



TECHNICAL SCIENTIFIC REPORT

Technical Report “Detection of environmental contaminants”

Hat sensor network for contaminant detection - (Specifications of)

Author
Fabrizio Silva
Ittalo Pezzotti Escobar
Giovanni Paolo Viganò

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1. INTRODUCTION

Leveraging the technology developed at the STIIMA institute, a 5-axis 3D printer was utilized to create a sensorized hat. The project aimed to employ a flexible, durable, and reproducible material, integrating sensors and technology for measuring analog variables. This type of machine enables the customization and personalization of objects—such as the hat—by embedding sensors, circuits, devices, and batteries, making them suitable for everyday use. The resulting wearable device can be worn daily, functioning seamlessly during routine activities. It has various applications, including the measurement of environmental contamination parameters, oxygen presence, hydrocarbon saturation, carbon monoxide levels, carbon dioxide increases, and localized climatic changes. Additionally, the system incorporates a camera for applications such as artificial vision, cartography, or mapping, among other uses.

The communication system for collecting data and images consists of the following components:

- An RTC clock to maintain configuration and register data by date and time,
- Bluetooth for communication with mobile devices (tablet, smartphone, smartwatch),
- An SD memory card for automatically storing hourly data,
- A GPRS system for cloud storage, enabling real-time data access.

The hat is constructed using filament weaving to form a circular structure, which is subsequently thermoformed with steam and high pressure. This wearable device is designed to be lightweight, compact, and durable, offering ample space to integrate sensors and hardware. Although alternatives such as backpacks or fanny packs were considered, these options failed to deliver equivalent sensor performance since the algorithm relies on the user's line of sight. Consequently, a "Panama" hat style was chosen, allowing it to rest on the user's head while leaving their hands free. Sensors are strategically placed around the brim and on the top of the hat, while the hardware—including the microcontroller, batteries, and communication devices—is housed inside for optimal sensor control.

To monitor gas concentrations, the system includes six gas sensors and one oxygen sensor, arranged in a circular formation. These sensors, which are sensitive to specific gases as shown in (Fig. 1), operate by varying resistance. The sensor sequence is as follows: MQ2, MQ3, MQ4, MQ5, MQ7, MQ135, followed by the oxygen sensor (WE2). This arrangement allows the system to detect and determine various concentrations or the presence of specific gaseous compounds or elements.

Additional features include:

- An integrated humidity sensor,
- A digital infrared temperature sensor,
- An optical particulate and dust sensor for measuring PPM (parts per million) at each location, which correlates humidity and temperature trends with gas parameter readings.

2. HAT REENGINEERING FOR ADDITIVE MANUFACTURING

2.1. Manufacturing Process

To simplify the production process and avoid the need for manual weaving and thermoforming, the hat is sometimes divided into three pieces, which are then sewn together using adapted sewing machines. This approach was adopted for this project, aiming to create three separate sections using additive manufacturing technology.

To replicate the geometry of the original sample, layers of paper tape were applied, and the contours of the individual pieces were identified. These pieces were detached and flattened onto sheets of paper, transforming a three-dimensional object into two-dimensional templates.

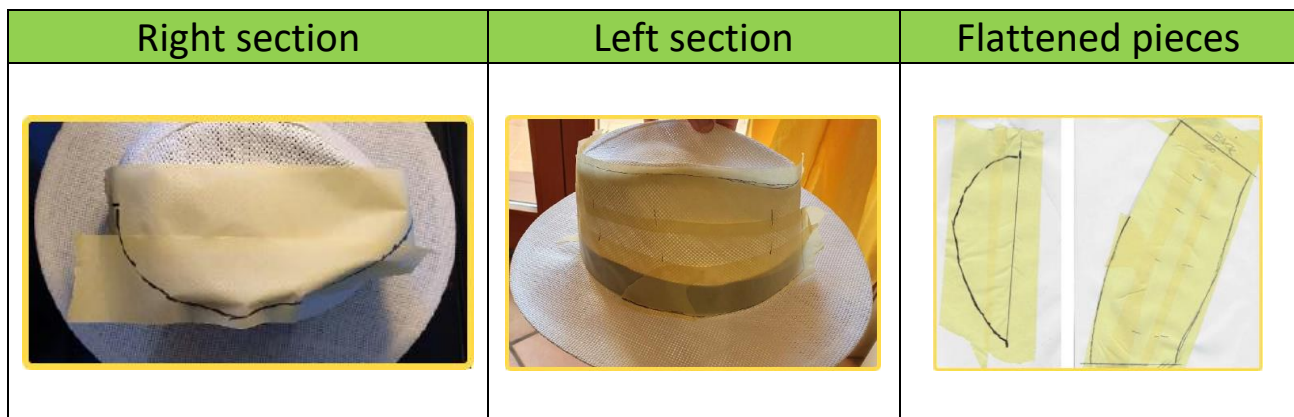


Figure 1 – Re-engineering of the hat through paper mode.

2.2. Design

The flattened, 1:1 scale templates were scanned and imported into **Rhinoceros**, a CAD software for 2D and 3D modeling. Using the software, planar geometries were derived by

tracing the scanned drawings, which were then converted into surfaces and 3D solids. These were optimized and finalized for additive manufacturing.

2.3. Toolpath Generation

The completed 3D models were exported in STL format, suitable for 3D printing. These STL files were processed in slicing software, which generates the toolpaths needed for printing and outputs the GCODE file.

Key printing settings:

- First layer height: 0.3mm (to improve adhesion to the printing surface),
- Nozzle diameter: 0.6mm,
- Layer height: 0.5mm,
- Infill: The first layer uses a 0.3 infill for solidity, while subsequent layers are set to a 4mm criss-cross infill pattern to mimic fabric-like properties.

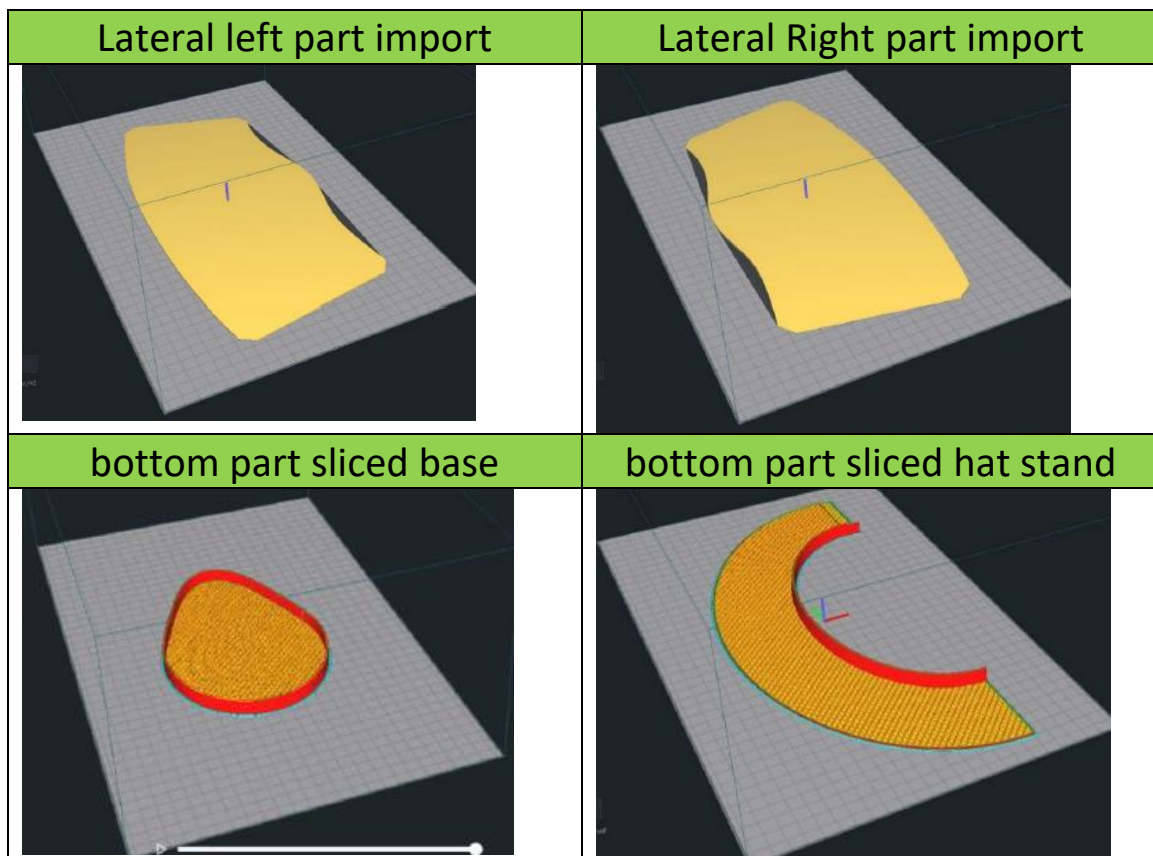


Table 1 – Toolpaths generation with slicer software.

2.4.3D Printing Technique

Image Acquisition and Algorithms:

Various 3D scanning techniques have been implemented to inspect the quality of 3D-printed objects. Notable approaches include:

- A **laser scanner system** developed by Heralic et al., used to monitor surface variations in metal wire deposition processes [15].
- A **stereo vision system** employed by Nuchitprasitchai et al., which performed a 360° scan to detect surface defects [16].
- **3D-SLSS** (Structured Light Scanning System) used by Li et al. to monitor surface topography and fusion areas during powder bed fusion processes [17].

3D-SLSS offers advantages such as high speed, automation, and precision. It generates high-quality 3D scans with approximately 100 µm accuracy, capturing millions of data points per object.

2.5. Image analysis

2.5.1. 3D-SLSS test setup

The two optical devices used in the 3D-SLSS system in this study were:

1. A **digital light processing (DLP) projector** (LightCrafter 4500 [29]), and
2. A **high-speed camera** (Phantom VEO 340L [30]) (Fig. 4).

Both devices were simultaneously controlled using a microcontroller (Arduino [31]). The projector and camera featured resolutions of 912×1140 pixels and 1280×960 pixels, respectively, and were calibrated using the method described by Li et al. [26]. The image acquisition rate was 166 Hz.

To retrieve phase data, three-step phase-shifted patterns were utilized, while an additional set of three-step phase-shifted binary dithered patterns facilitated phase unwrapping. This 3D-SLSS system achieved an impressive point accuracy of approximately 100 µm, capturing more than a million data points per object.

The system also demonstrated strong resistance to noise, leveraging phase information derived from the phase-shifted fringe patterns to reconstruct 3D geometry. This robustness allows it to quickly and precisely scan complex objects with high accuracy.

