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Novel proposal for a smart electronic taximeter based on microcontroller systems

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ABSTRACT

Public transport plays a significant role in the economic development of a country, so the state must guarantee its proper functioning, not only in terms of controlling vehicular traffic and generating adequate roads but also in terms of pricing and customer service. This article proposes a smart electronic taximeter that improves customer service quality and provides greater control for the taxi owner. To achieve this, the smart taximeter has a data entry module (keyboard), a location module (global position system), a time module (date and time), a storage module (memory), a display module (light emitting diode array), an auditory module (speech synthesizer), a communication module (Wi-Fi) and a microcontroller that controls the processes of setup, pricing, billing, and accounting. The results have shown a satisfactory response on the part of the client and the entrepreneur since it allows a higher level of inclusion from the auditory output in Spanish and English, as well as to carry out better financial accounting through the storage of information on the place, date and time, start and end, as well as the duration, distance, fare, surcharges, total cost, and number of each taxi service (ride). Finally, the smart electronic taximeter complies with all Colombian resolution No. 88918 relations of the Ministry of Commerce, Industry and Tourism.

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1. INTRODUCTION

Currently, the pricing of individual means of public transport, such as taxis, presents several problems that can translate into challenges to improvement. One of the main challenges is customers' strong distrust regarding the fee charged for the service provided [1]–[4]. In the first place, sometimes the rate of change of the units does not seem to coincide with what is regulated according to the time and distance traveled [5]–[8]. Secondly, sometimes the rate presented by the taximeter differs from the one charged by the taxi driver, with the argument that additional costs called surcharges must be added to the taximeter fare, such as night surcharge, Sunday and holiday surcharge, airport surcharge or door-to-door surcharge, which seem to be already contemplated by the rate presented by the taximeter. The above are cases that occur in the main cities of Colombia, especially in cities such as Bogotá [1], [2]. To mitigate the problems currently evidenced by the taxi pricing device (taximeter), the Colombian government has regulated the metrological technical operation applicable to electronic taximeters through different regulations, among which resolution number 88918 of December 28, 2017 [9] stands out. According to the Ministry of Commerce, Industry, and Tourism, this standard is established to ensure the quality of taximeter measurements to generate credibility and trust in users of the public taxi service [9]–[11].

This paper aims to propose an intelligent electronic taximeter to overcome several of the challenges currently presented by the public taxi transport service. This proposal seeks to increase the level of innovation and technology of the taxi service fare measurement process through the design and development of an innovative smart taximeter that has a data entry module (keypad), a location module global position systems (GPS), a time module (date and time), a storage module (memory), a display module light emitting diode (LED) array, an auditory module (speech synthesizer), a communication module (Wi-Fi) and a microcontroller that controls the processes of configuration, pricing, billing and accounting. This allows, among other advantages, to keep a financial accounting through the storage of information on the place, date, time, start, and end, as well as the duration, distance, fare, surcharges, total cost, and the number of each taxi service.

The proposal developed allows a greater degree of inclusion by allowing visually impaired people to know the relevant information about their taxi journey through the auditory output module. In the same way, a foreigner who does not understand Spanish but is familiar with the English language may also feel more comfortable obtaining travel information in English. This is thanks to the fact that the auditory output module works in both Spanish and English.

In the case of the entrepreneur or taxi owner, this proposal will also be of great value, as it has a complete financial accounting report, which can be downloaded from the smart electronic taximeter through a Wi-Fi connection. In this report, you can find out how many trips were made, the locations, start and end dates and times, and the duration, distance, and final costs of each trip. As a further aid to the entrepreneur, the smart taximeter will be able to track satellites and store information on sites visited during the last established period or determine their current location. Other related works, such as [12]–[16], propose significant improvements for these devices, but none present a complete solution like the one presented in this paper.

This article is composed as follows: section 2 presents the related works and the differentiation and contribution of this proposal. Section 3 presents the methodology used to develop the proposed smart electronic taximeter. Section 4 describes the operation of the designed device and the results achieved. Finally, section 5 presents the conclusions.

