

# Functional Testing – TRAQUA

## Introduction

To ensure that the TRAQUA smart bottle operates reliably and safely, several functional tests were performed during the prototype development process. These tests were conducted to validate the operation of the electrical systems, embedded sensors, wireless communication, power management, and subsystem integration. Because the prototype combines both hardware and software components, each subsystem was initially tested individually before evaluating the complete integrated system.

The testing procedures were designed to simulate realistic operating conditions for the smart bottle. Sensor outputs, voltage levels, communication behavior, and overall component performance were monitored using serial communication, multimeter measurements, and direct observation. The results obtained from these experiments provide insight into the reliability and functionality of the prototype while also identifying areas for future improvement.

## Water Quality Sensor Testing

### Objective

The objective of this test was to verify that the TDS sensor can accurately detect changes in water quality and correctly transmit the measured values to the ESP32 microcontroller.

### Background

Water quality monitoring is one of the primary functions of the TRAQUA smart bottle. The TDS sensor measures dissolved solids in water by detecting conductivity variations. Reliable measurements are essential because the mobile application depends on these values to inform users about the quality of the water inside the bottle.

### Components Tested

- ESP32 DevKit V1
- DFRobot SEN0244 TDS Sensor
- Analog input circuitry
- Serial communication interface

### Testing Method

The TDS sensor was connected to the ESP32 analog input according to the manufacturer's wiring diagram. Several water samples were prepared, including bottled water, tap water, and contaminated water containing higher impurity concentrations. Measurements were continuously monitored through the Serial Monitor.

Special attention was given to:

- Measurement stability
- Response speed
- Consistency between repeated measurements

### Observations

The sensor successfully detected clear differences between the tested water samples. Bottled water produced the lowest TDS readings, while contaminated water generated the highest values. Minor fluctuations were observed during idle operation; however, the readings remained stable overall.

### Results Table

Test Sample	Expected Result	Measured Value	Analog Output	Status
Bottled water	Low TDS	57 ppm	194 mV	PASS
Tap water	Medium TDS	83 ppm	283 mV	PASS
Dirty water	High TDS	110 ppm	375 mV	PASS
Idle stability	Stable readings	1–3 ppm fluctuation	4.7 mV fluctuation	PASS

### Conclusion

The TDS sensor operated successfully and responded correctly to different water quality conditions. The ESP32 accurately processed the analog values and converted them into readable ppm measurements. Although minor analog noise was present, the overall functionality satisfied the prototype requirements.

## Motion Sensor Testing

### Objective

The purpose of this test was to verify that the accelerometer-based motion detection system can accurately detect bottle orientation and movement.

### Background

The TRAQUA smart bottle uses an accelerometer to detect movement and orientation changes. This functionality improves measurement reliability by identifying unstable conditions while the bottle is moving or tilted.

### Components Tested

- LIS3DHTR Accelerometer
- ESP32 DevKit V1
- I2C communication interface

### Testing Method

The accelerometer was connected to the ESP32 using the SDA and SCL communication lines. The bottle was tested under several orientations, including:

- Upright position
- 30° tilt
- 60° tilt
- 90° tilt

Sensor values were monitored through the Serial Monitor during testing.

### Observations

The accelerometer accurately detected orientation changes and produced stable readings during stationary operation. Only very small fluctuations were observed during idle conditions.

### Results Table

Test Case	Expected Result	Actual Result	Status
30° tilt	Accurate angle	30°	PASS
60° tilt	Accurate angle	60°	PASS
90° tilt	Accurate angle	90°	PASS
Idle upright	Stable reading	0–1° fluctuation	PASS

### Conclusion

The motion detection system functioned correctly and provided accurate orientation measurements while maintaining stable communication with the ESP32.

## Power Supply Management Testing

### Objective

The purpose of this test was to verify that the power supply system can provide stable voltage to all components during operation.

### Background

The power management system is essential because all sensors, communication systems, and the UV-C sterilization module depend on stable electrical power. The prototype uses a lithium-ion battery pack connected to a Battery Management System (BMS) protection module.

### Components Tested

- 4S lithium-ion battery pack
- BMS protection module
- Buck converter (16 V to 5 V)
- ESP32 DevKit V1
- Sensor systems
- UV-C sterilization module

### Testing Method

Voltage measurements were collected using a multimeter during several operating conditions. Individual battery cell voltages and BMS input/output voltages were verified throughout operation.

### Observations

The battery pack successfully powered all connected systems during testing. The buck converter operated as intended by stepping down the battery voltage from approximately 16 V to a stable regulated 5 V output required by the ESP32 and sensor systems. The output voltage remained stable during operation without noticeable fluctuations. However, incompatibility was identified between the charger and the selected 4S battery and BMS configuration.