2.5.2. 3D image creation

Images were captured from four different directions (0°, 90°, 180°, and 270°). The resulting scans provided side and top views of the printed samples (Fig. 5).

2.5.3. 2D plots and geometry characteristics

After scanning and reconstructing the images of a sample, 16 two-dimensional (2D) cross-sectional plots, referred to as surface profiles (Positions 1–16 in Fig. 5b), were extracted from the sides of the samples. These profiles were used to quantify various parameters, including:

- **Sample height** (H_{total}),
- **Layer thickness** (TL),
- **Surface roughness** (R),
- **Surface angle** ($S\alpha$), and
- **Semi-cross-sectional area** (XA) (Fig. 6a).

Additionally, eight 2D cross-sectional plots (Sections 1–9, 2–10, ... 8–16 in Fig. 5b) were extracted from the top view images. These plots were analyzed to determine the **outer diameter** of the sample (DM_{outer}) and the **layer width** (WL) (Fig. 6b).

2.6. Materials and methods

2.6.1. 3D printing materials

The hat to be printed will be divided into three pieces and must be lightweight and highly flexible. To achieve this, we have chosen TPU (Thermoplastic Polyurethane) as the material. This selection ensures that the final object has a realistic and flexible appearance.

Material Characteristics:

- **Material:** YOYI TPU Filament
- **Specifications:**
 - 1.75mm TPU Flexible 3D Printer Filament
 - Weight: 0.8kg
 - Dimensional Accuracy: +/- 0.02mm
 - Color: Orange

Since TPU is a relatively new material, a printing campaign was conducted to characterize its behavior before using it for the project. The testing involved a multi-axis system equipped with a filament extruder. Based on the material specifications, its operating temperature ranges from 200°C to 240°C.

2.6.2. Process preparation, accessories and tools.

The primary objective of this process is to carefully select the accessories, procedures, and machine configuration parameters required to generate the model in sections. Due to the model's large size, certain variables—such as temperature, printing speed, and material type—play a crucial role in ensuring the success of the project.

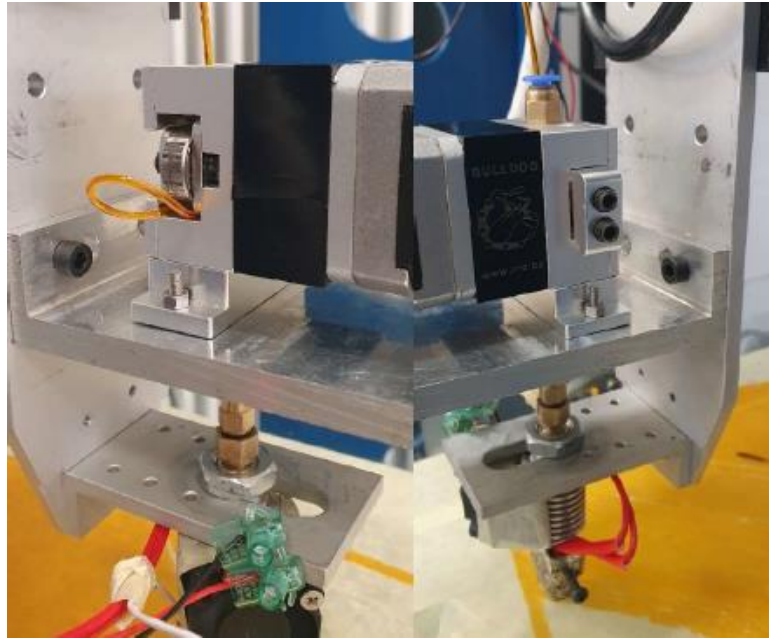


Figure 2 – Process preparation, accessories and tools.

2.6.3. Configuration and parameters for printing

As illustrated in the accompanying image, the 3D printer generates the model by printing the material in sections. The process begins with the sides and progresses to the main base. Once all parts are completed, the assembly is finalized using heat and appropriate adhesive, resulting in a solid structure capable of supporting the sensors and other components.



Figure 3 – Configuration and parameters for printing.

Table 1 shows some parameters such as payment, heat welding, cooking and the advantages and disadvantages.

metodo	Pro	Contro	Voto
Termosaldatura con colla a caldo	Velocità nell'applicazione, buona tenuta	Le alte temperature deformano/sciolgono il materiale tpu	5
Termosaldatura a caldo	Buona tenuta all'incollaggio	Difficoltà su superfici curve o tridimensionali	4
Colla a contatto	Buona tenuta, flessibilità del pezzo incollato	Tempi lunghi di asciugatura	6
Colla millechiodi	Trasparenza del materiale	Rigidità della parte dopo l'asciugatura; tempi lunghi di asciugatura	6
Cianoacrilato(loctite)	Ottima tenuta; tempi brevi di asciugatura	Leggera rigidità dopo l'asciugatura	7
Cucitura punti metallici	Velocità di applicazione; buona tenuta	Non di semplice impiego su forme non planari	6
Cucitura punti a filo		L'ago spesso rompeva il pezzo da cucire o la trama del medesimo; poca tenuta	4

Table 2 – Analysis of the method with respect to other parameters

3. DATA MEASUREMENT SYSTEM WITH GAS SENSORS CONCENTRATION

3.1. Sensor measurement method for the hat

The measurement method depends on the environmental contaminant that is nearby, and in the first case, it also depends on the application.

In contamination function: When the firmware or program is parameterized in this mode, the system analyzes the environment to determine its status. During this mode, the number of steps, the sector, and the area location are determined and schematized using GPS and a camera.

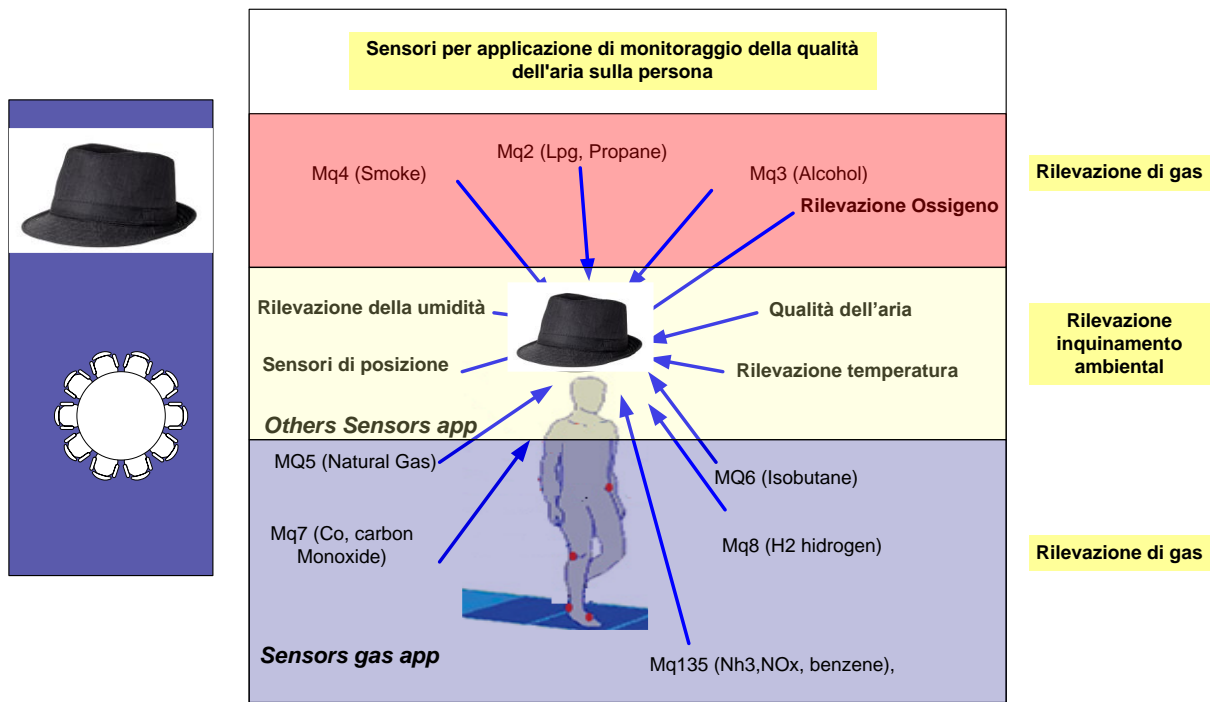


Figure 4 – Sensor measurement method for the hat .

3.2. System composition

Figure 4 – Sensor measurement method for the hat

3.2. System Composition

The sensors have been selected for specific applications to detect certain pollutants, including:

- MQ2 (Smoke)
- MQ3 (Alcohol)
- MQ4 (Methane)
- MQ5 (Natural Gas)
- MQ6 (LPG)
- MQ7 (Carbon Monoxide)
- MQ135 (Air Quality and CO₂)

The first challenge is the calibration of these sensors for the custom-built application, which involves monitoring gases in a transient state, using an open-loop system in uncontrolled conditions.

During measurement, it is necessary to record the time and date, humidity, internal and external temperature using a PIR sensor, Voltage_Resolution, ADC_Bit_Resolution, and GPS coordinates from the start button to map the system's area and travel time. Each sensor for independent measurements must include oxygen. For carbon monoxide and air quality applications, all sensors are used.

3.3. Composition of the data line

- Detection of smoke gases

Conventional smoke detection in fire alarm systems relies on measuring physical properties of smoke aerosols (ionization and optical detectors), temperature increases (thermal detectors), or electromagnetic radiation emitted by the fire (radiation detectors).

*[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ2]+[MQ135_QUALITY]+[IMAGE]+[FILM]+[GPS]+*

In this mode, the application focuses on measuring smoke contaminants using the MQ2 sensor.

- **Sensor for alcohol detection**

Sensor for Alcohol Detection

For gases like ethylene oxide, cross-sensitivity can be problematic because it requires an active working electrode catalyst and high operating potential for oxidation. Gases more easily oxidized, like alcohols and carbon monoxide, may also trigger responses. Cross-sensitivity can be mitigated with chemical filters that remove common interferences.

*[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ3]+[IMAGE]+[FILM]+[GPS]+*

While electrochemical sensors offer many advantages, they are not suitable for detecting every type of gas. Since the detection mechanism involves the oxidation or reduction of the target gas, electrochemical sensors are typically limited to electrochemically active gases. However, it is possible to detect electrochemically inert gases indirectly if the gas interacts with another species in the sensor, which then produces a measurable response.[3] Sensors for carbon dioxide are an example of this approach and have been commercially available for several years.

The cross-sensitivity of electrochemical sensors can also be exploited in the design of chemical sensor arrays, which use a combination of specific sensors that are cross-reactive. This allows for fingerprint detection of target gases in complex mixtures."

