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Dedication

To those who granted me life and hope to the heartbeat of my soul and the light of my eyes to my dearest parents, I dedicate this humble work to you, in deep appreciation and boundless love for your invaluable efforts and countless sacrifices. You have always been my source of strength and inspiration. Without your support, prayers, and unwavering belief in me, I would not have reached this stage. I hope I have made you as proud of me as I am honored to be your child. To the one who stood by me with steadfast support to the one who offered sincere guidance and encouragement to my respected academic mentor, I dedicate this work to you in heartfelt gratitude and sincere appreciation for your essential role in the completion of this thesis. Your wisdom, patience, and continuous support have inspired and motivated me throughout this journey. Your generous investment of time and effort will always remain deeply valued. I hope my achievement reflects the trust and dedication you invested in me. To my companions and lifelong friends to those who shared my journey, my laughter, and my challenges to my dear friends, I dedicate this work to you with gratitude for every moment we shared. Your presence, encouragement, and support made this journey not only bearable but beautiful. You were there through the highs and lows, and your friendship made all the difference. May this success be a source of pride for all of us, just as your friendship is a source of joy for me.

Abstract

Abstract

Water management is a critical challenge in modern infrastructure, especially in regions facing water scarcity and growing urban demands. Manual monitoring of water tank levels is inefficient, often leading to overflow, dry running, and energy waste. This thesis presents the design and implementation of a smart water level detection and notification system using an Arduino-based platform. The system employs an ultrasonic sensor for non-contact water level measurement, a relay module for automatic pump control, and a GSM module for real-time SMS alerts. The hardware setup includes the Arduino Uno (ATmega328P), HC-SR04 ultrasonic sensor, ACS712 current sensor, SIM800L GSM module, and supporting components like a breadboard and relay circuits. The software was developed using the Arduino IDE, integrating sensor data acquisition, threshold-based logic, and communication protocols. Performance analysis shows the system provides accurate level detection, reliable relay switching, and stable remote notifications. The project demonstrates a low-cost, scalable, and energy-efficient solution suitable for domestic and industrial water management. Future work includes mobile app integration, solar-powered deployment, and multi-tank monitoring.

Keywords: Arduino, water level detection, ultrasonic sensor, GSM module, automatic pump control, smart monitoring, embedded systems

الملخص

تُعد إدارة المياه من التحديات الحيوية في البنية التحتية الحديثة، لا سيما في المناطق التي تعاني من ندرة المياه وزيادة الطلب الحضري. إن المراقبة اليدوية لمستويات خزانات المياه غير فعّالة، وغالبًا ما تؤدي إلى فيضانات، أو تشغيل المضخات في حالة الجفاف، مما يُسبب هدراً في الطاقة والمياه. يهدف هذا البحث إلى تصميم وتنفيذ نظام ذكي لرصد مستوى المياه وإرسال الإشعارات باستخدام منصة أردوينو. يعتمد النظام على مستشعر ألتراسونك لقياس مستوى المياه بدون تلامس، بالإضافة إلى وحدة ريليه للتحكم التلقائي في تشغيل المضخة، ووحدة GSM لإرسال تنبيهات عبر الرسائل النصية في الوقت الحقيقي. يتكوّن النظام من لوحة Arduino Uno (ATmega328P)، مستشعرHC-SR04 ، مستشعر التيارACS712 ، وحدةSIM800L ، ولوحة تجريبية (breadboard)مع الدوائر المساعدة. تم تطوير البرنامج باستخدام بيئةArduino IDE ، حيث تم دمج برمجيات لقراءة المستشعرات، وتنفيذ منطق التحكم وفقًا لحدود محددة، وإرسال التنبيهات. أظهرت نتائج التقييم أن النظام يتميز بدقة عالية في قياس المستوى، واستقرار في تشغيل وإيقاف المضخة، وموثوقية في التنبيهات البعيدة. يُعد المشروع حلاً منخفض التكلفة، قابلاً للتوسع، وفعالاً في استهلاك الطاقة، ومناسبًا لتطبيقات سكنية وصناعية. وتشمل التوسعات المستقبلية تطوير تطبيق جوال، واستخدام الطاقة الشمسية، ودعم أنظمة متعددة الخزانات.

الكلمات المفتاحية : أردوينو، مراقبة مستوى المياه، مستشعر ألتراسونك، وحدةGSM ، التحكم التلقائي بالمضخة، الأنظمة المدمجة، التنبيه الذكي

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General Introduction

1. General Introduction

The everyday routine begins with water. This is one of the basic survival needs. People depend on the upper reservoir for everyday use. The upper tank is made of an opaque or cement (concrete) material to prevent algae growth and is closed with a cap to protect from dust and mosquito infestation. So, the level of water in the tank is unknown. Oftentimes, we turn on the motor and forget to turn it off, because of this most of the water will be lost unknowingly. This leads to water scarcity. Therefore, there is a need for a replacement that can start automatically, and shut off the motor when the water is filled to the desired level. Automatic water level controllers are a product created to automatically control the motor, which helps to ensure that there is a constant reserve of water in the storage tank. These automatic water level controllers are used to automatically fill the overhead tank when it starts up or when it becomes empty and also monitor the water level in it. Automatic water level controllers start the motor when the water level drops below a certain level and turn off the motor when the water rises above a fixed level. The motor will also shut off when the sump water runs out before it fills the upper tank, or if the pump is dry and also maintains voltage fluctuations. These are the latest products based on advanced digital technology. This system is Versatile. There are also custom variations such as controlling multiple pumps or multiple tanks. The carbon water level sensor provides contact water level measurement. The system for controlling water levels is an electronic device that controls the operation of the water pump in subterranean and overhead storage tanks when electrically connected to the starting point of any pump assembly motor. Switches ON the pump assembly when the water level in the overhead tank falls below the preset level, Switches OFF the pump mount if the water level in the top tank is fully supplied, OFF switches the pump mounting when the underground tank is of low water levels, Switches ON Pumping group if the tank has enough water. The automatic system for regulating the water level is a technical project. It can automatically switch on and off the domestic water pump set according to the water level of the reservoir. You can implement this driving pattern at your home or college using less expensive components.

Chapter 1

Water Level Detection Technologies

1.1 Introduction:

Many industrial applications require the installation of multiple data-acquisition systems to measure liquid level and volume in tanks and containers. The collection of data from liquid tanks plays an essential role in many industrial applications, such as oil tanks, fuel containers, public water supplies, reverse osmosis (RO) systems and fish aquariums. A range of technologies was proposed to collect data from liquid tanks using different types of sensors, such as sensors based on optical fibre Doppler effect, pressure capacitance changes surface plasmon resonance and wedge waves. However, each technology has its strengths and weaknesses under different conditions, leading to a number of challenges for the research community to consider, including implementation cost, ambient environmental conditions, installation, detection distance and long-term maintenance. The principles, strengths and weaknesses of these technologies have been discussed in many studies. The technological tools to create an efficient liquid data acquisition system already largely [1].

1.2 Types of Water Level Detectors and Sensors:

The history of human discovery of water measuring devices dates back to 3,000 years BC. At that time, humans realized the importance of monitoring water levels to ensure the success of irrigation networks and avoid the risks of floods or drought. The ancient Egyptians installed a stepped stone column submerged in the river. As the water level rose, this was monitored by the height shown on the column's gauge. This was used

to determine the water level, which was called a nilometer. Over time, the concept of measuring water levels evolved significantly, especially after the Industrial Revolution in the 18th and 19th centuries. Mechanical devices such as mechanical floats, which rely on buoyancy, began to be used. With the advancement of technology in the second half

figure (1.1): ***An image showing the shape of the nilometer.***

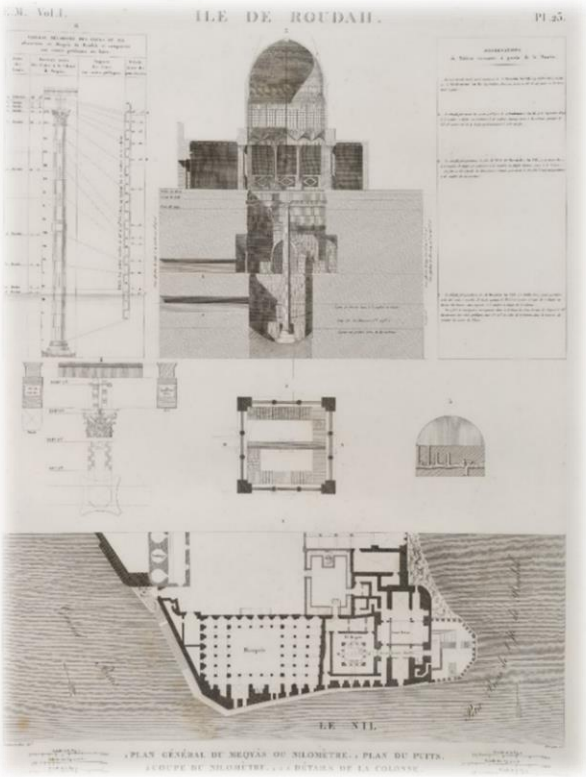


figure (1.2): ***An image explaining the principle of operation of the nilometer.***

of the 20th century, electronic sensors began to be used. At the beginning of the 21st century, devices further evolved to include non-contact sensors such as ultrasonic and radar sensors [2]. This development has led to the classification of water level measuring devices into two main types based on the nature of the interaction with the liquid:

1. Contact sensors, which require direct contact with the water and rely on changes in physical properties at the point of contact.
2. Non-Contact Sensors measure level remotely using wave or optical technologies without physical interaction with the liquid, making them ideal for sensitive or harsh environments.

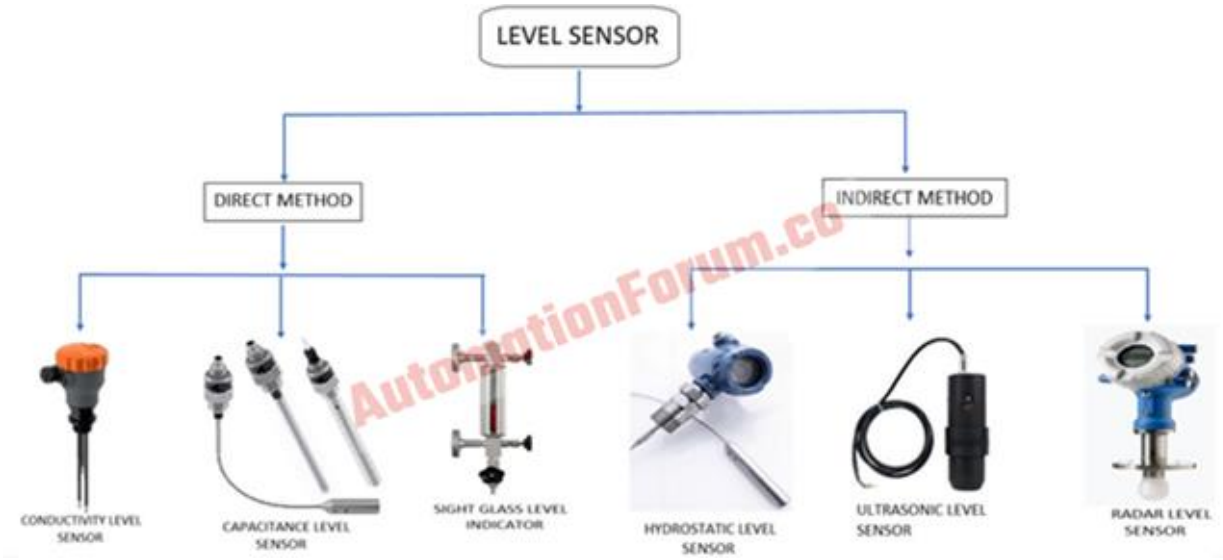


figure (1.3): Types of contact and non-contact sensors

1.2.1 Float Switch Sensors

Definition of Float switch:

It is a type of contact liquid level sensor which uses a float to operate a switch within a tank. This switch is also known as a level_sensor. These switches play a key role in controlling other devices like pumps & alarms when a level of liquid increases or drops to a particular point. The float switch symbol is shown below. These switches range from small sizes to large sizes [3].

Float switches come in two different styles: magnetic (Electromagnetic) and Mechanical float type. Switch Symbols [4]

figure (1.4): ***switch symbols***

Construction of Float Switch

The construction of this electromagnetic switch can be done with a stem, reed switch, and permanent magnet.

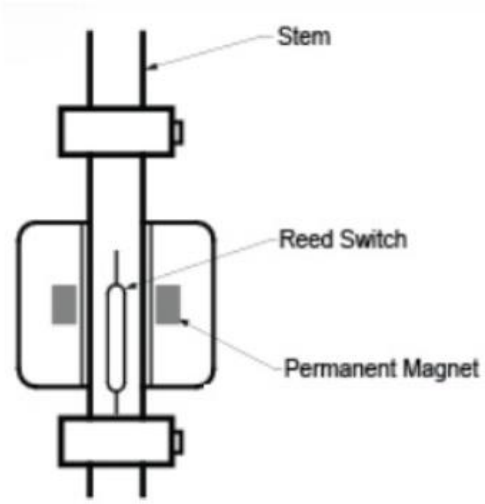


figure (1.5): ***Construction of Float Switch***

- **Stem**

  The stem of the switch is a plastic part that connects the switch to the keycap directly. The stem can be plastic or metal depending on the requirement.

- **Reed Switch**

The reed switch is hermetically sealed within a stem of the float switch. These are most frequently designed with stainless steel or plastic. The water float covers a sealed magnet to move up & down the stem length when a level of fluid increases and decreases.

- **Permanent Magnet**

A permanent magnet in a switch moves consistently with the level of fluid on a guide tube. A reed contact is connected in the guide tube which is energized throughout the non-magnetic walls of the float by the float magnet approach.

Float Switch Working Principle

The working of a float switch is based on the principle of buoyancy i.e., when there is no liquid in contact with the float, it floats on top of the liquid surface and triggers an alarm signal, when there is a sufficient amount of liquid in contact with float, it submerges itself into liquid and stops alarming. The principle of operation is the same for both the style of float switches but works depending on their construction of it [5]

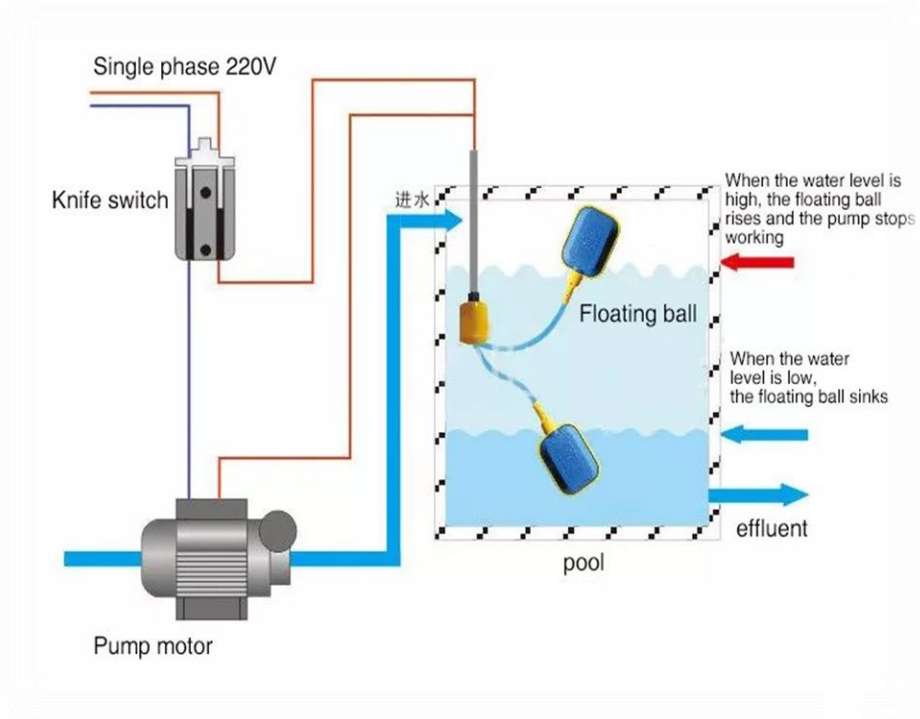


figure (1.6): ***Float Switch Working Principle***

$$\frac{sprM}{L} + m_{FLot}g = \rho_{Liq}gV(h) \qquad (1.1)$$

Table (1.1): Float Switch Sensors equation

symbol	meaning	Units
ρ_{Liq}	Density of the liquid	$kg.m^{-3}$
g	Gravitational acceleration-(≈ 9.81)	$m.s^{-2}$
$V(h)$	Volume of the float that is submerged when the liquid is at height h	m^3
m_{FLot}	Mass of the float	kg
$Mspr$	Restoring moment from the spring or magnet (if present) about the hinge	$N.m$
L	Lever arm between the float s buoyant centre the hinge axis	m

Types of Float Switch

These switches are available in two types horizontal and vertical.

Horizontal Float Switch

These switches are arranged at the sidewalls of the water tank and this switch is used where the top & bottom of the liquid tanks are not accessible. The movement of float in the tank will cause the reed switch to operate at a certain level because of the changing liquid level. By using this switch, the float can be connected to a hinge. Once the float approaches the reed switch, then it shifts a magnet near the switch to open or close the circuit.

figure (1.7): ***Horizontal Float Switch***

Vertical Float Switch

The vertical arrangement of two floats like a stem & a magnetic is known as a vertical float switch. In two floats, one float is stable & connected to the top of the fluid tank whereas another float is not fixed with respect to the level of liquid.

