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Reading and storage of library resources using UHF RFID technology with IoT

Lectura y almacenamiento de recursos bibliográficos empleando tecnología RFID de ultra alta frecuencia con internet de las cosas

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Abstract

Libraries supervisors have the administrative duty of control and keep safe their inventories, such as books, documents, manuals, and theses, facilitating access to their users to this information and helping them loan and return, internal or external, in case it's permitted. We wanted to design and build a prototype for a device capable of complementing these tasks in a low cost. We go through the processes in the design of a prototype for a simultaneous Radio Frequency Identification Reader using Ultra High Frequencies with Internet of Things technologies for data storage and communication between multiple stations, to do so we use a decision matrix method to select hardware tools, and software programming languages and libraries, needed to build such device, comparing, and weighting the characteristics that fit our needs. The resulting hardware selection was the Raspberry Pi and the RedBoard with a 59,7% and 12,4% respectively, and NodeJS with WebSockets for the software selection with a 53,8%. Finally, we present the designed architecture and a working prototype of the device that was built. Obtained response times from the reader and the database storage were as low as 10 milliseconds and as high as 20 milliseconds.

Keywords: Radio Frequency IDentification (RFID); Ultra High Frequency (UHF); Internet of Things (IoT); Raspberry Pi, NodeJS; Python, WebSockets; Libraries; Library Management; Algorithms.

Resumen

Los funcionarios de las bibliotecas cuentan con la obligación administrativa de velar por el control e inventario de sus recursos, tales como libros, documentos, manuales, y tesis de grado, facilitando a sus usuarios el acceso a esta información y proveyendo las facilidades para su préstamo y devolución, interna o externamente, en caso de ser permitido. Queríamos diseñar y construir un prototipo para un dispositivo capaz de complementar estas tareas en un bajo costo. En este documento atravesamos los diferentes procesos en el diseño de un prototipo para un lector simultáneo de alta frecuencia por identificación de radiofrecuencia con tecnologías de Internet de las Cosas para el almacenamiento de datos y la comunicación entre múltiples estaciones, para hacerlo empleamos el método de matriz de decisión para seleccionar herramientas de hardware y librerías para lenguajes de programación en software,

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necesarias para construir tal dispositivo, comparando y pesando las características que se ajustaran a nuestras necesidades. La selección de hardware resultante fue la Raspberry Pi y la RedBoard con 59,7% y 12,4% respectivamente, y NodeJS con WebSockets para la selección de software con un 53,8%. Finalmente, presentamos el diseño de la arquitectura y un prototipo funcional del dispositivo que fue construido. Los resultados obtenidos del lector y el almacenamiento en la base de datos fueron en su punto más bajo de 10 milisegundos y en su tiempo más alto de 20 milisegundos.

Palabras clave: identificación por Radiofrecuencia; ultra alta frecuencia; internet de las cosas; Raspberry Pi; NodeJS; Python; WebSockets; bibliotecas; administración de bibliotecas; algoritmos.

1. Introduction

Papers, books, and academic research started an increasing trend after World War II [1], with a rapid grow of US student college enrollment from 2,4 million students in the 50s, 8 million in the beginning of the 70s and totaling more than 20 million by 2014, about a 17% increasing rate by decade. Libraries followed a similar trend, with a 6% increase rate with more than 4000 libraries in the US by the end of 2015 [2]. This put universities and libraries administrators in the position and sometimes in the obligation of having better management practices for their resources and data gathered, be it material obtained directly through research [3], being required to get grants by the National Science Foundation (NSF) [4] to submit with their results, all primary data and samples of the work in all sponsored projects by the NSF; or indirectly from their acquired assets, because positive user experience with library services in the big data helps achieve innovation and identity and prepares the way in having a total virtual library environment [5], [6].

Therefore, good practices in library management help minimizing or completely preventing piracy or theft of their assets, which causes loses of $198.000 Colombian peso millions (the equivalent of about USD $55.000), according to Cámara Colombiana del Libro [7], [8].

Similarly, library managements systems can be accomplished using different technologies such as QR codes [9], [10], which are variations of the classic barcodes used in many places like stores and retails, to identify products, but those are more prone to falsification as it can be easily self-generated, unless the strings encoded are only interpretable by the end or final devices [11]. Internal work and organization can also be done by state-of-the-art robotic transportation [12], aiming to help library managers in their daily work.