- **Methane measurement**

Methods for measuring enteric methane from livestock include enclosure chambers, tracer techniques, "sniffer" techniques, and handheld laser methane detectors. The "gold standard" for measuring enteric methane emissions from farm animals (ruminants and nonruminants) is the respiration chamber.

*[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ4]+[MQ135_QUALITY]+[IMAGE]+[FILM]+[GPS]+*

- **Measure natural gas**

Catalytic sensors detect the presence of combustible gases by means of a catalytic reaction. The sensor contains a small heated element covered by a catalyst. When the gas comes into contact with the element, it oxidizes, generating heat. The increase in temperature causes a change in the electrical resistance of the element, which is measured to determine the concentration of the gas.

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ5]+[MQ135_QUALITY]+[IMAGE]+[FILM]+[GPS]+

Catalytic sensors have several advantages:

- Lower Cost: Catalytic sensors are generally cheaper to manufacture and purchase than infrared sensors.
- Wide Range of Detectable Gases: They can detect a wide range of combustible gases, including methane, propane, and hydrogen.
- Reliability in Various Conditions: They perform well in a variety of environmental conditions and are suitable for many industrial applications."

• MEASURE LIQUEFIED PETROLEUM GAS (LPG)

Liquefied petroleum gas, also known as liquid petroleum gas (LPG or LP gas), is a fuel gas that contains a flammable mixture of hydrocarbon gases, primarily propane, n-butane, and isobutane. It can also sometimes contain small amounts of propylene, butylene, and isobutene.

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ6]+[MQ135_QUALITY]+[IMAGE]+[FILM]+[GPS]

• MEASURE CARBON MONOXIDE (CO)

Carbon monoxide (chemical formula CO) is a poisonous, flammable gas that is colorless, odorless, tasteless, and slightly less dense than air. It consists of one carbon atom and one oxygen atom connected by a triple bond, making it the simplest carbon oxide. In coordination complexes, the carbon monoxide ligand is called carbonyl. CO is a key component in many industrial chemistry processes.

Measure carbon Monoxide (CO)

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ7]+
[Mq2]+[Mq3]+[Mq4]+[MQ5]+[MQ6]+ [Mq135{2}] + [Mq135](air quality)
+[IMAGE]+[FILM]+[GPS]

• MEASURE CARBON DIOXIDE (CO2)

Carbon dioxide is a chemical compound with the formula CO₂, composed of one carbon atom covalently double-bonded to two oxygen atoms. It is a gas at room temperature and plays a key role in the carbon cycle as the primary carbon source for life on Earth. While CO₂ is transparent to visible light, it absorbs infrared radiation, acting as a greenhouse gas. CO₂ is soluble in water, forming carbonate and bicarbonate (HCO₃⁻) ions, contributing to ocean acidification as atmospheric levels rise.

Measure Carbon dioxide (CO₂)

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ135{1}] + [MQ135{2}_QUALITY] + [IMAGE]+[FILM]+[GPS]+

3.4. Measure air quality

Air pollution measurement involves collecting and analyzing the components of air pollution, such as gases and particulates. Early devices included rain gauges for studying acid rain, Ringelmann charts for measuring smoke, and soot/dust collectors known as deposit gauges.[1] Modern air pollution measurement is automated, utilizing a range of devices from simple absorbent diffusion tubes to advanced sensors that provide near real-time data.

These devices measure pollutants like O₃, NO₂, and SO₂ and generate air quality indexes (AQI).

Pollutants O₃, NO₂, SO₂

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[MQ135_QUALITY]+ [MQ2] +[IMAGE]+[FILM]+[GPS]+

Air quality is measured using the Air Quality Index (AQI), which operates like a thermometer ranging from 0 to 500. Instead of indicating temperature, the AQI reflects the amount of pollution in the air.

3.5. Measure air

Measurements of air pollutant concentrations are normally carried out at fixed site monitoring stations. An alternative for some pollutants is to attach personal monitors to volunteers to measure personal exposure directly. Such measurements can differ greatly from fixed site measurements of concentration as the population spend majority of their time indoors, where concentrations can differ appreciably from those out-of-doors. Measurements of air pollutant concentrations are best considered in the context of the entire air quality management process. In general, the purpose of local air quality management is to safeguard human health, and hence an understanding of the overall process is valuable.

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[Mq2]+[Mq3]+[Mq4]+[MQ5]+[MQ6]+[MQ7]+[Mq135{2}]+ [Mq135](air quality)
+[IMAGE]+[FILM]+[GPS]

3.6. All sensors methods measure:

In this method, the mobile and portable device is simply used to measure different concentrations of present gases, while moving through some sector of the city. This method allows mapping addresses through GPS, with photos and videos attached to the sensors.

[Date]+ [Time]+[Method]+[PIR-TEMP]+[HUMIDITY]+[TEMP]+[Q1]+[PPM]+[OXIGEN]+
[Mq2]+[Mq3]+[Mq4]+[MQ5]+[MQ6]+[MQ7]+[Mq135{1}]+ [Mq135](2)+[IMAGE]+[FILM]+[GPS]

4. GAS SENSOR SYSTEM

To verify gas concentrations, a system of 9 in-line sensors that are sensitive to gases is proposed and give a response by varying the resistance. The sequence of the sensors is given as follows: MQ2, MQ4, MQ5, MQ6, MQ8, MQ135, MQ9, MQ7, MQ3. The system is designed to determine different concentrations or presence of some compound or gaseous element, data obtained using equation (Ec-1) during the time of each test.

$$R_s = A * C^{-\alpha} \quad \text{Ec1}$$

It is a complementary system that can be used in the study where sensors, materials or simply a reaction must be tested at controlled temperature and humidity, to check the emission of these gases.

MQ2	MQ3	MQ4
-----	-----	-----

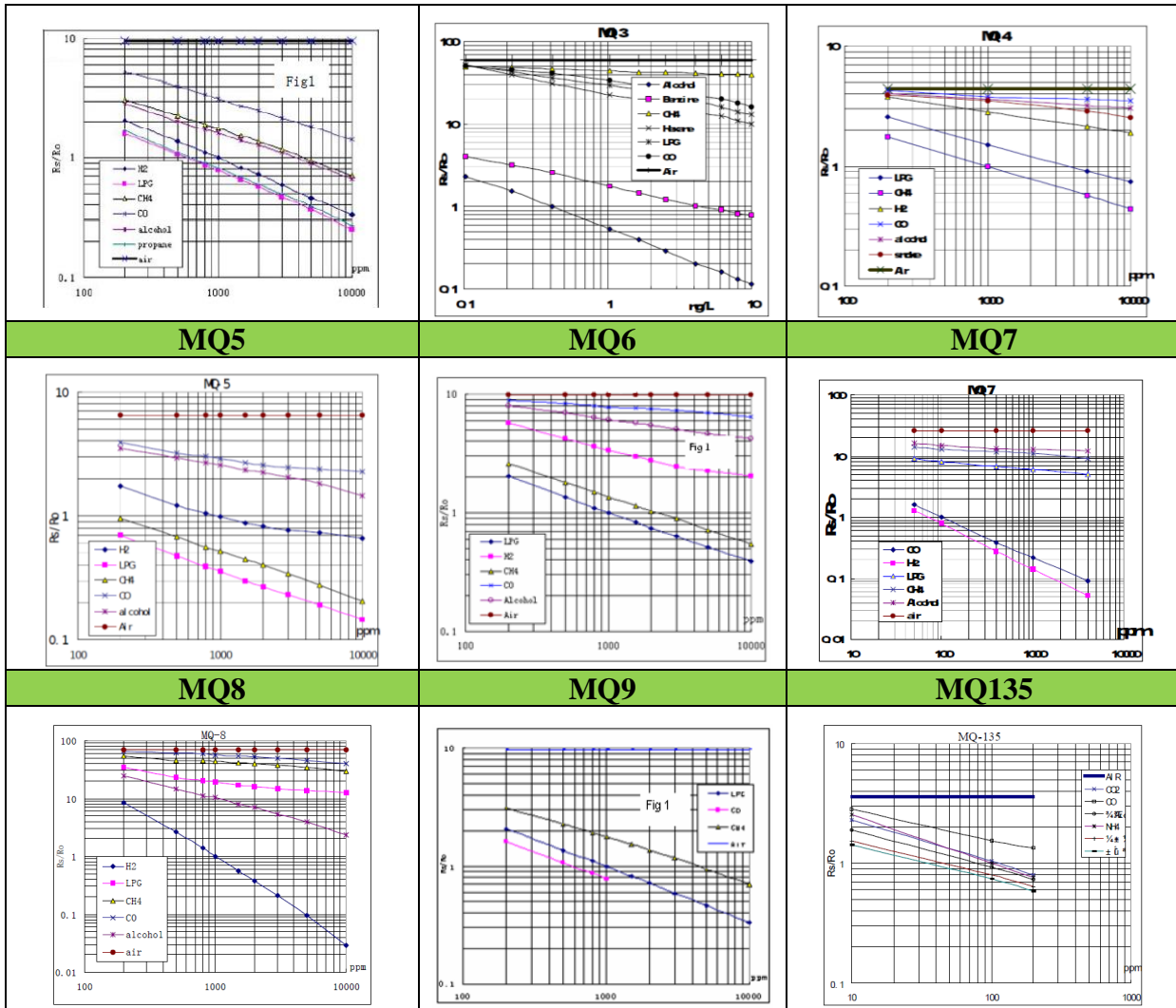


Table 3 – Gas Sensor Datasheet Response.

4.1. System construction and arguments

This paper presents a system composed of several sensors and actuator devices that monitor environmental conditions inside a container. The system verifies that the measurement ranges of the gas sensors are accurate and correspond to the data specified in the sensor datasheets. The specific application of this system is to measure air quality, detect possible changes in the air, monitor contamination levels, and identify the presence of certain harmful gases.

The table below shows the sensor response based on the resistance ratio (R_s/R_o) of the gas sensors, with respect to humidity and temperature conditions. For the MQ3 and MQ4 sensors, the response is only represented within humidity values ranging from 33% to 85%, which is common in populated areas. This range is used to assess air quality.