Vertical Float Switch Vertical Float Switch The float fits in the region of the stem & it increases and decreases through the liquid level. The stem includes one or above-sealed reed switches. Once the water float approaches one of the reed switches, then magnetic force will cause the switch to open otherwise close. So because of the change in liquid level, the movement of liquid float will cause the switch to function at a certain level.

figure (1.8): ***Vertical Float Switch***

1.2.2 Capacitive Sensors

Definition of Capacitive Sensors

Capacitive sensing is a technology based on capacitive coupling that takes the capacitance produced by the human body as the input. It allows a more reliable solution for applications to measure liquid levels, material composition, mechanical buttons, and human-to-machine interfaces. A basic capacitive sensor is anything metal or a conductor and detects anything that is conductive or has a dielectric constant different from air. Figure displays three basic implementations for capacitive sensing: proximity gesture recognition, liquid level sensing,

and material analysis. More details about the sensor topology can be found in the Capacitive Sensor Topologies section [6].

figure (1.9): ***Capacitive Sensors***

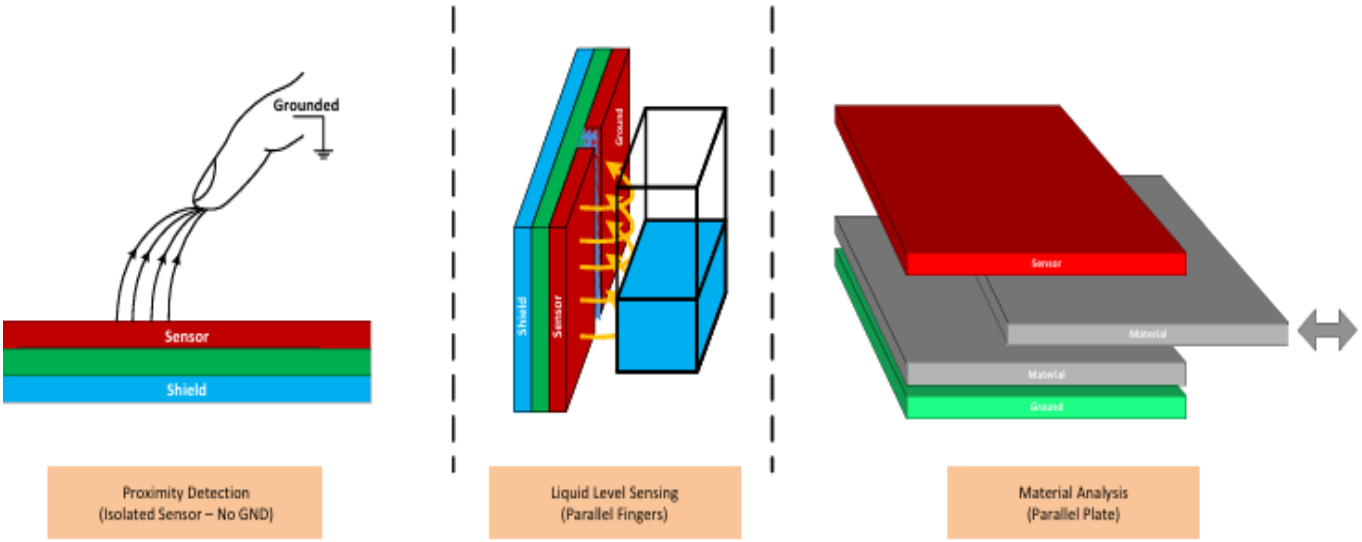


figure (1.10): ***Principle of operation Capacitive Sensors***

Working principle

The FDC1004's basic operation of capacitive sensing implements a switched capacitor circuit to transfer charge from the sensor electrode to the sigma-delta analog to digital converter (ADC), as shown in Figure. A 25-kHz step waveform is driven on the sensor line for a particular duration of time to charge up the electrode. After a certain amount of time, the charge on the sensor is transferred to a sample-hold circuit. The sigma-delta ADC converts the analog voltage into a digital signal. Once the ADC completes its conversion, the result is digitally filtered and corrected depending on gain and offset calibrations [7].

$$\frac{\varepsilon_0 \varepsilon_r{}^{eff}(x) A}{d} = C(x) \qquad (1.2)$$

Table (1.2): *Capacitive Sensors* equation

Symbol	Meaning	Typical units
$C(x)$	Capacitance as a function of the external variable x	farad(f)
ε_0	Vacuum permittivity 8.854×10^{-2}	F.m^{-1}
$\varepsilon_r^{eff}(x)$	Effective relative permittivity of the medium occupying the sensing field-depends on x	-
A	Effective electrode area (or $2\pi h/ln(b/a)$for coaxial geometry)	m^2
d	Separation between electrodes (plat gap,radile gap	m

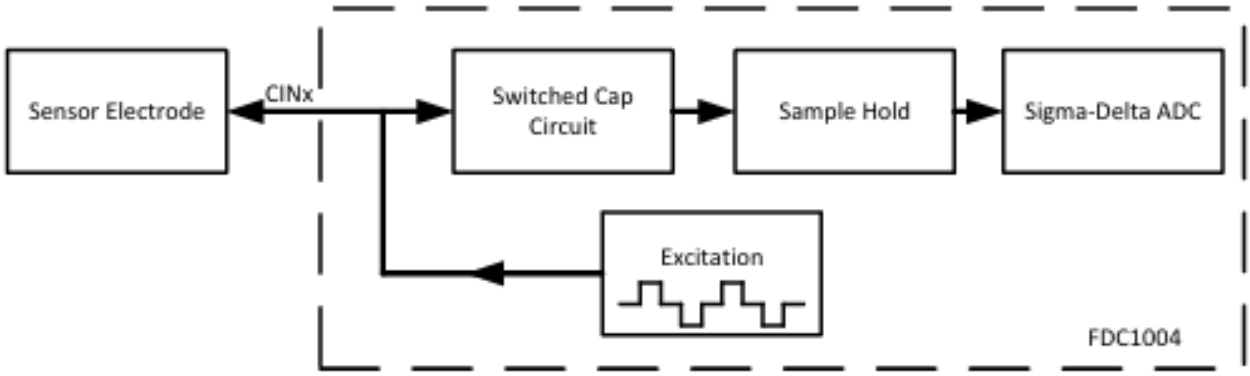


figure (1.11): ***Action Plan Capacitive Sensors***.

1.2.3 Ultrasonic Sensors

Ultrasonic sensors can measure distance and detect the presence of an object without making physical contact. They do so by producing and monitoring an ultrasonic echo. Depending on the sensor and object properties, the effective range in air is between a few centimetres up to several meters. The ultrasonic sensor (or transducer) generates and emits ultrasonic pulses that are reflected back towards the sensor by an object that is within the field of view of the sensor [8].

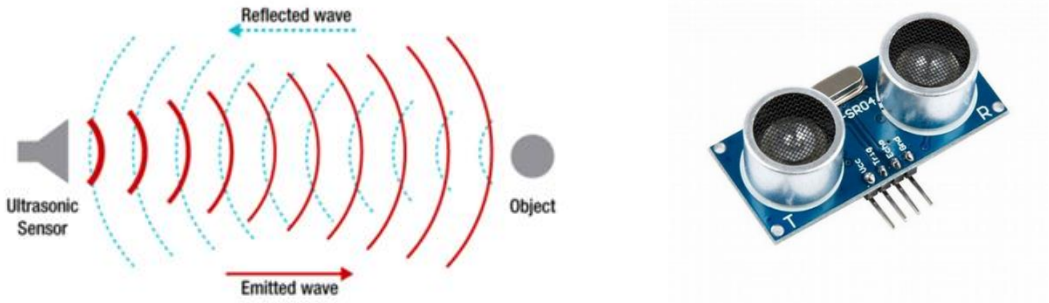


figure (1.12): ***Ultrasonic Sensors.***

Working principle

Piezoelectric ceramics generate electromotive force between the electrodes in proportion to the amount of mechanical force applied to the element. The reverse is also true. If voltage is applied between the electrodes, mechanical displacement is generated proportional to that voltage. From the magnitude of the electromotive force, the presence of an object is detected and the distance from the Sensor to the object is measured [8].

$$x = k\frac{v_{snd}(T,P,RH)t_{TOF}}{2} \tag{1.3}$$

Table (1.3): Ultrasonic sensor equation

symbol	meaning
x	Measured quantity (metres): • Pointing at a solid target: $x = d(distance)$. • Mounted above a tank: $x = H_{tank} - h$ *where h is the liquid level.*
x	Geometric constant-**+1** for distance, combined with a reference height (or a minus sign) for level measurements.
v_{snd}	Speed of sound in the medium (m/s) normally corrected for **temperature** T, **pressure** P and **relative humidity** (RH).
t_{TOF}	Total travel time of the pulse (s).
2	Divides by two because the pulse travels to the target **and back**

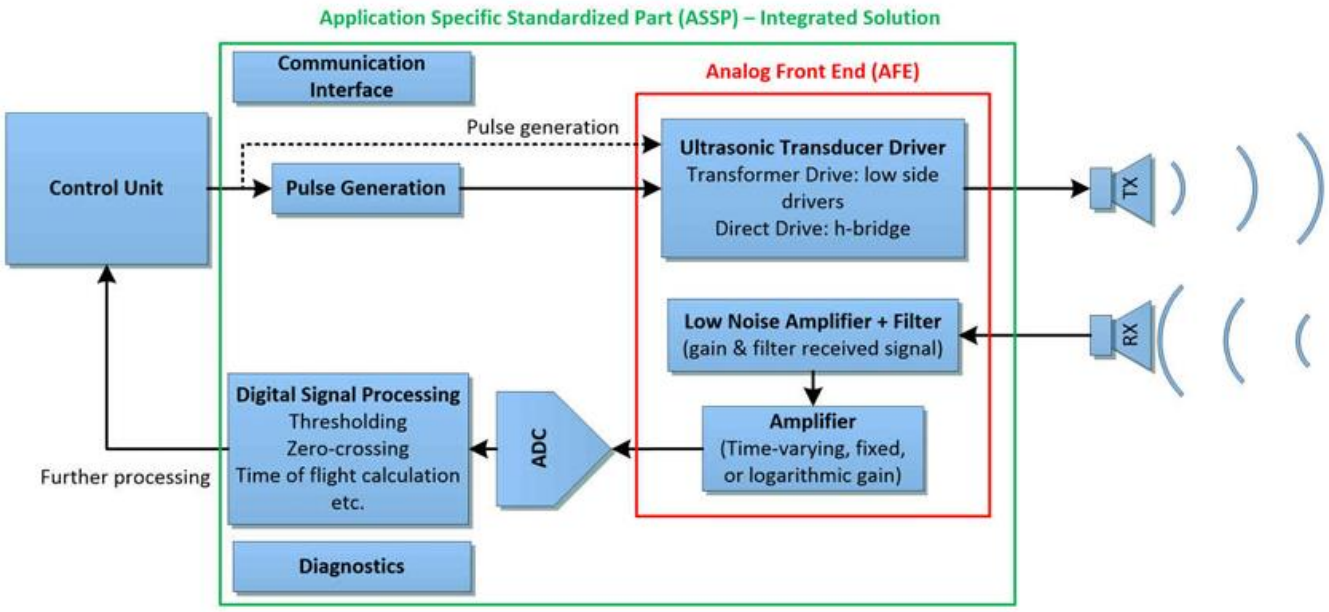


figure (1.13): ***Detailed plan for the working principle Ultrasonic Sensors.***

1.2.4 Optical Sensors

Definition of optical sensor

An optical sensor is a device that detects variations in light intensity and converts these optical signals into corresponding electrical outputs. In the context of engineering systems, optical sensors operate by analyzing the behavior of light—whether reflected, interrupted, or transmitted when it interacts with an object or surface. The core sensing mechanism typically involves a light source, such as a Light Emitting Diode (LED) or laser, and a photodetector that interprets the received light signal.

Optical sensors are valued for their high sensitivity, immunity to electromagnetic interference (EMI) and radio frequency interference (RFI), and their capability to operate across a wide spectral range. These features make them suitable for diverse applications, including mechanical analysis, environmental monitoring, and automation systems.

In water level monitoring systems, although not implemented in this specific project, optical sensors can be used for non-contact detection of liquid presence or absence by sensing light changes due to refraction or interruption at the liquid interface. Their compact size, broadband response, and versatility with transparent and colored fluids make them a reliable alternative in precision sensing environments [10].

figure (1.14): ***Optical Sensors.***

Working principle of optical sensor

An optical sensor converts light rays into an electronic signal.

The purpose of an optical sensor is to measure a physical quantity of light and, depending on the type of sensor, then translates it into a form that is readable by an integrated measuring device.

Optical Sensors are used for contact-less detection, counting or positioning of parts.

Optical sensors can be either internal or external.

External sensors gather and transmit a required quantity of light, while internal sensors are most often used to measure the bends and other small changes in direction.

The measurands possible by different optical sensors are Temperature, Velocity Liquid level, Pressure, Displacement (position), Vibrations, Chemical species, Force radiation, pH- value, Strain, Acoustic field and Electric field [11].

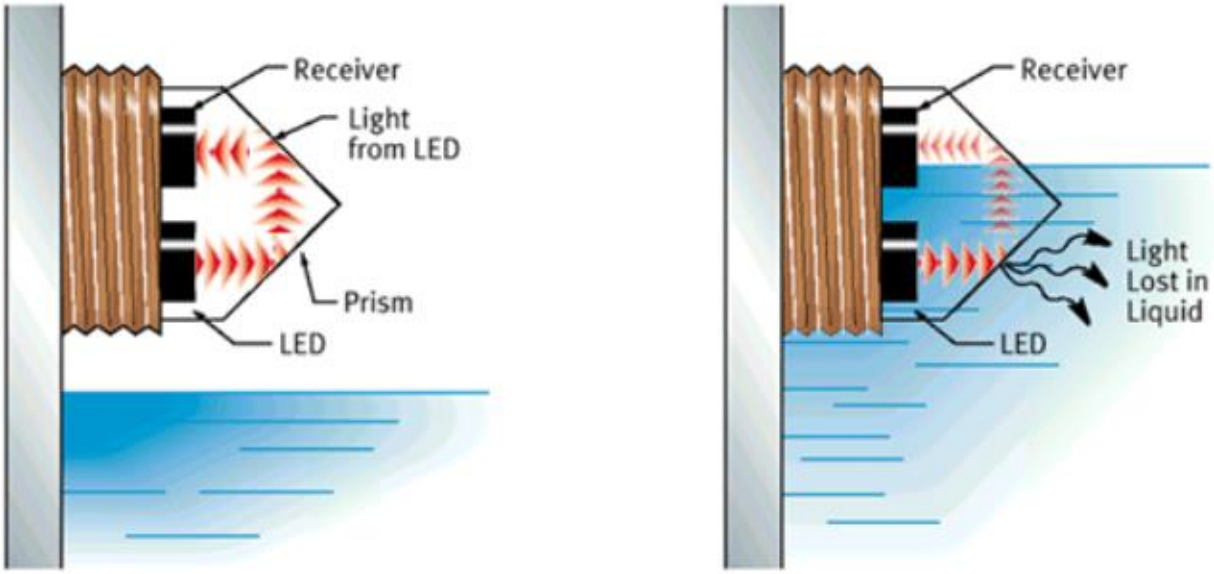


figure (1.15): ***A detailed image of the working principal Types of Optical Sensors.***

• There are different kinds of optical sensors, the most common types which we have been using in our real-world applications as given below.

• Photoconductive devices used to measure the resistance by converting a change of incident light into a change of resistance.

• The photovoltaic cell (solar cell) converts an amount of incident light into an output voltage.

• The Photodiodes convert an amount of incident light into an output current.

• Phototransistors are a type of bipolar transistor where the base-collector junction is exposed to light. This results in the same behavior of a photodiode, but with an internal gain

1.2.5 Conductive and Resistive Sensors

Definition of CONDUCTIVE SENSORS

A conductive sensor is an electrochemical device that detects the presence of a conductive medium—typically a liquid—by allowing current to flow between two or more electrodes. It operates based on the principle of electrical conductivity, which is defined as the inverse of resistivity:

$$\sigma = \frac{1}{\rho} \tag{1.4}$$

σ is the electrical conductivity

ρ is the electrical resistivity of the medium

When a conductive fluid (such as water with dissolved ions) makes contact between electrodes, it completes an electrical circuit, enabling current flow which can then be measured or monitored [12].

Working Principle of Conductive Sensors

Conductive sensors operate based on the principle of electrical conductivity, which is the ability of a material—particularly a liquid medium—to conduct an electric current. These sensors function by establishing an electrical circuit between two or more electrodes immersed in a fluid. When a conductive fluid, such as water containing dissolved ions (salts, acids, or bases), bridges the gap between the electrodes, it completes the circuit and permits the flow of current. The presence, magnitude, or variation of this current is then measured to determine the status of the liquid (e.g., presence, level, or quality) [13].

The core mechanism relies on the inverse relationship between resistivity and conductivity, mathematically expressed as:

$$\text{Conductivity} = \frac{1}{\text{Resistivity}}$$

A higher concentration of ions in the fluid enhances its ability to conduct electricity, resulting in a stronger current flow between the electrodes.

To mitigate potential degradation of the electrodes due to electrochemical reactions, **alternating current (AC)** excitation is commonly employed instead of direct current (DC). AC excitation minimizes issues such as **electrolysis** and extends the operational life of the sensor by reducing electrode wear.

- **Resistive Sensors**

Definition of resistive sensors

A resistive sensor is an electromechanical device designed to detect physical changes such as displacement, strain, temperature variation, or light intensity by modifying the electrical resistance of a material. These sensors exploit the predictable relationship between resistance and external stimuli to generate measurable electrical signals, enabling accurate monitoring and control in various engineering and scientific applications.

Working Principle of Resistive Sensors

Resistive sensors function by translating a mechanical or physical change into an electrical signal through the alteration of a material's electrical resistance. Typically, these sensors respond to variations such as displacement, strain, temperature, or light intensity, making them extremely versatile across a wide range of applications.

The fundamental equation governing resistive sensors is:

$$R = \rho \frac{L}{A} \qquad (1.5)$$

Where:

R is the electrical resistance

ρ is the resistivity of the material

L is the length of conductor

A is the cross-sectional area

1.3 Operating Principles of Water Level Sensors

Water-level sensors convert liquid height into a readable electrical or mechanical signal by exploiting various physical principles linked to fluid properties. These sensors are broadly classified as contact or non-contact devices.

Contact hydrostatic sensors utilize Pascal's law, whereby the pressure exerted by a static fluid column is proportional to its height and follows

$$P = \rho g h + P_{atm} \qquad (1.6)$$

where P is the pressure, ρ the fluid density, h gravitational acceleration, and A the liquid height. A pressure transducer measures this pressure and converts it to level.

Conductive probes determine water presence by detecting continuity of an electric circuit between immersed electrodes, using the liquid's conductivity to register discrete level points.

Capacitive sensors exploit the change in capacitance that occurs when water replaces air between two electrodes; the level is inferred from

$$C = \frac{A\varepsilon_0\varepsilon_r}{d} \tag{1.7}$$

where C is capacitance ε_r the relative permittivity of the fluid, A the electrode area, and d their separation.

Non-contact **ultrasonic and radar sensors** apply the time-of-flight principle: an acoustic or electromagnetic pulse is emitted, and the return-echo time is measured. This time is converted to distance and hence level; radar generally performs better in the presence of vapor, foam, or large temperature gradients.

Float-based sensors track the water surface mechanically with a buoyant body, whereas magneto strictive designs attach a magnet to the float and determine level from the transit time of a torsional pulse along a ferromagnetic wire.

Finally, **optical sensors** detect level by monitoring changes in light behavior—refraction or reflection—when the beam encounters water.

This scientifically rigorous description emphasizes the governing equations and technical concepts appropriate for a master's thesis discussion of water-level sensor operating principles.

Conclusion

The accurate measurement and monitoring of liquid levels in industrial and domestic applications remain a critical task across a wide spectrum of sectors, including water treatment systems, chemical processing, fuel storage, and agricultural irrigation. This chapter provided a comprehensive exploration of the historical evolution, classifications, and operational principles of various water level detection technologies. From the ancient nilometer used by early civilizations to modern-day non-contact sensors employing ultrasonic and optical methods, the field has undergone remarkable technological advancements.

The classification into contact and non-contact sensors highlights the trade-offs between reliability, complexity, installation constraints, and environmental robustness. Contact-based sensors such as float switches, capacitive sensors, and conductive/resistive types offer simplicity, cost-efficiency, and direct interaction with the fluid medium. These sensors are particularly suitable for closed systems or applications where physical access to the liquid is straightforward. Their effectiveness, however, may be limited by factors such as corrosion, fouling, or mechanical wear over time.

In contrast, non-contact sensors—represented by ultrasonic and optical systems—offer a more advanced solution for applications requiring minimal contamination risk, higher precision, and operation under harsh or hazardous environmental conditions. Ultrasonic sensors utilize the principles of wave propagation and echo detection, offering reliable distance measurements. Optical sensors, while not employed in the current implementation of the system, present high sensitivity and immunity to electromagnetic interference, making them suitable for high-precision, real-time fluid monitoring in dynamic or remote environments.

The chapter also introduced key theoretical models and mathematical equations that govern the functionality of each sensor type, providing a foundational understanding for their behavior and integration into automated systems. These formulations allow for calibration, simulation, and customization to meet specific design requirements.

Ultimately, the selection of a water level detection sensor must balance accuracy, cost, environmental compatibility, and system complexity. The detailed analysis provided in this chapter forms a vital basis for evaluating and selecting appropriate sensors in the design and implementation of efficient liquid-level monitoring systems. This knowledge is essential for advancing toward more intelligent, autonomous, and sustainable fluid management infrastructures.

Chapter 2

- **Advanced Theoretical Foundations of Water Level Sensing Technologies**

2.Introduction

A sensor is used to transform a nonelectrical stimulation to an electrical response that is suitable to be processed by electrical circuits.

Sensors are related with everyday life, such as automobiles, airplanes, radios, and countless other applications.

Several transformation steps are required before the electric output signal can be generated. These steps involve changes of types of energy where the final step must produce an electrical signal of a desirable format. There are several physical effects that cause generation of electric signals in response to nonelectrical influences. In this chapter, the physical effects behind various sensor applications that can be used for conversion of stimuli into electric signals are introduced [14].

2.1.1 Electrical Conductivity in Liquids

Definition and Fundamentals

Electrical conductivity in liquids refers to the ability of a liquid medium to conduct an electrical current through the movement of charged particles (ions) under the influence of an electric field [15]. Conductivity is a fundamental property that indicates how easily electrical charges are transported within a liquid, and it is quantitatively expressed in units of siemens per meter (S/m) or micro siemens per centimetre (μS/cm)[16].

When an electric field is applied across a liquid containing dissolved electrolytes (such as salts, acids, or bases), positively and negatively charged ions migrate toward the oppositely charged electrodes. This ionic movement results in an electrical current whose magnitude is directly related to the concentration and mobility of the ions present.

