fully programmable with any standard RC remote control.
* Heat sink with a high-performance heat transmission membrane for better thermal management.
* 3 start modes: Normal / Soft / Super-Soft, compatible with fixed-wing aircraft and helicopters.
* Throttle range can be configured to be compatible with any remote control available in the market.

## 4.4 MPU 6050

The MPU-6050 is 6-axis (combines 3-axis Gyroscope, 3-axis Accelerometer) motion tracking devices. Changes in motion, acceleration and rotation can be detected. It is commonly used in robotics, gaming controllers, and other electronic devices that require motion detection. Its high accuracy and cheap cost make it very popular among the DIY community.

**Principle**

An MPU-650 sensor module consists of a 3-axis accelerometer and a 3-axis gyroscope.

Its three coordinate systems are defined as follows:



Fig. 4.4.1 MPU 6050

Put MPU6050 flat on the table, assure that the face with label is upward and a dot on this surface is on the top left corner. Then the upright direction upward is the z-axis of the chip. The direction from left to right is regarded as the X-axis. Accordingly, the direction from back to front is defined as the Y-axis.

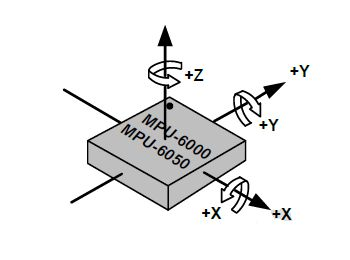
[](https://docs.sunfounder.com/projects/ultimate-sensor-kit/en/latest/_images/05_mpu_2.png)

Fig. 4.4.2 Axis of MPU6050

**3-axis Accelerometer**

The accelerometer works on the principle of piezo electric effect, the ability of certain materials to generate an electric charge in response to applied mechanical stress.

Here, imagines a cuboidal box, having a small ball inside it, like in the picture above. The walls of this box are made with piezo electric crystals.

Whenever you tilt the box, the ball is forced to move in the direction of the inclination, due to gravity.

The wall with which the ball collides, creates tiny piezo electric currents. There are totally, three pairs of opposite walls in a cuboid. Each pair corresponds to an axis in 3D space: X, Y and Z axes.

Depending on the current produced from the piezo electric walls, we can determine the direction of inclination and its magnitude.

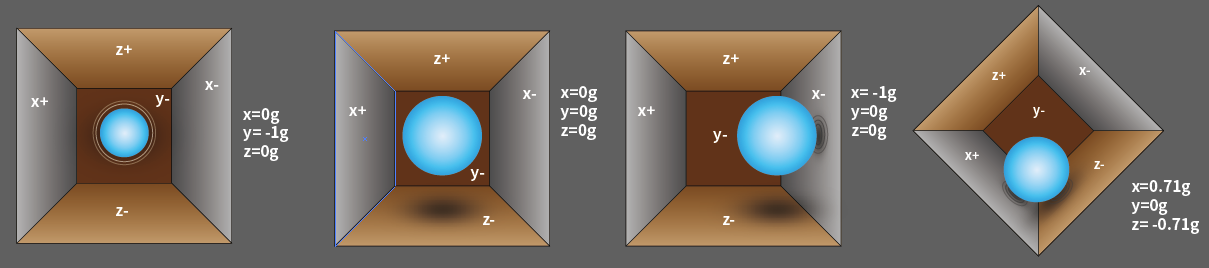
[](https://docs.sunfounder.com/projects/ultimate-sensor-kit/en/latest/_images/05_mpu_3.png)

Fig. 4.4.3 3-axis Accelerometer

We can use the MPU6050 to detect its acceleration on each coordinate axis (in the stationary desktop state, the Z-axis acceleration is 1 gravity unit, and the X and Y axes are 0). If it is tilted or in a weightless/overweight condition, the corresponding reading will change.

The reading of accelerometer is converted to an acceleration value by mapping the reading from the reading range to the measuring range.

Acceleration = (Accelerometer axis raw data / 65536 \* full scale Acceleration range) g

Take the X-axis as an example, when Accelerometer X axis raw data is 16384 and the range is selected as +/-2g:

Acceleration along the X axis = (16384 / 65536 \* 4) g =1g

**3-axis Gyroscope**

Gyroscopes work on the principle of Coriolis acceleration. Imagine that there is a forklike structure, that is in constant back and forth motion. It is held in place using piezo electric crystals.

Whenever, you try to tilt this arrangement, the crystals experience a force in the direction of inclination. This is caused as a result of the inertia of the moving fork. The crystals thus produce a current in consensus with the piezo electric effect, and this current is amplified.

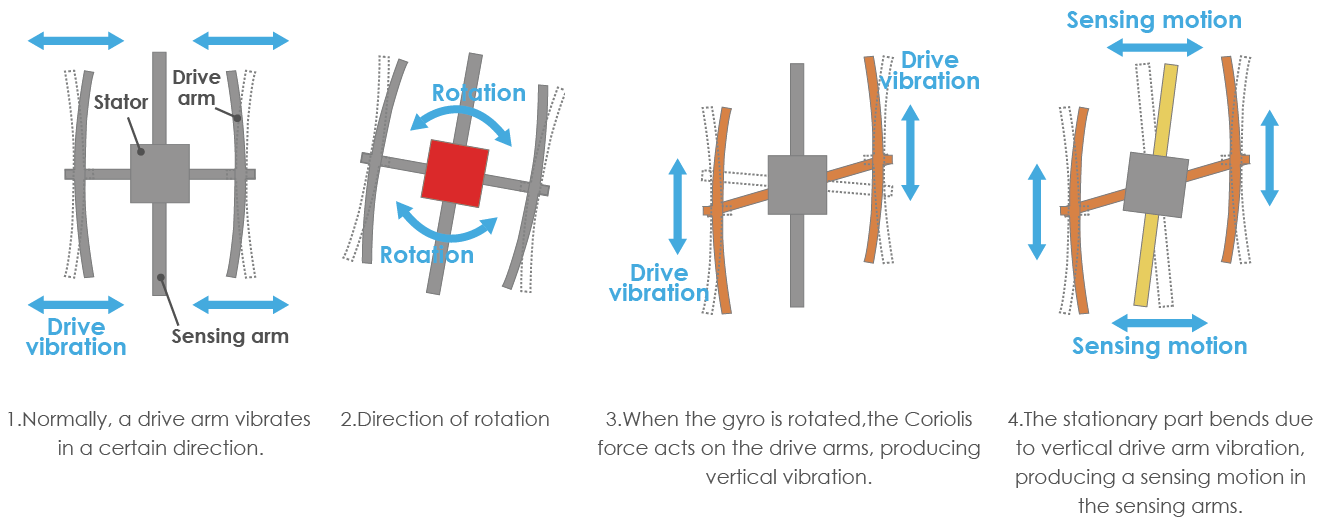
[](https://docs.sunfounder.com/projects/ultimate-sensor-kit/en/latest/_images/05_mpu_4.png)

Fig. 4.4.4 3-axis Gyroscope

The Gyroscope also has four kinds of measuring ranges: +/- 250, +/- 500, +/- 1000, +/- 2000. The calculation method and Acceleration are basically consistent.

The formula for converting the reading into angular velocity is as follows:

Angular velocity = (Gyroscope axis raw data / 65536 \* full scale Gyroscope range) °/s

The X axis, for example, the Accelerometer X axis raw data is 16384 and ranges + / - 250°/ s:

Angular velocity along the X axis = (16384 / 65536 \* 500) °/s =125°/s

**MPU6050 Module Hardware Overview**

At the core of the module is a low-power, low-cost 6-axis Motion Tracking chip – MPU6050 – that integrates a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor (DMP) into a tiny 4mm x 4mm package.

It can measure angular momentum or rotation along all three axes, static acceleration caused by gravity, and dynamic acceleration caused by motion, shock, or vibration.

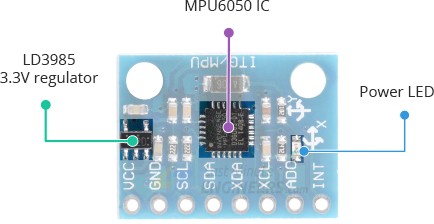


Fig. 4.4.5 MPU6050 Hardware overview

The module includes an on-board LD3985 3.3V regulator, so you can safely use it with a 5V logic microcontroller like Arduino.

The MPU6050 consumes less than 3.6mA during measurements and only 5μA when idle. Because of its low power consumption, it can be used in battery-powered devices.

Additionally, the module has a Power LED that illuminates when the module is powered on.

**Measuring Acceleration**

The MPU6050 has an on-chip accelerometer that can measure acceleration over four programmable full-scale ranges of ±2g, ±4g, ±8g, and ±16g.

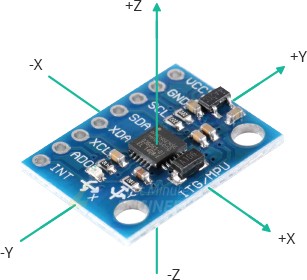


Fig. 4.4.6 MPU6050 Module Accelerometer Axis

The MPU6050 is equipped with three 16-bit analogy-to-digital converters that simultaneously sample the three axes of movement (along the X, Y, and Z axes).

**Measuring Rotation**

The MPU6050 has an on-chip gyroscope that can measure angular rotation over four programmable full-scale ranges of ±250°/s, ±500°/s, ±1000°/s, and ±2000°/s.