MQ2	MQ3	MQ4
-----	-----	-----

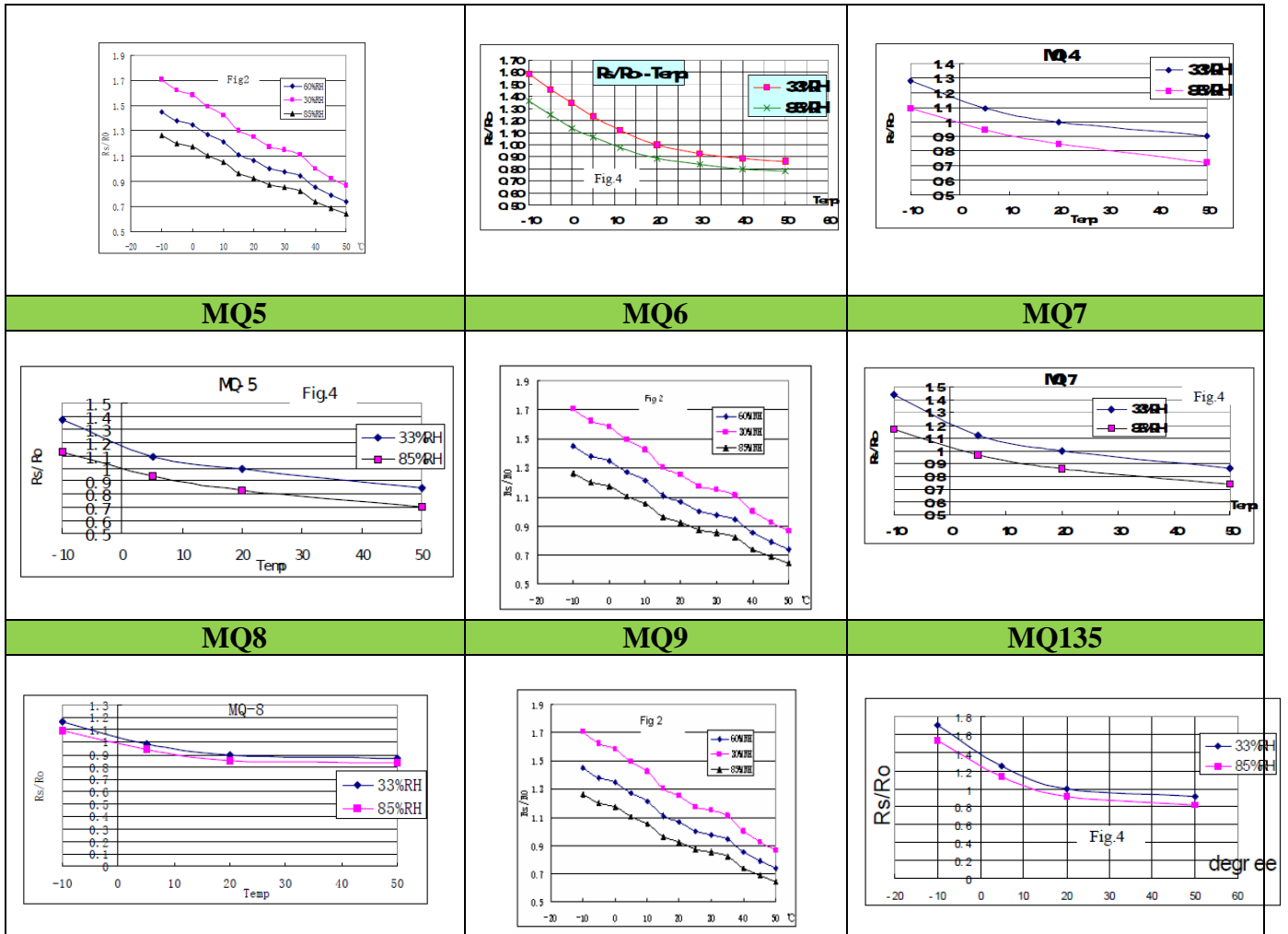


Table 4 – The response between the humidity values of 33% to 85%.

4.2. Brief explanation of gas sensors

The objective was always to measure the continuity state and, subsequently, with the coating applied, to assess the fixed and variable resistance values in response to temperature changes. Initially, the general concept did not work as outlined in Figure 5, so various sensors with different shapes were developed.

Based on the MQ-7 gas sensor's datasheet, its structure and configuration are presented in Figure 5 (Configuration A or B). The sensor consists of a micro AL2O3 ceramic tube, a tin dioxide (SnO2) sensitive layer, measuring electrodes, and a heater, all encased in a plastic and stainless steel net. The heater provides the necessary working conditions for the sensor's sensitive components.

Pure tin oxide (SnO2) is an n-type semiconductor due to oxygen vacancies that act as electron donors. The chemical sensitivity of the sensor can be attributed to two main functions: the receptor function, which identifies the chemical substance, and the transducer

function, which converts the chemical signal into an output signal. The receptor function occurs on the surface of each semiconductor particle, while the transducer function is influenced by the overall microstructure of the sensor element.

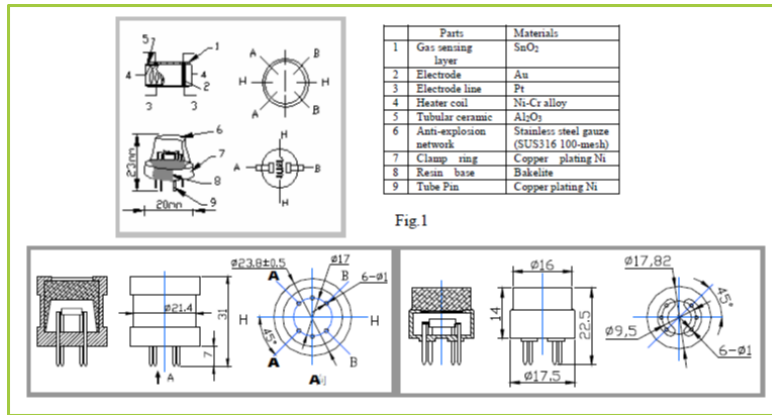


Figure 5 – Structure and configuration of MQ-7 gas sensor

4.3. SNO2 in the presence of gas

When SnO₂ is exposed to a gaseous atmosphere at moderate temperatures, two processes can occur: gas adsorption due to the high reactivity of the SnO₂ surface, or interaction between the gas molecules and the chemisorbed molecules on the SnO₂ surface. Gas adsorption, which involves a direct chemical interaction between gas molecules and the semiconductor surface, is accompanied by charge exchange. From an electronic perspective, this is interpreted as the creation of a level in the 'gap,' whose probability of occupation is determined by the Fermi-Dirac distribution function. Whether it behaves as a donor or acceptor depends on the type of adsorbed molecule.

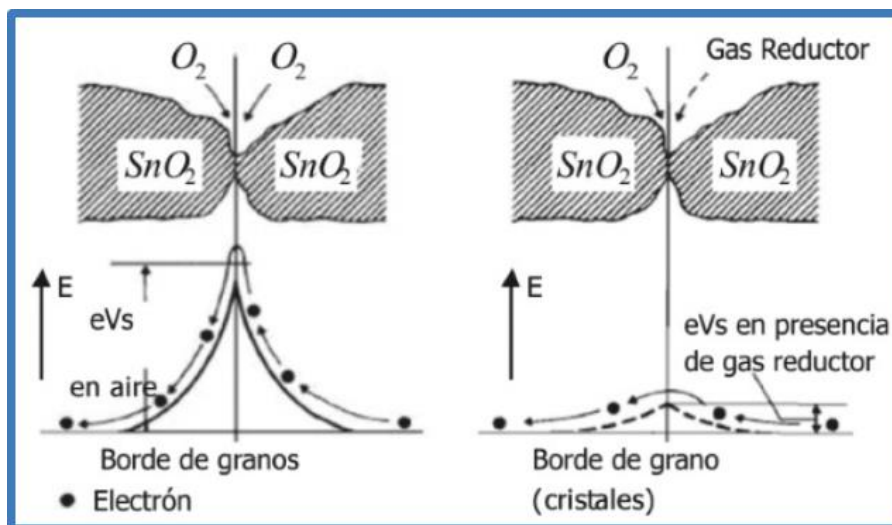


Figure 6 – Diagram of SnO₂ gas sensor conductivity, Image Pearce(2003)

Thus, gases that capture electrons from the SnO₂ bulk when adsorbed create acceptor levels, while gases that donate electrons to SnO₂ by creating oxygen vacancies introduce donor levels. On the other hand, the reaction of gas molecules with those already on the semiconductor surface is interpreted as the annihilation of previously created gap states.



Figure 7 – Testing of other gas sensor models.

Since the responses from previous sensors were not satisfactory, I opted to purchase two MQ2 sensors from Seed Studio to determine the concentration of carbon monoxide. By utilizing the target variables from Seed Studio, and comparing the signals from both sensors, I found that although the signals were not identical, they were close enough to give a reliable result of partial increase in sensitivity in the presence of gas.

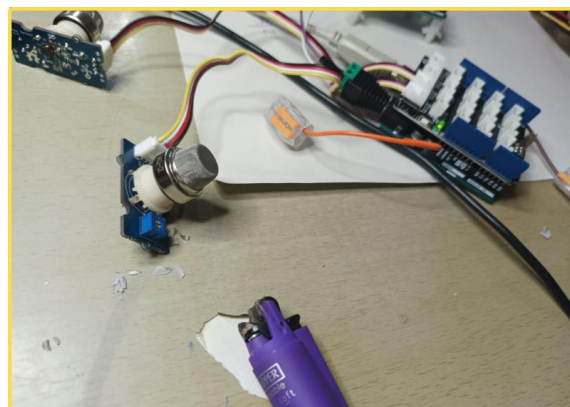


Figure 8 – Test the 2 gas sensors with the carbon monoxide

In the next step, I simply mounted the sensor (colored orange) to measure the resistive change. Using a ceramic bath, I observed the resistance change. Without any blocking, the

changes were minimal. This may indicate the need for a larger surface area of the ceramic coating or a higher concentration of the substrate. Another issue noticed was that the heat increased on the electrode, but the temperature varied by up to 8 degrees, which is problematic since heat is necessary for the system to function properly.