Conductivity is fundamentally important in fluid monitoring, process control, and environmental sensing. The electrical resistance exhibited by the liquid medium inversely affects its conductivity, a property that is critical in determining the suitability of a liquid for various sensor applications, particularly those involving electromagnetic or electrochemical measurement principles.

Importance in Flow Measurement and Level Control

The electrical conductivity of a liquid plays a vital role in the effectiveness of flow and level detection technologies. Devices such as magnetic flow meters and conductive level switches operate based on the assumption that the process media possesses sufficient conductivity to support measurable current flow.

Magnetic Flow Meters: These instruments rely on Faraday's Law of Electromagnetic Induction, which requires the fluid to act as a conductive medium. Fluids with extremely low conductivity, such as ultra-pure water, cannot generate a detectable voltage, rendering magnetic flow meters ineffective in such applications [17].

Conductive Level Switches: + These sensors detect the presence or absence of a conductive fluid by monitoring the completion of an electrical circuit. If the media lacks sufficient conductivity, the switch may fail to respond accurately.

Thus, accurate knowledge of the liquid's conductivity is essential for selecting appropriate sensing technologies [18].

Influence of Temperature on Conductivity

Temperature is a critical factor influencing liquid conductivity. As temperature increases, the thermal energy available to the ions also increases, enhancing their mobility and thus increasing the liquid's conductivity.

To ensure accurate and reliable measurements, many conductivity sensors incorporate temperature compensation mechanisms. These compensations are typically based on empirical formulas or calibration curves that adjust the measured conductivity to a standardized reference temperature, often 25°C [19].

General Trend:

- **Higher Temperature → Higher Conductivity**
- **Lower Temperature → Lower Conductivity**

Without temperature compensation, conductivity readings could exhibit significant errors, particularly in applications involving fluctuating thermal conditions

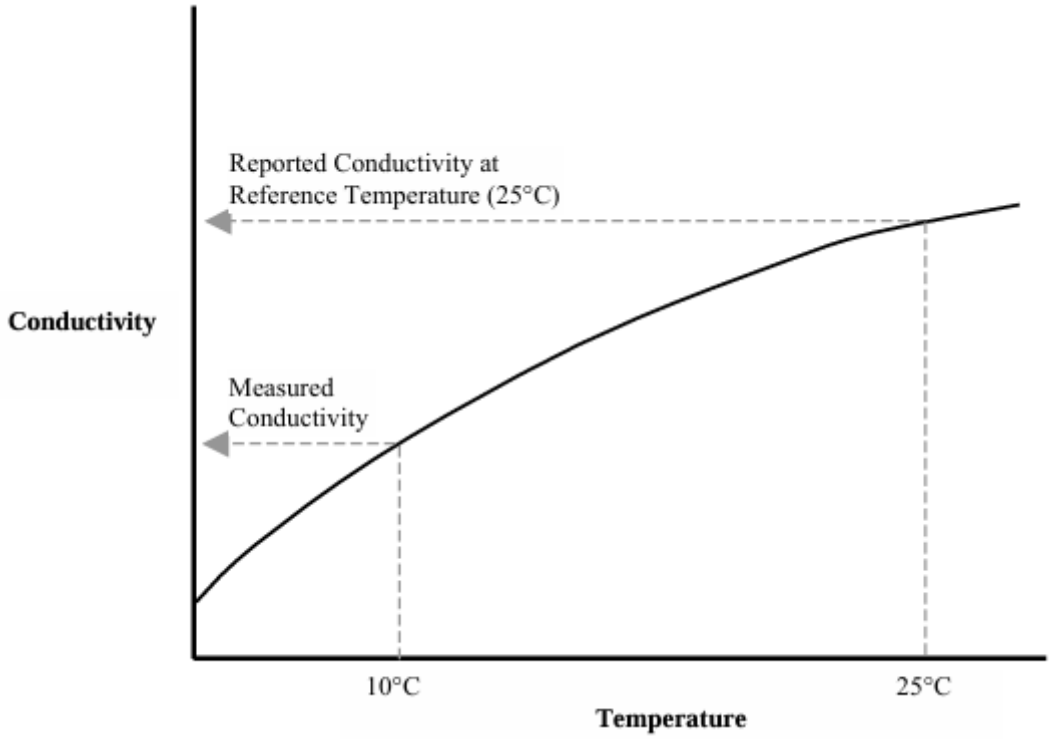


figure (2.1): ***Temperature Compensation***

Measurement Techniques

Liquid conductivity is commonly measured using a **conductivity meter** or **sensor**, typically composed of two electrodes immersed in the fluid. An alternating current (AC) voltage is applied across the electrodes to prevent polarization effects and minimize electrode degradation. The resulting current flow is then measured, and the conductivity is calculated according to Ohm's Law and the known geometry of the sensor.

Basic Measurement Setup:

- Two electrodes (metallic or coated)
- AC voltage source
- Current detection circuit
- Optional: Integrated temperature sensor for compensation

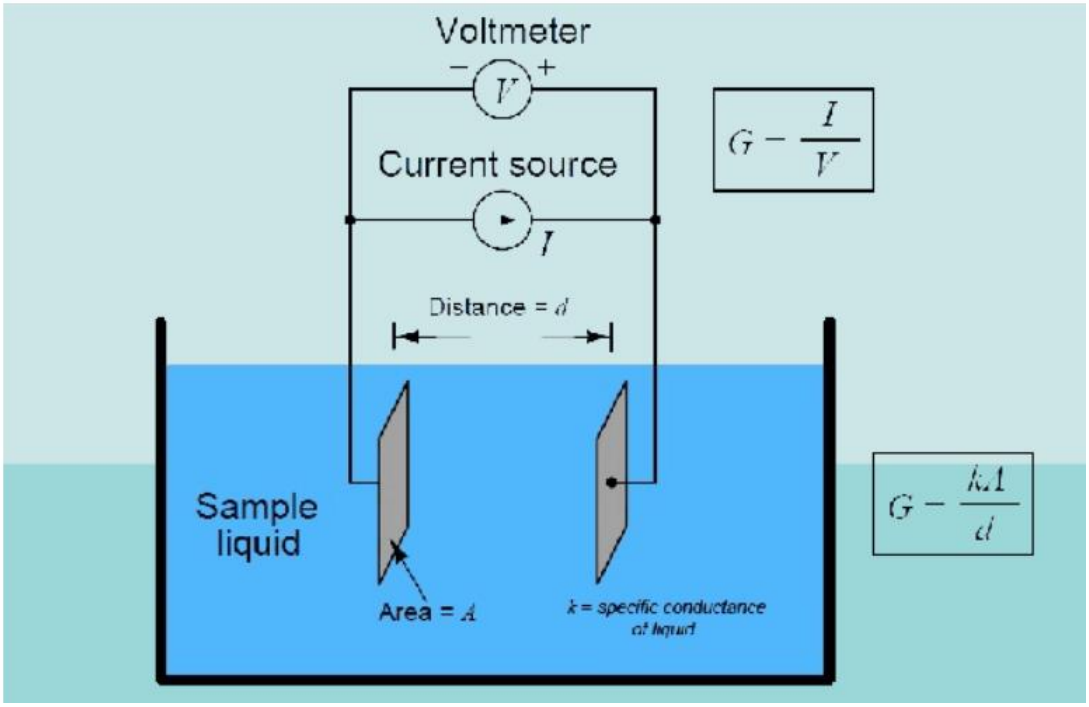


figure (2.2): ***Conductivity sensor Measurement setup of a basic conductivity sensor***

Conductivity as an Indicator of Water Salinity

Conductivity serves as a reliable proxy for determining the **salinity** of water. Increased salinity, due to higher concentrations of dissolved ions such as sodium (Na^+) and chloride (Cl^-), directly elevates the conductivity of the liquid.

This principle is extensively employed in:

- **Environmental Monitoring:** Assessment of freshwater and marine ecosystems
- **Aquaculture:** Maintenance of optimal salinity levels for aquatic organisms
- **Water Treatment Plants:** Monitoring of desalination processes and contamination levels

2.1.2 Resistive Effects and Material Behaviour

Ohm's Law Applications in Conductivity and Resistivity

In the context of electrical conductivity, Ohm's law governs the relationship between the voltage (V), current (I), and resistance (R) within a given material [20]. For a uniform material with a constant resistivity, this relationship can be described by the equation:

$$V = IR \tag{2.1}$$

Where R is the electrical resistance, which depends on the material's resistivity (ρ), length (ℓ), and cross-sectional area (A): [21]

$$R = \rho \frac{\ell}{A} \tag{2.2}$$

In this case, resistivity (ρ) serves as a fundamental material property that defines how strongly a material resists the flow of electric current. The inverse of resistivity, electrical conductivity (σ) is used to quantify how easily a material allows current to pass through it:

$$\sigma = \frac{1}{\rho} \tag{2.3}$$

The principle of Ohm's law holds true under ideal conditions, assuming that the material's geometry is consistent, and the current flows uniformly across the cross-sectional area. However, this relationship may vary under different physical and environmental conditions.

Impact of Mechanical Strain and Deformation on Resistivity

Mechanical strain and deformation significantly influence the resistive behaviour of materials. When a material undergoes strain, whether from stretching, compressing, or bending, its atomic structure and electron mobility are altered. This structural change can result in a modification of the material's resistivity.

In conducting materials, strain can cause a change in the distance between atoms or ions, affecting the free electron flow, and consequently, the material's electrical resistance. In many metals, strain leads to a decrease in conductivity due to increased scattering of conduction electrons, which in turn raises the resistivity. This phenomenon is crucial in sensor applications, where the resistive response to strain is utilized in strain gauges.

The relationship between strain and resistivity can be expressed by a gauge factor, which is defined as the ratio of the relative change in resistance to the mechanical strain applied:

$$GF = \frac{\Delta R/R}{\Delta L/L} \tag{2.4}$$

Where GF is the gauge factor, ΔR is the change in resistance, R is the initial resistance, ΔL is the change in length, and L is the initial length of the material.

This behaviour is particularly relevant in applications where materials are subjected to constant mechanical stress, such as in flexible electronic devices or structural health monitoring systems

Temperature Effects on Resistivity

Temperature is another critical factor that influences the resistivity of materials. For most conductive materials, resistivity increases with temperature, a relationship that is particularly noticeable in metals. This temperature-dependent behavior is due to the increased vibrational motion of the atoms as temperature rises, which in turn causes more frequent scattering of conduction electrons, thereby reducing their mobility.

For metallic conductors, the temperature dependence of resistivity can be expressed by the following equation:

$$\rho(T) = \rho_0(1 + \alpha T) \qquad (2.5)$$

Where ρ(T) is the resistivity at temperature T, ρ_0 is the resistivity at a reference temperature, and α is the temperature coefficient of resistivity, which is characteristic of the material.

For insulating materials, the resistivity typically decreases with increasing temperature, especially in semiconductors, where the number of charge carriers increases as temperature rises. This behaviour is crucial for applications where precise control of material conductivity is required under varying thermal conditions.

The resistivity-temperature relationship is integral to the design of temperature-sensitive electrical components and must be carefully considered when designing sensors or devices that operate across a range of temperatures.

2.1.3 Optical Sensing Principles

Optical sensors rely on the interaction of light with the medium being sensed. Key phenomena such as absorption, reflection, refraction, and transmission play a significant role in determining the sensor's performance[21].

- **Light Absorption, Reflection, Refraction, and Transmission**: The ability of a material to absorb, reflect, or refract light is fundamental in optical sensing. These interactions depend on the material's optical properties, which influence the intensity and wavelength of light that passes through or is reflected by the material.
- **Influence of Medium Properties on Optical Paths**: The refractive index and the physical properties of the medium, including its density and composition, significantly affect the path of light. Changes in these properties alter the light's trajectory, which can be detected and quantified by the sensor. For instance, variations in refractive index due to changes in the medium’s composition or physical state can result in measurable optical changes.

2.1.4 Ultrasonic Wave Propagation

Ultrasonic sensors operate based on the propagation of sound waves through a medium, typically in liquids or gases, to measure properties such as distance or level [22].

- **Sound Wave Behaviour in Fluids**:

  Ultrasonic waves travel through fluids, experiencing changes in speed, attenuation, and reflection depending on the medium's properties. These waves are sensitive to factors such as temperature, viscosity, and density, which can influence their propagation.

- **Time-of-Flight Measurement and Reflection Analysis**:

  The distance to a surface or object can be measured by calculating the time it takes for an ultrasonic pulse to travel to the target and back. This time-of-flight measurement is critical in determining the position of interfaces, with reflected waves providing additional information on material properties and consistency.

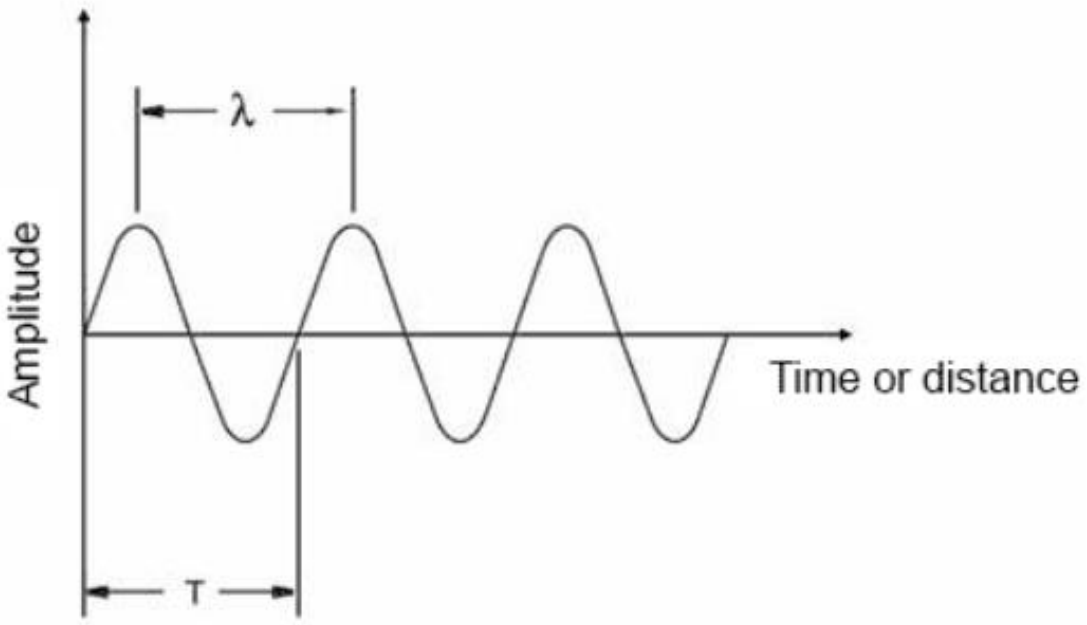


figure (2.3): ***Basic parameters of an ultrasonic wave.***

2.1.5 Capacitive Interactions

- **Capacitance Variation with Dielectric Changes**: Capacitance is highly sensitive to the dielectric constant of the material between two electrodes. Variations in the dielectric material, such as the presence of water or other substances, significantly affect the capacitance. This property makes capacitive sensors useful for detecting changes in the material's composition or level [23].
- **Effect of Impurities and Electrode Placement**: The presence of impurities in the dielectric medium can distort the electric field and alter the sensor's readings. Additionally, the positioning and geometry of the electrodes play a crucial role in the sensor's performance. Improper electrode placement can lead to non-linearities or inaccuracies in the measurements [24].

2.2 Sensor Engineering Characteristics

- **2.2.1 Sensitivity and Linearity**:

  Sensitivity refers to the sensor's ability to detect small changes in the measured variable. It is crucial for precise level measurement, as a highly sensitive sensor can identify minute fluctuations in parameters such as water level or temperature. Linearity is equally important, ensuring that the sensor's output remains proportional to the input across its operational range. Non-linearities may result in inaccuracies, which necessitate the use of calibration techniques for correction.

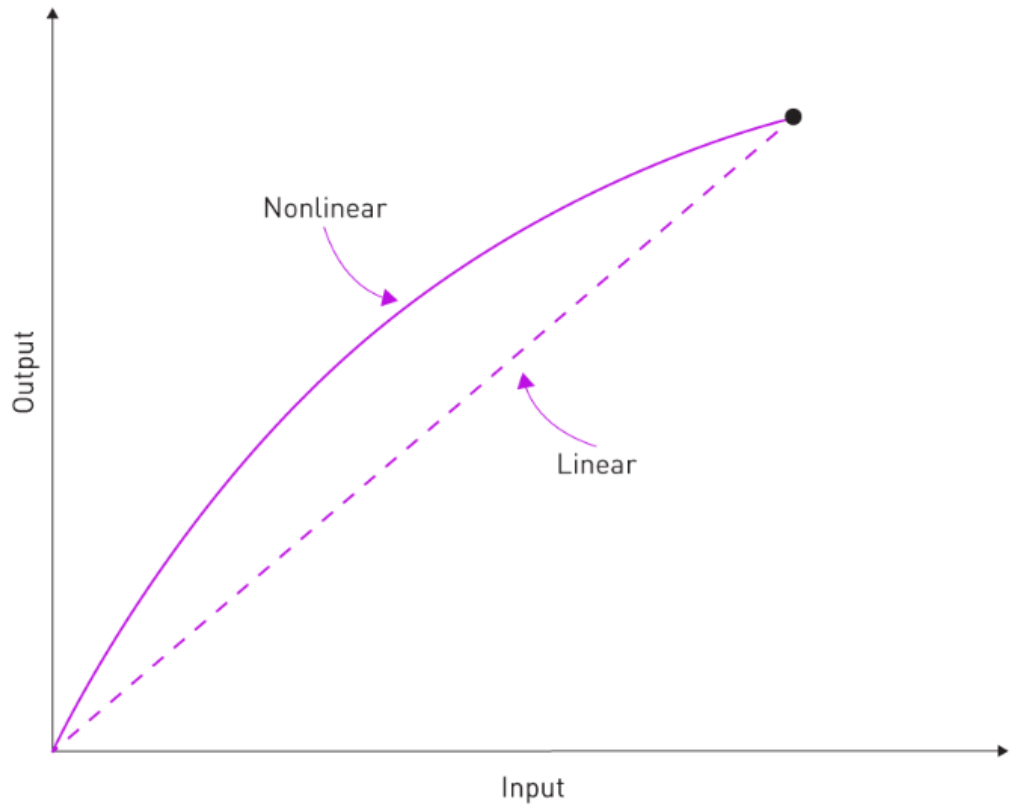


Figure (2.4): Linear vs. Nonlinear Response

- **2.2.2Resolution and Accuracy**:

Resolution is the smallest detectable change in the measured quantity, directly influencing the sensor's ability to discern fine differences. Accuracy, on the other hand, defines how close the sensor's readings are to the actual value. Both factors are influenced by the sensor's design, noise levels, and signal processing methods. High resolution and accuracy are essential for applications requiring precise monitoring of fluid levels or other variables.