In addition, Radio Frequency IDentification (RFID) is today standards for resources managements systems, be it warehouse inventory [13] or supply chains [14], and the most important industry for the scope of this document, libraries [15], where the use of passive and active tags in a controlled environment monitors the flow of the users attending and using their resources.

On the other hand, Internet of Things (IoT) is the given name to the group of technologies that interconnect devices [16] such as sensors and gateways [17], and it can work on different layers of the OSI standard [18] through different protocols and services such as MQTT, XMPP, CoAP and WebSockets. While MQTT operates in layer 4, WebSockets operates in layer 7, the lowest layer of the model, granting open and long-running connections between clients, in contrast with the publish-subscribe (Pub-Sub) model that MQTT uses. Even though MQTT offers better reliability or a Quality of Service (QoS) higher than WebSockets, being used in environments where connectivity is not always guaranteed, it lacks faster transmission times or higher Round-Trip Time (RTT) values than WebSockets, which can accomplish 1 ms of RTT even on bigger packets [19]. The most popular database engines are Oracle, MongoDB [20] and MySQL, the latter being the most popular in social media platforms like Facebook [21], YouTube, Twitter and MediaWiki.

Likewise, the industrial internet of things (IIOT), presents autonomous work systems operating in real time with diverse architectures and communication protocols that handle large amounts of data with computer security alternatives that allow offering cloud services and that present an alternative for the management of bibliographic resources [22], [23]. In addition, with the current technological advances, it is possible to talk about intelligent power plants that implement automatic learning algorithms with data science to improve the management of machinery and information [24], [25].

Industry 4.0 proposes the development of intelligent and automated systems involved with industrial machinery to improve production and connectivity [26], [27]. This makes it possible to propose alternatives for the management of bibliographic resources that involve hardware and software technology to automate processes and manage resources with better quality [28].

In this document, we go through the processes of designing and developing the architecture for a hybrid hardware and software which uses WebSockets for communication Ultra High Frequency (UHF) reading device and building a first-phase prototype of such device.

2. Materials and methods

The proposed architecture for the device in simple terms is presented in Figure 1, from left to right: UHF Antennas are connected to UHF Reader, then to the processing Device, which presents the data in the Activity Monitor and communicates with the Database, which inter-connects the hardware and software options of the device, selection that is presented as follows. It follows similar and standard implementations of reading devices to databases or software applications [29], [30].

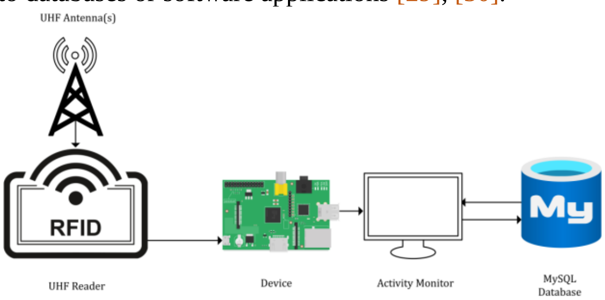

Figure 1. Proposed architecture for the device.

2.1. Hardware and software selection

The process of selecting hardware and software was made using the Pugh concept selection (also known as decision-matrix method) [31] arranging devices such as Arduino, Raspberry Pi (RPi) and FPGA from different manufactures, the chosen parameters are presented in Table 1. In defining the parameters for the selection of the hardware, the needs of the system were analyzed, among which are the capacity for simultaneous reading of tags, so that there is no possibility of skipping the system when trying to pass multiple bibliographic materials simultaneously, the storage of the readings in a database to analyze the movement of the material and the response of the status of the material from the query in the database, in order to detect an authorized withdrawal or otherwise activate an alert to the user.

Each parameter was giving a relative weight [32] from each other, where a higher value for the parameter in the row equals to better or more important towards the parameter in the column, as displayed in Table 2.

Those parameters were weighted for the following devices: Raspberry Pi 3B+, SparkFun RedBoard, Arduino UNO, Nexys 2 Spartan 3E and Teensy 3.5. Table 3 illustrates the selection of hardware that, according to the criteria established based on the literature review regarding the management of bibliographic resources, the Raspberry Pi is selected as the first hardware that meets the parameters.

Table 1. Parameters in the hardware selection process

Parameters	Indicator
CPU Speed	A
Versatility Modularity	B
RAM	C
Price	D
Multi-threading	E
Amount of information	F

Source: authors.