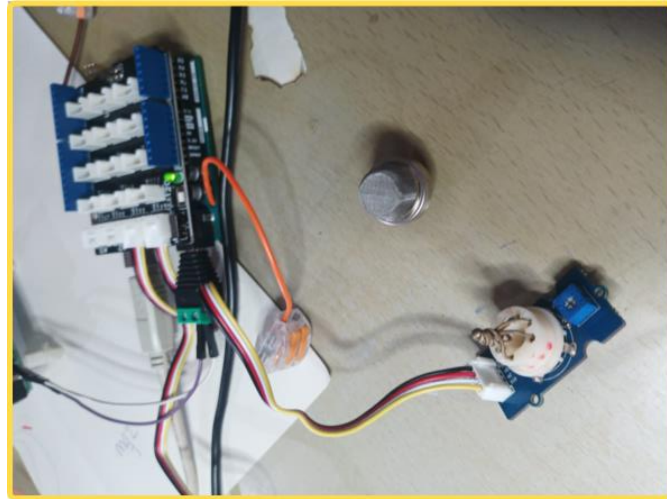


Figure 9 – Test the New sensors with the carbon monoxide

4.4. Introduction to the operation of sensors

These sensors share the same structure and configuration, comprising a ceramic microtube of Al_2O_3 and a sensitive layer of tin dioxide (SnO_2), which causes a change in load resistance [3]. The datasheet recommends a load resistance value of 10 k Ω for MQ7 and MQ8 sensors, 20 k Ω for MQ4, MQ5, MQ6, and MQ135, and 200 k Ω for MQ3. For MQ2 and MQ9, the load resistance is adjustable. However, this value can be fine-tuned depending on the concentration and type of gas. The MQ-135 gas sensor uses SnO_2 , which has lower conductivity in clean air. When contaminant gases are present, the conductivity of the sensor increases in proportion to the concentration of the gas. This makes it easy to use for detecting carbon monoxide (CO). The MQ-7 can detect CO concentrations in the range of 20 to 2000 ppm. Equations for MQ6, MQ2, and MQ9 sensors are as follows:

- **Power of Sensitivity body (P_s):**

$$P_s = V_c^2 \times R_s / (R_s + R_L) \quad (Ec-1)$$

- **Sensor Resistance (R_s):**

$$R_s = (V_c / V_{RL} - 1) \times R_L \quad (Ec-2)$$

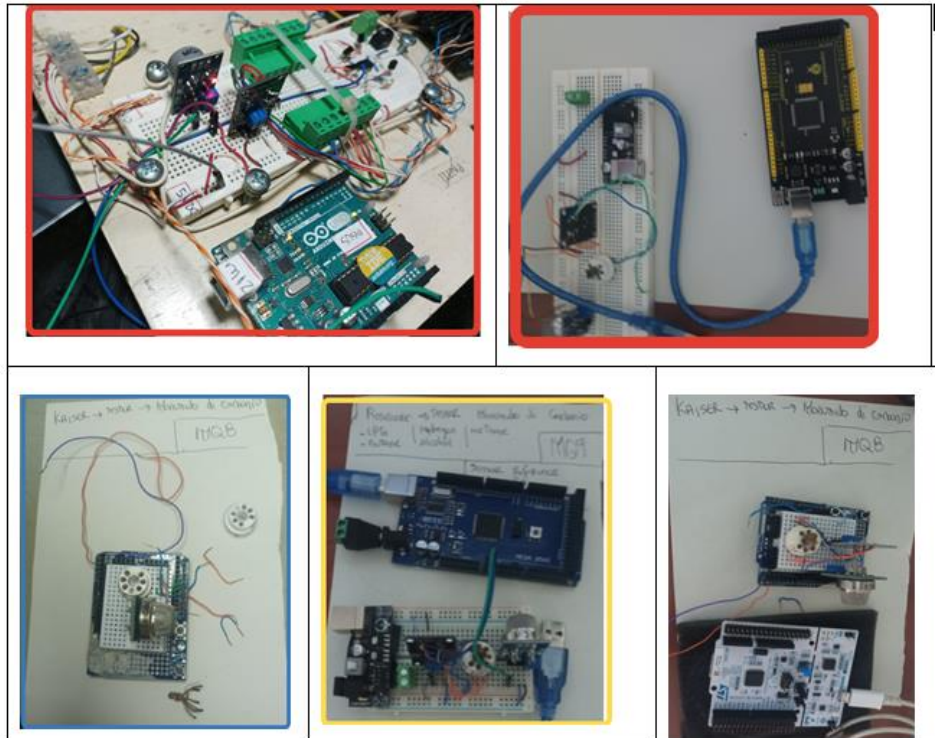


Figure 10 – Sensors Assembly and installation of sensors on a test bench.

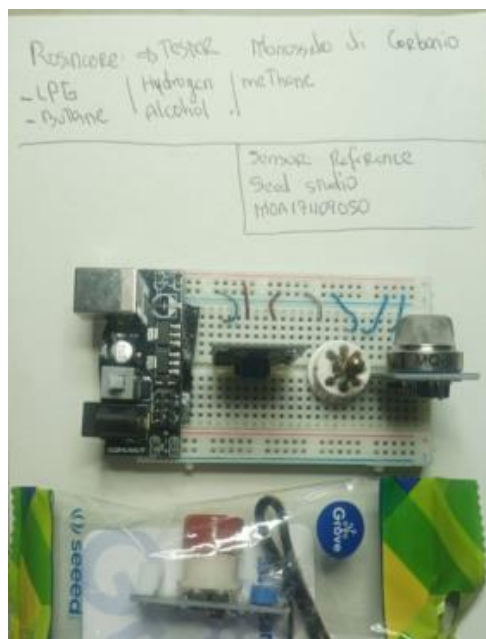


Figure 11 – Testing amplifier board with respect to MQ sensors.

The main goal is to pass each functionalized electrode and compare it with an equivalent sensor to identify each substance and characterize its operation. It is important to note that

the responses vary due to the different materials and techniques used. In this assembly, the MQ9 sensor and a custom sensor for carbon monoxide testing were used.



Figure 12 – To pass each functionalized electrode.

Different sensors were compared while attempting to stabilize the measurements with a heating period of approximately 6 hours. However, stability was not achieved. Although the MQ9 sensor demonstrated gas sensitivity, the results lacked long-term stability. This issue may require additional chemical sensitivity to improve the sensor's long-term response.

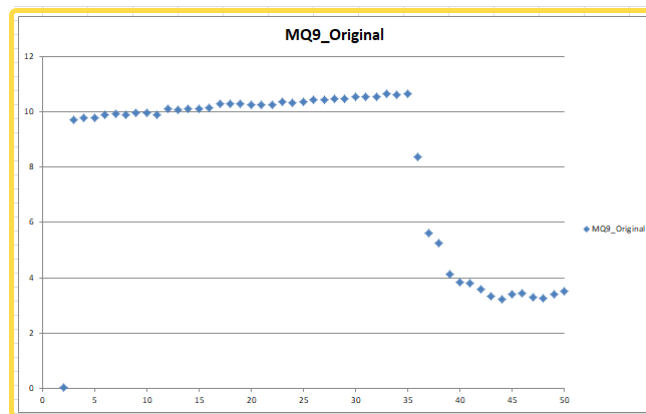


Figure 13 – Commercial MQ9 sensor response to carbon monoxide program

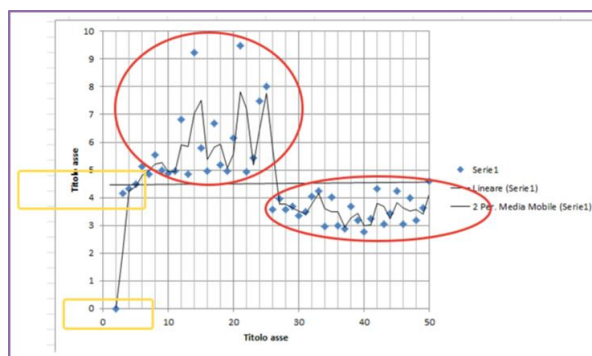


Figure 14 – Spider sensor assembly response to carbon monoxide program

It is still too early to make definitive statements about the performance of the custom-made sensors. While they do work, further study, characterization, measurement, and comparison with other physicochemical properties are needed.



Figure 15 – Assembly of the two sensors exposed to carbon monoxide

The assembly of two sensors exposed to carbon monoxide in this initial phase requires improvement in data acquisition and standardization of sensor parameters.

5. ALGORITHMS AND COMMAND HANDLING WITH THE POSITION OF THE HAT

The following describes the communication interconnection scheme for sending and receiving information between various devices. In general, for all data-related processes, the system is integrated as follows: A microSD card is used in the ESP32 camera (ESPcam32) to store images and videos directly. A real-time clock (RTC1204) is employed to maintain accurate time and date records for the data structures, all of which are controlled by an embedded system.

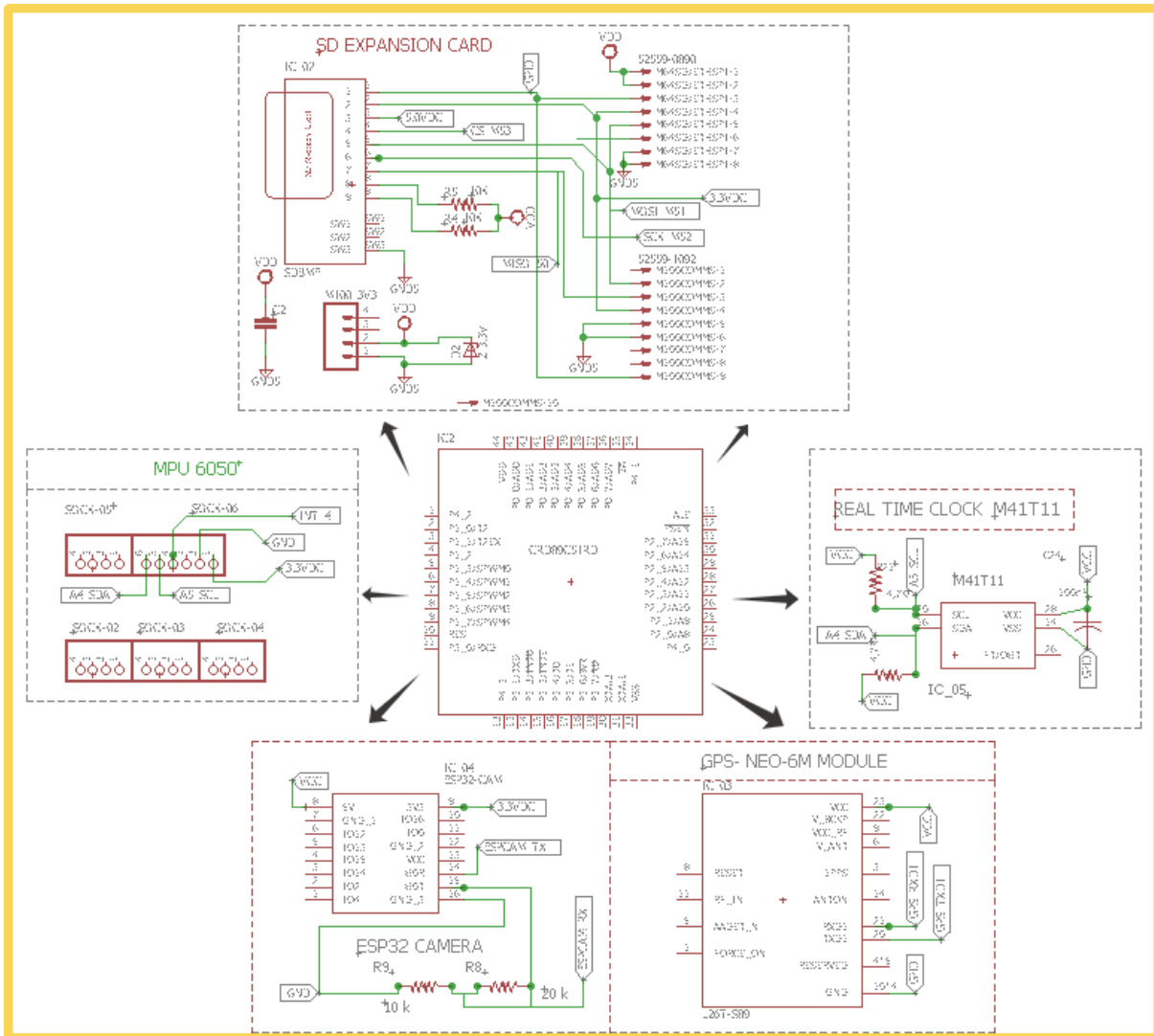


Figure 16 – Interconnection scheme for sending and receiving

The diagram in Figure 17 illustrates the main devices responsible for managing the accelerometer, SD card, clock, camera, and microphone, and their interactions with the program and database where routines are selected. The key concept in this section is to explain how the system interacts with the user via the hat, which lacks a keyboard and screen for manual input. The operator, who observes points of interest, cannot easily use a cell phone or a Bluetooth watch to adjust parameters while walking, as stopping to make adjustments would be impractical. While such accessories can be installed, a brief review indicated they were not ideal. Therefore, a 9-axis accelerometer and gyroscope were integrated to allow for routine and command control via head movements. Figure 18 provides an overview of the main commands.