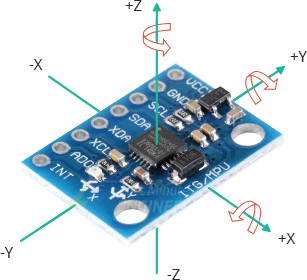
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Fig. 4.4.7 MPU6050 Module Gyroscope Axis

The MPU6050 is equipped with three more 16-bit analogy-to-digital converters that simultaneously sample the three axes of rotation (along the X, Y, and Z axes). The sampling rate can be adjusted from 3.9 to 8000 samples per second.

**Measuring Temperature**

The MPU6050 includes an embedded temperature sensor that can measure temperatures from -40 to 85°C with a ±1°C accuracy.

Note that this temperature measurement is of the silicon die itself, not the ambient temperature. These measurements are typically used to compensate for accelerometer and gyroscope calibration or to detect temperature changes rather than measuring absolute temperatures.

**The I2C Interface**

The module communicates with the Arduino via the I2C interface. It supports two different I2C addresses: 0x68HEX and 0x69HEX. This allows two MPU6050s to be used on the same bus or to avoid address conflicts with other devices on the bus.

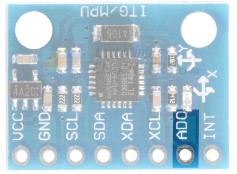


Fig. 4.4.8 MPU6050 I2C bus (ADO)

The ADO pin determines the I2C address of the module. This pin is pulled down with a 4.7K resistor. Therefore, when you leave the ADO pin unconnected, the default I2C address is 0x68HEX; when you connect it to 3.3V, the line is pulled HIGH, and the I2C address becomes 0x69HEX.

**Adding External Sensors**

You can improve the accuracy of the MPU6050 module even further by connecting external sensors to it. These external sensors can be connected to the MPU6050 via a second, completely independent I2C bus (XDA and XCL).

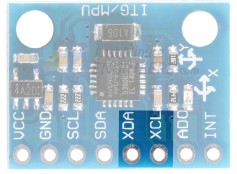


Fig. 4.4.9 MPU6050 I2C bus (XDA and XCL)

This external connection is usually used to attach a magnetometer, which can measure magnetic fields along three axes. The MPU6050 has six Degrees of Freedom (DOF), three for the accelerometer and three for the gyroscope combined. The addition of a magnetometer increases the sensor’s degree of freedom from 6 to 9 DOF.

**Table 5 : MPU 6050 Technical Specifications**

|  |  |
| --- | --- |
| Operating Voltage | 5V (typical) |
| Accelerometer Range | ±2g, ±4g, ±8g, ±16g |
| Gyroscope Range | ±250°/s, ±500°/s, ±1000°/s, ±2000°/s |
| Temperature Range | -40 to +85°C |
| Absolute Maximum Acceleration | Up to 10,000g |

**MPU6050 Module Pinout**

The MPU6050 module’s pinout is as follows:

**VCC** supplies power to the module.

**GND** is the ground pin.

**SCL** is a serial clock pin for the I2C interface.

**SDA** is a serial data pin for the I2C interface.

**XDA** is the external I2C data line. The external I2C bus is for connecting external sensors, such as a magnetometer.

**XCL** is the external I2C clock line.

**AD0** allows you to change the I2C address of the MPU6050 module. It can be used to avoid conflicts between the module and other I2C devices or to connect two MPU6050s to the same I2C bus. When you leave the ADO pin unconnected, the default I2C address is 0x68HEX; when you connect it to 3.3V, the I2C address changes to 0x69HEX.

**INT** is the Interrupt Output pin. The MPU6050 can be programmed to generate an interrupt upon detection of gestures, panning, zooming, scrolling, tap detection, and shake detection.

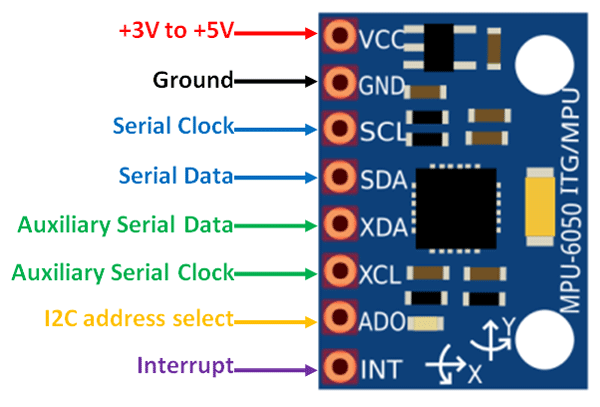


Fig. 4.4.10 MPU6050 Module Pinout

Wiring an MPU6050 Module to an Arduino

Let’s hook the MPU6050 module to the Arduino.

Connections are straightforward. Begin by connecting the VCC pin to the Arduino’s 5V output and the GND pin to ground.

Now we are left with the pins that are used for I2C communication. Note that each Arduino board has different I2C pins that must be connected correctly.  On Arduino boards with the R3 layout, the SDA (data line) and SCL (clock line) are on the pin headers close to the AREF pin. They are also referred to as A5 (SCL) and A4 (SDA).

## 4.5 NRF24LO1 Antenna



Fig. 4.5.1 NRF24LO1 Antenna

**Hardware Overview**

The nRF24L01+ is a budget-friendly, single-chip wireless device that sends and receives radio signals over short distances. It works in the 2.4-2.5 GHz frequency range (the same range used by Wi-Fi and Bluetooth) and doesn’t require any special license to use. This little module can transfer data at different speeds: 250 kbps, 1 Mbps, or 2 Mbps​.

We need to power the nRF24L01+ with a voltage between 1.9 and 3.9 volts. Be careful! Using 5 volts will probably damage the module.

However, its logic pins are 5-volt tolerant, which means you can connect it directly to a 5-volt microcontroller such as an Arduino without needing any level shifter.

The module lets you adjust its transmission power to four different levels: 0 dBm, -6 dBm, -12 dBm, or -18 dBm. At its highest power setting (0 dBm), it only uses 12 mA of electricity during transmission – that’s less than what a single LED uses! Even better, when not actively sending data, it uses extremely little power: only 22 µA in standby mode and a tiny 900 nab in power-down mode. This super-low power usage makes it perfect for battery-powered projects.

The nRF24L01+ connects to microcontrollers using a 4-pin SPI connection and can transfer data at speeds up to 10 Mbps.

In open spaces with no obstacles, the standard version (with PCB antenna) can communicate over distances of about 50-100 meters (150-300 feet), especially when using slower data rates.

If you need to reach farther, there are special versions with power amplifiers and external antennas that can reach up to 1000 meters (or 1 kilometre, which is about 0.6 miles) when you have a clear line of sight between devices.

**Table 6 : NRF24L01 Technical Specifications**

Here are the specifications:

|  |  |
| --- | --- |
| Frequency Range | 2.4 GHz ISM Band |
| Maximum Air Data Rate | 2 Mb/s |
| Modulation Format | GFSK |
| Max. Output Power | 0 dBm |
| Operating Supply Voltage | 1.9 V to 3.6 V |
| Max. Operating Current | 13.5mA |
| Min. Current (Standby Mode) | 26µA |
| Logic Inputs | 5V Tolerant |
| Communication Range | 800+ m (line of sight) |

**Enhanced Shock Burst Protocol**

The nRF24L01+ uses a special communication protocol called Enhanced Shock Burst™. This protocol helps make sure messages get delivered correctly by:

* Buffering data packets (storing packets temporarily before processing)
* Acknowledging received packets (so the sender knows the message was received)
* Automatically resending lost packets (to ensure reliable communication)

These features make wireless communication more reliable, especially over longer distances. It also makes things easier for the microcontrollers (like Arduino), since they don’t have to handle all these things themselves.

**Block diagram**

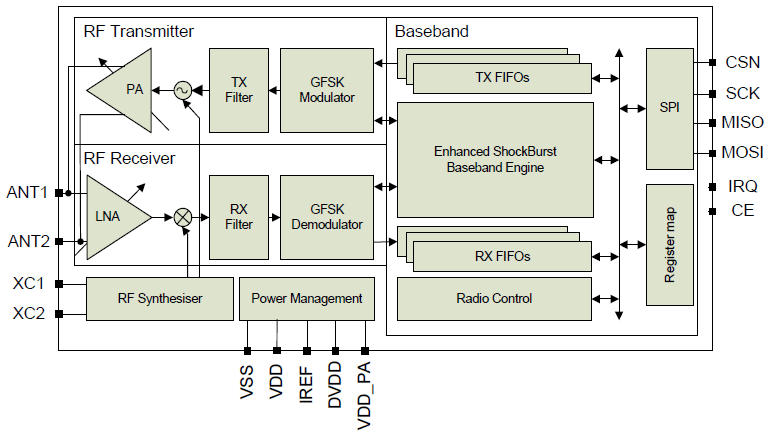


Fig. 4.5.2 Block Diagram of nRF24L01

The nRF24L01 module, along with a Power Amplifier (PA) and Low Noise Amplifier (LNA), is a common setup for wireless communication, particularly for longer distances. A block diagram would visually represent how these components work together.

**nRF24L01+ Module Pinout**

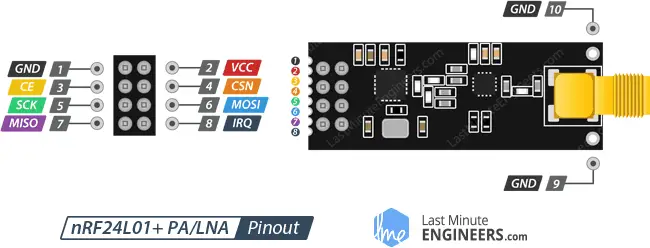


Fig. 4.5.3 nRF24L01+ Module Pinout

**GND** is the ground pin. You can identify it by its square marking that makes it different from the other pins.

**VCC** pin powers the module. Its needs between 1.9 to 3.9 volts to work properly. Connect this to your Arduino’s 3.3V output. Never connect this to the 5V pin or you might damage your module!