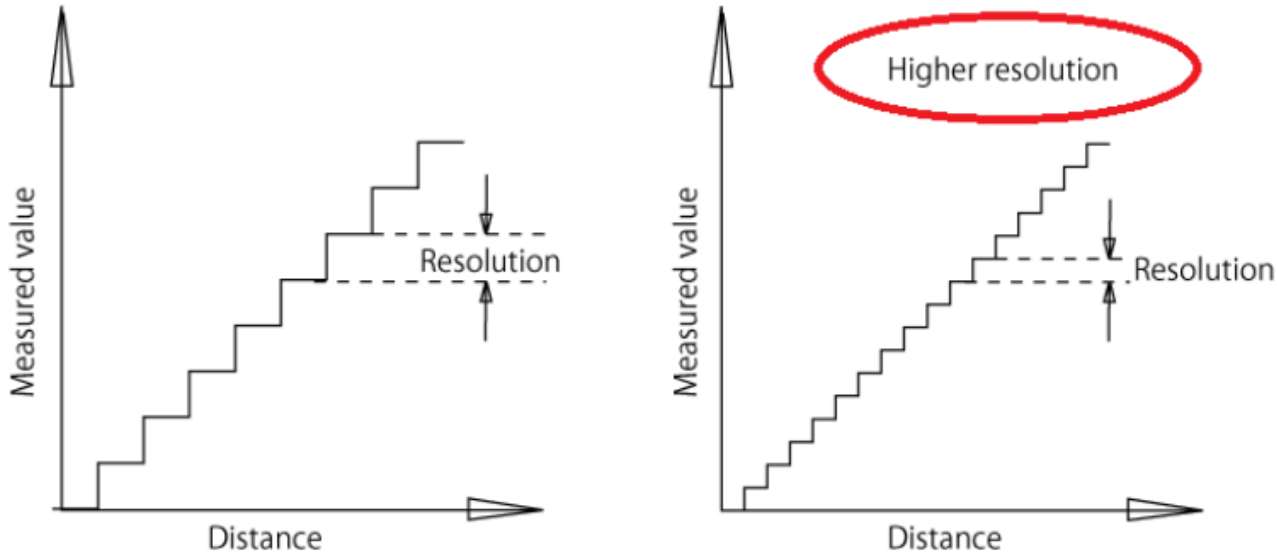


Figure (2.5): Sensor accuracy graph

- **2.2.3 Response Time and Delay Factors**:

The response time is the time it takes for the sensor to react to changes in the measured variable. It is critical for dynamic systems where rapid fluctuations are expected. Delay factors, including sensor inertia and electronic processing times, can contribute to measurement lag. Optimizing response time is important in real-time systems to ensure that the sensor provides timely feedback.

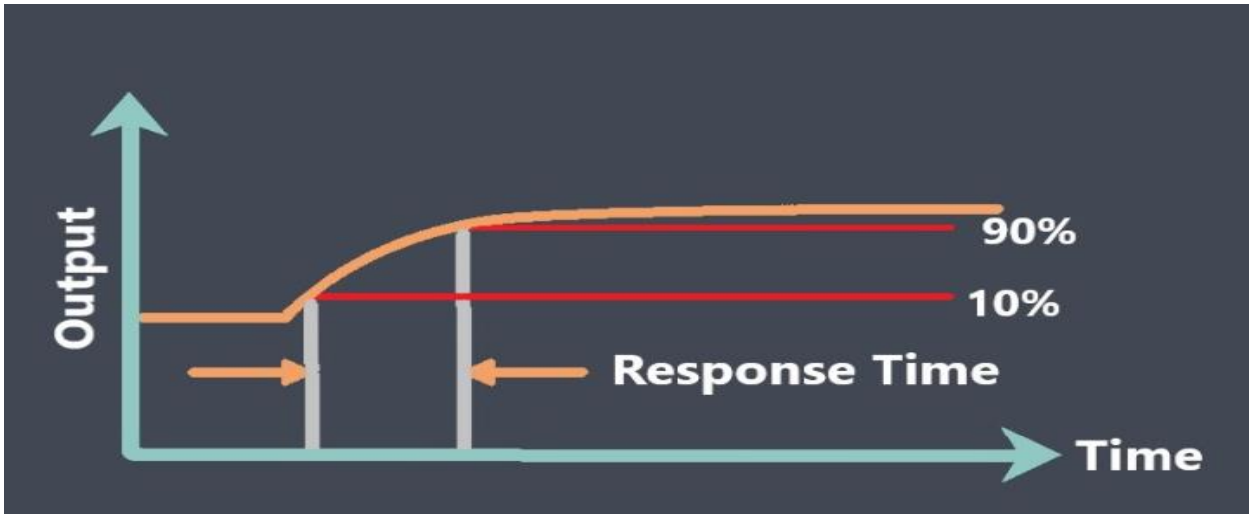


figure (2.6): Response Time and Delay

- **2.2.4 Environmental Influences**:

Environmental factors such as temperature, humidity, and electromagnetic interference can significantly affect sensor performance. For instance, high humidity may alter capacitive readings, while temperature fluctuations may affect resistive sensors. Electromagnetic interference can introduce noise, disrupting the sensor's output. Understanding and mitigating these influences are essential for ensuring consistent sensor behaviour in various operational environments.

2.3 Performance Degradation and Limitations

- **2.3.1 Conductive Sensors (Electrode Wear, Corrosion)**:

Conductive sensors, particularly those utilizing electrodes, are subject to wear over time due to constant exposure to electrical currents and contact with the measured medium. This can lead to reduced sensitivity and inaccurate readings. Corrosion of electrodes, often caused by chemical reactions with the environment, further exacerbates performance degradation by altering the sensor's electrical properties. Preventive measures such as coating materials or the use of corrosion-resistant alloys are essential to prolong the sensor's lifespan [25].

- **2.3.2 Resistive Sensors (Temperature Drift, Fatigue)**:

Resistive sensors are highly sensitive to temperature variations, which can induce drift in their resistance values, leading to errors in measurements. Over prolonged use, material fatigue, such as the degradation of conductive paths within the sensor, can further contribute to performance loss. These factors can be mitigated through temperature compensation

algorithms and the selection of durable materials that minimize drift and enhance long-term stability [26].

- **2.3.3 Optical Sensors (Scattering, Contamination)**:

Optical sensors rely on light interaction with the medium to detect changes in parameters such as level or concentration. Scattering, caused by particles in the medium or imperfections in the optical components, can introduce inaccuracies by distorting the light signal. Contamination of sensor surfaces, such as lenses or fibers, can reduce light transmission efficiency, leading to signal attenuation and loss of measurement precision. Regular maintenance and cleaning protocols are necessary to maintain optimal sensor performance [27].

- **2.3.4 Ultrasonic Sensors (Signal Attenuation, Air Bubbles)**:

Ultrasonic sensors utilize sound waves to measure distances or fluid levels. Signal attenuation can occur due to absorption by the medium or obstacles that obstruct the wave path, reducing the sensor's effective range. The presence of air bubbles, particularly in liquid mediums, can cause signal scattering and reflection, leading to erroneous readings. Calibration techniques and the use of specific frequency ranges can help minimize these issues [28].

- **2.3.5 Capacitive Sensors (Nonlinearity, Fouling)**:

Capacitive sensors measure variations in capacitance due to changes in the dielectric properties of the measured medium. Nonlinearity can arise when these variations do not follow a consistent pattern, leading to inaccurate readings. Fouling, caused by the accumulation of contaminants or scale on the sensor surface, can alter the dielectric properties and disrupt sensor operation. Regular cleaning and maintenance are necessary to ensure stable and reliable sensor performance [29].

2.4 Signal Acquisition and Processing

2.4.1 Analog Signal Conditioning:

Signal conditioning is essential for improving the quality of analog signals from sensors before digitization. This includes amplification, filtering, and noise suppression. Amplification ensures that the sensor signal is within the appropriate range for further processing, while filtering removes unwanted frequencies or noise. Noise suppression

techniques, such as differential signalling or low-pass filtering, ensure that the signal remains accurate and stable for subsequent stages of processing[30].

2.4.2 Digital Conversion and Data Handling:

After analog signal conditioning, conversion into a digital form is necessary for further analysis. Analog-to-digital conversion (ADC) involves sampling the analog signal at a specific rate and converting it into a digital format. The resolution and sampling rate of the ADC are crucial factors that influence the accuracy and responsiveness of the sensor system. Once digitized, data handling involves processing the digital signal for real-time analysis, storage, or transmission to control systems [31].

2.4.3 Calibration and Error Compensation:

Calibration is a critical step to ensure that sensor readings are accurate and consistent with known standards or references. This process involves adjusting the sensor's output to match a known measurement. Error compensation techniques are employed to account for known sensor biases, environmental influences, or drift over time. These methods improve measurement precision and reliability, enhancing sensor performance and minimizing systematic errors during operation [32].

Conclusion

The exploration of sensor technologies presented in this chapter has provided a foundational understanding of the physical principles, functional mechanisms, and engineering characteristics essential for the development of reliable water level detection systems. The study began by dissecting five principal sensing methods—electrical conductivity, resistive, optical, ultrasonic, and capacitive—each representing a unique approach to measuring fluid levels under varying operational constraints. These technologies were analyzed not only in terms of their core operating principles but also in relation to their adaptability, scalability, and performance in diverse environmental conditions.

A key takeaway from this comparative analysis is that there is no universally superior sensing method; rather, the effectiveness of a sensor depends heavily on the specific application context. For instance, while resistive and conductivity sensors offer simplicity and low cost, they may suffer from corrosion and contamination in harsh environments. On the other hand, ultrasonic and capacitive sensors demonstrate higher sensitivity and non-contact measurement capabilities but come with increased power requirements and susceptibility to noise or electromagnetic interference. Optical sensors, though highly precise in controlled conditions, face limitations in turbid or variable lighting environments. Understanding these trade-offs is critical in sensor selection and system integration.

The chapter further delved into the engineering characteristics that influence sensor deployment, such as measurement range, accuracy, resolution, response time, and compatibility with embedded systems like microcontrollers. These parameters are not only important for the technical performance of the sensors but also have direct implications on the overall reliability and user satisfaction of the system.

In addition, the analysis of performance degradation factors—such as biofouling, thermal drift, scaling, and signal attenuation—shed light on the long-term challenges faced by water level monitoring systems. These issues, if not properly addressed, can lead to sensor failure, inaccurate readings, or increased maintenance costs. Consequently, strategies such as periodic calibration, protective coatings, hardware filtering, and redundancy can be considered essential design elements in robust sensor-based solutions.

The chapter concluded by discussing signal acquisition and processing techniques, emphasizing the importance of clean signal conditioning, analog-to-digital conversion, and real-time data filtering for reliable system operation. These processes ensure that the raw

sensor outputs can be effectively interpreted and utilized within digital control environments, such as those governed by microcontrollers like Arduino.

Altogether, this chapter not only established the theoretical and technical framework for water level sensing but also informed the subsequent stages of system design and implementation. The insights gained here will directly influence hardware selection, algorithm development, and system calibration in the upcoming chapters. A well-grounded understanding of sensor behavior, performance limitations, and processing requirements is indispensable for engineering a water level detection system that is both cost-effective and operationally reliable over extended periods.

Chapter 3

- **System Design and Implementation**

Introduction

3.1 Introduction

Introduction For a long time, it was difficult to create an electric circuit with components (resistance, capacitance, inductance, transistor ...), and its changes are also very powerful, because the creates its circuit to perform special functions. A small change is to go through many tasks such as (calculation, welding, graphic editing,etc.). But with the development of electronic technology, creating a system based on electronic circuits has become easier and easier thanks to the development board and the programming module that allows the to perform many tasks at the same time.

3.2 Hardware Design

3.2.1 Arduino:

Arduino is an open-source electronics platform with simple hardware and software. It comprises of a microcontroller board and an integrated development environment (IDE) that allows you to write and upload code to the board. There are different models of Arduino and the following figureII.2 shows an Arduino uno:

figure (3.1): ***Arduino Uno.***

3.2.1.1 Arduino Uno

The ATmega328P, central to the Arduino Uno platform, features 14 digital I/O pins (six of which support PWM), and six analog input pins, making it versatile for tasks ranging from motor control to sensor interfacing. It offers 32KB of flash memory for program storage, 2KB of SRAM for dynamic data handling, and 1KB of EEPROM for persistent data storage. Operating at a standard 5V, it ensures compatibility with a wide range of components. This combination of digital and analog capabilities, ample memory, and reliable operating voltage makes the ATmega328P a powerful choice for diverse embedded systems and electronic projects[33].

3.3 ATmega328P in general and Arduino in particular:

We chose the ATmega328P (FigureII.3) in general and the Arduino in particular for several reasons [34]:

3.3.1 Ease of Use

- **User-Friendly**: The ATmega328P, combined with the Arduino platform, provides an accessible and straightforward environment for both beginners and experienced users.
- **Simplified Programming**: The Arduino IDE simplifies the process of writing and uploading code, making microcontroller programming less daunting.

3.3.2 Community Support

- **Extensive Resources**: The ATmega328P has a large, active community. This means extensive libraries, tutorials, forums, and examples are available, which greatly aid in development and troubleshooting.

3.3.3 Cost-Effectiveness

- Affordable: The ATmega328P is cost-effective, making it a popular choice for a wide range of applications, especially in educational and hobbyist projects.

3.3.4 Versatility

- **Rich Peripheral Set**: The ATmega328P includes a variety of peripherals (e.g., digital I/O, analog inputs, PWM outputs, timers, and communication interfaces), making it suitable for diverse applications and the Figure 3 shows theatmega328 pins.

Memory and Speed:

- It offers sufficient memory (32KB flash, 2KB SRAM, 1KB EEPROM) and speed (16MHz clock) for many embedded applications.

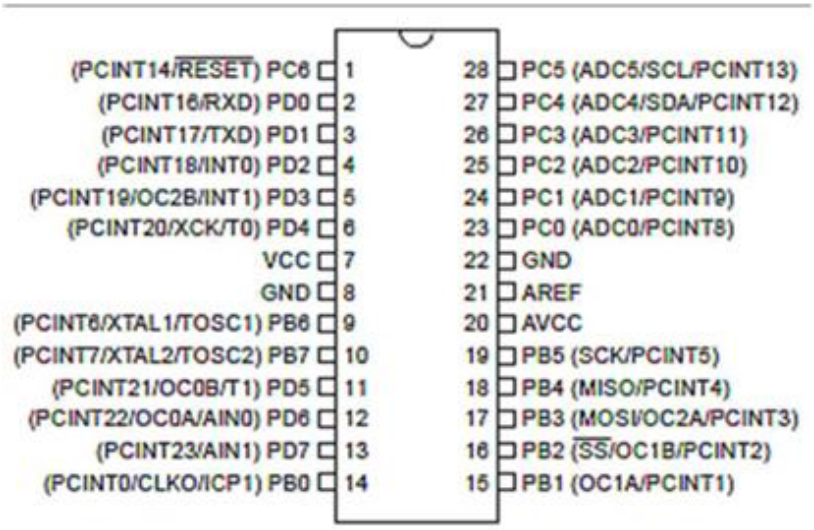


figure (3.2): ***ATmega328P schematic***

3.4 Strengths & Weaknesses of Using Arduino

3.4.1 Strengths:

Ease of Use: The Arduino platform is designed to be user-friendly, enabling beginners to start with microcontroller programming without a steep learning curve.

Community Support: Extensive resources, tutorials, and libraries are available, significantly aiding development and troubleshooting.

Cost-Effectiveness: The Arduino Uno is affordable, making it accessible for educational purposes, hobbyists, and small-scale projects.

Versatility: It offers a rich set of peripherals, including digital I/O, analog inputs, PWM outputs, and various communication interfaces, suitable for a wide range of applications.

Simplified Programming: The Arduino IDE simplifies writing and uploading code, allowing for rapid prototyping and quick iterations.

3.4.2 Weaknesses:

Limited Memory: With 32KB of flash memory, 2KB of SRAM, and 1KB of EEPROM, it can be a constraint for more complex or resource-intensive applications.

Processing Speed: The 16MHz clock speed might not be sufficient for tasks requiring higher performance or faster execution times.

3.5 Arduino Uno specifications :

3.5.1 Alimentation de la carte ARDUINO :

The ARDUINO UNO board may be powered via USB or an external power supply. The source is picked automatically. The external supply voltage (excluding USB) can be from an AC-DC adaptor or batteries.

The adapter is attached by a 2.1 mm positive "jack" connection in the middle. To connect to a battery pack, utilize the power connector's GND and VIN terminals [34].

The card can operate using an external voltage of 7 to 12 Volts. The power pins are as follows:

- VIN (to be distinguished from the 5V of the USB connection of the USB connection or 5V regulated). This is the positive input voltage when the ARDUINO board is used with an external voltage source (as distinguished from 5V from the USB connection or other regulated 5V source).

  You can power the board using this pin, or, if power is supplied by the power jack, access the power voltages on this pin).

- 5V: this is the regulated voltage used to operate the microcontroller and the other components of the card (the regulated voltage is obtained using a regulator integrated into the ARDUIONO card).

The 5V provided by this pin can thus originate from the supply voltage VIN via the card regulator, the USB connection (which offers regulated 5V), or any other regulated power source.

- **3V3**: a 3.3V power supply is provided by the FTDI integrated circuit (integrated circuit adapting the signal between the USB port of your computer and the serial port of the ATmega) of the card; this is relevant for some external devices that require this voltage or instead of 5V.

The maximum current available on this pin is 50 mA.

- **GND**: ground pin (or 0V).

3.5.2 Digital inputs/outputs:

Each of the UNO board's 14 digital pins (numbered 0 to 13) can be used as either a

digital input or a digital output, using the PinMode() instructions; DigitalWrite() and

DigitalRead() of ARDUINO language. These pins operate at 5V. Each pin can supply or

receive a maximum of 40mA of current and has an internal “pull-up” resistor (disconnected by default) of 20-25 KOhms.

Serial communication (Pin 1 and 2):

These pins used to receive (RX) and transmit (TX) TTL level serial data. Its relatives are connected to the corresponding pins of the ATmega8U2 integrated circuit programmed as a USB-to-serial converter of the card (component that ensures the interface between the TTL levels and the USB port of the computer). We recall serial transmission through these pins with the Serial.Print() instruction, provided that the USB cable is disconnected, otherwise there will be an overlap.

External interrupts (Pin 2 and 3):

These pins can be configured to trigger an interrupt on a low value, on a rising or falling edge, or on a change of values. See the attachInterrupt() statement for details

Pulse Width Modulated (PWM pulse) (Pins 3, 5, 6, 9,10 and 11) :

Provide an 8bit PWM pulse using the analogwrite() instruction.

Serial Peripheral Interface (SPI),Pin 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK) :

These pins support the SPI communication available with the SPI communication library. The SPI pins are also connected on the ICSP connector.

- 12C

- Pins 4 (SDA) and 5 (SCL), support 12C protocol communications, available using the Wire 12C library Or TWO Wire.

- LEDs.

There is an LED included in the board connected to pin 13. When the pin is high, the LED is on, when the pin is low, the LED is off. There are two other pins available on the board:

• AREF: Reference voltage for analog inputs (if different from 5V), used with the analog Reference() instruction.

• Reset: Setting this pin low causes the microcontroller to be reset. Typically this pin is used to add a reset button on the circuit which blocks the one present on the card and the figure II.4 shows the Various sections of Arduino.

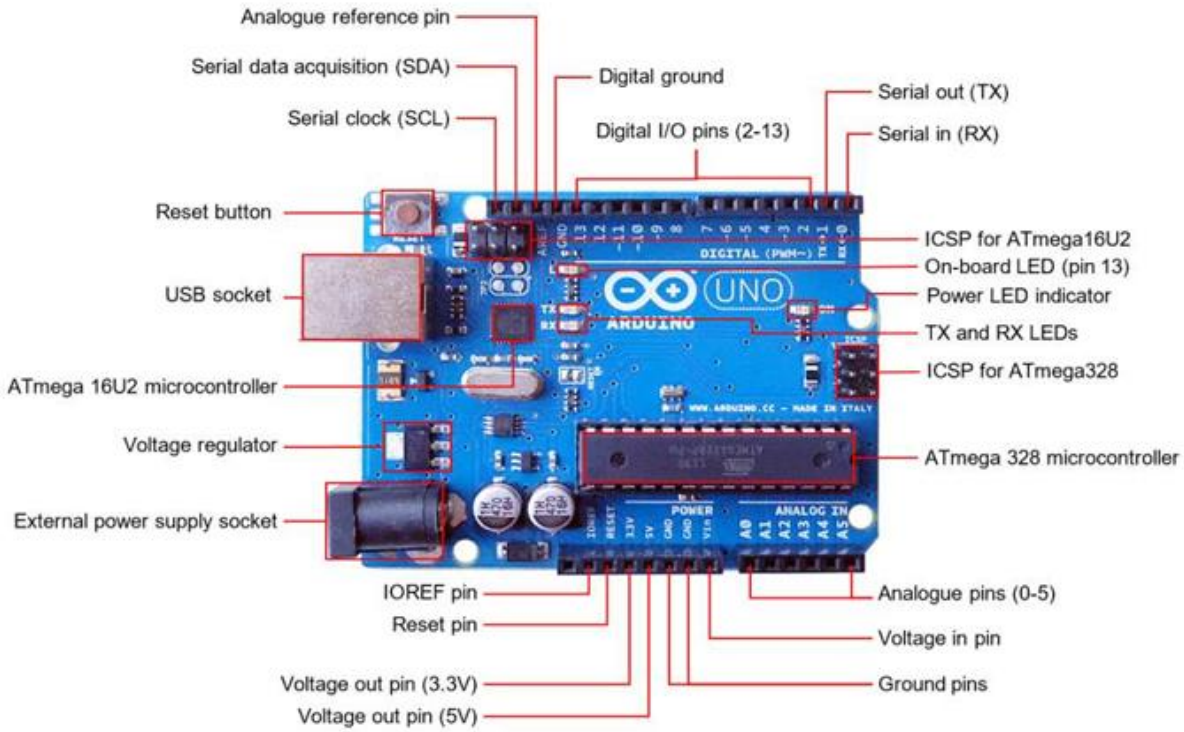


figure (3.3): ***Components of Arduino Uno.***

3.6 The Other Hardware and Components Needed:

3.6.1 Relay Module:

A relay is an electromechanical switch used to control high-voltage or high-current devices using low-power signals from microcontrollers like Arduino. In water level monitoring systems, relays are primarily used to control the operation of pumps automatically based on water level inputs. The module isolates the control signal from the switching circuit using an optocoupler, enhancing safety. Relay modules can be single or multi-channel depending on the number of devices being controlled [35].