Table 2. Relative weights between parameters

	A	B	C	D	E	F
A	X	4	2	8	6	10,00
B	1/4	X	1/2	2	1,5	2,50
C	1/2	2	X	4	3	5,00
D	1/8	1/2	1/4	X	3/4	1,25
E	1/6	2/3	1/3	1,33	X	1,67
F	1/10	2/5	1/5	4/5	3/5	X

Source: authors.

Table 3. Hardware selection

	A	B	C	D	E	F	T
R Pi	0,30	0,06	0,14	0,01	0,04	0,01	**0,59**
RBoard	0,02	0,008	0,01	0,06	0,006	0,004	0,12
Arduino	0,02	0,008	0,01	0,03	0,006	0,006	0,09
Nexys	0,04	0,01	0,03	0,03	0,005	0,003	0,10
Teensy	0,03	0,005	0,01	0,01	0,004	0,007	0,08

Source: authors.

Therefore, this selection allows the system to be modular, and therefore it can be easily improved or expanded by deepening the programming logic.

2.2. Reading hardware

Ultra-High Frequency RFID reading is achieved having specialized tags in the 859 – 930 MHz spectrum, parameters required by the ISO/IEC 18000-6 [33], placed in the objects to be read such as books, encyclopedias and magazines and a reader with the capability of reading these tags, and if the reading distance needs to be greater than the provided by the reader, attaching an antenna which complies with regional regulations [34].

UHF tags, in a physical level, can be either adhesive, to be easily adhered to hard resources such as books or water resistant, to get better results in potentially wet surfaces such as bottles or test tubes.

UHF tags contain, according to the EPC standard [35], is organized in 4 levels of data:

- A Tag ID / Unique Identifier (TID / UID)
- An Electronic Product Code (EPC).
- A User Memory Bank
- A Reserved Bank for destroying the tag data (irreversible).

The distribution of the data is shown in Figure 2, from left to right: Header (containing the TID / UID and Reserved Bank), EPC number (programmable), Object Class and Serial Number (User Memory Bank), with similar naming convention as the described above, as EPC is a standardized code for UHF RFID tags.

The TID / UID is a unique data given by the manufacturer and cannot be modified (it being the combination of the manufacturer ID, tag model and a tag serial given to the model). The TID is the identifier being stored for the RFID readings in the database for its uniqueness.

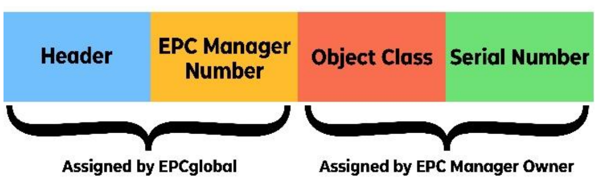

Figure 2. Proposed architecture for the device.
Source: authors.

The Electronic Product Code (EPC) is a hexadecimal pre-built value which can be modified to the RFID system administrators will, or in our case, as the RFID system programmers, and ca be any value equal or lower than 12 bytes (e.g., a word or an internal code). This data was being used in the RFID system tests (using it "as is", pre-programmed by the manufacturer), but as we latter found that it could be modified using similar equipment, and it being a security risk, we decided NOT to use this value for the data storing.

User Memory Bank or User Data is used when there is a need for additional information about a tag to singularly identify it (e.g., date of inclusion to the system). There is no use for this data, yet.

The Reserved Bank is a special section of the tag used to destroy all the information in the tags, specifically used when discontinuing the asset or library resource.

The M6E Nano [36] reader is a UHF reader designed as a mounted module form to be used with Arduino like boards, getting the data from the UHF tags, obtained after sending a continuous electromagnetic field (EMF) in the direction of the reader, and sending them over to the RedBoard through software serial. M6E Nano installations and use is required to comply with FCC regulation in long time exposure for personnel [37].

The reading distance of the M6E Nano reader is defined through programming and expressed in decibel-milliwatts (dBm), with a factory default value of 5 dBm achieves 20 cm without obstacles or obstructions. Increasing this value without an external antenna would cause temperature throttling and over- heating in the reader chip, and further usage may cause permanent damage in the connected hardware.