**CE** (Chip Enable) is an active-high pin. This pin acts like an on/off switch for the module. When you set it HIGH, the module becomes active and can send or receive data (depending on its configuration). When you set it LOW, the module goes into standby mode to save energy.

**CSN** (Chip Select Not) is also an active-low pin. It’s normally kept HIGH, but when you want your Arduino to talk to the module, you set it LOW. This is especially important when you have multiple SPI devices connected to your Arduino.

**SCK** (Serial Clock) pin receives SPI clock pulses from your Arduino. These clock pulses help synchronize the data transfer.

**MOSI** (Master Out Slave In) is the SPI input to the NRF24L01 from the Arduino.

**MISO** (Master in Slave Out) is the SPI output from the NRF24L01 back to the Arduino.

**IRQ** (Interrupt Request) is an active-low interrupt output. This pin alerts your Arduino when something important happens, like when data is received or sent. The module signals this by briefly setting the pin LOW. Many simple projects don’t use this pin, so you can leave it disconnected unless you plan to handle interrupts​.

**Wiring a nRF24L01+ module to an Arduino**

Now that we understand how the nRF24L01+ module works, let’s connect it to our Arduino.

First, connect the module’s VCC pin to Arduino’s 3.3V and the GND pin to Arduino’s ground. Important: Do not connect it to 5V, as this module operates at 3.3V and could get damaged by higher voltage.

The CSN and CE pins can be connected to any digital pin on your Arduino – in our example, we’ll use digital pin #8 for CSN and digital pin #9 for CE.

Next, we’ll connect the pins used for SPI communication. Since the nRF24L01+ module needs to transfer data quickly, it works best when connected to the hardware SPI pins on your Arduino. For Arduino boards like the UNO or Nano V3.0, these pins are: digital 13 (SCK), 12 (MISO), 11 (MOSI), and 10 (CS).

**Table 7 : NRF24L01 Pin Connections**

To make it easier to understand, here is a table summarizing the pin connections:

|  |  |
| --- | --- |
| **nRF24L01 + Module** | **Arduino pro mini** |
| GND | GND |
| VCC | 3.3 V |
| CE | 9 |
| CSN | 8 |
| SCK | 13 |
| MOSI | 11 |
| MISO | 12 |

**Ways to Improve the Range of the nRF24L01+ Module**

A key parameter for a wireless communication system is the communication range. This is often the deciding factor when selecting an RF solution. So, let’s talk about what we can do to improve the range of our module.

**Reduce Power Supply Noise**

A circuit that generates a radio frequency (RF) signal is extremely sensitive to power supply noise. Power supply noise, if not controlled, can significantly reduce the range you can achieve.

Unless the power source is a standalone battery, there is a good chance that the power output is noisy. To prevent this noise from entering the system, it is recommended that a 10 µf filter capacitor be placed across the power supply line as close to the nRF24L01+ module as possible.

The simplest way to reduce power supply noise is to use a low-cost[adapter for the nRF24L01+ module](https://geni.us/nRF24L01Adapter).

This adapter has an 8-pin female connector where you can plug in your nRF24L01+ module. It can accommodate both versions of the nRF24L01+ module, one with an integrated antenna and one with an external antenna (PA/LNA).

It also has a 2-pin connector for power input and a 6-pin male connector for SPI and interrupt connections.

Since the adapter has a built-in 3.3V voltage regulator and filter capacitors, you can safely power it with a 5V power supply.

**Change Channel Frequency**

The external environment can also be a source of noise for RF circuits, especially if neighbouring networks are set to the same channel.

Because Wi-Fi primarily uses lower frequency channels, it is recommended that you use the highest 25 channels of your nRF24L01+ to avoid interference from these signals.

**Use a Lower Data Rate**

At 250Kbps, the nRF24L01+ has the highest receiver sensitivity of -94dBm. However, at 2MBps data rate, receiver sensitivity drops to -82dBm. That is, at 250kbps, the receiver is approximately ten times more sensitive than at 2Mbps, allowing it to decode ten times weaker signals.

As a result, lowering the data rate can significantly improve the range you can achieve. Plus, a speed of 250kbps is sufficient for the majority of our projects.

**Use of Higher Output Power**

Setting the maximum output power can also help to extend the range of communication. The nRF24L01+ supports a variety of output power levels, including 0dBm, -6dBm, -12dBm, and -18dBm. Choosing 0dBm output power sends stronger signals into the air but consumes more power.

## 4.6 Battery



Fig. 4.6.1 Li-ion Battery 3.7V

In today’s tech-driven world, 3.7 Volt batteries are ubiquitous, powering many devices from smartphones to drones. Understanding these batteries’ various sizes and specifications is crucial for anyone looking to replace, upgrade, or learn more about the batteries that keep their gadgets running. This comprehensive guide will delve into the different sizes of 3.7 Volt batteries, their applications, and what to consider when choosing the right one for your needs.

**What is a 3.7V battery?**

A 3.7V battery is a rechargeable lithium-ion battery that provides a steady voltage output and is commonly used in electronics such as smartphones, drones, and cameras.

3.7-volt batteries offer several advantages over traditional disposable batteries:

* **Rechargeability:** You can reuse this hundreds of times, reducing waste and cost.
* **Higher Energy Density:** Provide more power in a smaller and lighter package.
* **Consistent Performance:** Maintain stable voltage output throughout the discharge cycle.
* **Environmentally Friendly:** Minimize environmental impact compared to disposable batteries.
* Despite their advantages, 3.7-volt batteries have some limitations:
* **Temperature Sensitivity:** Performance may degrade in extreme temperatures.
* **Safety Concerns:** Improper handling or charging can lead to overheating and safety hazards.
* **Initial Cost:** Higher upfront cost than disposable batteries, but cost-effective in the long run.

**How does a lithium-ion battery work?**

Lithium-ion batteries power the lives of millions of people each day. From laptops and cell phones to hybrids and electric cars, this technology is growing in popularity due to its light weight, high energy density, and ability to recharge.

**The Basics**

A battery is made up of an anode, cathode, separator, electrolyte, and two current collectors (positive and negative). The anode and cathode store the lithium. The electrolyte carries positively charged lithium ions from the anode to the cathode and vice versa through the separator. The movement of the lithium ions creates free electrons in the anode which creates a charge at the positive current collector.  The electrical current then flows from the current collector through a device being powered (cell phone, computer, etc.) to the negative current collector. The separator blocks the flow of electrons inside the battery.

**Charge/Discharge**

While the battery is discharging and providing an electric current, the anode releases lithium ions to the cathode, generating a flow of electrons from one side to the other. When plugging in the device, the opposite happens: Lithium ions are released by the cathode and received by the anode.

**Energy Density vs. Power Density**

The two most common concepts associated with batteries are energy density and power density. Energy density is measured in watt-hours per kilogram (Who/kg) and is the amount of energy the battery can store with respect to its mass.

Power density is measured in watts per kilogram (W/kg) and is the amount of power that can be generated by the battery with respect to its mass. To draw a clearer picture, think of draining a pool. Energy density is similar to the size of the pool, while power density is comparable to draining the pool as quickly as possible.

**Nominal Voltage**

Nominal voltage refers to the average operating voltage of a battery under normal conditions. It is a standardized reference value that helps users understand a battery’s expected performance during operation. This value is neither the maximum nor the minimum voltage but represents an approximate midpoint of the battery’s discharge curve.

Different battery chemistries have distinct nominal voltages:

* **Lithium Iron Phosphate (LiFePO4) batteries:** 3.2V per cell
* **Lithium-ion (Li-ion) batteries:** 3.7V per cell

For battery packs, the nominal voltage is calculated by multiplying the nominal voltage of a single cell by the number of cells in series. For example, a 11.7V Li-ion battery typically has a nominal voltage of 12V (3 cells × 3.7V).

**Nominal Capacity**

Nominal capacity indicates the amount of charge a battery can store and deliver under standard test conditions, typically measured in ampere-hours (Ah). It defines how long a battery can supply a certain current before depletion. For instance, **a 100Ah battery** can theoretically provide **1A of current for 100 hours or 10A for 10 hours.**

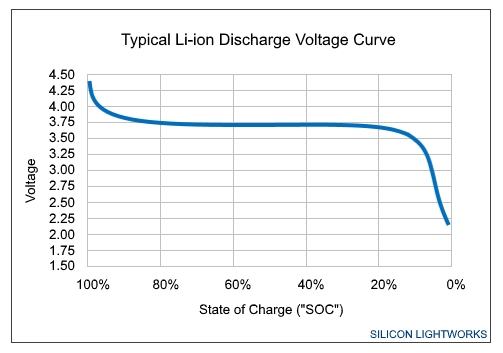


Fig. 4.6.2 Nominal Voltage and Nominal Capacity

**Why Are Nominal Voltage and Nominal Capacity Important?**

Nominal values provide a reference for battery selection and performance comparison. They allow users to:

* **Estimate runtime** for specific applications.
* **Compare batteries** of different chemistries and configurations.
* **Ensure compatibility** with electrical systems.
* **Predict charging and discharging behaviour** in practical applications.