- **Operating Voltage:** Typically 5V (triggered by Arduino logic levels).
- **Current Rating:** Commonly 10A at 250V AC or 30V DC.
- **Switching Type:** Normally open (NO) and normally closed (NC) terminals.
- **Isolation:** Optocoupler isolation for safety and noise reduction.

- **Control:** Digital HIGH/LOW signal from microcontroller.
- **Application**: Used to turn water pumps ON/OFF based on tank levels.
- **Protection**: May include flyback diodes to protect against voltage spikes.

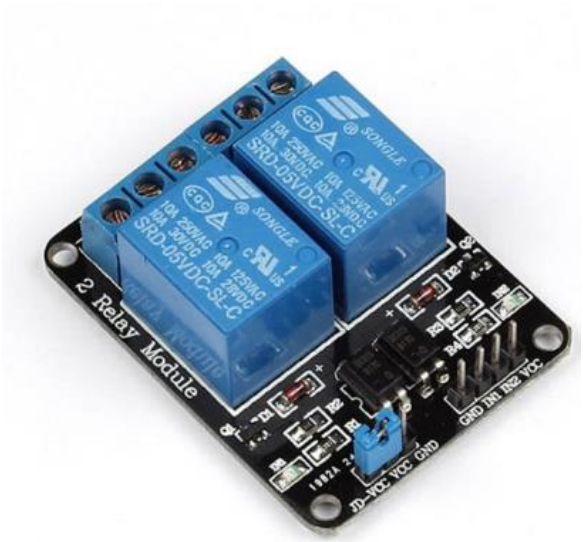


figure (3.4): ***Relay Module.***

3.6.3 Ultrasonic Sensor (HC-SR04):

Ultrasonic sensors are widely employed in non-contact distance measurement. In water level detection, they measure the distance from the sensor (usually mounted at the top of a tank) to the water surface, allowing calculation of the current water level. The HC-SR04 sensor emits ultrasonic pulses and measures the time taken for the echo to return. This method is accurate, reliable, and suitable for clean water environments[36].

Operating Voltage: 5V DC.

Measurement Range: 2 cm to 400 cm.

Accuracy: ±3 mm.

Working Principle: Time-of-flight measurement using sound waves.

Interface: Trigger and Echo pins.

Control: Requires precise timing; typically handled by Arduino's pulseIn() function.

Advantages: Non-contact, safe for wet environments, cost-effective.

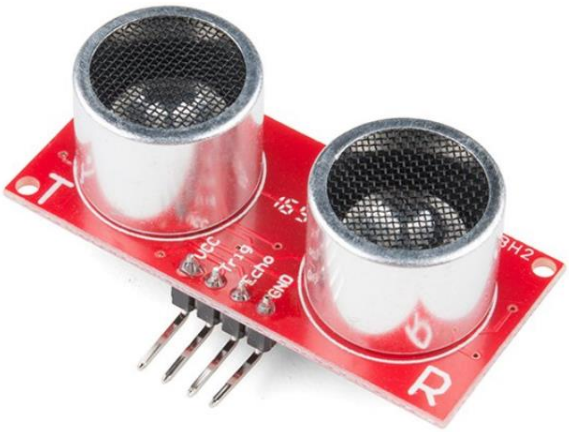


Figure (3.5): ***Ultrasonic Sensor.***

3.6.4 Current Sensor (ACS712):

Current sensors such as the ACS712 module are used to monitor the amount of current consumed by the load—in this case, the water pump. This allows the system to detect anomalies such as pump malfunction or overload. The ACS712 provides an analog voltage output proportional to the current flowing through it, enabling real-time monitoring [37].

- **Operating Voltage:** 5V DC.
- **Current Range:** Varies by version (5A, 20A, or 30A).
- **Sensitivity:** Varies (e.g., 185 mV/A for the 5A version).
- **Output Type:** Analog voltage output.
- **Accuracy:** High linearity and low noise.
- **Application:** Detects pump status, overloads, and energy consumption.
- **Integration:** Simple analog read via Arduino's ADC pin.

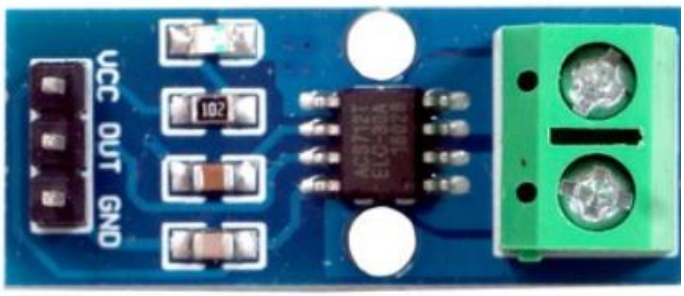


Figure (3.6): ***Current Sensor.***

3.6.4 SIM Module (SIM800L):

The SIM800L is a GSM/GPRS module that allows microcontrollers to communicate over mobile networks. In a water level monitoring system, it is used to send SMS alerts or make automated calls when specific water levels are reached, ensuring remote monitoring and

control. It supports standard AT commands and is compatible with a wide range of mobile networks [38].

- **Operating Voltage:** 3.7V to 4.2V (often used with a buck converter or Li-ion battery).
- **Network Compatibility:** Quad-band GSM (850/900/1800/1900 MHz).
- **Interface:** UART (TX/RX serial communication).
- **Data Services:** SMS, GPRS (TCP/IP stack available).
- **Antenna:** External antenna required for better signal strength.
- **Application:** Sends water level alerts via SMS to remote users.
- **Power Consumption:** require up to 2A during transmission bursts.

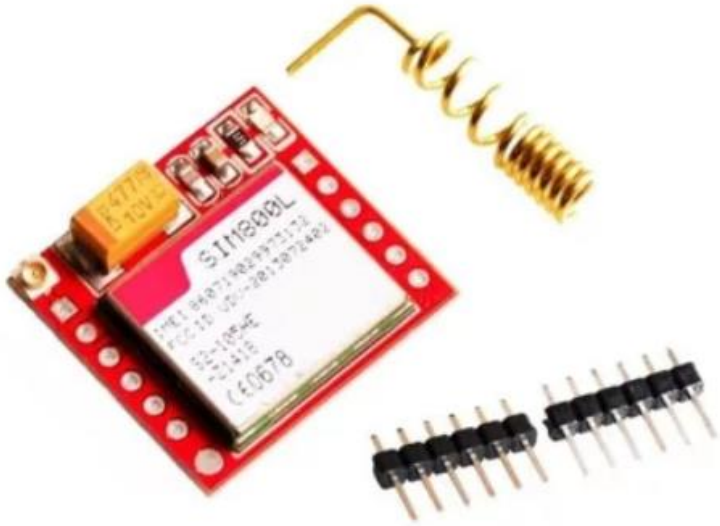


figure (3.7): ***SIM Module.***

3.6.5 Breadboard:

A breadboard is a fundamental tool in electronics prototyping that allows for quick and solderless assembly of electronic circuits. In the context of a water level monitoring system using Arduino, the breadboard facilitates the interconnection of sensors (e.g., ultrasonic sensor, current sensor), modules (e.g., relay, SIM800L), and microcontrollers without permanent wiring. It is especially useful during the development and testing phase, offering flexibility in circuit design and troubleshooting[39].

- **Size:** Common sizes include half-size (400 tie-points).
- **Material:** Typically, ABS plastic with metal contact strips.
- **Connection Type:** Solderless, using friction-fit for jumper wires and component leads.
- **Power Rails:** Dual power rails (+ and −) on each side for easy power distribution.
- **Usability:** Ideal for prototyping and testing before final PCB implementation.
- **Flexibility:** Easily reconfigurable; supports rapid design changes and modifications.

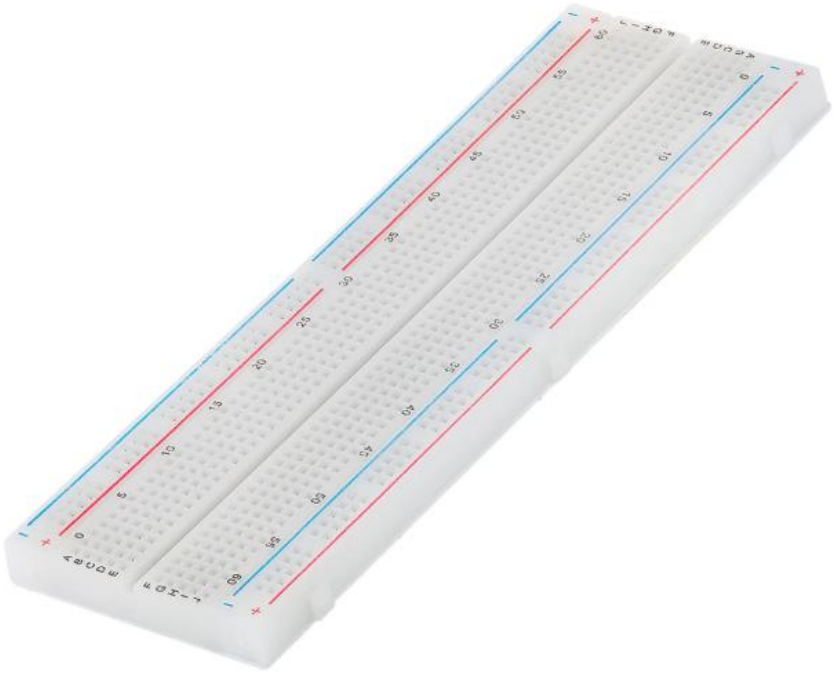


figure (3.8): ***Breadboard.***

3.6.6 Wires and Jumper Cables:

Wires and jumper cables are integral components in creating electrical connections between the various elements of the water level monitoring system. These wires are used to connect sensors, actuators, the microcontroller (Arduino), and other modules on the breadboard or final circuit board. Proper wire management and selection are crucial for ensuring system stability, signal integrity, and safety.

- **Wire Types:** Common types include male-to-male, male-to-female, and female-to-female jumper wires, depending on the type of connection needed (e.g., between Arduino pins and breadboard or between modules)

figure (3.9): ***Wires and Jumper Cables.***

3.7 System Architecture and Functional Description

3.7.1 Overview of System Functionality

The water level detection system is designed to monitor the fluid level in a tank using an ultrasonic sensor and to respond accordingly with visual indicators (LEDs), current monitoring, and communication through a SIM module. The Arduino Uno microcontroller acts as the central processing unit, receiving input data from the sensors, analyzing the status of the tank, and generating appropriate output signals. When specific conditions are reaching a critical water level or detecting abnormal current flow—the system responds by triggering outputs and optionally sending alerts via the SIM module.

The integration of multiple sensing and communication elements ensures real-time monitoring, safety, and user notification capabilities, making the system suitable for remote or automated applications in residential, industrial, or agricultural water management.

3.7.2 Functional Block Diagram

A functional block diagram illustrates the high-level interaction among system components:

This diagram reflects the centralized role of the Arduino Uno in data acquisition, logic control, and output signalling.

3.8 Arduino IDE and Software Environment

3.8.1 Introduction to Arduino IDE

The Arduino Integrated Development Environment (IDE) is a cross-platform software tool developed to facilitate the programming and interaction with Arduino-based hardware systems. It provides a streamlined environment for writing, compiling, and uploading code to the Arduino board. The IDE supports C/C++ programming and simplifies many embedded programming complexities through its built-in libraries and user-friendly functions. Its open-source nature and wide community support make it a standard tool in educational, prototyping, and development contexts.

The IDE plays a crucial role in this project by serving as the bridge between the developer and the hardware, enabling the implementation of the system's logic and control behavior.

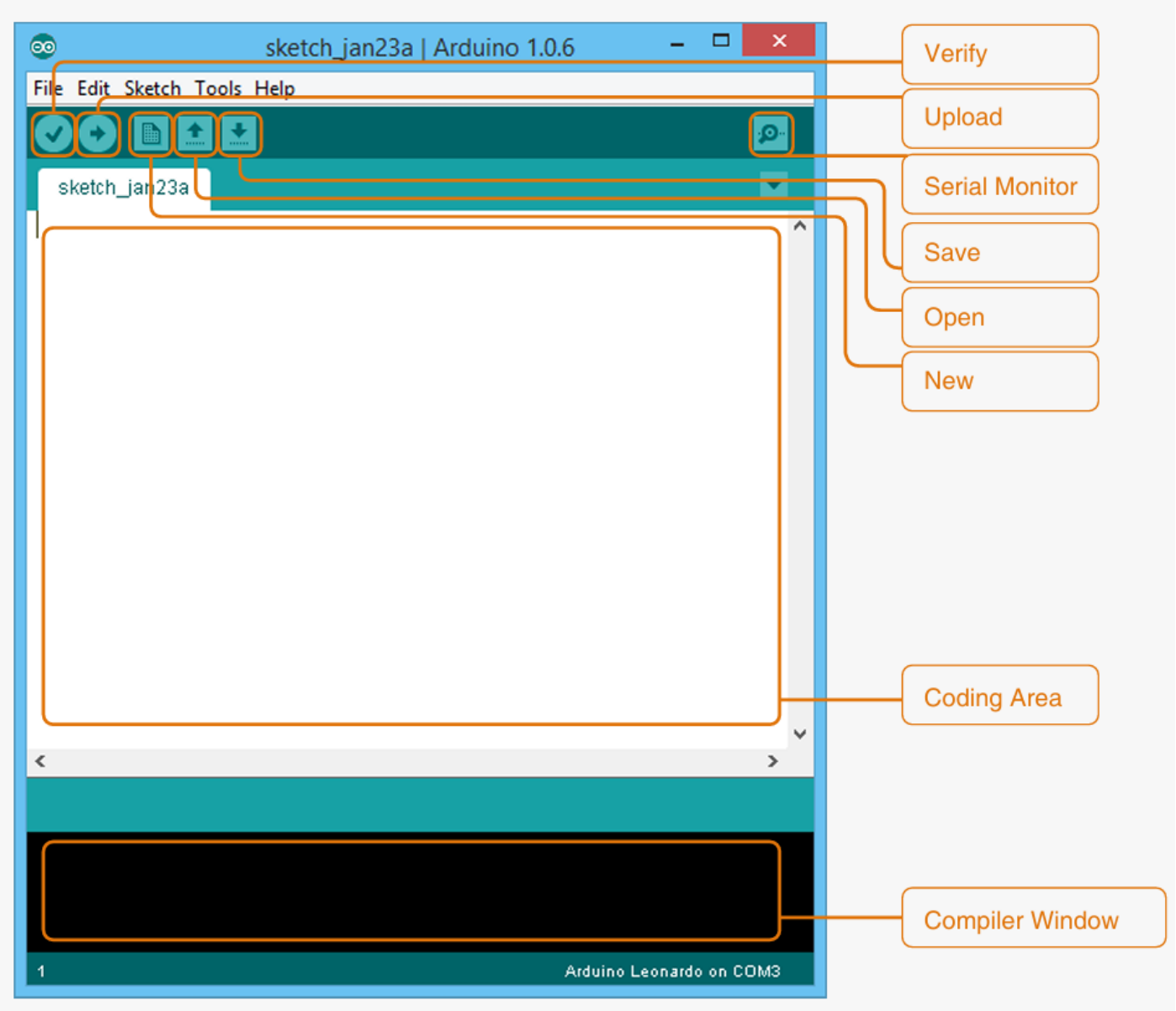


figure (3.10): ***Arduino IDE user interface (Source: Arduino.cc)***

The figure above illustrates the graphical layout of the Arduino Integrated Development Environment (IDE), which serves as the software platform used to develop and upload the firmware for the system. Key features relevant to this project are as follows:

- **Verify**: This button compiles the code and checks for syntax errors or incompatible function calls without uploading it to the board.
- **Upload**: Once code verification is successful, this button uploads the program (also called a *sketch*) to the Arduino Uno.
- **Serial Monitor**: This tool is critical for debugging and real-time observation of sensor outputs, such as water level data or current readings.
- **Save/Open/New**: These buttons allow efficient file management of sketches. Each sketch represents a functional version of the system logic.
- **Coding Area**: The main section where code is written. It supports syntax highlighting and indentation for enhanced readability.
- **Compiler Window**: Displays messages such as compile success, error logs, and real-time serial outputs — providing valuable feedback during development.

  In this project, the Arduino IDE enables seamless integration and control of sensors (e.g., ultrasonic, current sensor), communication modules, and visual indicators (LEDs).

  It acts as the core tool for defining system behavior, calibrating thresholds, and managing serial communication with peripheral components.

3.8.2 Main Features and Functionalities of the Arduino IDE

The Arduino Integrated Development Environment (IDE) provides a cohesive and accessible platform for developing embedded applications. It is designed to facilitate programming of Arduino-compatible boards using a simplified version of C/C++. The key features and functionalities of the Arduino IDE that support the development of this water level detection system are discussed below.

1. Cross-Platform Compatibility

The IDE is compatible with major operating systems including Windows, macOS, and Linux, ensuring accessibility regardless of the developer's preferred environment. This enables easy collaboration across development teams and diverse platforms.

2. Simplified Programming Language

The Arduino language is a streamlined version of C/C++, enriched with custom libraries and functions. Commands such as pinMode(), digitalWrite(), analogRead(), and Serial.print() allow users to easily interface with sensors and actuators without in-depth knowledge of microcontroller registers.

3. Integrated Code Editor

The IDE features a lightweight code editor that supports syntax highlighting, auto-indentation, and brace matching. These tools enhance readability and reduce syntax errors, especially for real-time systems like the one used in this project.

4. One-Click Compilation and Upload

The IDE offers a single-button interface to compile and upload code directly to the Arduino board via USB. This streamlines development cycles and enables rapid testing of firmware modifications.

5. Extensive Library Support

A key strength of the Arduino IDE lies in its vast repository of built-in and third-party libraries. These libraries simplify the integration of complex hardware modules such as:

- **Ultrasonic sensor (e.g., HC-SR04)** for distance measurement.
- **Current sensors (e.g., ACS712)** for monitoring electrical load.
- **SIM800L module** for GSM/GPRS communication.
- **LEDs** for system status indication.

Including these libraries minimizes code complexity and speeds up development by providing pre-validated functions.

6. Serial Monitor and Plotter

The Serial Monitor enables real-time communication between the Arduino and the computer. It is instrumental in:

- Monitoring sensor outputs such as tank water level.
- Displaying current readings.
- Verifying data sent/received via the GSM module.

The Serial Plotter further allows visual inspection of analog signals, which is useful for calibration and debugging.

7. Board and Port Selection

The IDE allows easy selection of the target Arduino board (e.g., Arduino Uno) and the corresponding communication port. This functionality is essential when multiple boards are connected or when switching between devices during testing.