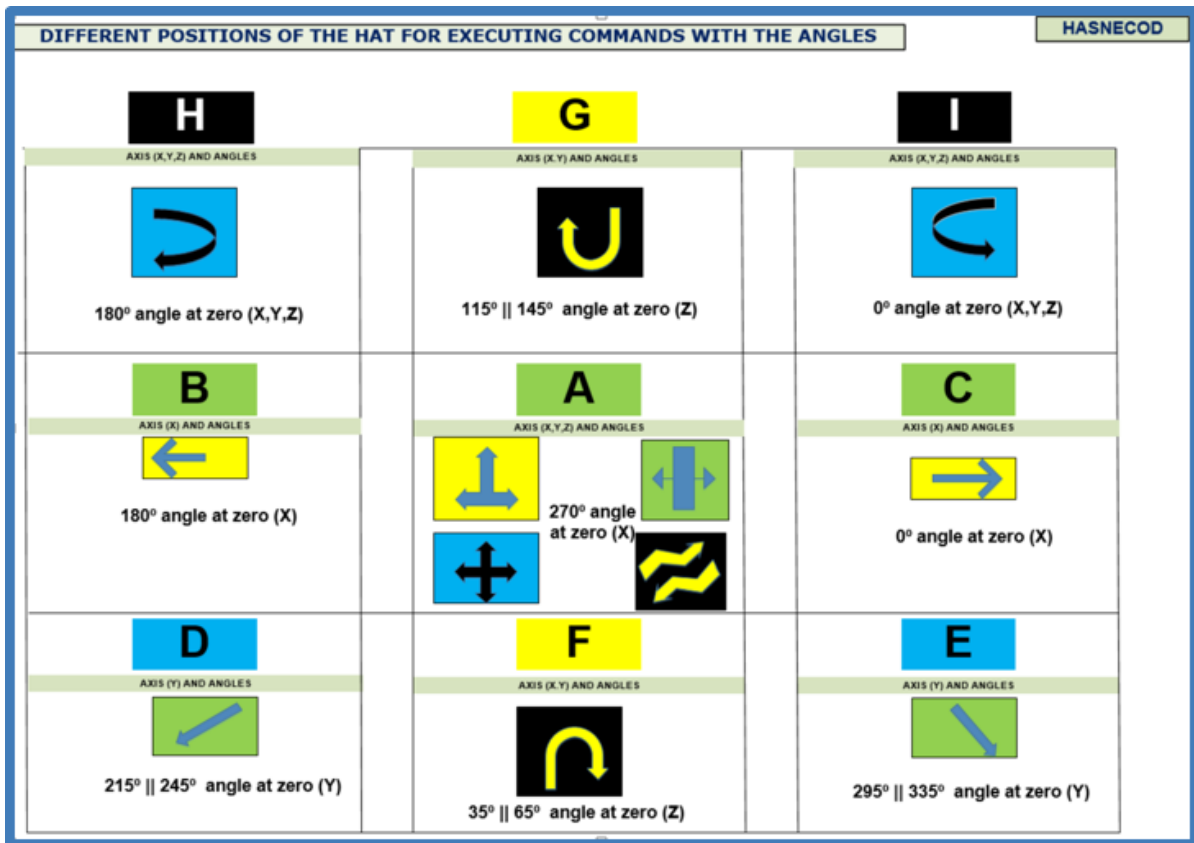


Figure 17 – Different positions of the HAT commands

The figure demonstrates a cross and star system where the user can change head movements and position naturally, accessing a simple menu for executing commands.

In the following figure, each letter is associated with a function, determined by the position of the hat and its operational angle, along with an access address. For example, the green letters (A, B, C) correspond to specific programs with pre-established routines and quick actions. For instance, pressing **B** initiates the carbon monoxide measurement program by activating all devices and sending the data directly to the SD card and an internet server via a Wi-Fi modem.

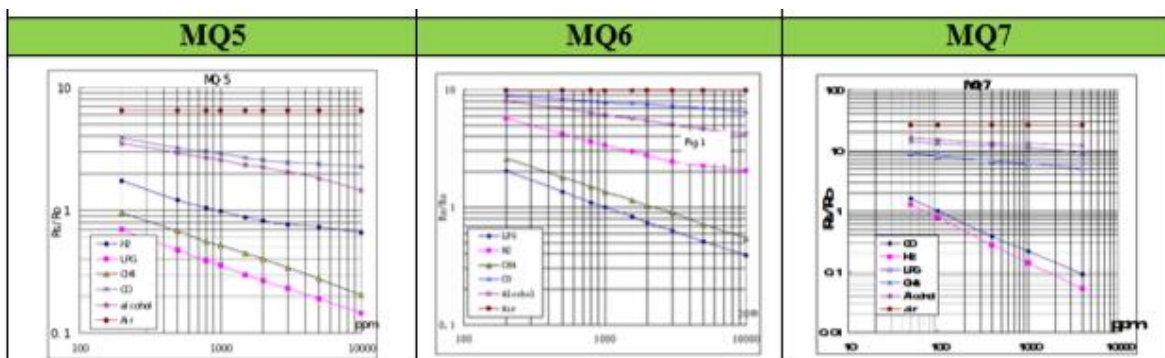


Figure 18 – To start the carbon monoxide measurement program (B)

Pressing **A** starts the carbon dioxide measurement program, which compares air quality parameters and uses additional sensors. Pressing **C** runs routines related to hydrocarbon measurement in specific areas.

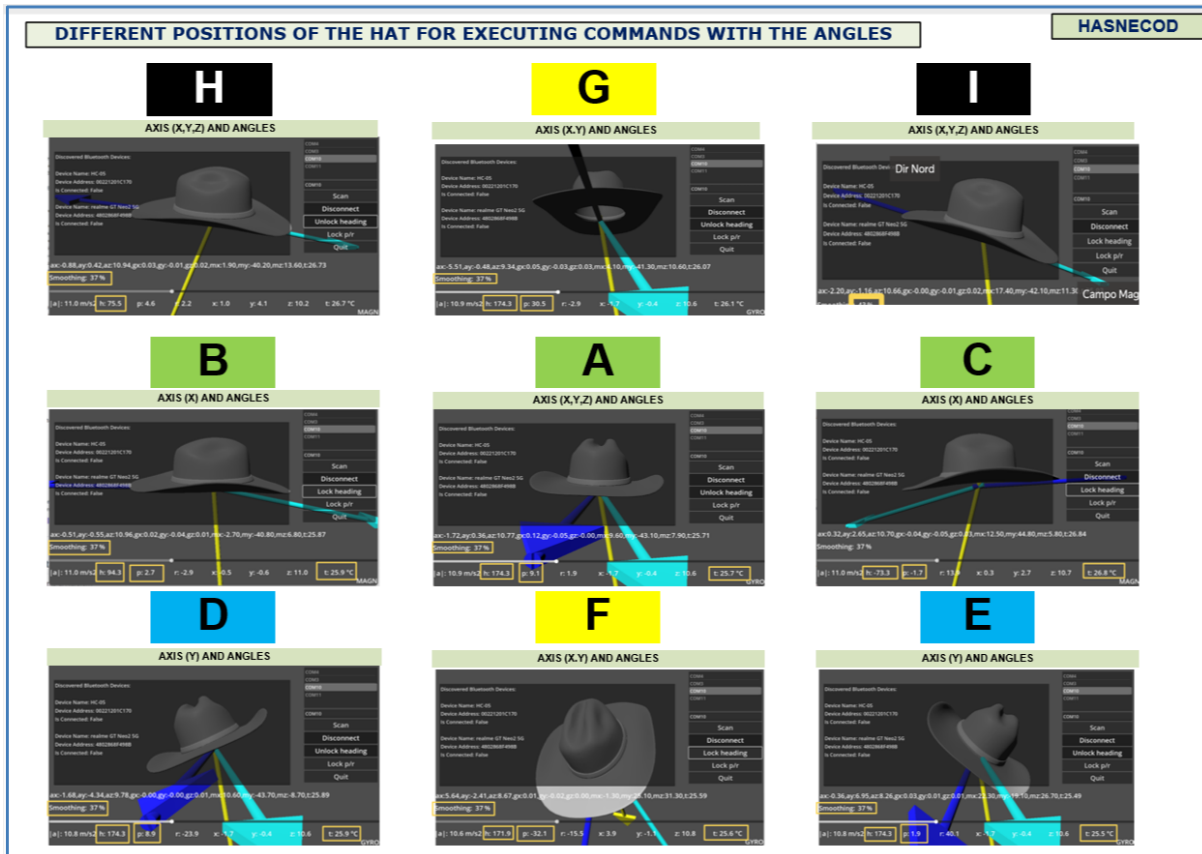


Figure 19 – Runs the carbon dioxide measurement program

As shown in Figure 19, another way to access the menu is through specific head movements. Each position of the hat corresponds to a function that runs for a designated time and involves the necessary sensors, such as the PIR sensor, camera, and clock.