**3. Other Voltage and Capacity Terms**

Beyond nominal voltage and capacity, several other key parameters define battery performance:

* **Operating Voltage (Working Voltage):** The actual voltage range during operation, which depends on the battery’s charge level, load, and battery management system (BMS) settings.
* Example: A 48V LiFePO4 battery may have an operating voltage range of 43.2V to 58.4V, depending on brand-specific BMS configurations.
* **Charging Voltage:** The voltage required to fully charge the battery. For LiFePO4 cells, this is typically 3.6V per cell, meaning a 48V pack (16 cells) requires a maximum charging voltage of 57.6V to 58.4V.
* **Discharge Cutoff Voltage:** The lowest voltage at which the battery is considered discharged. For LiFePO4 cells, this is typically 2.5V per cell, making a 48V pack’s cutoff voltage around 40V to 43.2V, depending on BMS settings.
* **Nominal Current:** The typical current draw for normal operation, impacting battery longevity and efficiency.
* **Internal Resistance**: The inherent resistance within the battery that affects efficiency, heat generation, and performance. Lower resistance leads to better efficiency and less heat.

**4. Common Terminology in Battery Specifications**

Manufacturers use different terms to describe battery characteristics, including:

* **Electrical Performance Parameters –** Covers all key electrical specifications.
* **Electrical Specifications –** Defines voltage, capacity, current ratings, and other operational details.
* **Battery Parameters –** Focuses on technical indicators specific to batteries.
* **Electrical Characteristics –** Highlights core electrical properties.
* **Rated Parameters –** Specifies standard values under controlled conditions.

This provides a stable power supply with long-lasting performance, making it ideal for golf carts that require consistent energy output over extended use.

Understanding nominal voltage and nominal capacity, along with other key battery parameters, is essential for selecting and using batteries effectively.

These specifications help ensure compatibility with different applications, optimize performance, and prolong battery lifespan. By considering these factors, users can make informed decisions when choosing batteries for electric vehicles, energy storage systems, and other power applications.

**BMS (Battery Management System)**

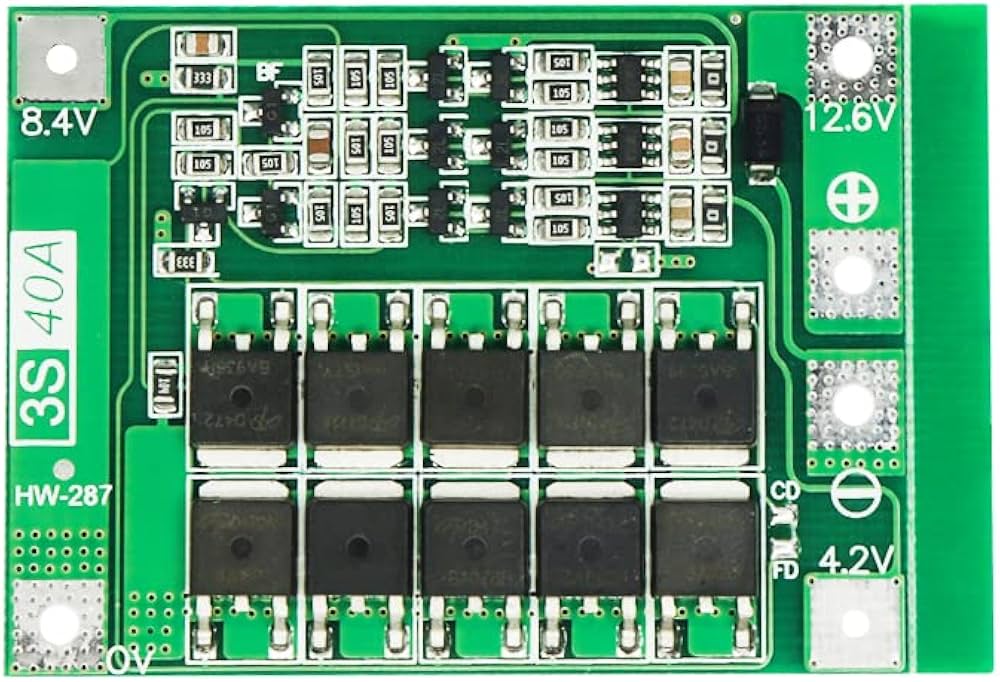


Fig. 4.6.3 BMS (12.6V, 40A) 3S

A Battery Management System (BMS) is an electronic system that acts as the "brain" of a rechargeable battery pack. Its primary role is to monitor, control, and protect the battery to ensure its safe operation, optimize performance, and extend its lifespan. This is especially crucial for modern battery chemistries like Lithium-ion, which are powerful but can be volatile if not properly managed.

Here's a breakdown of key information regarding BMS:

**I. Core Functions of a BMS:**

1. Monitoring: This is the foundational function. A BMS constantly monitors various parameters of the battery pack and individual cells within it:

* Voltage: Total pack voltage, individual cell voltages (to detect imbalances).
* Current: Charge and discharge current flowing in and out of the battery.
* Temperature: Individual cell temperatures and overall pack temperature (critical for preventing overheating).
* State of Charge (SoC): Estimates the remaining capacity of the battery, like a fuel gauge.
* State of Health (SoHo): Assesses the overall health and degradation of the battery compared to its original capacity.
* State of Power (Sop): Indicates the amount of power available for a defined time.
* State of Safety (SoS): Determines if the battery is operating within safe parameters.

1. Protection: This is arguably the most critical function, preventing dangerous conditions and extending battery life:

* Overcharge Protection: Prevents charging the battery beyond its safe voltage limit, which can cause overheating and damage.
* Over-discharge Protection: Stops the battery from being discharged below its minimum safe voltage, which can cause irreversible damage.
* Overcurrent Protection: Disconnects the battery if the current drawn or supplied exceeds safe limits, preventing overheating and potential short circuits.
* Overtemperature/Under temperature Protection: Manages the battery's thermal environment to keep it within an optimal operating temperature range. It can activate cooling or heating systems.
* Short Circuit Protection: Quickly detects and isolates short circuits to prevent catastrophic failures.

1. Cell Balancing: In a multi-cell battery pack (common in EVs and large storage systems), individual cells can have slight variations in capacity, internal resistance, or self-discharge rates. This leads to voltage imbalances over time, where some cells become overcharged while others are undercharged. Cell balancing ensures all cells in the pack charge and discharge uniformly, maximizing the pack's usable capacity and extending its overall lifespan.

* Passive Balancing: Dissipates excess energy from higher-charged cells as heat through resistors. Simpler but less efficient.
* Active Balancing: Transfers energy from higher-charged cells to lower-charged cells, improving efficiency but more complex.

1. Thermal Management: Actively controls the battery's temperature through cooling (e.g., air, liquid, or phase change materials) or heating systems to maintain optimal performance and prevent thermal runaway.
2. Communication: Interfaces with other electronic control units (ECUs) or external systems (e.g., vehicle central computer, charger, display). It provides critical data about the battery's status and receives commands. Common communication protocols include CAN (Controller Area Network) and Sambas.
3. Data Logging and Diagnostics: Records operational data over time, which can be used for performance analysis, fault diagnosis, and predictive maintenance.

**II. Key Components of a BMS:**

* Microcontroller (MCU): The brain of the BMS, processing data, executing algorithms, and making control decisions.
* Sensors:
* Voltage Sensors: Measure individual cell voltages and total pack voltage.
* Current Sensors: Measure charge and discharge current (e.g., Hall-effect sensors, shunt resistors).
* Temperature Sensors: Monitor temperatures at various points within the battery pack.
* Balancing Circuitry: Components (resistors, capacitors, inductors, switches) that facilitate cell balancing.
* MOSFETs/FETs (Field-Effect Transistors): Act as switches to connect or disconnect the battery pack from the load or charger for protection purposes.
* Communication Interface: Hardware and software for communicating with external devices.

## 4.7 CAMERA (ESP32 OV2640)

OV2640 is known as an evergreen image sensor from Omni Vision. It features DVP friendly interface, powerful on-chip ISP with JPEG encoding, and low power consumption, which makes the OV2640 image sensor unique and popular for IoT camera applications at all times.

The OV2640 is a 1/4-inch CMOS UXGA (1632\*1232) image sensor. The sensor's small size and low operating voltage provide all the features of a single UXGA camera and image processor.

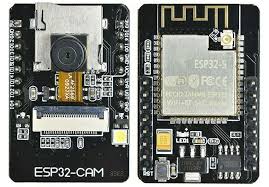


Fig. 4.7.1 OV2640 CAMERA

Through the SCCB bus control, it can output 8/10-bit image data of various resolutions such as full frame, sub-sampling, zooming and windowing. The UXGA image of this product can reach up to 15 frames per second (up to 30 frames for SVGA and 60 frames for CIF). Users have complete control over image quality, data format and transmission.

All image processing functions including gamma curve, white balance, contrast, chroma, etc. can be programmed via the SCCB interface. Image Sensors use unique sensor technology to improve image quality and reduce sharp and stable colour images by reducing or eliminating optical or electronic defects such as fixed pattern noise, smearing, and floating.