### Battery Pack Measurements

Battery	Expected Result	Actual Voltage	Status
B1	Charged	4.04 V	PASS
B2	Charged	3.66 V	PASS
B3	Charged	4.10 V	PASS
B4	Charged	3.61 V	PASS

### BMS and Buck Converter Measurements

Test Case	Expected Result	Actual Result	Status
BMS input voltage	Functional	15.37 V	PASS
BMS output voltage	Functional	15.36 V	PASS
Buck converter output	Stable 5 V output	5.01 V	PASS

## Charger System

Test Case	Expected Result	Actual Result	Status
Charging with BMS	System charges correctly	Charging failed due to 4S mismatch	FAIL

### Conclusion

The battery system, BMS, and buck converter operated successfully and provided stable voltage during operation. The buck converter reliably stepped down the battery voltage from 16 V to a regulated 5 V supply for the ESP32 and connected electronics. However, the charger system remained incompatible with the selected 4S configuration, preventing proper charging of the battery pack.

## UV-C Sterilization System Testing

### Objective

The purpose of this test was to verify that the UV-C sterilization system can be safely controlled through the ESP32 microcontroller.

### Background

The TRAQUA prototype includes a UV-C sterilization module designed to reduce bacterial contamination inside the bottle. Since UV-C systems require controlled operation, the switching behavior needed validation.

### Components Tested

- UV-C LED module
- IRLZ44N MOSFET
- ESP32 DevKit V1
- Battery system

### Testing Method

The UV-C module was connected through a MOSFET switching circuit controlled by the ESP32. Multiple activation and deactivation cycles were performed during testing.

### Observations

The UV-C module activated successfully whenever commanded by the ESP32. The MOSFET switching circuit provided stable operation with no unintended activation during idle conditions.

### Results Table

Function Tested	Expected Result	Actual Result	Status
ON command	UV-C activates	Turns on	PASS
OFF command	UV-C deactivates	Turns off	PASS
Idle state	No unintended activity	No activity observed	PASS

### Conclusion

The UV-C sterilization system operated successfully and responded correctly to ESP32 control signals during repeated operation cycles.

## Environmental Sensor Testing

### Objective

The purpose of this test was to verify that the environmental sensor can accurately measure ambient temperature and humidity.

### Components Tested

- Temperature and humidity sensor
- ESP32 DevKit V1

### Testing Method

The sensor was tested under normal room temperature conditions and direct body heat exposure. Measurements were continuously monitored through the Serial Monitor.

### Observations

The sensor successfully measured both temperature and humidity values. Temperature readings responded correctly to body heat exposure, while humidity values remained stable during operation.

### Results Table

Test Case	Expected Result	Actual Result	Status
Room temperature	~28°C	28.7°C	PASS
Body temperature	~33–36°C	34°C	PASS
Humidity	Stable reading	48–48.5%	PASS

### Conclusion

The environmental sensor operated successfully and provided stable temperature and humidity measurements throughout testing.

# Force Sensitive Resistor (FSR) Testing

## Objective

The purpose of this test was to verify that the force sensitive resistor can estimate bottle fill level by detecting changes in weight.

## Background

The TRAQUA prototype uses an FSR sensor to estimate the quantity of water remaining inside the bottle. This functionality may support hydration tracking and refill monitoring.

## Components Tested

- FSR406 Force Sensitive Resistor
- ESP32 DevKit V1
- Analog measurement circuit

## Testing Method

Different water levels were added to the bottle while monitoring the analog output values of the FSR sensor.

## Observations

The FSR successfully detected changes in applied force as the bottle weight increased. Higher water levels consistently produced larger analog readings.

## Results Table

Bottle State	Expected Result	Sensor Reading	Status
0–10% water level	Low reading	620	PASS
40–50% water level	Medium reading	2000	PASS
95–100% water level	High reading	3700	PASS
Idle/no load	Stable low reading	~620 stable	PASS

## Conclusion

The force sensitive resistor successfully detected weight changes and demonstrated the ability to estimate relative bottle fill level within the prototype.

# ESP32 Microcontroller Testing

## Objective

The purpose of this test was to verify the stability and communication performance of the ESP32 microcontroller.

## Components Tested

- ESP32 DevKit V1
- Wi-Fi communication system
- Sensor integration interfaces

## Testing Method

The ESP32 was tested during startup, wireless communication, and continuous operation while connected to the integrated sensor systems.

## Observations

The ESP32 remained stable throughout operation and successfully communicated with all connected systems. Wi-Fi connection times averaged approximately three seconds.

## Results Table

Test Case	Expected Result	Actual Result	Status
Connection speed	Instant connection	~3 s connection time	PASS
System stability	Stable operation	Stable with app connection	PASS

## Conclusion

The ESP32 microcontroller operated reliably and maintained stable communication with both hardware and software subsystems.

## Overall Conclusion

The functional testing confirmed that the TRAQUA smart bottle prototype operates reliably and that all major subsystems function as intended. The sensors, ESP32 microcontroller, UV-C sterilization system, and power management system all produced stable and consistent results during testing.

Although minor sensor fluctuations and a charger incompatibility with the 4S battery configuration were identified, the overall prototype successfully met the primary functional requirements and provides a strong foundation for future improvements and development.