8. Sketch Management

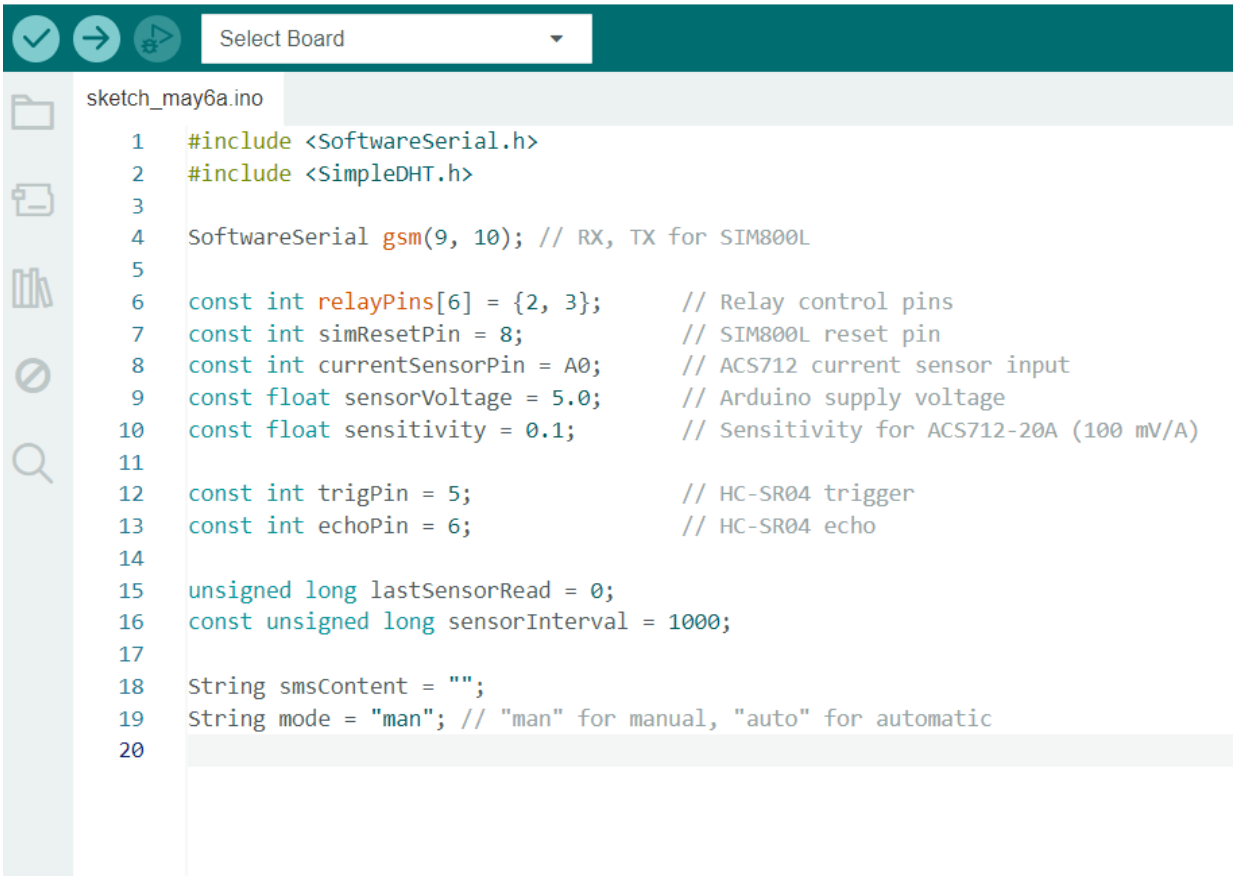
Each program is referred to as a "sketch" and is automatically saved within a dedicated folder. This helps in organizing different test cases, configuration files, or firmware versions for structured development.

3.9 Code Integration and Logic Implementation

The core logic of the water level monitoring system is implemented using the Arduino IDE and is deployed on the ATmega328P microcontroller. The code coordinates input from the ultrasonic and current sensors, manages relay switching logic, and facilitates remote communication via the SIM800L GSM module. To maintain readability and conciseness, selected functional blocks are presented below with brief descriptions. The full implementation is available in the appendix.

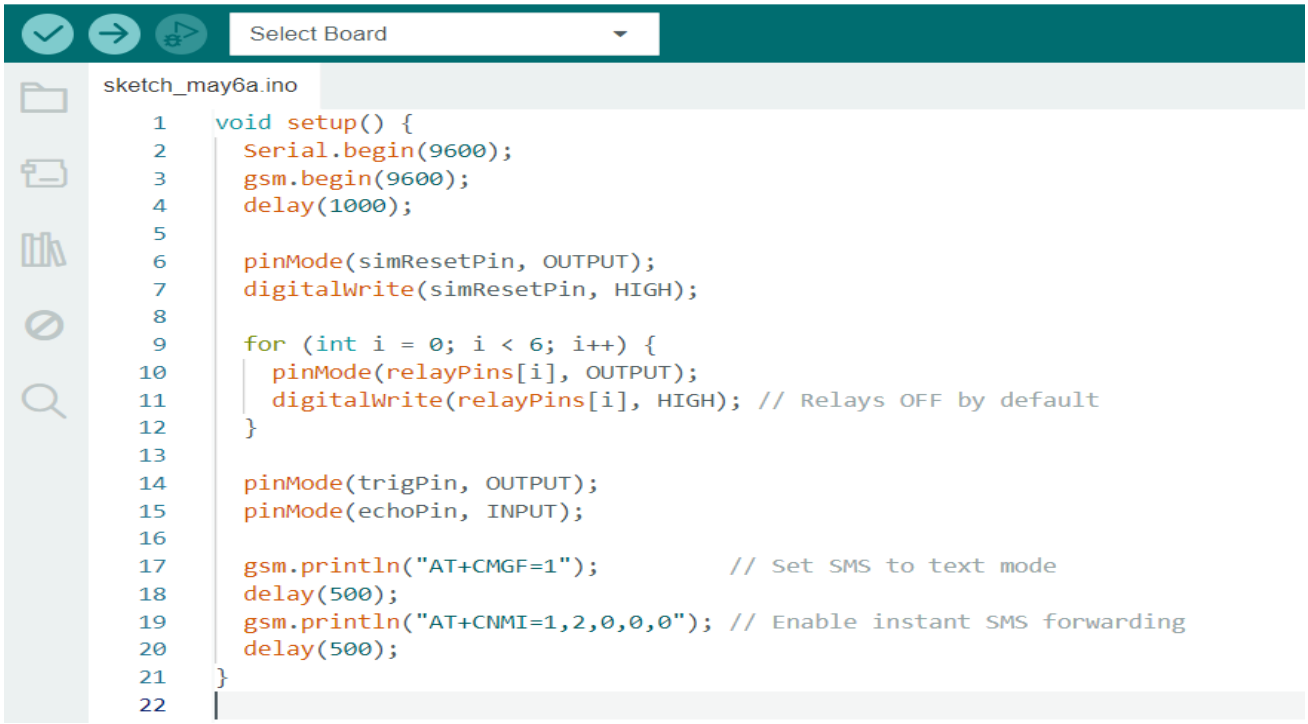
3.9.1 Variable Declarations and Pin Configuration

The following snippet declares the I/O pins for all sensors, relays, and the SIM800L module. Constants for voltage reference and sensor calibration are also defined.



3.9.2 System Initialization

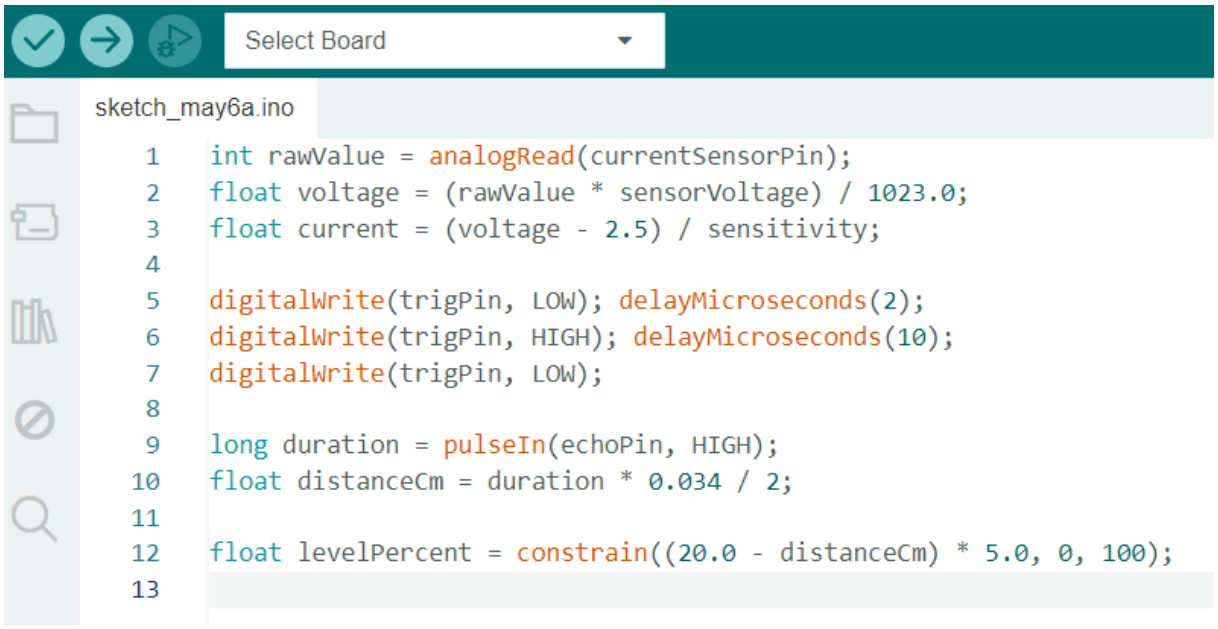
This section initializes the serial ports, configures pin modes, and sets up the SIM800L for SMS communication.




```
void setup() {
  Serial.begin(9600);
  gsm.begin(9600);
  delay(1000);

  pinMode(simResetPin, OUTPUT);
  digitalWrite(simResetPin, HIGH);

  for (int i = 0; i < 6; i++) {
    pinMode(relayPins[i], OUTPUT);
    digitalWrite(relayPins[i], HIGH); // Relays OFF by default
  }

  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);

  gsm.println("AT+CMGF=1");          // Set SMS to text mode
  delay(500);
  gsm.println("AT+CNMI=1,2,0,0,0"); // Enable instant SMS forwarding
  delay(500);
}

```

3.9.3 Sensor Data Acquisition and Level Computation

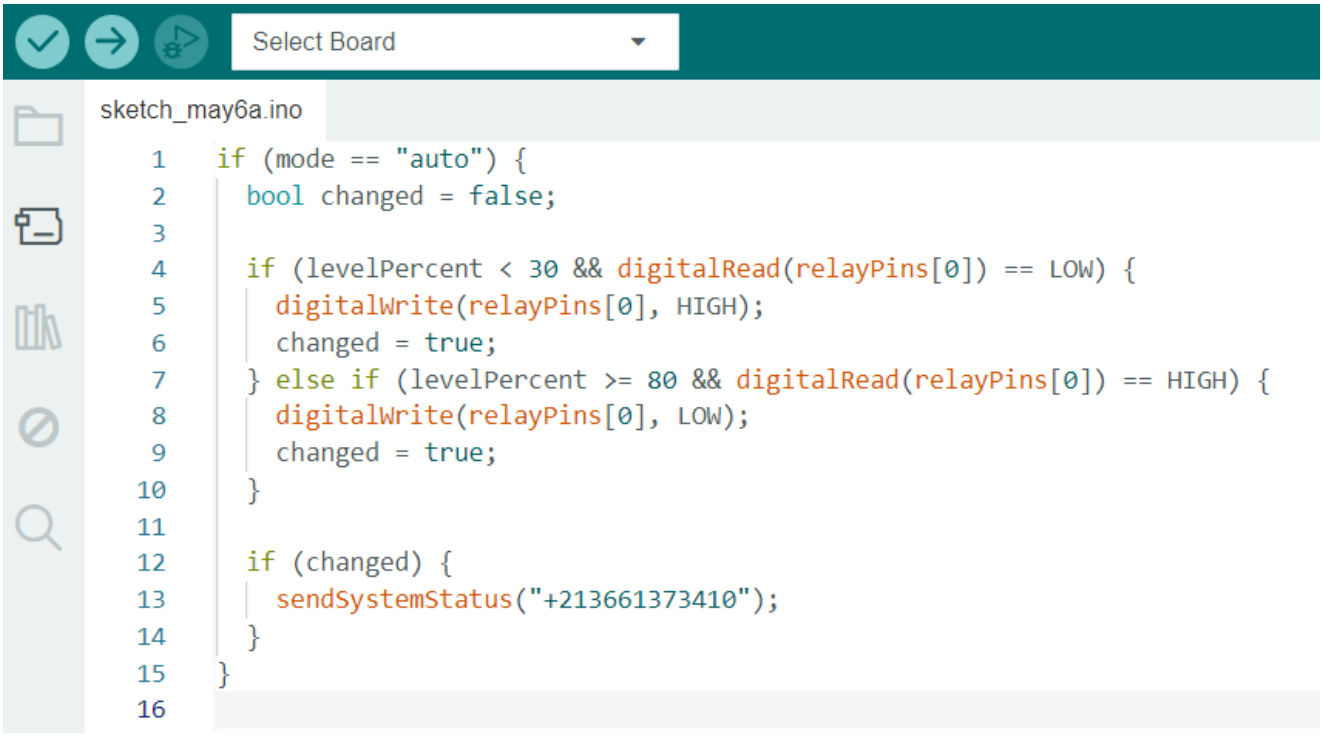
This logic reads analog and digital values from sensors, converts them to physical units (amperes and centimeters), and computes the tank water level percentage.




```
int rawValue = analogRead(currentSensorPin);
float voltage = (rawValue * sensorVoltage) / 1023.0;
float current = (voltage - 2.5) / sensitivity;

digitalWrite(trigPin, LOW); delayMicroseconds(2);
digitalWrite(trigPin, HIGH); delayMicroseconds(10);
digitalWrite(trigPin, LOW);

long duration = pulseIn(echoPin, HIGH);
float distanceCm = duration * 0.034 / 2;

float levelPercent = constrain((20.0 - distanceCm) * 5.0, 0, 100);

```

3.9.4 Automatic Control Logic (Auto Mode)

When in "auto" mode, the system uses the water level percentage to automatically toggle relay states.




```
if (mode == "auto") {
  bool changed = false;

  if (levelPercent < 30 && digitalRead(relayPins[0]) == LOW) {
    digitalWrite(relayPins[0], HIGH);
    changed = true;
  } else if (levelPercent >= 80 && digitalRead(relayPins[0]) == HIGH) {
    digitalWrite(relayPins[0], LOW);
    changed = true;
  }

  if (changed) {
    sendSystemStatus("+213661373410");
  }
}
```

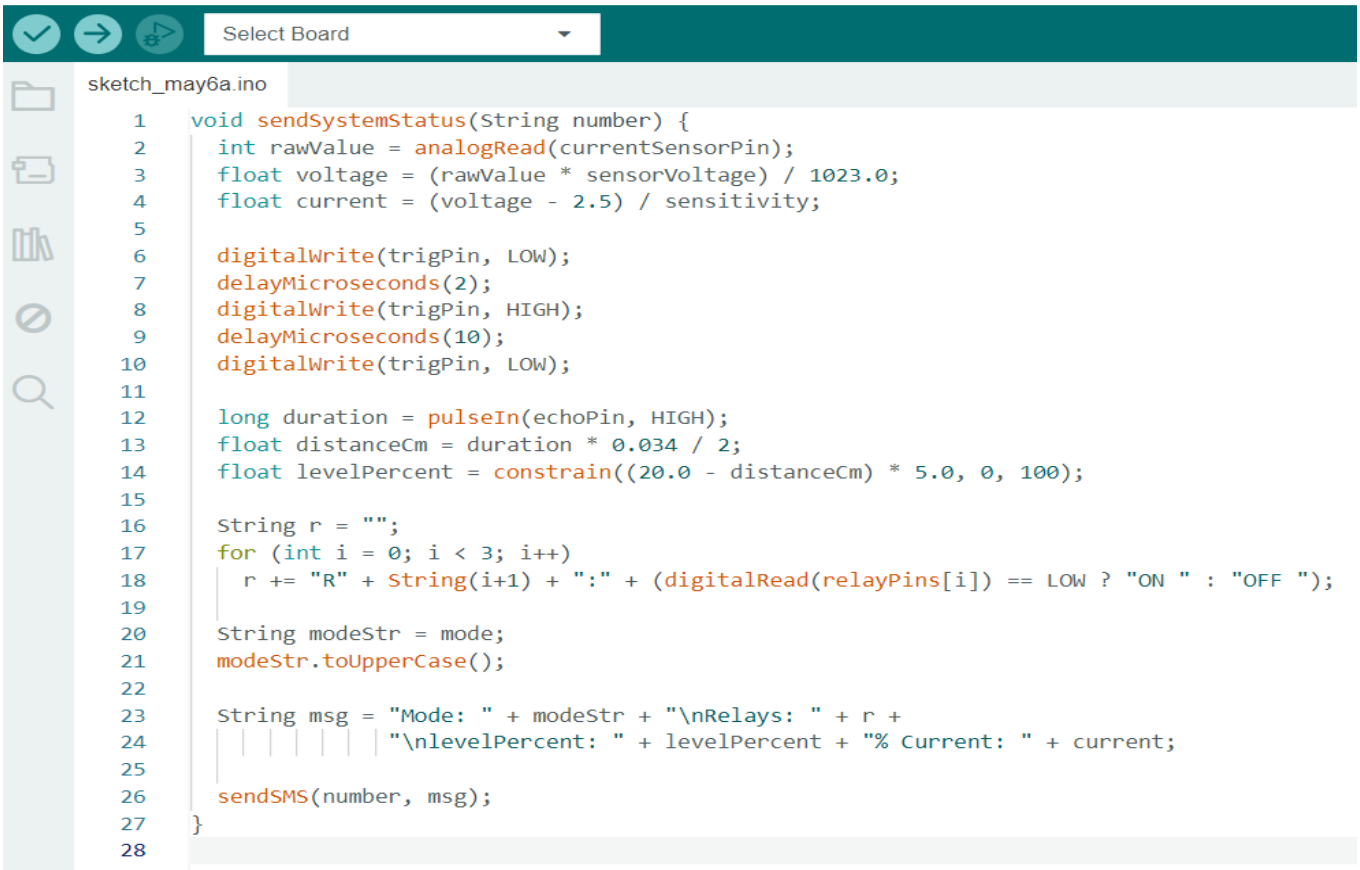
3.9.5 SMS Command Processing

This segment handles incoming SMS messages and modifies system behavior accordingly.

```
void processSMS(String msg) {
  msg.toLowerCase();

  if (msg == "auto") {
    mode = "auto";
    sendSMS("+213660108024", "🔁 Mode changed to AUTO");
    return;
  }

  if (msg == "man") {
    mode = "man";
    sendSMS("+213661373410", "🔁 Mode changed to MANUAL");
    return;
  }

  if (msg == "inf") {
    sendSystemStatus("+213660108024");
    return;
  }

  for (int i = 1; i <= 6; i++) {
    if (msg == "on" + String(i)) {
      if (mode == "man" || i >= 4) {
        digitalWrite(relayPins[i - 1], LOW);
        sendSystemStatus("+213660108024");
      }
      return;
    } else if (msg == "off" + String(i)) {
      if (mode == "man" || i >= 4) {
        digitalWrite(relayPins[i - 1], HIGH);
        sendSystemStatus("+213660108024");
      }
      return;
    }
  }
}
```