* OV2640 is a 1/4-inch CMOS UXGA (1632\*1232) image sensor
* Standard SCCB interface
* Small in size
* Video or snapshot operation

**Features**

* High sensitivity for low-light operation
* Low operating voltage for embedded portable apps
* Standard SCCB interface
* Line optical black level output capability
* Video or snapshot operation
* Zooming, panning, and windowing functions
* Internal/external frame synchronization
* Variable frame rate control
* Supports LED and flash strobe mode
* Supports scaling
* Supports compression
* Embedded microcontroller

**Specifications:**

* Output support for Raw RGB, RGB (RGB565/555), GRB422, YUV (422/420) and CyBC (4:2:2) formats
* Supports image sizes: UXGA, SXGA, SVGA, and any size scaling down from SXGA to 40x30
* Image quality controls including colour saturation, gamma, sharpness (edge enhancement), lens correction, white pixel cancelling, noise cancelling, and 50/60 Hz luminance detection
* Automatic image control functions including Automatic Exposure Control (AEC), Automatic Gain Control (AGC), Automatic White Balance (AWB), Automatic Band Filter (ABF), and Automatic Black-Level Calibration (ABLC).

**Interfacing:**

The OV2640 typically interfaces with microcontrollers or development boards like the ESP32-CAM. The SCCB interface is used to configure the camera settings, while the DVP is used to transfer image data. Many modules integrate the OV2640 with necessary components, making it easier to interface. For example, the ESP32-CAM board is a popular choice as it includes an ESP32 microcontroller with Wi-Fi and Bluetooth, specifically designed to work with the OV2640 camera.

**Core Functionality and Architecture**

The OV2640 is not just a bare image sensor; it's a **System-on-Chip (SoC) camera.** This means it integrates an entire image processing pipeline on a single chip, significantly simplifying its use and offloading processing power from the host microcontroller.

Its internal architecture generally includes:

* **Image Sensor Array:** A 1632 x 1232 active pixel array with a Bayer colour filter pattern (alternating red, green, blue pixels) to capture colour information.
* **Analog Signal Processor:** Handles the initial analogy signal conditioning from the sensor.
* 10-Bit A/D Converters: Converts the analogy pixel data into digital values.
* **Digital Signal Processor (DSP):** This is the heart of the on-chip image processing. It performs a wide array of functions to improve image quality and prepare the data for output.
* **Output Formatter:** Prepares the processed image data into various selectable formats.
* **Compression Engine:** A crucial feature, this hardware engine provides on-chip JPEG compression. This is a major advantage as it drastically reduces the data size that needs to be transferred to the microcontroller, freeing up its processing power and memory. For instance, a 1600x1200 RGB565 or YUV image would typically occupy about 3.66MB of RAM, but the OV2640 can compress it to around 150KB as JPEG, a compression ratio of approximately 25:1.
* **Microcontroller:** An embedded microcontroller handles the overall control and configuration of the sensor and its various functions.
* **Serial Camera Control Bus (SCCB) Interface:** This is the primary control interface, compatible with the widely used I2C protocol. Through SCCB, the host microcontroller can set camera parameters, modes, and read status.
* **Digital Video Port (DVP):** This is the parallel interface used for outputting the actual image data. It typically involves 8-bit data lines, a pixel clock (PCLK), and horizontal (HREF) and vertical (VSYNC) synchronization signals.

# **CHAPTER 5**

# **SCHEMATIC DIAGRAM**

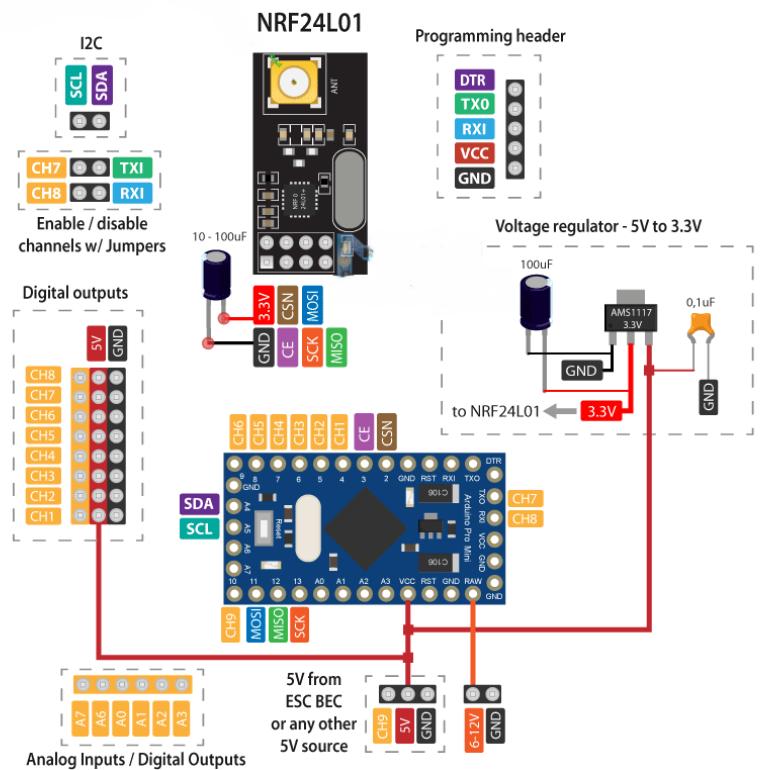




Fig. 5.1 Schematic Diagram of Underwater Drone with Visual Output

A schematic diagram of an underwater drone with visual output illustrates the interconnected components that enable the drone to operate underwater, capture visual data, and transmit or store it. Here's a breakdown of the key elements you'd typically find in such a diagram.

**I. Core Components (The Brain and Body):**

1. Microcontroller/SBC (Single Board Computer):

* Function: This is the "brain" of the drone. It processes data from sensors, controls motor, manages communication, and handles image/video processing. Examples include Raspberry Pi, Arduino (for simpler tasks), or more specialized embedded systems.
* Connections: Connected to almost all other components, especially sensors, motor drivers, and communication modules.

1. Power Management Unit (PMU):

* Function: Regulates and distributes power from the battery to all the drone's components, ensuring stable voltage and current. May include voltage regulators, current sensors, and battery protection circuits.
* Connections: Connects the battery to the microcontroller, motors, cameras, and other electronics.

1. Battery Pack:

* Function: Provides the necessary electrical power for the drone's operation. Typically, Li-ion (Lithium-ion) batteries due to their high energy density.
* Connections: Connects to the Power Management Unit.

1. Pressure Hull/Enclosure:

* Function: The watertight casing that protects all the internal electronics from the high pressure and corrosive nature of seawater. It's crucial for the drone's survival.
* Connections: Houses all internal components, with penetrators for external connections (thrusters, cameras).

**II. Propulsion System:**

1. Brushless DC Motors (Thrusters):

* Function: Provide the thrust for movement in three dimensions (forward/backward, up/down, left/right, and yaw). Typically configured in an array (e.g., 4-6 thrusters for full manoeuvrability).
* Connections: Connected to Electronic Speed Controllers (ESCs).

1. Electronic Speed Controllers (ESCs):

* Function: Translate signals from the microcontroller into motor speed and direction commands. Each thruster usually has its own ESC.
* Connections: Connect to the microcontroller and the respective thrusters.

**III. Sensory Input (Understanding the Environment):**

1. Underwater Camera(s):

* Function: Captures video and still images. High-resolution, low-light performance, and wide-angle lenses are often preferred. May include multiple cameras for different views or stereo vision.
* Connections: Connects to the microcontroller (via USB, CSI, or other interfaces).

**IV. Communication and Visual Output:**

1. Communication Module (on drone side):

* Function: Handles the data transmission over the tether. Could be Ethernet, serial communication, or specialized protocols.
* Connections: Connects the microcontroller to the tether.

1. Surface Station/Control Unit:

* Function: The human interface for controlling the drone and viewing the visual output.
* Components:
* Monitor/Display: For real-time video feed from the underwater camera.
* Joystick/Controller: For manual control of the drone's movement.
* Computer/Laptop: Runs software for drone control, data logging, mission planning, and video recording.
* Communication Module (on surface side): Interfaces with the tether to send/receive data.