2. SMART ELECTRONIC TAXIMETER DESIGN

The design of the smart electronic taximeter is made up of the following modules: a data entry module (keypad), a location module (GPS), a time module (date and time), a storage module (memory), a display module (LED array), an auditory module (speech synthesizer), a communication module (Wi-Fi) and a microcontroller that controls the processes of configuration, pricing, billing, and accounting, are shown in Figure 1. Figure 1 describes the design of the smart electronic taximeter in detail. According to the design presented in Figure 1, the microcontroller is the main element, which is responsible for initializing and controlling all the modules. All modules work according to the initial configuration made by the company to which the taxi belongs or by the vehicle's owner in its absence.

The input module allows the taximeter user (taxi driver or owner) to send information to the system for module configuration or option selection. The time module will let you know the date and time in real time. The location module lets you set the vehicle's exact position in real-time. Once a race or service is initiated, the Pricing module begins the pricing process according to the charging mode selected in the configuration module. Pricing works through counting units, which are increased by time or distance according to the collection method chosen, and the unit's value is established annually by the Colombian state. When the service ends, the invoice module generates the corresponding invoice and sends the information to the accounting module to record each financial transaction. At the end of each entry, the accounting module sends the information to the storage module to store the data.

From the moment the service starts, the display module also begins to work, showing the passenger or customer the value of the units that are registered, the value in pesos of these units, and the date and time of that moment. When the service bill is generated, the display module shows the total cost, and the hearing module audibly reproduces this value so that the blind or non-blind person can hear it in Spanish or English according to the customer's preference through a power amplifier and the corresponding speaker. Finally, at any time the owner wishes, he can make use of the communication module to download the accounting to date and the information of the place, date and time, start and end, as well as the duration, distance, fare, surcharges, total cost and number of each taxi service. Each of these modules will be described below.

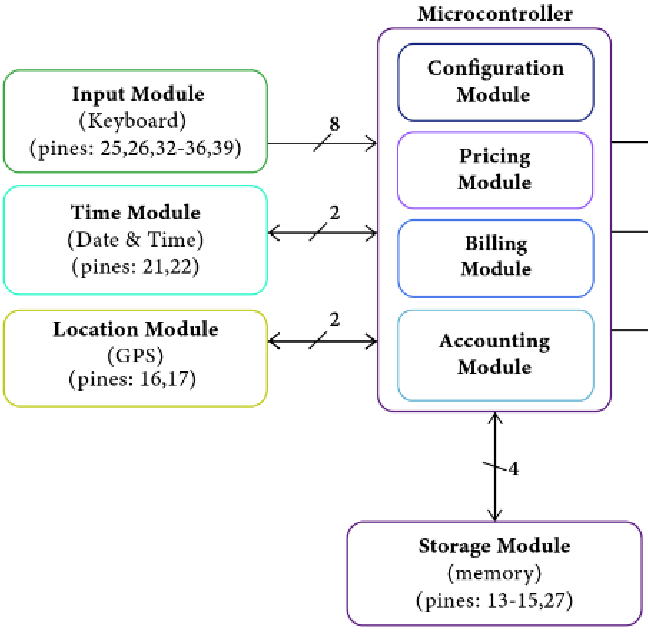


Figure 1. Block diagram of the design of the smart electronic taximeter

2.1. Microcontroller

The microcontroller is the brain of the taximeter. It executes essential tasks such as interacting between each of the modules, calculating fares, sending information to the LED array, managing geographical coordinates, and interacting with the user. The microcontroller selected was the WROOM 32 ESP as shown in Figure 2.

Figure 2. ESP Wroom32 microcontroller. Taken from [17]

The WROOM 32 ESP microcontroller has a 32-bit Xtensa LX6 dual-core processor with adjustable clock frequencies. It includes a built-in flash memory for program storage and a random-access-memory (RAM) for data. It features an 802.11 b/g/n Wi-Fi module and a Bluetooth BLE 4.2/Bluetooth classic module. It has various peripherals and interfaces, such as universal asynchronous receiver/transmitter (UART), serial peripheral interface (SPI), inter-integrated circuit (I2C), pulse width modulation (PWM), and analog to digital converter (ADC), connecting with sensors, actuators, and other devices. It incorporates security features, such as cryptography and support for secure connections using secure sockets layer (SSL)/transport layer security (TLS). It provides general purpose input/output (GPIO) pins for connecting external devices and expanding functionality as shown in Figure 3. It can be programmed using the Arduino development environment, PlatformIO, or tools and software development kit SDKs provided by Espressif.