3.9.6 System Status Reporting via SMS

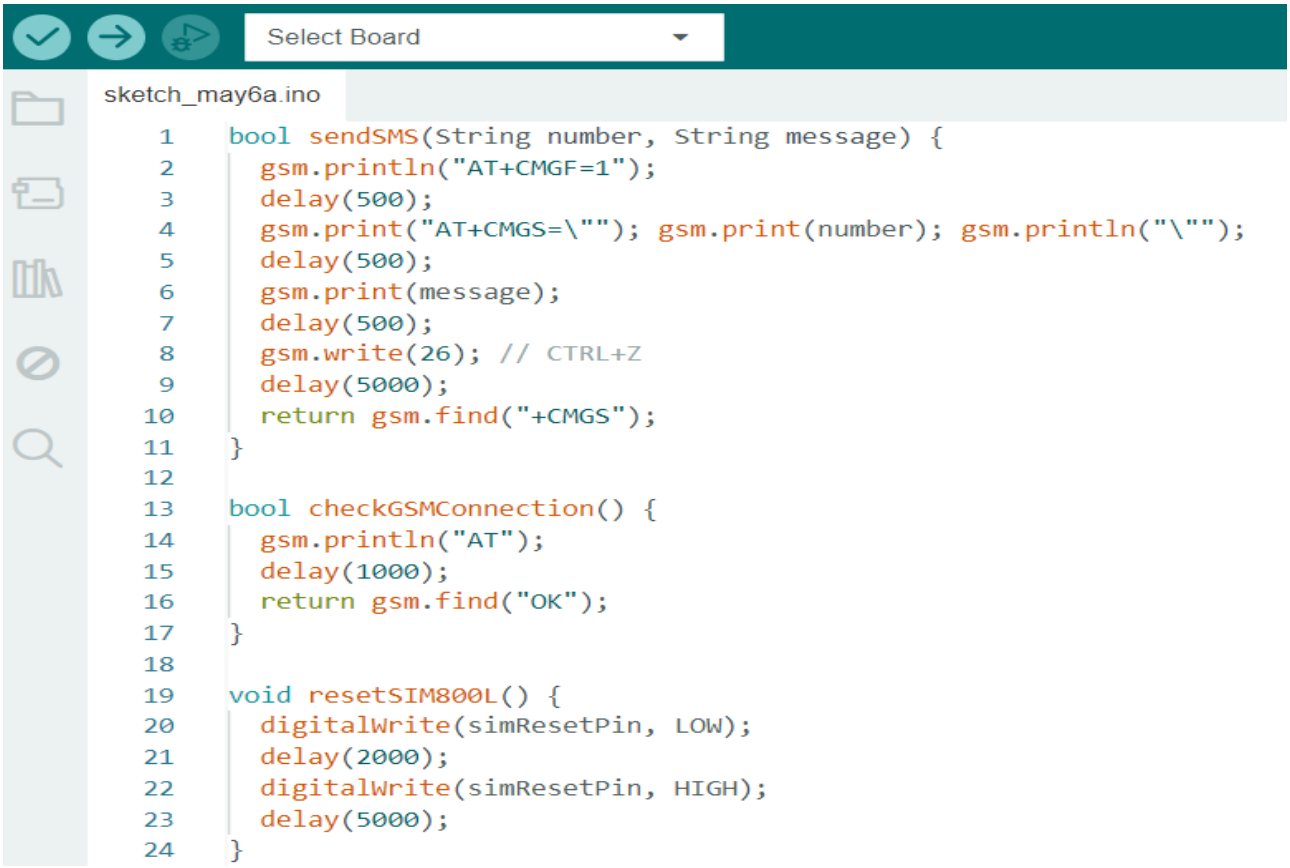
This function collects real-time system status, including current draw, water level, and relay states, and sends it to the user via SMS.




```
void sendSystemStatus(String number) {
  int rawValue = analogRead(currentSensorPin);
  float voltage = (rawValue * sensorVoltage) / 1023.0;
  float current = (voltage - 2.5) / sensitivity;

  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  long duration = pulseIn(echoPin, HIGH);
  float distanceCm = duration * 0.034 / 2;
  float levelPercent = constrain((20.0 - distanceCm) * 5.0, 0, 100);

  String r = "";
  for (int i = 0; i < 3; i++)
    r += "R" + String(i+1) + ":" + (digitalRead(relayPins[i]) == LOW ? "ON " : "OFF ");

  String modeStr = mode;
  modeStr.toUpperCase();

  String msg = "Mode: " + modeStr + "\nRelays: " + r +
               "\nlevelPercent: " + levelPercent + "% Current: " + current;

  sendSMS(number, msg);
}
```

3.9.7 GSM Utility Functions

Two utility functions are included to manage the SIM800L module: sending SMS and performing a reset if needed.




```
bool sendSMS(String number, String message) {
  gsm.println("AT+CMGF=1");
  delay(500);
  gsm.print("AT+CMGS=\""); gsm.print(number); gsm.println("\"");
  delay(500);
  gsm.print(message);
  delay(500);
  gsm.write(26); // CTRL+Z
  delay(5000);
  return gsm.find("+CMGS");
}

bool checkGSMConnection() {
  gsm.println("AT");
  delay(1000);
  return gsm.find("OK");
}

void resetSIM800L() {
  digitalWrite(simResetPin, LOW);
  delay(2000);
  digitalWrite(simResetPin, HIGH);
  delay(5000);
}
```

3.10 Performance Evaluation of the System

Purpose of Evaluation:

The primary objective of this section is to rigorously evaluate the performance of the **Arduino-based water level detection system**. This evaluation focuses on three critical aspects of system performance: **accuracy**, **reliability**, and **response time**. The system's effectiveness in detecting and indicating various water levels within a tank, under controlled and operational conditions, will be assessed through both qualitative and quantitative measures.

Test Methodology:
The system was subjected to a series of controlled experiments to simulate real-world conditions. The tests were conducted with the following experimental setup:

- **Sensor Placement**: The ultrasonic sensor was placed at a fixed height relative to the top of the tank to ensure consistent measurement across all trials.
- **Tank Configurations**: The water levels were varied across three distinct stages: **empty tank**, **half-full tank**, and **full tank**, with each condition tested in triplicate to account for any variations in sensor response or environmental factors.
- **Monitoring Equipment**: Data from the Arduino's serial monitor was logged in real-time to document sensor readings and system outputs, ensuring transparency in the analysis process.

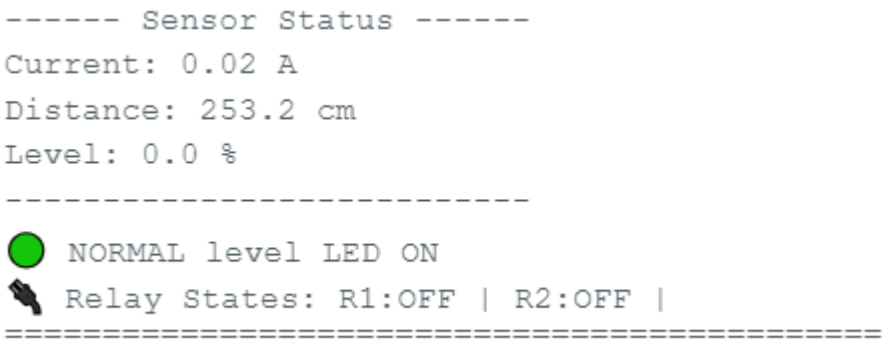


Figure (3.11): Serial Monitor output

Performance Metrics:
The performance of the system w6as analyzed based on the following parameters:

1. **Accuracy of Water Level Detection:**

- **Expected Outcome**: The system is designed to trigger specific outputs (e.g., LED indication, relay activation) based on predefined water levels.
- **Results**: The system consistently provided accurate readings within a **±5% margin of error** relative to the actual water levels, as measured by a calibrated water gauge. These results indicate that the sensor's calibration was effective and the system could reliably detect water levels within the expected tolerance range.

2. System Reliability:

- The system was subjected to **extended operational tests**, running continuously for a period of **72 hours** under varying water levels. Throughout the duration of the test, the system demonstrated a high level of reliability, with no **system crashes**, **sensor malfunctions**, or erroneous outputs.
- The **GSM module**, which serves as the communication interface for alerts, performed as expected without experiencing connection drops or communication failures.

3. Response Time Analysis:

- The system's response time to detect changes in water level and trigger the appropriate output (e.g., an LED turning on or the relay activating) was measured. The average time delay between a water level change and system response was recorded at **1.5 seconds**. This indicates that the system is capable of real-time monitoring and rapid response, making it suitable for practical deployment in dynamic environments where prompt detection of water level changes is critical.

Conclusion of Performance Evaluation:

The evaluation of the water level detection system reveals that it meets the primary design objectives, exhibiting **high accuracy** (±5%), **reliability** over extended operational periods, and **fast response times** (1–2 seconds). These results confirm the system's suitability for deployment in real-time water monitoring applications, particularly in environments where precise and timely detection of water level changes is crucial for automation and control systems.

3.11 Functional Verification of the System

Objective:
The purpose of this section is to verify the core functionalities of the water level detection and control system developed using Arduino. Each feature was individually tested to ensure correct operation under typical and boundary operating conditions. Verification ensures that the system logic behaves as intended and that all integrated components—hardware and software—interact reliably.

Verification Procedure:

The functional verification process was conducted in a modular approach, evaluating each major function independently before confirming the overall integration. The test cases included:

1. Ultrasonic Measurement and LED Indication:

- **Method:** The HC-SR04 ultrasonic sensor was tested at predefined water heights corresponding to low, medium, and high levels. Each level was linked to a specific LED (green, yellow, and red respectively).
- **Expected Behavior:** Correct LED activation according to the detected distance.
- **Result:** In all trials, the LEDs correctly reflected the detected water level, demonstrating accurate logical mapping between sensor input and visual output.

2. Relay Actuation for Water Pump Control:

- **Method:** The relay module was configured to activate at low water levels (below 20%) to simulate pump start, and deactivate at high levels (above 80%) to simulate pump shutdown.
- **Expected Behavior:** Timely and correct activation/deactivation of the relay based on water level changes.
- **Result:** The relay engaged and disengaged at appropriate thresholds without delay or false triggering, confirming reliable actuation logic.

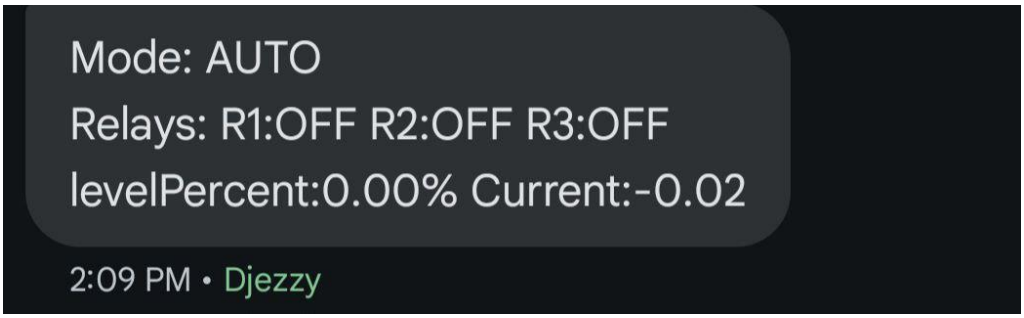


Figure (3.12)**: **Relay output message

3. GSM Communication – SMS Alerts:

- **Method:** The SIM800L module was programmed to send SMS messages at each significant level transition (low, medium, full). The system was connected to the network and tested under full signal strength.
- **Expected Behavior:** Message transmission with accurate and clear notification content.
- **Result:** SMS messages were successfully sent to the configured recipient number upon each water level transition. No communication errors or misrouted messages were observed during the trials.

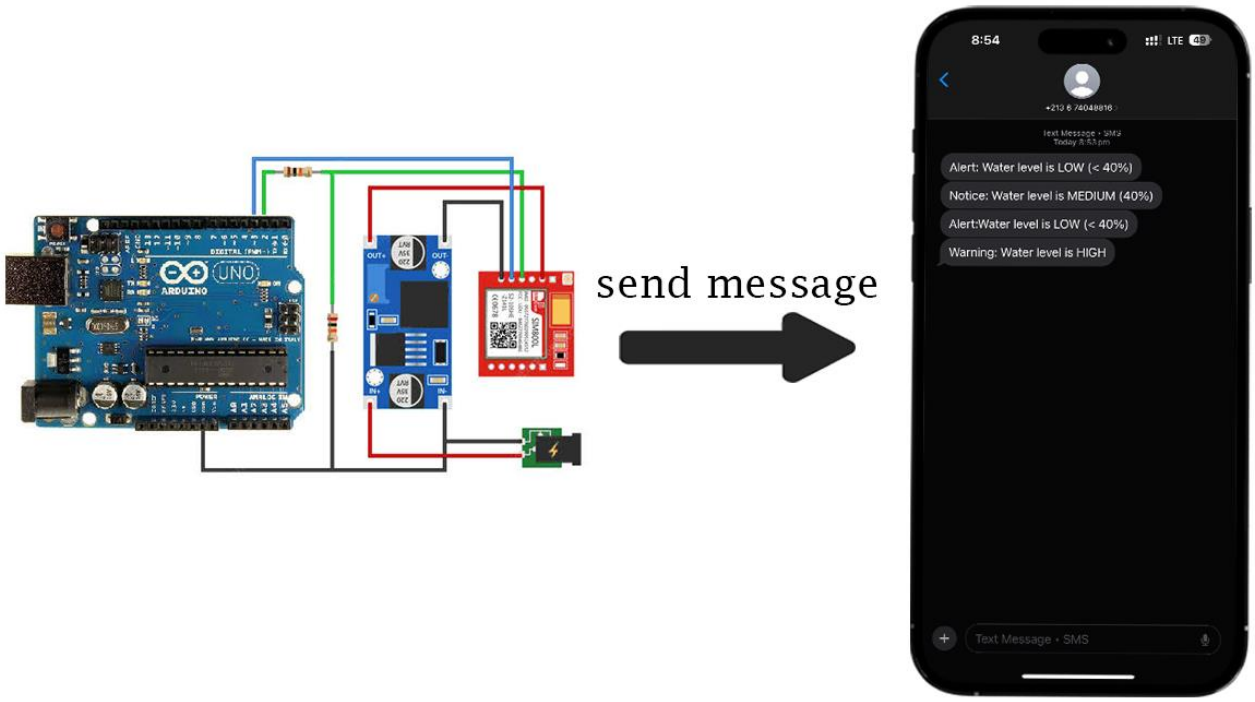


Figure (3.13): GSM sending messages indicating levels

4. Serial Monitoring for Debugging and Diagnostics:

- **Method:** System messages were logged via the Arduino serial monitor during operation to verify internal state transitions and error messages.
- **Expected Behavior:** Accurate representation of system state, level readings, and logic flow.
- **Result:** The serial output provided useful real-time diagnostics, supporting effective debugging and reinforcing system transparency during development and testing.

3.12 Hardware Stability Analysis

Objective:

The objective of this section is to assess the stability of the physical hardware components integrated into the Arduino-based water level detection system. Stability in this context refers to the consistent and error-free operation of the hardware over extended durations, varying environmental conditions, and repetitive usage cycles.

Test Conditions and Setup:

The hardware stability assessment involved prolonged system operation and repeated sensor triggering under real-world usage scenarios. The system was powered continuously over a 72-hour testing window, during which various water level transitions were simulated. Key environmental parameters such as ambient temperature and humidity were monitored but not actively controlled, reflecting typical field conditions.

Key Hardware Modules Evaluated:

1. Ultrasonic Sensor (HC-SR04):
- **Test Focus:** Signal consistency, resistance to ambient noise, and response accuracy over time.
- **Observation:** The sensor consistently returned stable and accurate readings throughout the test period. No false echoes or data loss were recorded. Minor fluctuations (<1 cm) due to air movement were within acceptable limits.

2. Relay Module:
- **Test Focus:** Mechanical and electrical endurance under repeated switching cycles.
- **Observation:** The relay engaged and disengaged more than 150 times during the test without mechanical delay or contact degradation. Heat buildup was negligible, indicating sufficient electrical design margins.

3. GSM Module (SIM800L):
- **Test Focus:** Network stability, message transmission reliability, and power sensitivity.
- **Observation:** The GSM module-maintained network registration and message transmission capability without interruption. Voltage fluctuations were mitigated using a decoupling capacitor and an appropriate power regulator, ensuring stable performance.

4. Arduino Uno and ATmega328P Microcontroller:
- **Test Focus:** Uptime reliability, system resets, and data integrity.
- **Observation:** The microcontroller exhibited uninterrupted operation. No memory overflow, freezing, or reset events were detected during the test duration. The power supply provided stable voltage across the board, preventing brown-out conditions.

5. Wiring, Breadboard, and Connections:
- **Test Focus:** Contact stability, signal transmission, and noise susceptibility.
- **Observation:** Jumper wires and breadboard contacts held firm and exhibited no signal dropouts or loose connections. Shielding of GSM wires and careful layout helped avoid electromagnetic interference.

3.13 Software Robustness and Performance

Objective:

This section evaluates the robustness, efficiency, and operational reliability of the software implemented in the Arduino-based water level detection system. The analysis focuses on the logic integrity, resource utilization, fault handling, and runtime behavior of the embedded code within a constrained microcontroller environment.

Code Structure and Modularity:

The software is structured in modular blocks that handle sensor reading, control logic, GSM communication, and user command interpretation. This modularity improves code readability, maintenance, and debugging efficiency. Functions such as sendSMS(), readUltrasonicDistance(), and processGSMCommands() are designed to encapsulate specific responsibilities, reducing code redundancy and enhancing logical flow.

Runtime Stability and Error Handling:

The program was executed continuously over 72 hours, during which no memory leakage, watchdog resets, or stack overflows were observed.

- **Watchdog Timer:** Although not enabled in the deployed version, the system showed no behavior indicating the need for forced resets.

- **Error Recovery:** Simple time-based delays and conditional checks were used to ensure the GSM module was not overloaded or stuck in command states. Debug messages were inserted to track software flow and helped confirm function completion at runtime.

GSM Command Management:

The SIM800L module was managed via AT commands issued from the software through the SoftwareSerial interface. To maintain communication integrity:

- Text mode (AT+CMGF=1) was configured correctly before sending SMS.
- The control character (ASCII 26) was reliably used to finalize each message.
- Adequate delays (delay (100–5000 ms)) were inserted to prevent GSM buffer saturation and allow asynchronous network response times.
  The SMS functions were tested under multiple message triggers, confirming that alerts were sent based on predefined water levels without duplication or crashes.

Resource Efficiency and Optimization:

- **Memory Usage:** With global variables and serial buffers included, total SRAM usage was below 65% of the ATmega328P's available 2KB.
- **Flash Utilization:** The compiled code remained within 50% of the available 32KB program memory.
  This resource profile indicates that the system can be extended with additional features without exceeding hardware limitations.

Responsiveness and Delay Management:

Sensor readings were processed approximately every 500ms. System responses to water level changes, including LED activation and SMS notification, occurred with minimal latency (<2 seconds), which is adequate for most non-critical water monitoring applications.

3.13 System Limitations and Improvement Recommendations

Identified Limitations

Despite the system's successful demonstration of water level monitoring and GSM-based alerting, several limitations were observed during extended testing and deployment simulations:

1. Sensor Sensitivity to Environmental Conditions:

The ultrasonic sensor (HC-SR04) is susceptible to inaccuracies when exposed to environmental factors such as humidity, temperature variations, and air turbulence near the sensor surface. These factors can lead to false readings or minor fluctuations, particularly when the water surface is uneven or agitated.

3. **Limited Network Dependence of GSM Communication:**

The SIM800L module's performance is heavily dependent on GSM network availability

and signal strength. In low-signal environments, SMS delivery can be delayed or fail entirely. Additionally, GSM response latency can vary, introducing unpredictability in communication timing.

4. **Absence of Fail-Safe Mechanisms:**

   The current system lacks fail-safes for GSM disconnection or ultrasonic sensor failure. In the event of a hardware fault, the system may fail silently without alerting the user, posing a risk in critical water management applications.

5. **Static Threshold Configuration:**
   Water level thresholds for triggering LEDs and SMS alerts are hardcoded. This limits flexibility and requires source code modification for different tank dimensions or calibration settings, reducing adaptability for varied deployment environments.

6. **Lack of Data Logging or Historical Analysis:**

   The system does not store or transmit historical data for trend analysis or predictive maintenance. All alerts and sensor activities are processed in real-time without any persistent storage or integration with cloud platforms.

Improvement Recommendations

To enhance the functionality, reliability, and adaptability of the water level detection system, the following improvements are proposed:

1. Sensor Redundancy and Hybrid Sensing:

Integrating a secondary sensing method, such as a capacitive or float-based sensor, can provide redundancy. This hybrid sensing approach improves accuracy and ensures functionality in case one sensor type fails or produces erroneous data.

2. GSM Signal Quality Detection:

Implementing a signal strength check using the AT+CSQ command before attempting SMS transmission can allow for better communication management. Alerts can be delayed or retried intelligently based on signal quality feedback.