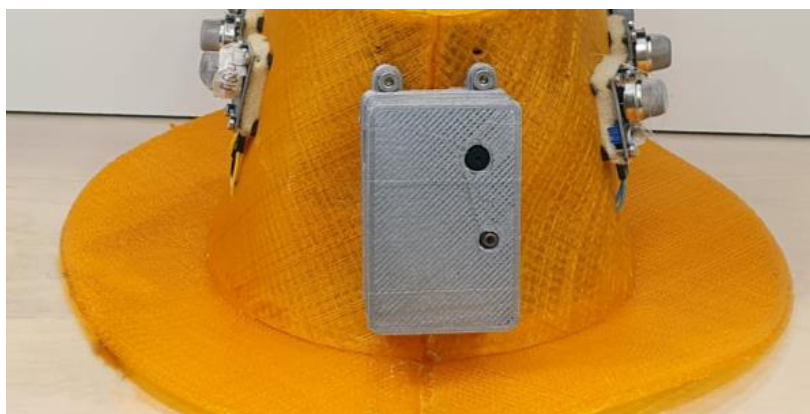


Figure 20 – Necessary sensors such as PIR, camera, Clock

When movements **H** and **I** are executed, commands and functions related to the identification of environmental pollutants or gases, as well as the measurement of ppm levels in the environment, are activated.





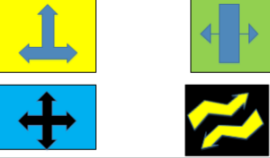




DIFFERENT POSITIONS OF THE HAT FOR EXECUTING COMMANDS WITH THE ANGLES		
<p>H</p> <p>AXIS (X,Y,Z) AND ANGLES</p>  <p>Air quality and particulate matter (ppm)</p>	<p>G</p> <p>AXIS (X,Y) AND ANGLES</p>  <p>Temperature and Humidity Studies</p>	<p>I</p> <p>AXIS (X,Y,Z) AND ANGLES</p>  <p>Environmental Identification with Gas Sensors</p>
<p>B</p> <p>AXIS (X) AND ANGLES</p>  <p>carbon dioxide(CO2) and air quality</p>	<p>A</p> <p>AXIS (X,Y,Z) AND ANGLES</p> 	<p>C</p> <p>AXIS (X) AND ANGLES</p>  <p>Identification of hydrocarbons and combinations</p>
<p>D</p> <p>AXIS (Y) AND ANGLES</p>  <p>Make a film</p>	<p>F</p> <p>AXIS (X,Y) AND ANGLES</p>  <p>Map and GPS sector location</p>	<p>E</p> <p>AXIS (Y) AND ANGLES</p>  <p>photos and recognition system</p>

Table 5 – Process-related commands and functions

Additionally, when movements **D** and **E** are performed, commands and functions associated with identifying locations via GPS and capturing videos of pollution-emitting sites are initiated. This process also includes taking photos to recognize color patterns related to pollutants.

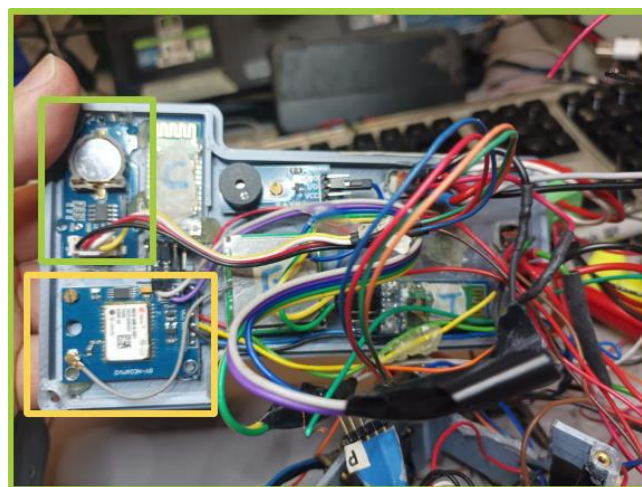


Figure 21 – The identification of places by position (GPS) and movies

Pressing **A** in this case allows the user to navigate between different positions and access different sections. Pressing **G** enables the system to measure temperature and humidity at specific locations when an environmental assessment is underway.

DIFFERENT DEVICES HAT FOR EXECUTING COMMANDS			HASNECOD
<p>H</p> <ul style="list-style-type: none"> -YE00 -RTC -SD -WIFI GPRS -IMU <p>Air quality and particulate matter (ppm)</p>	<p>G</p> <ul style="list-style-type: none"> -SD -WIFI GPRS -IMU <p>Temperature and Humidity Studies</p>	<p>I</p> <ul style="list-style-type: none"> -MQ135 -RTC -SD -WIFI GPRS -IMU <p>Environmental Identification with Gas Sensors</p>	
<p>B</p> <ul style="list-style-type: none"> -MQ135 -ME-WO -RTC -SD -WIFI GPRS -IMU <p>carbon dioxide(CO2) and air quality</p>	<p>A</p>	<p>C</p> <ul style="list-style-type: none"> -MQ135 -RTC -SD -WIFI GPRS -IMU <p>Identification of hydrocarbons and combinations</p>	
<p>D</p> <ul style="list-style-type: none"> -ESP32 -RTC -SD -WIFI GPRS -IMU <p>Make a film</p>	<p>F</p> <ul style="list-style-type: none"> -ESP32 -RTC -SD -WIFI GPRS -IMU -GPS <p>Map and GPS sector location</p>	<p>E</p> <ul style="list-style-type: none"> -ESP32 -RTC -GPRS -IMU -GPS <p>photos and recognition system</p>	

Table 6 – Function and command table by variable

6. DELIVERY ALGORITHM, DEPENDING ON THE PACKAGE (I)

A low-cost, wearable hat was developed, consisting of a system of gas sensors and other mixed sensors integrated with a communications system. This system is designed to detect environmental pollutants while walking, with the aim of studying the increase in environmental pollution and the rise in respiratory diseases associated with vehicular emissions and gas mixtures in certain urban areas.

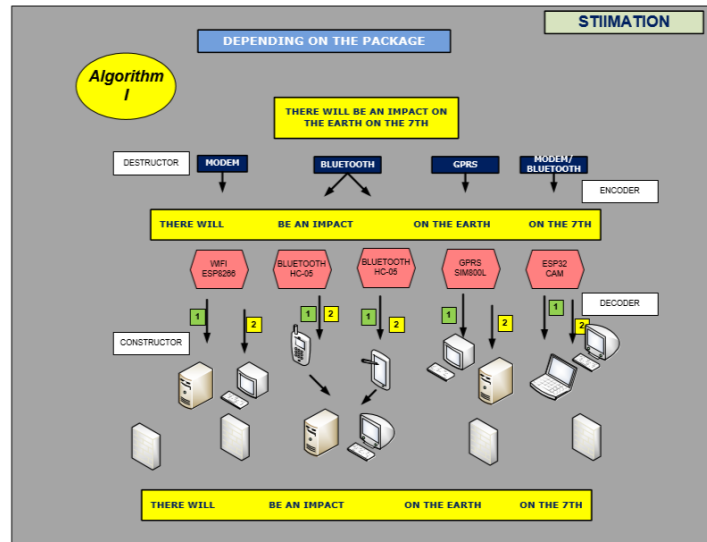


Figure 22 – Delivery algorithm, depending on the package

A control algorithm was developed for sending data packets using a low-cost, mixed communications system, designed for portable mobile prototypes equipped with sensors for environmental applications. The goal is to present and analyze the data using various communication methods on a central server.

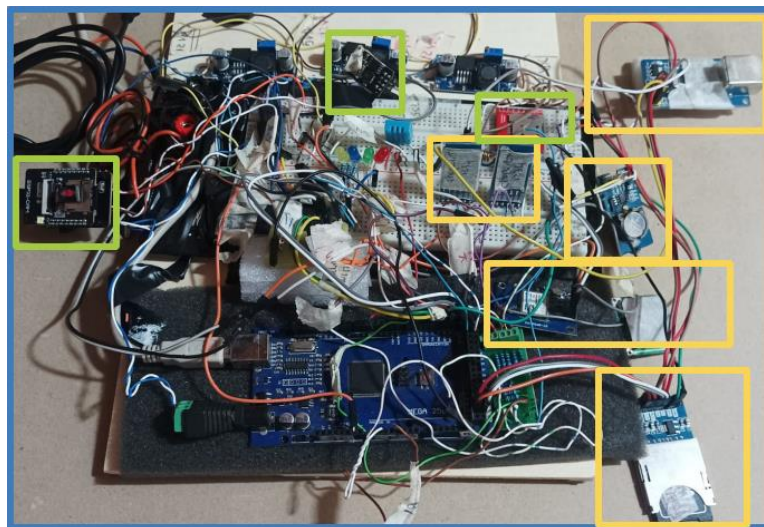


Figure 23 – Sensors test algorithm, depending on the package

7. ALGORITHM DEPENDING ON THE DEVICE (II)

Given the increase in environmental pollution and respiratory diseases related to vehicle emissions and gas mixtures, which exacerbate air pollution, a wearable hat was developed. This hat uses sensors to measure transient gas levels, compounds, temperature, humidity, and particulate matter, among other factors.

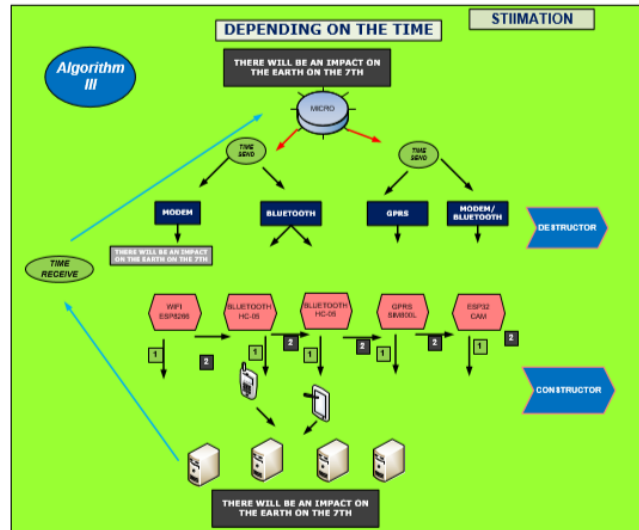


Figure 26 – Delivery algorithm, depending on the time

Recognizing this challenge, a series of devices were integrated into a low-cost communications board, compatible with many technologies and platforms. The system includes a camera, Wi-Fi module, Bluetooth modules, GPS, IMU, GPRS, compass, magnetometer, battery management modules, and both shortwave and long-range radio systems. The primary idea is to incorporate this system within a wearable hat to conduct environmental measurements while the user moves around the city. This setup allows for real-time data transmission to internet servers.