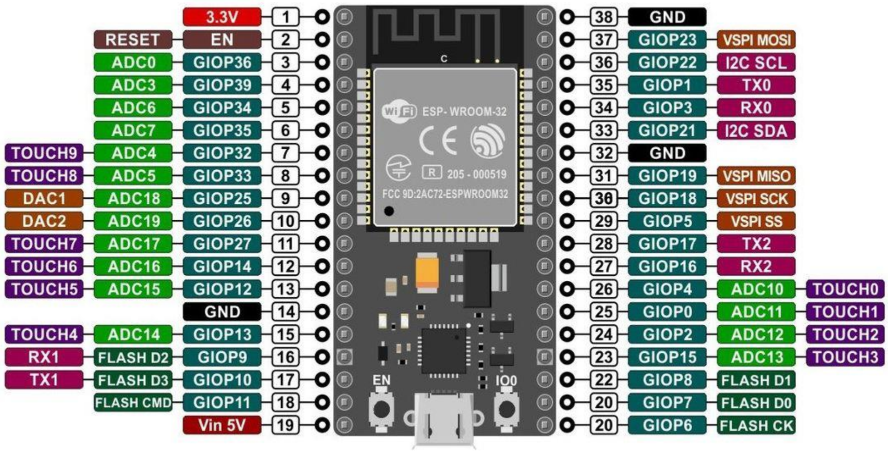


Figure 3. Pin configuration of the WROOM 32 ESP microcontroller. Taken from [18]

2.2. Input module

The input module mainly comprises a matrix keyboard as shown in Figure 4. This module facilitates the user's interaction with the taximeter, sending information to the microcontroller to execute specific actions. The keyboard is composed of an array of interconnected buttons arranged in rows and columns. Each button on the keyboard is connected to the intersection of a row and a column. When a button is pressed, the circuit between the row and the corresponding column is closed. According to the above, the number of pins the microcontroller requires is less than the number of buttons the keyboard has. For our case, a 16-button keyboard was selected in Figure 5, and eight microcontroller pins were needed. Some of the functions of the keyboard are: i) Enter the initial setup password when you turn on your device for the first time; ii) The initial configuration using number keys; iii) Activation/deactivation of services with the asterisk (*) and numeral (#) keys; iv) Key (*): Start and end a service. Start the fare calculation or end the ride depending on the status of the taximeter; and v) Key (#): Send trip information to the cloud system, structuring the data in a Google Drive spreadsheet.

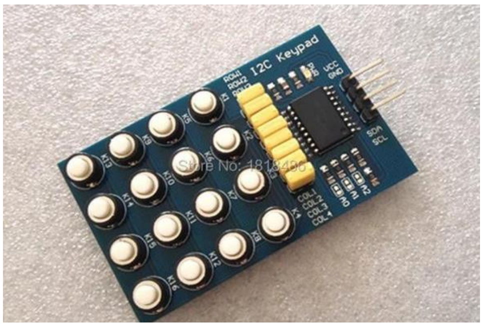


Figure 4. Hexadecimal dot matrix keyboard. Taken from [19]

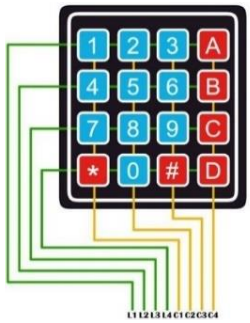


Figure 5. Hexadecimal dot matrix keyboard used. Taken from [20]