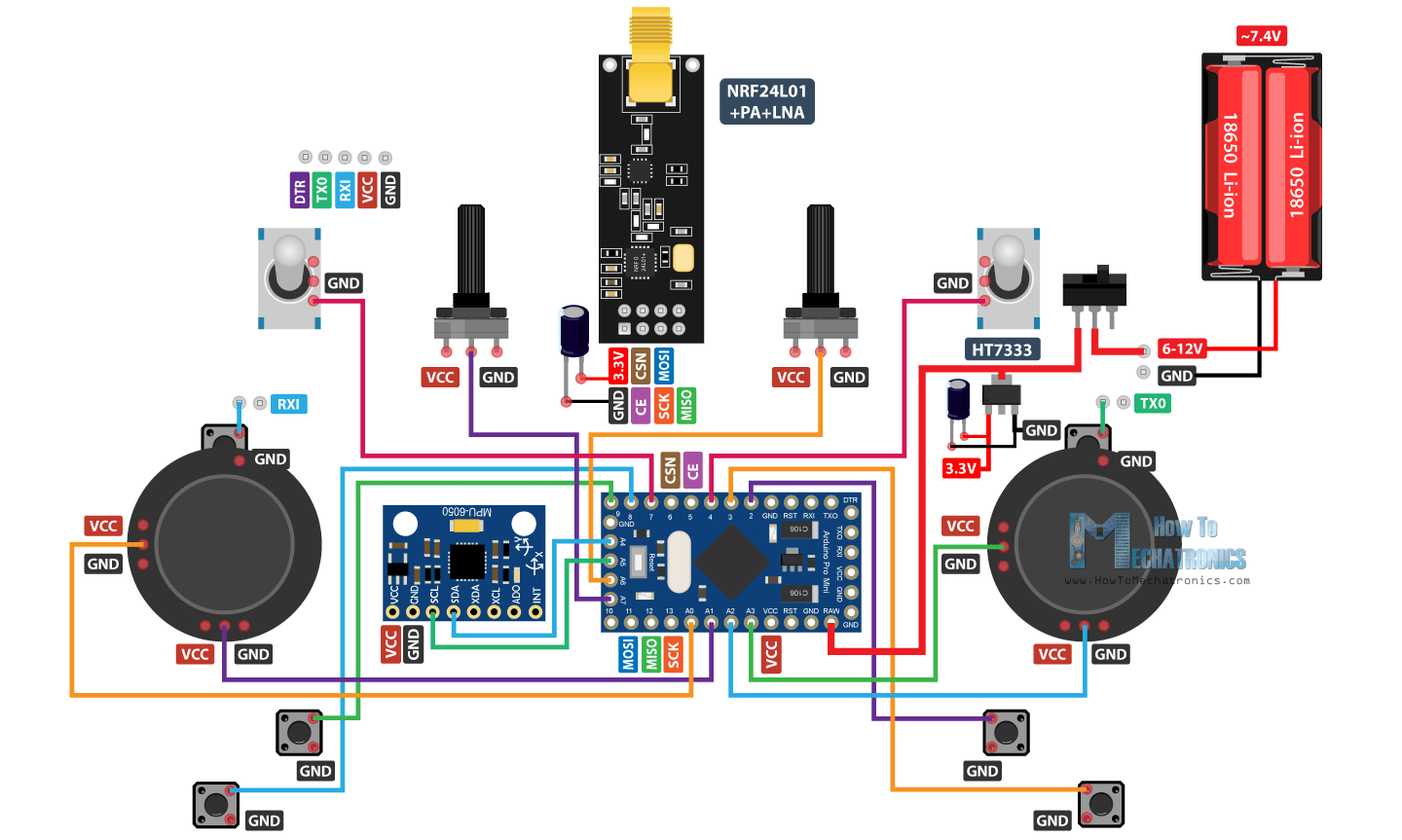


Fig. 5.2 Schematic Diagram of Transmitter

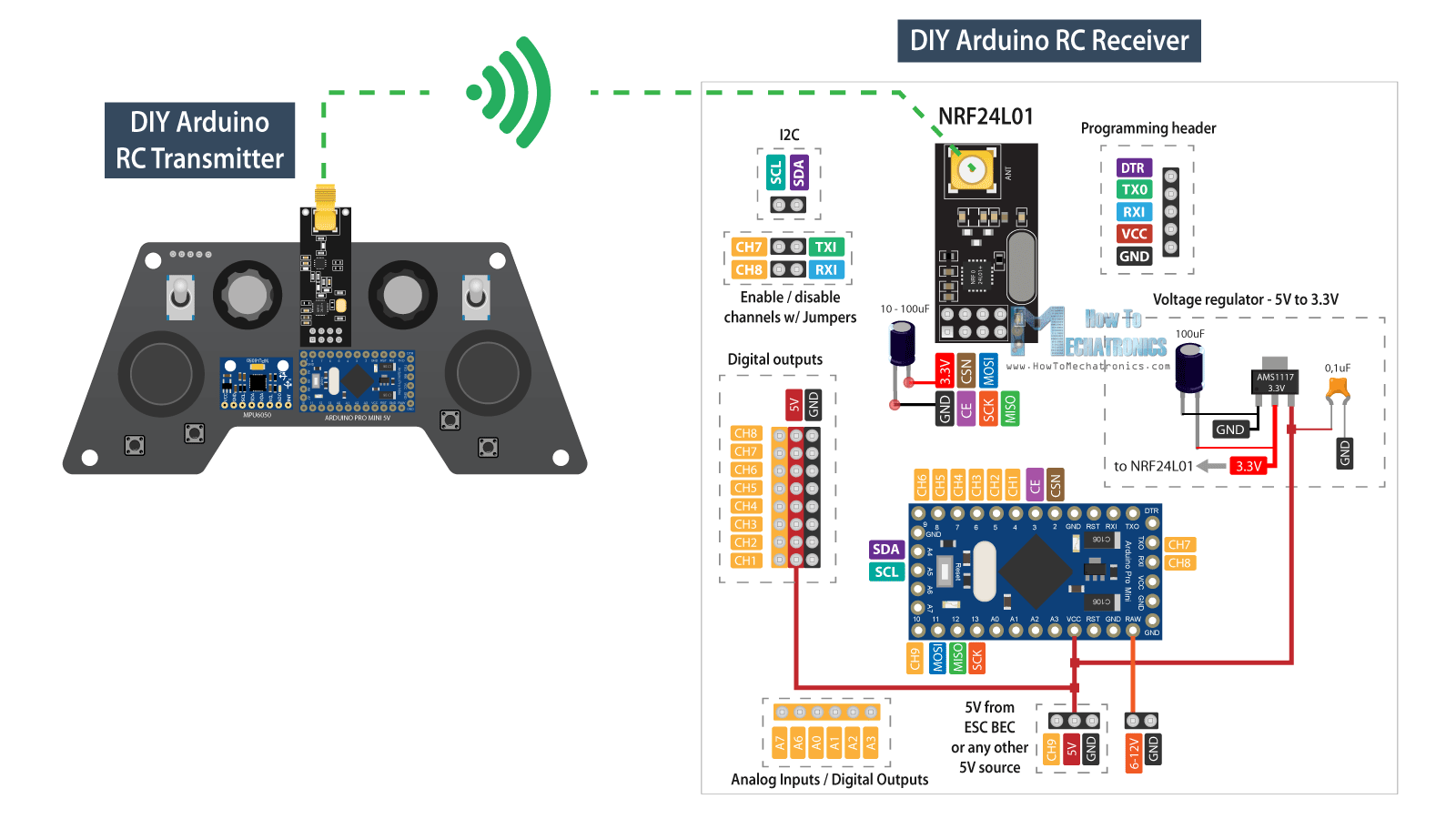


Fig. 5.3 Schematic Diagram of Receiver

Video Encoder/Streamer (if needed for high-res video over long tethers):

Function: Compresses video data for efficient transmission over the tether to the surface station.

Connections: Connects between the camera and the communication module.

**How it Works (Simplified Flow):**

1. Power: The battery provides power to the PMU, which distributes it to all components.
2. Control Input: The operator at the surface station uses a joystick to send commands through the tether to the drone's microcontroller.
3. Movement: The microcontroller processes these commands and sends signals to the ESCs, which in turn control the speed and direction of the thrusters, causing the drone to move.
4. Visual Capture: The underwater camera captures video, which is sent to the microcontroller.
5. Data Transmission: The microcontroller packages sensor data and video streams. This data is then sent through the communication module and tether back to the surface station.
6. Visual Output: The surface station receives the video data, decodes it, and displays it on a monitor, allowing the operator to see the underwater environment in real-time. Sensor data is also displayed and logged.

A schematic diagram would use symbols for each of these components and lines to represent their electrical or data connections, often with arrows indicating the direction of data flow. It's a blueprint for understanding the system's architecture and how its parts interact.

# **CHAPTER 6**

# **CODE**

## Receiver code

#include <SPI.h>

#include <nRF24L01.h>

#include <RF24.h>

#include <Servo.h>

// NRF24L01 Setup

RF24 radio(10, 9); // CE, CSN

const byte address[6] = "00001";

unsigned long lastReceiveTime = 0;

unsigned long currentTime = 0;

// Data structure from transmitter

struct Data\_Package {

  byte j1PotX;

  byte j1PotY;     // Vertical movement (Up/Down)

  byte j1Button;

  byte j2PotX;     // Forward/Reverse

  byte j2PotY;     // Left/Right

  byte j2Button;

  byte pot1;

  byte pot2;

  byte tSwitch1;

  byte tSwitch2;

  byte button1;

  byte button2;

  byte button3;

  byte button4;

};

Data\_Package data;

// ESCs

Servo esc1, esc2, esc3, esc4; // Vertical motors

Servo esc5, esc6;             // Horizontal motors

void setup() {

  Serial.begin(9600);

  // Attach ESCs to respective pins

  esc1.attach(2);

  esc2.attach(3);

  esc3.attach(4);

  esc4.attach(5);

  esc5.attach(6);

  esc6.attach(7);

  // Set output pins

  pinMode(8, OUTPUT);     // Digital output

  pinMode(A0, OUTPUT);    // A0 used as digital output

  stopAllMotors();

  // NRF24L01 setup

  radio.begin();

  radio.openReadingPipe(0, address);

  radio.setAutoAck(false);

  radio.setDataRate(RF24\_250KBPS);

  radio.setPALevel(RF24\_PA\_LOW);

  radio.startListening();

  resetData();

}

void loop() {

  // Receive data

  if (radio.available()) {

    radio.read(&data, sizeof(Data\_Package));

    lastReceiveTime = millis();

  }

  currentTime = millis();

  if (currentTime - lastReceiveTime > 1000) {

    resetData(); // Signal lost

  }

  // Vertical control using j1PotY (Up/Down)

  int verticalPWM = map(data.j1PotY, 0, 255, 1000, 2000);

  esc1.writeMicroseconds(verticalPWM);

  esc2.writeMicroseconds(verticalPWM);

  esc3.writeMicroseconds(verticalPWM);

  esc4.writeMicroseconds(verticalPWM);