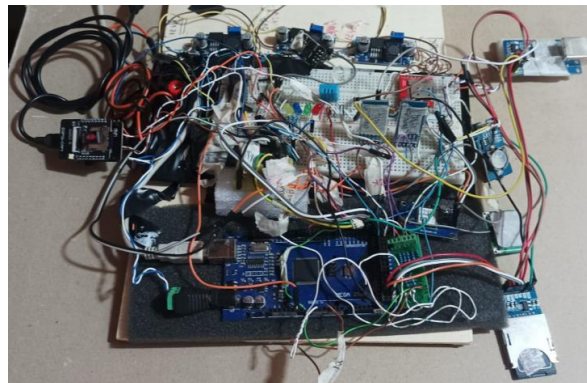


Figure 27 – Communications system test prototype

9. RESULTS OBTAINED AND IN PROGRESS

1.1. Prototype

- Construction of a sensorized hat.
- Construction of a monitored low-cost portable battery bank.
- Development of a communications system.

1.2. Papers (in progress)

- Data acquisition, global positioning and artificial vision using a hat-mounted system with camera and gprs, *Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*
- Hat sensor network for contaminant detection, *Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*
- Materials, procedure and construction of a sensorized hat, *Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*
- Development of a low-cost communications system for portable or wearable prototypes such as sensorized hats in environmental applications, *Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*
- Control algorithm for sending packages using a low-cost mixed communications system for portable or wearable sensorized mobile prototypes in environmental applications, *Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*
- Integration of a smartphone as a search engine for dust increase or ppm concentration for a portable sensorized hat in environmental applications for cities, *Ittalo Pezzotti, Gianni Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*

1.3. Poster

- Low-cost wearable hat composed of a sensing and communication system for the detection of some environmental pollutants while walking, *Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva.*

1.4. Participation in conference

- Materials, procedure and construction of a sensorized device using an additive manufacturing system, *Fabrizio Silva, Ittalo Pezzotti, Giovanni Paolo Viganò.*

DATA ACQUISITION, GLOBAL POSITIONING AND ARTIFICIAL VISION USING A HAT-MOUNTED SYSTEM WITH CAMERA AND GPRS

Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva

ABSTRACT

Due to the increase in environmental pollution and the increase in respiratory diseases that are associated with the vehicular impact with the mixture of gases, which increase the pollution of fuels in the air, an endorsable hat was developed that allows, through its sensors, to measure the state transient levels of gases, compounds, temperatures, humidity and particulate matter among other aspects, adding an artificial vision component made up of a series of logical algorithms sufficiently trained for this system to make decisions and recognize these areas of concentration of environmental contamination, associating images and positions with the measurement data and follow-up, daily or weekly, in each zone in a very simple way, since it is enough to walk in each zone to determine these levels. This technology has applications in the diagnosis and monitoring of sectors with a statistical evaluation of improvements and changes.

Keywords: *wearable hat, sensors gas, environmental monitoring, Artificial Vision, Gps.*

HAT SENSOR NETWORK FOR CONTAMINANT DETECTION

Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva

ABSTRACT

A System composed of a hat is proposed, this serves as a support and at the same time as a container, they have an arrangement of 7 gas detector sensors, a dust particle sensor, and other accessories that are used to integrate a communications scheme to send data to the internet, cell phone or tablet that is linked to a camera for artificial vision processes.

With this work it is intended that while the person walks, sectors where there is a presence of contaminants, changes in temperature and humidity are determined, to be traced and documented in a database using a gps and a gprs system for the construction of specific tables in sectors. contaminated.

Keywords: *Humidity, sensors, electronic instruments, environmental monitoring, environmental sensors, PID controllers, controlled laboratory, data analysis, IOT.*

MATERIALS, PROCEDURE AND CONSTRUCTION OF A SENSORIZED HAT

Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva

ABSTRACT

The purpose of this work is to present the development of an wearable hat, captured in 3D by integrating sufficient sensor technology for the collection of environmental data as the person performs his daily tasks.

For the development of the prototype if I use a 3D printer of 5 hours, with integrated sections for the electronic card, the batteries and the sensor placement. The chosen color is a reflective orange with the objective that you see during the night.

Keywords: *3D printed, wearable hat, sensors gas, environmental monitoring, environmental materials.*

DEVELOPMENT OF A LOW-COST COMMUNICATIONS SYSTEM FOR PORTABLE OR WEARABLE PROTOTYPES SUCH AS SENSORIZED HATS IN ENVIRONMENTAL APPLICATIONS

Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva

ABSTRACT

In many technological solutions of systems in tracking, measuring or verifying movements of objects, processes, plants or animals, drones, robots, electric vehicles or portable devices are currently used, connectivity and information sending problems are found, for this reason It is necessary to incorporate a communications system to send information when in the field.

Identifying this situation, a series of devices have been integrated into a card for low-cost communications, compatible with many technologies and platforms, the system includes a camera, Wi-Fi module, Bluetooth modules, GPS, IMU, GPRS, compass, magnetometer, management battery modules, shortwave and long band radio system. The main idea is to incorporate this system within a hat to perform environmental measurements while the user moves around the city, allowing information to be sent in real time to internet servers.

Keywords: *Board communications, smart cities, mobile systems, autonomous devices, portable accessories, Wi-Fi, Bluetooth, GPS, GPRS.*

CONTROL ALGORITHM FOR SENDING PACKAGES USING A LOW-COST MIXED COMMUNICATIONS SYSTEM FOR PORTABLE OR WEARABLE SENSORIZED MOBILE PROTOTYPES IN ENVIRONMENTAL APPLICATIONS

Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva

ABSTRACT

A low-cost, wearable hat was developed, composed of a system of gas sensors and other mixed sensors, integrated with a communications system for the detection of some environmental pollutants when walking, to study the increase in environmental pollution and the increase in respiratory diseases associated with vehicular impact with the mixture of gases, in certain sectors of cities, for this reason a control algorithm was developed for sending packets using a low-cost mixed communications system for portable mobile prototypes with sensors in environmental applications, the idea is to present data and analyze them using different means of communication on a central server.

Keywords: *wearable hat, sensors gas, mobile prototypes, control algorithm, environmental applications*

**INTEGRATION OF A SMARTPHONE AS A SEARCH ENGINE
FOR DUST INCREASE OR PPM CONCENTRATION FOR A
PORTABLE SENSORIZED HAT IN ENVIRONMENTAL APPLICA-
TIONS FOR CITIES.**

*Ittalo Pezzotti, Gianni Pezzotti, Giovanni Paolo Viganò,
Fabrizio Silva.*

ABSTRACT

A technological integration of a smartphone as a ppm concentration search system was carried out as a comparator for a low-cost wearable hat composed of a system of gas sensors and other mixed sensors, integrated with a communications system for the detection of some environmental pollutants when walking, to study the increase in environmental pollution, in public spaces or production companies where there are dust concentrations, the idea is to present an analysis by sector or by companies with databases and analyze them comparing the increases in ppm.

Keywords: *wearable hat, smartphone, environmental monitoring, ppm concentration, technological integration.*

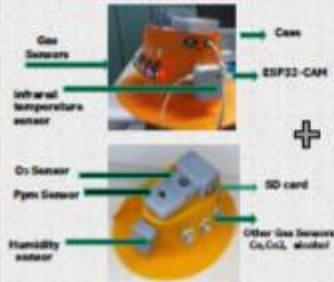
LOW-COST WEARABLE HAT COMPOSED OF A SENSING AND COMMUNICATION SYSTEM FOR THE DETECTION OF SOME ENVIRONMENTAL POLLUTANTS WHILE WALKING

Ittalo Pezzotti, Giovanni Paolo Viganò, Fabrizio Silva

Rationale

A System is proposed, composed of a hat mounting 7 gas detector sensors, a dust particle sensor, and other accessories. Some of these mounted devices are used to integrate a communication scheme to send data to the Internet, cell phone or tablet, linked to the mounted camera for artificial vision processes. This work is intended to enable a person to walk through sectors where there is a presence of contaminants, changes in temperature and humidity are determined, to be traced and documented in a database using a GPS and a GPRS system for the construction of specific tables in contaminated sectors.

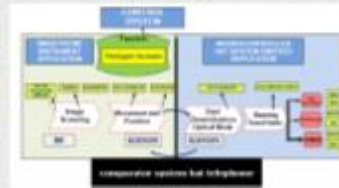
Wearable Hat Development



Battery tests with different load current sections



Function for Find ppm increase



Algorithms and command handling with the position of the hat



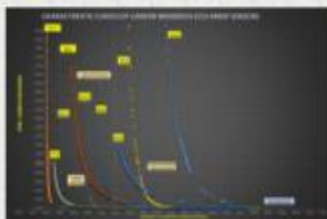
Algorithms for sending information

Algorithms and representation of the information flow of the mobile system using different communication systems, such as Wi-Fi, Bluetooth, GPRS system and GPS, to send the information to the server for data processing and analysis.

The following is the communications interconnection scheme for sending and receiving information, communication between different devices, in general for everything related to data, the system is integrated as follows: a microSD memory in the camera (ESP32-CAM) that aims to save images and videos directly, to preserve data structures with the time and date is the real time clock (RTC1294), everything is controlled through the embedded card.



In the datasheets of MQ2, MQ4, MQ5, MQ6, MQ9 they present the same concentration limits (100-10000) for the ordinates on the X axis, and for the RS/R0, (0.1-10), (Fig.2) shows the value of carbon monoxide reported in the datasheet of each sensor, confirming that the calculated value of (ppm) is within this range, while for the sensors MQ135, MQ7 and MQ3, they have limits of concentration in the axes (X) and (Y) different, the value is too low in (ppm), this is represented in graph 2, trying to unify a unit of ppm for (Co) with different sensors in the same climatic conditions. As can be seen in the graph, the value of the MQ6 sensor has a very high RS/R0, but also the relationship for the ppm value is high.



The sensors have been selected for specific contaminant applications such as: MQ2 (LPG, propane), MQ3 (alcohol), MQ4 (smoke), MQ5 (natural gas), MQ6 (isobutane), MQ7 (CO, carbon monoxide), MQ9 (H₂ hydrogen), MQ9 (CH₄), MQ135 quality (NH₃, NO_x, benzene). The main problem is related to the calibration of these sensors for the developed application, which consists of a camera for the monitoring of gases in transitory state in controlled conditions; it was also found that these sensors have in common: the line of response to air and CO (carbon monoxide), also all sensors use the electrochemical method of resistance variation vs the presence of gas; however, the only sensor that has a response curve for smoke is the MQ4; although it is not sensitive to smoke, it will be used as a reference to build the smoke concentration line of the MQ135 sensor, which is sensitive to smoke.

Calibration of sensors according to their function



However, the only sensor that has a response curve for smoke is the MQ4, although it is not sensitive to smoke, it will be used as a reference to build the smoke concentration line of the MQ135 sensor, which is sensitive to smoke. The MQ7 high sensitivity carbon monoxide sensor retains the characteristics using the equation (Eq-2), ideal for detecting (Co) concentrations in the air.