2.3. Input module

This device ensures the system's temporal accuracy. The real-time date and time are obtained through the software installed on the microcontroller, allowing accurate tracking of each service provided. The device selected to develop this module was the RTC DS 1307; as shown in Figure 6. The RTC DS 1307 module is an electronic device that records accurate data and time in real-time applications. The RTC DS 1307 communicates via the I2C protocol, allowing it to be easily integrated into microcontroller systems such as the ESP32. To set the date and time, the microcontroller sends write commands over the I2C bus, and the RTC DS 1307 logs store the information for seconds, minutes, hours, day of the week, day of the month, month, and year. The RTC DS 1307 features a real-time clock and non-volatile memory to store date and time information even when the device is turned off; it requires 5 V power, and some versions support 3.3 V power, which helps integrate with microcontrollers that operate at 3.3 V, such as the ESP32; it uses the I2C communication protocol to exchange data with the microcontroller. The I2C bus uses serial data line (SDA) and serial clock line (SCL); these lines allow the transfer of bidirectional information between the RTC DS 1307 and the microcontroller.

Figure 6. RTC DS 1307 module. Taken from [21]

2.4. Location module

The location module calculates the latitude, longitude, and altitude coordinates of the position of the individual utility vehicle from a global positioning system (GPS). The GPS selected for our case was the NEO 6M as shown in Figure 7. The location module determines each trip's start and end points, transmits them to the microcontroller for processing, and finally, saves them in the storage module via a comma-separated values (CSV) file. Due to the storage module's capacity, only the start and end locations of each service are held. However, the location module can transmit the current location at any time it is required.

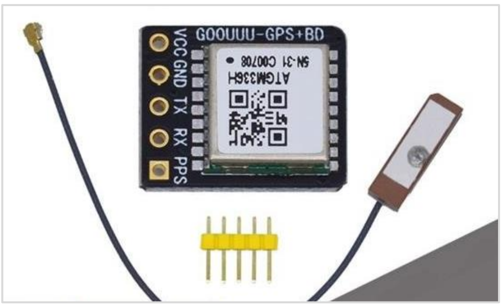


Figure 7. GPS NEO 6M. Socket [22]

2.5. Pricing module

The Pricing module is a function within the microcontroller's main program. This function configures how the taximeter will be charged according to the mode of use selected in the configuration module. There can be three modes of use according to the latest regulations of the Colombian state, and are configured through the following functions:

- *Fcn_metodo_normal_D*: The taximeter works with the double fare, time, and distance; each gradually increases according to the time delta and the distance delta without restarting.
- *Fcn_metodo_normal_S*: When the taxi's speed is lower than the crossing speed (crossing speed = time rate (rate/hour)/distance rate (rate/km)), the taximeter must operate only for a time. When the taxi's speed is equal to or greater than the crossing speed, the taximeter should operate only by distance.
- *Fcn_metodo_normal_T*: The taximeter works in combination with time and distance; if the time is met first, it increases one unit and resets the time and distance, and if the distance is met first, it increases one unit and resets the time and distance.

Additionally, the pricing module considers surcharges through the function: *Fcn_Recargo_o_Carrera_Minima* to determine the final collection rate. It applies additional surcharges according to various conditions, such as holidays, night hours, or location near an airport. It also guarantees a minimum race fee.

2.6. Invoice module

The invoice module generates an invoice corresponding to the value of the final collection rate provided by the pricing module. It uses a thermal printer for this purpose. Such invoices must comply with the respective regulatory requirements.

2.7. Invoice module

The accounting module is another function within the microcontroller's main program. This function aims to keep a complete and organized accounting of the services performed by the individual public service vehicle (taxi) so that the taxi owner can better control his accounting statements and tax liabilities. This information includes the location, date and time, start and end, duration, distance, fare, surcharges, total cost, and taxi service number. To ensure that the accounting information is not deleted, it is stored in the storage module with the capacity to save data corresponding to more than three months of operation.

2.8. Storage module

The storage module stores the detailed information of each service performed on a secure digital (SD) memory card through a CSV file, as shown in Figure 8. This CSV file contains the information described in the accounting module. Additionally, a CSV file containing the dates of holidays allows the taximeter to determine additional surcharges corresponding to operating on those days.