  // Horizontal control

  int basePWM = map(data.j2PotX, 0, 255, 1000, 2000);     // Forward/Reverse

  int turnOffset = map(data.j2PotY, 0, 255, -250, 250);   // Left/Right

  int esc5\_pwm = constrain(basePWM + turnOffset, 1000, 2000); // Left motor

  int esc6\_pwm = constrain(basePWM - turnOffset, 1000, 2000); // Right motor

  esc5.writeMicroseconds(esc5\_pwm);

  esc6.writeMicroseconds(esc6\_pwm);

  // Control both pin 8 and A0 using tSwitch2

  bool switchState = (data.tSwitch2 == 0);

  digitalWrite(8, switchState ? HIGH : LOW);

  digitalWrite(A0, switchState ? HIGH : LOW);

  // Debug info

  Serial.print("Vertical PWM: ");

  Serial.print(verticalPWM);

  Serial.print(" | ESC5 (L): ");

  Serial.print(esc5\_pwm);

  Serial.print(" | ESC6 (R): ");

  Serial.print(esc6\_pwm);

  Serial.print(" | tSwitch2: ");

  Serial.println(data.tSwitch2);

}

void stopAllMotors() {

  esc1.writeMicroseconds(1000);

  esc2.writeMicroseconds(1000);

  esc3.writeMicroseconds(1000);

  esc4.writeMicroseconds(1000);

  esc5.writeMicroseconds(1000);

  esc6.writeMicroseconds(1000);

}

void resetData() {

  data.j1PotX = 127;

  data.j1PotY = 127;

  data.j2PotX = 127;

  data.j2PotY = 127;

  data.j1Button = 1;

  data.j2Button = 1;

  data.pot1 = 1;

  data.pot2 = 1;

  data.tSwitch1 = 1;

  data.tSwitch2 = 1;

  data.button1 = 1;

  data.button2 = 1;

  data.button3 = 1;

  data.button4 = 1;

  stopAllMotors();

  // Reset outputs

  digitalWrite(8, LOW);

  digitalWrite(A0, LOW);

}

## 6.2 Transmitter code

#include <SPI.h>

#include <nRF24L01.h>

#include <RF24.h>

#include <Wire.h>

// Define digital inputs

#define jB1 1

#define jB2 0

#define t1 7

#define t2 4

#define b1 8

#define b2 9

#define b3 2

#define b4 3

const int MPU = 0x68;

float AccX, AccY, AccZ;

float GyroX, GyroY, GyroZ;

float accAngleX, accAngleY, gyroAngleX, gyroAngleY;

float angleX, angleY;

float AccErrorX, AccErrorY, GyroErrorX, GyroErrorY;

float elapsedTime, currentTime, previousTime;

int c = 0;

RF24 radio(5, 6);

const byte address[6] = "00001";

struct Data\_Package {

  byte j1PotX;

  byte j1PotY;

  byte j1Button;

  byte j2PotX;

  byte j2PotY;

  byte j2Button;

  byte pot1;

  byte pot2;

  byte tSwitch1;

  byte tSwitch2;

  byte button1;

  byte button2;

  byte button3;

  byte button4;

};

Data\_Package data;

void setup() {

  Serial.begin(9600);

  initialize\_MPU6050();

  radio.begin();

  radio.openWritingPipe(address);

  radio.setAutoAck(false);

  radio.setDataRate(RF24\_250KBPS);

  radio.setPALevel(RF24\_PA\_LOW);

  pinMode(jB1, INPUT\_PULLUP);

  pinMode(jB2, INPUT\_PULLUP);

  pinMode(t1, INPUT\_PULLUP);

  pinMode(t2, INPUT\_PULLUP);

  pinMode(b1, INPUT\_PULLUP);

  pinMode(b2, INPUT\_PULLUP);

  pinMode(b3, INPUT\_PULLUP);

  pinMode(b4, INPUT\_PULLUP);

  data.j1PotX = 127;

  data.j1PotY = 127;

  data.j2PotX = 127;

  data.j2PotY = 127;

  data.j1Button = 1;

  data.j2Button = 1;

  data.pot1 = 1;

  data.pot2 = 1;

  data.tSwitch1 = 1;

  data.tSwitch2 = 1;

  data.button1 = 1;

  data.button2 = 1;

  data.button3 = 1;

  data.button4 = 1;

}

void loop() {

  // Read analog inputs

  int raw\_j1PotX = map(analogRead(A1), 0, 1023, 0, 255);

  int trim = map(analogRead(A7), 0, 1023, -30, 30);  // pot1 used for trim

  int trimmed\_j1PotX = constrain(raw\_j1PotX + trim, 0, 255);

  data.j1PotX = trimmed\_j1PotX;

  data.j1PotY = map(analogRead(A0), 0, 1023, 0, 255);

  data.j2PotX = map(analogRead(A2), 0, 1023, 0, 255);

  data.j2PotY = map(analogRead(A3), 0, 1023, 0, 255);

  data.pot1 = map(analogRead(A7), 0, 1023, 0, 255);  // keep pot1 raw value

  data.pot2 = map(analogRead(A6), 0, 1023, 0, 255);

  // Digital inputs

  data.j1Button = digitalRead(jB1);

  data.j2Button = digitalRead(jB2);

  data.tSwitch1 = digitalRead(t1);

  data.tSwitch2 = digitalRead(t2);

  data.button1 = digitalRead(b1);

  data.button2 = digitalRead(b2);

  data.button3 = digitalRead(b3);

  data.button4 = digitalRead(b4);

  if (digitalRead(t1) == LOW) {

    read\_IMU();

  }

  radio.write(&data, sizeof(Data\_Package));

}

void initialize\_MPU6050() {

  Wire.begin();

  Wire.beginTransmission(MPU);

  Wire.write(0x6B);

  Wire.write(0x00);

  Wire.endTransmission(true);

  Wire.beginTransmission(MPU);

  Wire.write(0x1C);

  Wire.write(0x10);

  Wire.endTransmission(true);

  Wire.beginTransmission(MPU);

  Wire.write(0x1B);

  Wire.write(0x10);

  Wire.endTransmission(true);

}

void read\_IMU() {

  Wire.beginTransmission(MPU);

  Wire.write(0x3B);

  Wire.endTransmission(false);

  Wire.requestFrom(MPU, 6, true);

  AccX = (Wire.read() << 8 | Wire.read()) / 4096.0;

  AccY = (Wire.read() << 8 | Wire.read()) / 4096.0;

  AccZ = (Wire.read() << 8 | Wire.read()) / 4096.0;

  accAngleX = (atan(AccY / sqrt(pow(AccX, 2) + pow(AccZ, 2))) \* 180 / PI) + 1.15;

  accAngleY = (atan(-1 \* AccX / sqrt(pow(AccY, 2) + pow(AccZ, 2))) \* 180 / PI) - 0.52;

  previousTime = currentTime;

  currentTime = millis();

  elapsedTime = (currentTime - previousTime) / 1000;

  Wire.beginTransmission(MPU);

  Wire.write(0x43);

  Wire.endTransmission(false);

  Wire.requestFrom(MPU, 4, true);

  GyroX = (Wire.read() << 8 | Wire.read()) / 32.8;

  GyroY = (Wire.read() << 8 | Wire.read()) / 32.8;

  GyroX += 1.85;

  GyroY -= 0.15;

  gyroAngleX = GyroX \* elapsedTime;

  gyroAngleY = GyroY \* elapsedTime;

  angleX = 0.98 \* (angleX + gyroAngleX) + 0.02 \* accAngleX;

  angleY = 0.98 \* (angleY + gyroAngleY) + 0.02 \* accAngleY;

  data.j1PotX = map(angleX, -90, 90, 255, 0);

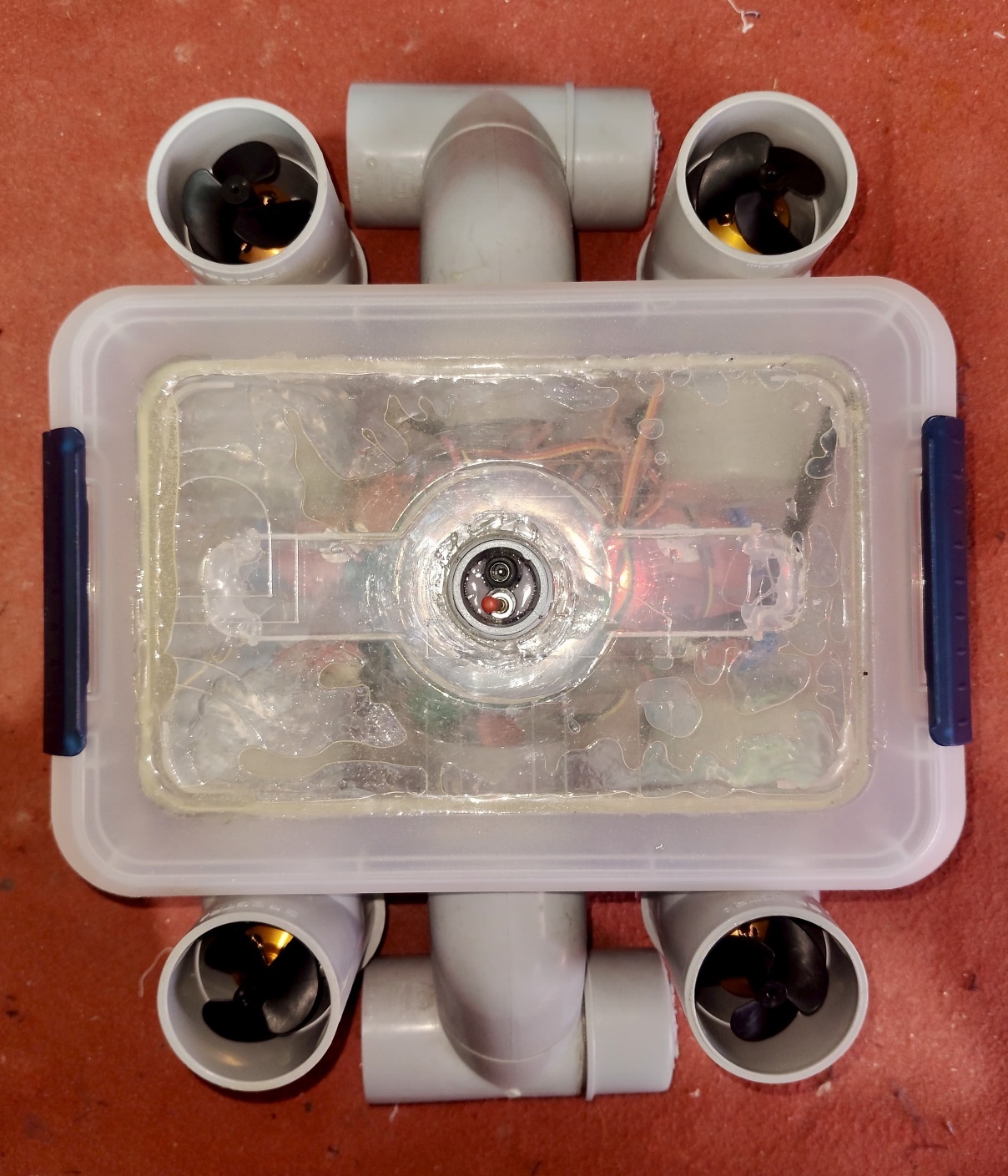
  data.j1PotY = map(angleY, -90, 90, 0, 255);

