COMPONENTS & TECH STACK (Expanded):

1. Rover Body

The physical design of the AquaSentinel rover is crucial for efficient movement and durability inside pipelines. It is typically cylindrical or elliptical to easily navigate through standard 4 to 6-inch diameter water pipes commonly found in residential buildings.

The body can be made using PVC tubing, which is waterproof, cost-effective, and easy to machine, or it can be 3D-printed using robust materials like PLA or ABS plastic for more customized, lightweight shapes. The casing is tightly sealed to prevent water ingress, ensuring protection for all internal electronic components.

Locomotion is achieved using rubberized wheels or tank-style crawler tracks, which offer better grip on slippery or wet surfaces. The wheelbase is optimized for maneuverability and stability, even in inclined or slightly curved pipeline sections. The design also considers compactness and modularity, allowing easy repair or replacement of parts.

2. Sensors

Sensors are the eyes and ears of the AquaSentinel rover. They continuously gather environmental and pipeline data that is vital for detecting leakages and anomalies.

1. Moisture Sensor (YL-69 or Capacitive Type):

The moisture sensor helps detect water presence on pipe surfaces where moisture should not exist. The YL-69 is a resistive sensor that works by measuring conductivity between two prongs, but it corrodes over time in wet conditions. Capacitive sensors, on the other hand, measure changes in dielectric constant and are corrosion-resistant, longer-lasting, and more accurate in continuous water environments.

2. Water Flow Sensor (YF-S201 or FS300A):

These sensors detect changes in the flow rate of water within the pipeline. They work by using a rotating turbine with a magnetic sensor that sends electrical pulses based on the speed of water flow. Any significant drop, spike, or irregularity in the pulse frequency can indicate a blockage or leak. Flow data can also help in identifying pipe narrowing due to sediment or corrosion.

3. Ultrasonic Sensor (HC-SR04):

This sensor emits high-frequency sound waves and measures the time it takes for the echo to bounce back from surfaces. In the rover, it is used for distance measurement from pipe walls or obstacles. This allows the rover to stay centered within the pipe and avoid collisions with unexpected debris or narrowing sections. It also helps in mapping the internal pipe geometry.

4. Camera (ESP32-CAM or Pi Camera):

A compact visual surveillance system can be integrated using a Wi-Fi-enabled camera like the ESP32-CAM. It provides live video streaming or image capture of the pipe’s interior. This is useful in identifying physical damage like cracks, biological growth, or sediment buildup. It complements the sensors by offering visual verification, especially when sensor data is ambiguous.

3. Controller (Microcontroller Unit)

The microcontroller is the brain of the AquaSentinel. It processes sensor input, makes logical decisions, and controls the movement and communication of the rover.

ESP8266 NodeMCU is a popular Wi-Fi-enabled microcontroller known for its small size, low power consumption, and affordability. It allows real-time transmission of sensor data to the cloud or a mobile app through platforms like Arduino IoT Cloud, Blynk, or Firebase.

Alternatively, an Arduino Uno can be used in combination with an external Wi-Fi module (like ESP01), especially if the system needs more GPIO pins for interfacing additional sensors and actuators.

The controller is programmed using Arduino IDE or PlatformIO, and it uses algorithms to:

- Analyze moisture/flow data.
- Detect anomalies.
- Control the direction/speed of motors.
- Transmit alert signals and logs to users wirelessly.

The controller is also designed to enter low-power sleep modes when idle, improving battery efficiency.

4. Power Supply System

Powering the AquaSentinel efficiently is crucial for autonomous operation over long periods inside inaccessible pipelines.

The rover uses rechargeable lithium-ion batteries (like 18650 cells), chosen for their high energy density, reusability, and compact form. Depending on the expected runtime, 1–2 cells can be used in series or parallel configurations.

To manage power distribution, a battery management system (BMS) is integrated to protect the battery from overcharging, deep discharge, and short circuits.

Voltage regulators (like AMS1117 or buck converters) are used to provide stable 5V or 3.3V outputs to sensitive electronics like microcontrollers and sensors.

Motors are controlled by efficient motor driver ICs such as L293D or L298N, which can handle DC motor direction and speed using PWM (pulse width modulation) signals.

The entire system is optimized for minimal energy loss, allowing extended missions without frequent recharging.