The micro-SD memory card is a removable external memory device commonly used for data storage in cameras, mobile phones, and other embedded systems, such as the ESP32 microcontroller. It allows the latter to read and write data to memory. The micro-SD memory card is connected to the ESP32 microcontroller via a serial peripheral interface (SPI) interface, using connection lines including master out slave in (MOSI), master in slave out (MISO), serial clock (SCK) and chip select (CS) pins. Before the micro-SD card can be used, it is necessary to perform a proper initialization; this involves configuring the micro-SD card reading module registers and establishing communication with the card. Once initialized, the ESP32 can send commands to the micro-SD card read module to perform read and write operations on the card. For example, you can read existing files, create new files, write data to files, and more.

Figure 8. SD card. Taken from [23]

2.9. Visualization module

The display module mainly comprises the LED array, which provides relevant visual information, such as the date, time, rate, and final price based on the number of units. This device ensures clear and direct communication with users. For this development, a module of four arrays MD_MAX72XX with 64 LEDs each was selected as shown in Figure 9.

Figure 9. Matrix of LEDs. Taken from [24]

The MD_MAX72XX LED array comprises a series of LEDs arranged in rows and columns. The array size may vary depending on the specific model, but standard sizes include 8×8 (64 LEDs) and 4×8 (32 LEDs). The MD_MAX72XX LED array is based on maxim integrated's MAX72XX drivers. These controllers allow you to control the LED array efficiently and quickly through a (SPI) communication interface.

The LED array MD_MAX72XX connects to a microcontroller or other device using connection lines including MOSI, MISO, SCK, and CS. These lines allow communication between the microcontroller and the MAX72XX drivers of the LED array. The LED array MD_MAX72XX requires a suitable power supply to power the LEDs. In addition, the MAX72XX drivers can adjust the current supplied to the LEDs, allowing brightness to be controlled efficiently.

2.10. Hearing module

The function of the auditory module is to express the final price of the degree in an auditory format as a complement to the visual representation, and it can do so in both Spanish and English, according to the client's preference. The hearing module must be initialized by the taxi operator. The main element of the voice module is the speech synthesis device SYN6988 showed in the Figure 10.

The integrated speech synthesis is manufactured in China and features a simple hardware interface and low power consumption; the tone is transparent and round, close to the human voice. In addition, the SYN6988 module has added English text analysis and the English sound library. The chip SYN6988 achieves a hardware and communication interface, allowing you to implement Spanish words by playing with the syllables of various English words, as it is not originally designed to work in Spanish.

Figure 10. Voice synthesizer module. Taken from [25]

2.11. Communication module

The communication module is based on Wi-Fi technology integrated into the ESP32 microcontroller. This module allows you to establish communication between a mobile device or computer that incorporates Wi-Fi communication and the smart electronic taximeter so that the information stored in the CSV files can be downloaded. The only requirement to be able to carry out this operation is to enter the security key generated at the beginning of the taximeter installation by the owner of the individual public service vehicle.

2.12. Power amplifier and speaker

Finally, to reproduce the messages of the hearing module, the intelligent electronic taximeter has a power amplifier. The power amplification module has an 8-ohm speaker. The power for this module is taken from the taxi's power source.

2.13. Development tools

To program the ESP32 microcontroller, the Arduino IDE development environment was used. The programming was based on threads to have the possibility of executing several functions and actions simultaneously, significantly improving the efficiency of the program. Finally, an exhaustive review was carried out to guarantee proper functioning of the program.

3. DEVELOPMENT OF THE SMART ELECTRONIC TAXIMETER

This section describes the operation of the smart electronic taximeter in Figure 11, which is explained in section 3.1. The operation of the taximeter is described through 24 steps, each one with a well-defined function. This section also explains the updating of parameters and rates within the code, the tests and adjustments carried out and the marginal development costs.