}

# **CHAPTER 7**

# **RESULT**

**ACTUAL OUTPUT OF UNDER WATER DRONE WITH VISUAL OUTPUT**



**Fig. 7.1 Actual Output of Under Water Drone with Visual Output**

**DESIGNED OUTPUT OF UNDER WATER DRONE WITH VISUAL OUTPUT**



**Fig. 7.2 Designed Output of Under Water Drone with Visual Output**

**OUTPUT OF TRANSMITTER**



**Fig. 7.3 Output of Transmitter**

**WORKING OUTPUT OF UNDER WATER DRONE WITH VISUAL OUTPUT**



**Fig. 7.4 Working Output of Under Water Drone with Visual Output**

# **CHAPTER 8**

# **CONCLUSSION**

Underwater drones equipped with visual output capabilities represent a significant leap forward in our ability to explore, monitor, and interact with the subsea environment. Their sophisticated integration of propulsion, sensors, communication, and a robust visual system offers a myriad of benefits that were previously challenging, costly, or dangerous to achieve.

In conclusion, underwater drones with visual output are transformative tools that:

* Expand Accessibility: They allow us to access hazardous, deep, or remote underwater locations without risking human divers, opening up vast unexplored regions of our oceans, lakes, and rivers.
* Enhance Data Collection: With high-resolution cameras, these drones provide invaluable real-time visual feedback, enabling detailed inspection, mapping, and scientific observation. This visual data, combined with other sensor inputs (depth, temperature, sonar, etc.), creates a comprehensive understanding of underwater environments and structures.
* Improve Efficiency and Cost-Effectiveness: By automating or remotely controlling underwater tasks, they reduce the need for extensive human diving operations, specialized vessels, and associated logistical complexities, leading to significant cost and time savings.
* Drive Diverse Applications: Their versatility makes them indispensable across various sectors:
* Scientific Research: Studying marine life, ecosystems, geological formations, and the impacts of climate change.
* Industrial Inspection: Assessing pipelines, offshore wind farms, hydroelectric dams, and other submerged infrastructure for maintenance and safety.
* Search and Rescue: Locating missing persons, sunken objects, or wreckage in challenging underwater conditions.
* Environmental Monitoring: Monitoring water quality, pollution, and the health of aquatic habitats.
* Security and Défense: Surveillance, reconnaissance, and my detection.
* Media and Entertainment: Capturing stunning underwater footage for documentaries, films, and tourism.

While challenges such as communication limitations (especially for untethered autonomous systems), power management, and navigation in murky waters remain, ongoing advancements in artificial intelligence, sensor technology, battery efficiency, and robust structural designs are continuously enhancing their capabilities. The future of underwater drones with visual output points towards even greater autonomy, higher data fidelity, and expanded functionalities, solidifying their role as indispensable instruments for understanding and managing our aquatic world.

# **CHAPTER 9**

# **FUTURE SCOPE**

The future scope of underwater drones with visual output is incredibly vast and promising, driven by advancements in several key technological areas. These advancements will address current limitations and unlock new capabilities, making these drones even more indispensable across various industries.

Here's a breakdown of the future scope:

**I. Enhanced Visual Capabilities:**

* **Improved Image Quality in Challenging Conditions:**
* **Advanced Low-Light Sensors:** Development of cameras that perform exceptionally well in deep, dark, or murky waters, reducing reliance on artificial lighting and enhancing natural light capture.
* **Real-time Image Enhancement:** AI-powered algorithms will significantly improve image clarity, colour correction, and artifact removal in real-time, compensating for water absorption, scattering, and turbidity.
* **3D and Volumetric Imaging**: More sophisticated stereo cameras and multi-camera arrays will enable highly accurate 3D reconstruction of underwater environments and objects, crucial for detailed mapping and inspection.
* **Panoramic and Spherical Vision:** 360-degree cameras with advanced stitching algorithms will provide a more immersive and comprehensive view of the surroundings.
* **Hyperspectral and Multispectral Imaging:** These technologies will allow for the detection of subtle changes in water chemistry, marine life health, and pollutant distribution that are invisible to the naked eye.
* **Intelligent Vision for Autonomy:**
* **AI-driven Object Recognition and Classification:** Drones will autonomously identify and classify marine species, infrastructure components (e.g., pipeline defects, cable damage), and potential threats with high accuracy using deep learning.
* **Visual SLAM (Simultaneous Localization and Mapping):** Breakthroughs in underwater visual SLAM will enable drones to navigate complex, GPS-denied environments purely based on visual cues, creating accurate maps while simultaneously localizing themselves within those maps. This is critical for autonomous exploration and docking.
* **Anomaly Detection:** AI will analyse visual data to automatically flag anomalies, deviations from norms, or potential issues on structures or in ecosystems, alerting operators to problems quickly.

**II. Increased Autonomy and Intelligence:**

* **Longer Endurance and Untethered Operations:**
* **Advanced Battery Technologies:** Next-generation batteries (e.g., solid-state, higher energy density Li-ion) will significantly extend operational durations, enabling longer, untethered missions.
* **Energy Harvesting**: Exploration of methods to harvest energy from ocean currents or thermal gradients to recharge while submerged.
* **Swarm Robotics and Collaborative Missions:**
* **Coordinated Operations:** Multiple drones will work together to cover larger areas, perform complex tasks, and share visual and sensor data in real-time, greatly increasing efficiency.
* **Inter-drone Communication:** Development of more reliable and higher-bandwidth underwater communication methods (e.g., improved acoustic modems, hybrid optical-acoustic systems) to facilitate swarm intelligence.
* **Adaptive Navigation and Mission Planning:**
* **Environmental Awareness:** Drones will intelligently adapt their navigation and data collection strategies based on real-time visual and sensor feedback (e.g., avoiding obstacles, following terrain contours, optimizing routes based on water clarity).
* **Human-Robot Teaming:** More intuitive interfaces and advanced AI will enable seamless collaboration between human operators and autonomous drones, where the human provides high-level guidance and the drone handles the complex underwater execution.

**III. Expanded Applications:**

* **Precision Aquaculture:** Visual monitoring of fish health, growth, feeding patterns, and net integrity in fish farms.
* **Offshore Energy (Wind, Oil & Gas):** Highly autonomous inspection, maintenance, and repair (IMR) of subsea infrastructure, including blades of offshore wind turbines, risers, pipelines, and wellheads.
* **Underwater Construction and Mining:** Visual guidance for robotic manipulators, quality control of construction, and surveying of mineral deposits.
* **Environmental Forensics and Disaster Response:** Rapid assessment of pollution spills, monitoring of ecological recovery after disasters, and locating submerged debris.
* **Archaeology and Cultural Heritage:** Non-invasive visual surveys of shipwrecks and ancient ruins, creating highly detailed 3D models for preservation and study.
* **defence and Security:** Enhanced intelligence, surveillance, and reconnaissance (ISR), mine countermeasures, port security, and monitoring of critical subsea cables.
* **Deep-Sea Exploration:** Pushing the boundaries of ocean discovery, exploring hydrothermal vents, trenches, and previously inaccessible ecosystems with advanced visual capture.

**IV. Miniaturization and Bio-inspiration:**

* **Smaller, More Agile Drones:** Continued miniaturization of components will lead to smaller, more agile drones capable of navigating confined spaces or delicate environments with minimal disturbance.
* **Bio-inspired Designs:** Drones mimicking the propulsion and sensing of marine life (e.g., jellyfish, fish) will offer increased stealth, energy efficiency, and manoeuvrability, allowing for closer and less intrusive observation.

While challenges like wireless communication range underwater, energy density, and the complexity of real-time deep-sea data processing remain significant, the rapid pace of technological innovation ensures that underwater drones with visual output will continue to evolve, becoming even more capable, autonomous, and impactful in exploring and managing our planet's aquatic frontiers.

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