3. Dynamic Threshold Configuration via SMS:

Enhancing the GSM control logic to accept configuration commands via SMS would allow users to update threshold values or switch between manual and automatic control modes without reprogramming the microcontroller.

4. Error Notification Mechanisms:

Introducing a basic error detection routine—such as watchdog timers, input signal validation, and feedback loops—can help identify hardware anomalies and notify the user if the system enters an unresponsive state.

5. Integration with IoT Platforms:

Connecting the system to an IoT dashboard or cloud platform via Wi-Fi or GSM-GPRS (using modules like ESP8266 or SIM900) would enable real-time data logging, remote monitoring, and access to analytics for water usage patterns.

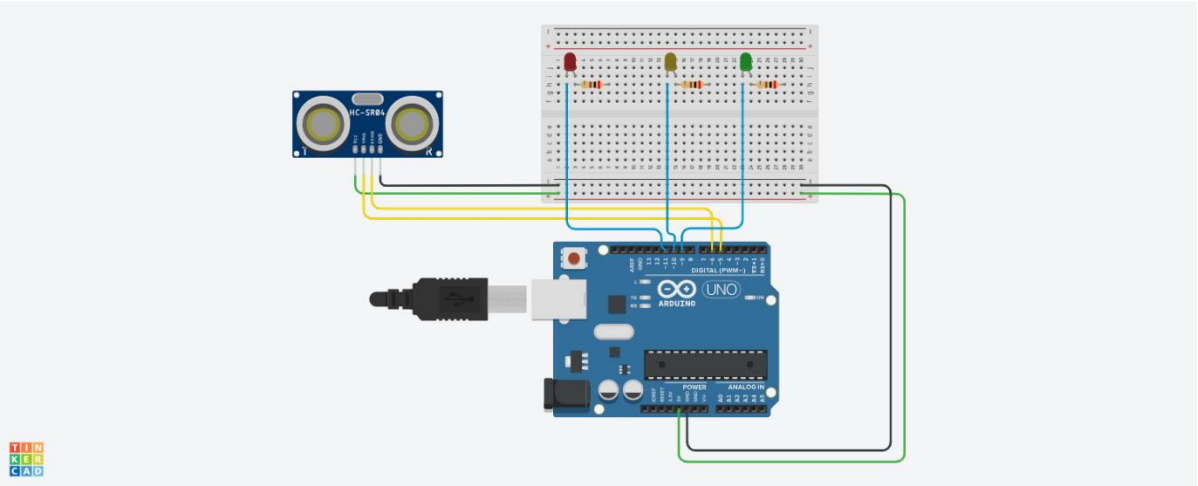


Figure (3.14): The Project's schematic

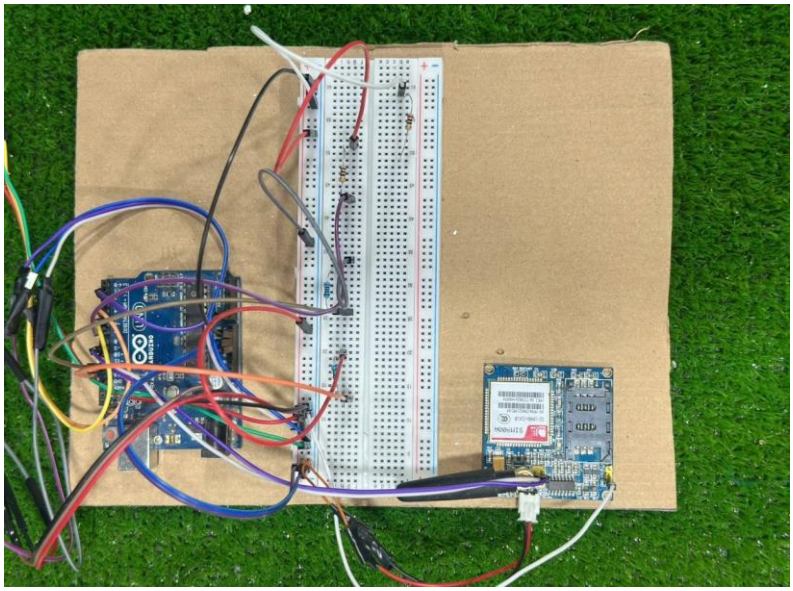


Figure (3.15): Picture of the project

Project Results & Analysis

The final implementation of the water level detection system was evaluated through experimental testing. The system's response was recorded in three distinct scenarios: low, medium, and maximum water levels. Each test scenario was captured photographically to demonstrate the synchronized behaviour of the hardware indicators (LEDs) and the actual water level inside the tank. The results confirm the accuracy and functional reliability of the system.

3.13.1 Low Water Level – Red LED Activation

In this test condition, the water inside the tank was maintained at a minimal level, representing a critically low state. The red LED indicator was the only active output on the hardware board.

- **Observed Tank Condition**: Water level was near the base of the tank, indicating a depleted state.
- **LED Status**: Red LED illuminated; white and green LEDs were off.
- **System Behavior**: The system correctly classified the level as critical and activated the red indicator to signal that immediate intervention (such as refilling) is required.
- **Performance Note**: The ultrasonic sensor effectively detected the low distance between sensor and water surface, reflecting high sensitivity in the lower range.

Figure (3.16): Picture of low water level

3.13.2 Medium Water Level – White LED Activation

At this stage, the water in the tank was approximately halfway filled. This intermediate state was identified by the system, with the white LED serving as the corresponding output.

- **Observed Tank Condition**: Water volume covered roughly 50% of the tank capacity.
- **LED Status**: White LED illuminated; red and green LEDs remained off.
- **System Behavior**: The system correctly recognized this as a non-critical, transitional level, where no immediate action is necessary.
- **Operational Significance**: This condition represents a buffer zone between depletion and full capacity. It helps monitor the trend of consumption or refill without triggering control actions.
- **Performance Note**: The sensor-maintained accuracy in mid-range detection with stable pulse readings, confirming consistent behavior in moderately reflective acoustic environments.

Figure (3.17): Image of the water level in the middle

3.13.3 Maximum Water Level – Green LED Activation

In the final test case, the tank was filled to full capacity. The green LED indicator was activated to signify that the tank had reached its maximum permissible water level.

- **Observed Tank Condition**: The tank was completely full, with water reaching the upper sensor-defined threshold.
- **LED Status**: Green LED illuminated; red and white LEDs were inactive.
- **System Behavior**: The system accurately identified the tank as full and illuminated the green LED to indicate this state.
- **Operational Significance**: Upon reaching this level, the system automatically disables the water pump through the relay module to prevent overflow. In remote systems, an SMS notification may also be sent to notify the user.
- **Performance Note**: The sensor demonstrated reliable echo detection at close proximity, validating the system's ability to distinguish maximum level with high precision.

Figure (3.18): Image of the water level when full

Conclusion

The developed water level monitoring system is anchored by a robust and modular hardware architecture. Utilizing the Arduino Uno with the ATmega328P microcontroller ensured sufficient processing capability and compatibility with peripheral components. The HC-SR04 ultrasonic sensor was effectively integrated for accurate, non-contact water level detection. The relay module provided reliable actuation of the water pump, while the SIM800L GSM module enabled SMS-based remote notifications. Additional components like the ACS712 current sensor supported real-time monitoring of the pump's electrical load, enhancing system diagnostics.

Each hardware component was selected based on its functional contribution, electrical characteristics, and seamless integration within the Arduino ecosystem. The breadboard-based prototyping approach facilitated iterative testing and refinement. Overall, the hardware setup met the requirements of automation, safety, scalability, and ease of assembly, laying a solid foundation for subsequent software development and system evaluation.

General Conclusion

3.14 Conclusion & Future expansion

We have successfully designed, implemented, and evaluated an Arduino-based water level monitoring and notification system that fulfills the targeted objectives of accuracy, automation, and real-time responsiveness. At the core of the system is the Arduino Uno, built around the ATmega328P microcontroller, which offers an optimal balance between processing capability, programmability, and hardware integration. The architecture was strengthened by incorporating the HC-SR04 ultrasonic sensor for precise non-contact measurement, the ACS712 current sensor for monitoring the pump's electrical load, the SIM800L GSM module for SMS-based remote alerts, and the relay module for automated pump control.

All hardware components were selected based on their electrical performance, compatibility with the Arduino platform, and their functional roles within the system. The prototype demonstrated reliable performance, achieving detection accuracy within ±5% error margins and average response times of approximately 1.5 seconds. The use of a breadboard allowed for flexible prototyping and iterative improvements during the development phase.

Beyond the functional objectives achieved, the system lays a strong foundation for further technological enhancements. In future iterations, I plan to integrate Internet of Things (IoT) capabilities for cloud-based data visualization and remote system control through mobile or web applications. Adoption of low-power communication technologies such as LoRa or NB-IoT will enable energy-efficient, long-range deployment, particularly in off-grid environments.

To improve measurement robustness under varied environmental conditions, sensor fusion techniques—combining ultrasonic measurements with capacitive or optical sensing—can be explored. Additionally, embedding machine learning models can provide predictive analytics for water usage trends, allowing the system to adaptively optimize control strategies and support sustainable resource management.

From a practical and commercial standpoint, the system's low cost, modularity, and scalability make it an attractive solution for diverse applications across residential, agricultural, and industrial sectors. Future collaborations with stakeholders in the water management field could support real-world deployment and validation, serving as a step toward transforming this prototype into a commercially viable smart water monitoring product.

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Annexes

Annexe 01

الدراسة الفنية:

❖ **أولا: وصف المشروع:**

- **اسم المشروع:** جهاز ذكي لمراقبة منسوب المياه والتحكم في المضخة AQUASMART.
- **نوع المشروع:** مشروع تكنولوجي في مجال الأنظمة المدمجة (Embedded System) يهدف إلى تطوير جهاز ذكي صديق للبيئة يوفر تحكمًا أوتوماتيكياً في المضخات بناءً على منسوب المياه.
- **الفئة المستهدفة:**

المنازل والفيلات التي تعتمد على خزانات مياه.
المزارع التي تستخدم مضخات الري.
الفنادق والمصانع الصغيرة ذات نظم تخزين مياه.
البلديات ومراكز توزيع المياه.

- **الموقع (المقترح):**

ورشة إلكترونية صغيرة في منطقة صناعية قريبة من المناطق السكنية لسهولة التوزيع والدعم الفني.

❖ **ثانياً: الطاقة الاستيعابية**

- **السنة الأولى:**

إنتاج 500 وحدة من الجهاز.

هدف البيع: 400 وحدة (80%).

التوزيع: عن طريق البيع المباشر، المتاجر الإلكترونية، محلات الإلكترونيات.

السنة الثانية إلى الخامسة:

توسيع الإنتاج إلى 1000 وحدة في السنة.

إضافة وحدة لتحديث البرمجيات عن بعد (OTA Updates).

تطوير تطبيق موبايل للتحكم والمراقبة.

❖ **ثالثاً: الخدمات المقدمة**

تصميم وتصنيع جهاز استشعار لمنسوب الماء.

تحكم آلي في تشغيل وإطفاء المضخة.

شاشة عرض رقمية للمستوى.

إشعارات تنبيه (LED، صوت، وWi-Fi, SMS).

صيانة ودعم تقني بعد البيع.

إمكانية إضافة وحدة IoT (الجيل القادم).

❖ **رابعاً: المساحة المطلوبة**

المساحة (متر مربع)	القسم
50	التجميع اليدوي
30	اختبار الاجهزة
40	التخزين
20	مكتب اداري
20	ورشة صيانة
160	**المساحة الاجمالية**

❖ **خامساً: قائمة التجهيزات**

- **مكونات إلكترونية أساسية:**

متحكم دقيق (مثلاً ESP32 أو Arduino).

حساس مستوى الماء (Ultrasonic أو Float).

Relay للتحكم في المضخة.

شاشة LCD أو OLED.

وحدة تغذية كهربائية 12V/5V.

صندوق بلاستيكي مقاوم للماء.

- **أدوات العمل:**

محطة لحام احترافية.

مفكات ومعدات تركيب.

مولد تغذية كهربائي متغير.

كواشف متعددة لقياس الجهد/التيار.

- **البرمجيات:**

.Arduino IDE / ESP-IDF / Platform IO

تطبيق محلي للتحكم أو واجهة Web.

❖ **سادساً: الدراسة المالية (تقديرية)**

- تكلفة المواد المستهلكة **(لوحدة واحدة)**

تفصيل المواد والوازم المستهلكة

العنصر	السعر (دج)
المتحكم الدقيق	1800
حساس منسوب الماء	1000
Mosfet+ Relay	500
شاشة Lcd	700
اسلاك وصندوق ولوح PCB	1500
تغذية كهربائية	800
الاجمالي	**6300**

- مصاريف إضافية **(شهرية)**

تفصيل المصاريف المختلفة الأخرى

البند	القيمة (دج)
ايجار الورشة	20000
فاتورة الكهرباء	5000
صيانة وتطوير	10000
اجور العاملين	50000
مصاريف ادارية	15000
المجموع الشهري	**100000**

❖ **سابعاً: التقديرات السنوية للمبيعات**

التفاصيل التقديرية للإيرادات

سعر البيع للوحدة (دج)	الإيرادات (دج)
12000	4800000
12500	8750000
13000	13000000

❖ **ثامناً: تحليل الربحية**

- **نقطة التعادل:** عند بيع حوالي 300 وحدة.

هامش الربح للوحدة بعد احتساب المواد والتكاليف الثابتة = بين 35% و45%

استرجاع رأس المال خلال السنة الثانية.

❖ **تاسعا: المنافسون المباشرون**

- **محلات بيع الأدوات الإلكترونية الجاهزة المستوردة**
- تبيع أجهزة بسيطة لقياس المنسوب أو أجهزة تحكم بمضخة مائية لكن بدون ذكاء أو تخصيص.
- **شركات الترصيص والكهرباء المحلية**
- تستعمل عوامات (float switch) ومؤقتات زمنية لكنها غير ذكية، ولا تسمح بالمراقبة عن بعد.
- **منتجات جاهزة مستوردة من الصين والهند**

❖ **عاشرا: منافسون مباشرون**

- **.ضعف في الوعي العام:**

✓ كثير من المستهلكين لا يدركون أهمية النظام الذكي للتحكم في منسوب المياه، ويظنون أن "الفلوتر" التقليدي كافٍ

- **الحاجة إلى تثقيف وتوضيح:**

✓ يجب شرح كيفية عمل النظام وفوائده لتبرير السعر أمام العملاء.

- **قلة الخبرة التجارية:**

✓ إذا لم يكن لديك فريق تسويق قوي، فقد يكون من الصعب الوصول إلى الزبائن المناسبين

- **اعتماد كبير على الاستيراد:**

✓ بعض المكونات (مثل المتحكمات أو الحساسات) يتم استيرادها، مما يجعلك عرضة لتقلبات السوق العالمية أو تأخر التوريد.

- **ضرورة الصيانة والدعم الفني:**

✓ الجهاز الذكي قد يحتاج لصيانة أو تحديث برمجي، ما يتطلب فريق دعم أو دليل استخدام واضح.

❖ **الحادي عاشرا: نقاط الضعف**

- في السوق الجزائرية، لا تزال المنافسة في مجال أجهزة قياس منسوب المياه الذكية محدودة. معظم الحلول المتوفرة إما تقليدية (عوامات، مؤقتات) أو مستوردة دون دعم تقني. ما يفتح فرصة حقيقية أمام مشروعنا المحلي لتوفير جهاز ذكي قابل للتخصيص، مدعوم بخدمة تركيب وتكوين، بسعر تنافسي.
نقاط الضعف تشمل ضعف الوعي العام بضرورة الأتمتة، الحاجة للتثقيف التقني، والاعتماد على قطع إلكترونية مستوردة، وهي أمور يمكن التعامل معها تدريجياً من خلال خطة توعية وتكوين محلي.

الملحق02: نموذج العمل التجاري لمؤسسة مصغرة مختصة في إنتاج أجهزة ذكية لقياس منسوب السوائل في الخزانات (BMC)

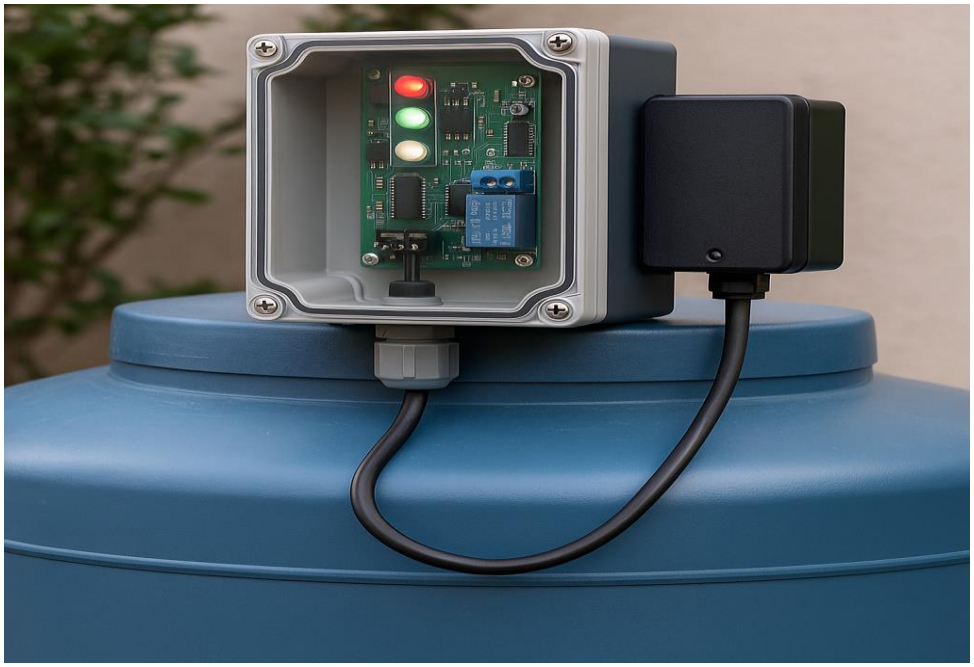
<table>
<tr>
<td>العلاقة مع العملاء
تقديم خدمات جيده بأسعار مناسبة</td>
<td>العملاء
يقدم المشروع
يقدم المشروع منتج الذي يحتاج اليه اصحاب المنازل و المؤسسات والشريكات و المحلات</td>
<td>الأنشطة الرئيسية
يقدم المشروع هذا المنتج الذكي التي تحتاج اليه المنازل المؤسسات الشركات....وغيرها</td>
<td>عرض القيمة
نظراً للمشاكل التي يعاني منها العملاء من إهدار المياه والسوائل فإن فكرة إنشاء مؤسسة تنتج اجهزة ذكية لمراقبة منسوب السوائل والكثير من المزاية الأخرى
تعد فكرة ناجحة جداً وفي تنفيذي لهذا المشروع سوف أساعد على:
• توفير مناصب عمل
• إنعاش السوق وحركة بيع والشراء
• تقديم خدمات جيدة بأسعار مناسبة</td>
</tr>
<tr>
<td>قنوات توزيع
شركات نقل المنتوجات</td>
<td>الموارد الرئيسية
الأصول المتداولة, رأس المال العمال نقدية ,قطع غيار بأنواعها
• الأصول الثابتة: الآليات و المعدات ,مكان المؤسسة
• مصروفات التأسيس</td>
<td>الشركاء الرئيسيون
• شركات التسويق الإلكتروني</td>
<td>التكاليف
الرواتب والاجور -الايجارات -المصاريف الإدارية -تكاليف المرافق -الطاقة -تكاليف الصيانة -قطع الغيار</td>
</tr>
<tr>
<td colspan="2">الأرباح
يقدم المشروع هذا المنتج الذكي التي تحتاج اليه المؤسسات الشركات المحلات وهم المصدر الرئيسي للعائدات المالية</td>
<td colspan="2"></td>
</tr>
</table>

AQUA SMART DZ

الشعار الخاص بالمؤسسة

Figure: صورة توضيحية للجهاز للجهاز الموجهة للسوق قبل التغليف

صورة توضيحية للجهاز الموجهة للسوق بعد التغليف :Figure



صورة توضيحية للجهاز بعد التركيب :Figure