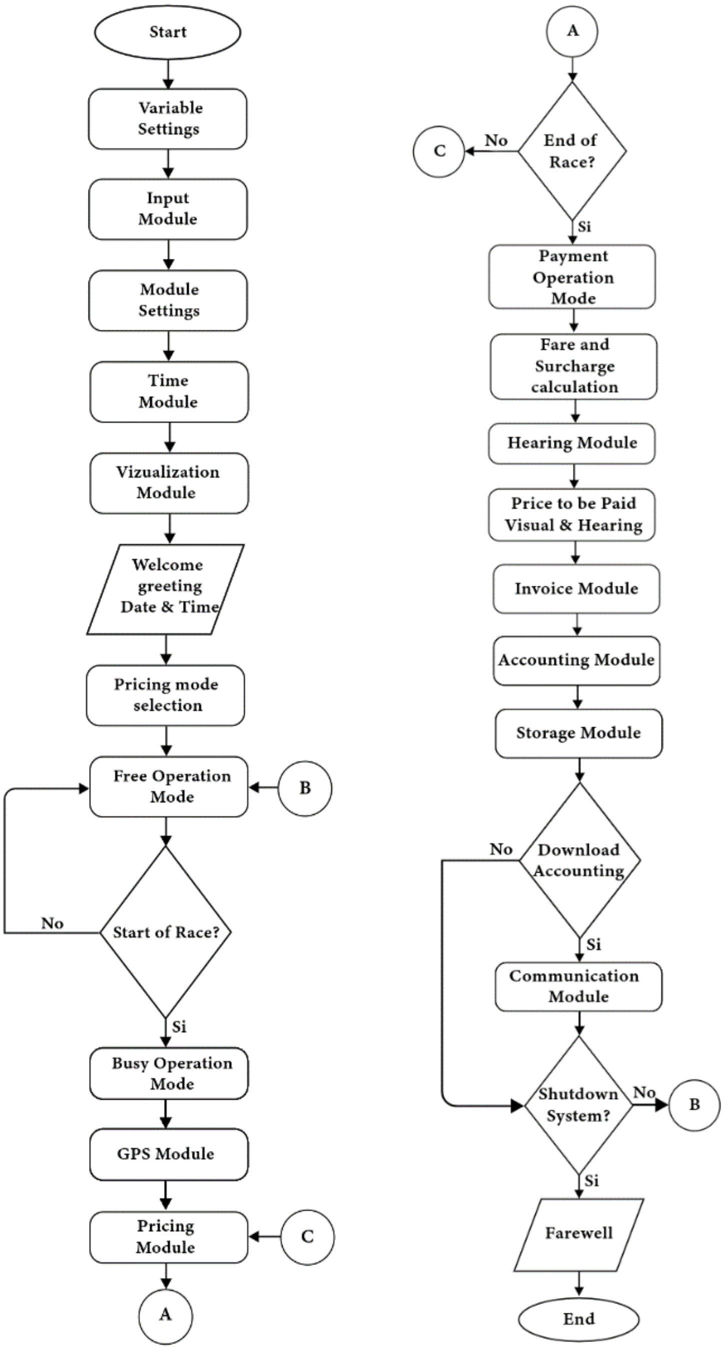


Figure 11. Flowchart of the operation of the intelligent electronic taximeter

3.1. How the smart electronic taximeter works

Step 0: Password creation

When you energize the device for the first time, you will be prompted to create a unique password from the hexadecimal keyboard on a one-time basis. This password should be known only by the taxi company or owner. Subsequently, when the taximeter is turned off and on again, the password will not be prompted to be created again. This password will be used to make adjustments and configurations only authorized workshops, the company, or the owner must make according to the regulations.

Step 1: Configuring variables

The first action when energizing the taximeter is the configuration and initialization of variables.

Step 2: Input module

Subsequently, the hexadecimal keypad is configured and initialized to operate the taximeter.

Step 3: Configuring modules

The rest of the modules presented in the previous section are configured here.

Step 4: Time module

The time module is initialized to know the date and time in real-time.

Step 5: Visualization module

The display module is then initialized to display the relevant taximeter information.

Step 6: Welcome greeting

Subsequently, both a visual and auditory welcome message will be uploaded.

Step 7: Selecting pricing mode

Here, you must select the mode of use with which the taximeter will operate: D, S, or T.

- D Mode: The taximeter works with double fare, time, and distance, each gradually increasing according to the time delta and distance delta, without restarting.
- S Mode: When the taxi's speed is less than the crossing speed (crossing speed = time rate (rate/hour)/ distance rate (fare/km)), the taximeter should operate only for a time. When the speed of the taxi is equal to or greater than the crossing speed, the taximeter should operate only by distance.
- T Mode: The taximeter works in combination with time and distance; if the time is met first, it increments one unit and resets the time and distance, and if the distance is met first, it increments one unit and resets the time and distance.

Step 8: Free operation mode

Subsequently, the taximeter enters free operation mode, where the taxi driver seeks a service. During this mode, the LED array displays the current date and time and the free word alternately until a service or race starts. When the taximeter is in pay mode and you want to return to free operation mode, press the * key.

Step 9: Start of career or service?

If a ride or service is initiated, the taxi driver must press the * key to switch to busy operation mode (step 10). Otherwise, the taximeter will continue in free operation mode (step 8).

Step 10: Busy operation mode (* key)

In busy operation mode, the taximeter is prepared to display the units' value and corresponding price in real-time and alternately.

Step 11: Location module

Immediately, the taximeter goes into busy operation mode; the location module sends the current location information to the accounting module.

Step 12: Pricing module

Immediately, the taximeter enters busy operating mode; the charging module starts operating according to the selected charging mode.

Step 13: Completion of the race or service?

Once the service or ride is finished, the taxi driver must press the * key to switch to the pay mode. Otherwise, the taximeter will continue in the busy operation mode.

Step 14: Pay mode of operation

In the mode of operation, paying, the taximeter will present the customer with the price to be paid, corresponding to the final value in units of the service and its corresponding equivalent in Colombian pesos or dollars, according to the initial configuration. It is important to note that the amount to be paid will also be presented disaggregated, indicating the charge for the value of the fare and the charge for the value of the surcharges.

Step 15: Calculating the fee and surcharges

Here, the final fare is calculated according to the selected pricing mode, and the corresponding surcharges will also be calculated if applicable: night, holiday, airport, door-to-door.

Step 16: Hearing module

According to the initial configuration, the final amount to be paid and its breakdown into rates and surcharges will be presented visually and audibly in English or Spanish. So here, the auditory module is prepared to reproduce the necessary information.

Step 17: Final price to be charged

Finally, the final price to be charged in Colombian pesos or dollars is presented, visually and audibly, in Spanish or English, according to the configuration made.

Step 18: Invoice module

Then, after presenting the final price to be collected, the invoice module is initialized to generate the corresponding invoice for the customer. To do this, the taximeter sends the corresponding information to a small thermal printer in charge of printing the invoice.

Step 19: Accounting module

Immediately, the accounting module is put into operation and organizes the information of the place, date and time, start and end, as well as the duration, distance, fare, surcharges, total cost, and number of each taxi service (race), to store it later.

Step 20: Storage module

All the information organized by the accounting module is saved in a CSV file and stored on the micro-SD memory card via the # key.

Step 21: Download the accounting report.

If the company or taxi owner wants to download the accounting report, the taximeter goes to step 22; otherwise, it continues to step 23.

Step 22: Communication module

The communication module operates to transmit the accounting report via Wi-Fi technology once the password is entered correctly.

Step 23: Turn off the meter.

If the taxi driver wants to turn off the meter, he goes to step 24; otherwise, he goes back to step 8.

Step 24: Farewell

Here, the taximeter visually and audibly presents a farewell greeting and switches off.

3.2. Updating rates and parameters

Rates and surcharges change every year, and some parameters, thresholds, and conditions may also need to be updated. Because of this, several variables were configured at the beginning of the code, allowing these changes and updates to be made easily and quickly. These variables and their initial values for Bogotá are mentioned below.

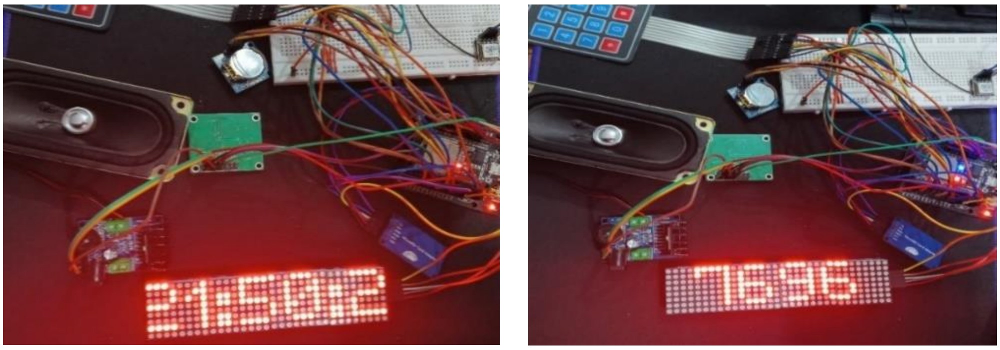
- *valor_unidad* = 104; //*Unit value, currently at 104 Colombian pesos (COP)*
- *valor_tarifa_distancia* = 104; //*Fare value in COP for a given distance*
- *valor_tarifa_tiempo* = 104; //*Fare value in COP for a given period*
- *incremento_distancia* = 100; //*How many meters a unit increases, currently 100m*
- *incremento_tiempo* = 24; //*in how many seconds does a unit increment, currently 24s*
- *velocidad_cruce* = (3600/*incremento_tiempo*)/(1000/*incremento_distancia*)
- *metodo_calculo* = 'S' *//The fare is calculated using D, S, or T. D is combined time and distance, and S is only time or distance according to the crossing speed. T is the traditional one today*.
- *conteo_tiempo* = 1; *//Calculation method in which the fare increases in proportion to the duration of the trip*.
- *conteo_distancia* = 1; *//A calculation method in which the fare increases in proportion to the trip's distance*.
- *conteo_tiempo_distancia* = 1; *//Method of calculation in which the fare increases in proportion to the distance and time of the trip*.
- *carrera_minima* = 50 *//Minimum number of units in a race*
- *distancia_inicial = carrera_minima×incremento_distancia*; *//Distance that can be traveled based on the initial charge rate*.
- *tiempo_inicial = carrera_minima×incremento_tiempo*; *//Time that can be traveled based on the initial charge rate*.
- *recargo_aeropuerto* = 50 *//Surcharge to or from the airport*.
- *recargo_nocturno* = 24 *//Nightly surcharge between 20:00 and 5:00*.
- *recargo_domingo_festivo* = 24 *//Sunday or holiday surcharge; in this case no night surcharge is charged*.
- *recargo_puerta_puerta* = 9 *//Door-to-door service surcharge*.
- *Flag* = 28 *//Initial value in units with which the units of the race begin to be counted*.
- *k* = 400 *//Taximeter constant k expressed in pulses per kilometer. Four hundred pulses per km or 2000 pulses per km*.
- *posición_operativa* = L, O, P *// L for free, O for occupied, P for pay*.

3.3. Testing and adjustment

Several experimental tests were conducted in the laboratory and vehicles for optimal operation. Figure 12 shows some of them, for example, Figure 12(a) shows the display of the time, and Figure 12(b) shows the value of a taxi service. The most important results of the tests and adjustments carried out, apart from the correct operation of the intelligent electronic taximeter, are:

- Maximum error of downtime measurement is 0.2 s or 0.1% in time;
- Maximum error of distance measurement without service is 4m or 0.2% in distance;
- Maximum error of fee determination is 0.1%, rounded to the least significant digit;

- Maximum error of time measurement with service is 0.2% in time;
- Maximum error of distance measurement with service is 2% in distance.



(a) (b)

Figure 12. Experimental tests of the intelligent electronic taximeter. (a) final price test and (b) time test

4. CONCLUSION

The smart electronic taximeter developed in this research is a novel device that significantly mitigates current gaps in quality of service and fair price for individual public transport services in the main cities of Colombia. Additionally, this novel proposal can increase the level of inclusion by allowing a blind person to know the total price to be paid, disaggregated by rate and surcharge, through auditory feedback, in the same way a foreign person can see this cost through an auditory response. But in English and even in dollars, it is important to understand the pay better. Wire programming made the device's development more flexible. It allowed the implementation of a greater number of significant improvements that directly affected the Smart Electronic Taximeter's performance.

ACKNOWLEDGEMENTS

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