The RedBoard is SparkFun's variation of the popular Arduino UNO microcontroller board, designed to be used plug and play-like with the M6E Nano reader, as both designs complement each other in terms of size, connections, and hardware capabilities. The reason behind its selection is explained in the PUGH method previously mentioned and presented in the results.

Raspberry Pi is a small single board computer developed specifically for IoT applications due to its size, modularity, and open-source operating system, which allow it to use a great variety of libraries built for the Linux environment. It receives data from the RedBoard through its USB ports using the USB serial protocol and interpret such data with the reading algorithm (Table 4).

2.3. Reading algorithm

The algorithm to develop must be able to keep reading data from the hardware device(s) and send the data over to the database, and, at the same time, send each reading to the other hybrid devices (in case they exist in the network) before or the same moment the information is being stored in the database.

Table 4. Decision matrix for hardware selection

	A	B	C	D	E	F	SUM
Raspberry Pi	0,306001	0,066638	0,149482	0,014014	0,047265	0,013924	0,597325
RedBoard	0,027347	0,008885	0,010608	0,066566	0,006452	0,004177	0,124036
Arduino UNO	0,027347	0,008885	0,010608	0,031531	0,006452	0,006614	0,091438
Nexys 2 S. 3E	0,045724	0,011195	0,033754	0,003503	0,005652	0,002228	0,102057
Teensy 3.5	0,036931	0,005997	0,017221	0,019853	0,004376	0,000766	0,085145

Source: authors.

This is explained easily witha flow chart shown in Figure 3, from top to bottom: Startthe reading device, check if the reader(s) are connected (or shut the program down if not), keep requesting data from the reader(s), interpret the incoming data if present, store and broadcast the formatted data and validate the results depending if the resource is moving in or out from the room.

The reading algorithm from the first device, the RedBoard, must have a proper implementation of the ISO 18000-6C RFID protocol [38], in order to prevent data misreading which would be unfixable in other stages of the algorithm development, and the serial ports reading code may match the configured in the hardware, being it 115200 bauds, or else wrong data serialization would be presented and couldn't be analyzed and later stored.

All new incoming data to the serial ports is expected to have as an End of Line (EOL) the line feed ('\n') character, also known as newline. When present, all previous data will be decoded and sent to the registry database, and, if present or connected, to the IoT clients.

For this kind of communication, we must go with the IoT communication route, to ensure the exchanged data is only shared to authorized devices in the network, and prevent direct access from the outside, letting the database configuration manage the incoming requests for first or third parties.

A similar selection for programming language and IoT protocols was established to select the best combination of technologies based on the parameters shown in Table 5. The technologies to be weighted are Python with MQTT, Python with WebSockets, NodeJS with MQTT and NodeJS with WebSockets. The selected protocol(s) are presented in the results.

However, while the IoT protocol is sending the datato the IoT devices, the algorithm must check with the database if the resource's tag that is being read is enteringor exiting the room where the device is located, to notify the other devices or itself whether make an alertor not. Such check must be made in the least amount of time possible to prevent resource lost or data misreadingin other devices in the network.

In Figure 3, the flowchart of the reading algorithm is illustrated.

Table 5. Parameters in the IoT protocols selection

Parameters	Indicator
Asynchronous support	A
Round-Trip Time	B
Installation Size on Disk	C
Resources' usage	D

Source: authors.

3. Results and discussion

The use of an external antenna for the M6E required the use of two converters: a Reverse Polarity Threaded Neill–Concelman (RP-TNC), the reverse polarity version of the standard for antenna connections [39], to a Reverse Polarity SubMiniature A (RP-SMA) connector, and a RP-SMA to UFL [40], the miniature RF connector for high frequency applications, located in the M6E Nano reader board.

Using the internal antenna grants a maximum reading distance in the free space of 20 cm with the default power level values in the programming, and 10 cm with obstacles such as book covers and sheets. Using the external antenna and an external power supply in the RedBoard gives the possibility of increasing the power level to as much as 27 dBm, but using this maximum value would overheat and damage the chip and other components if they are intended for extended use. Through arbitrary measurements we found that the ideal power level for the reader is 23 dBm, giving readings as far as 2 meters from the antenna, even when surrounded by other books, bag packs and other electronics such as laptops and tablets, and readings in a radius of 0,8 meters in the direction of the antenna. Higher values of power levels before the limit demonstrated data misreading and collision of tags not even intended to be read.

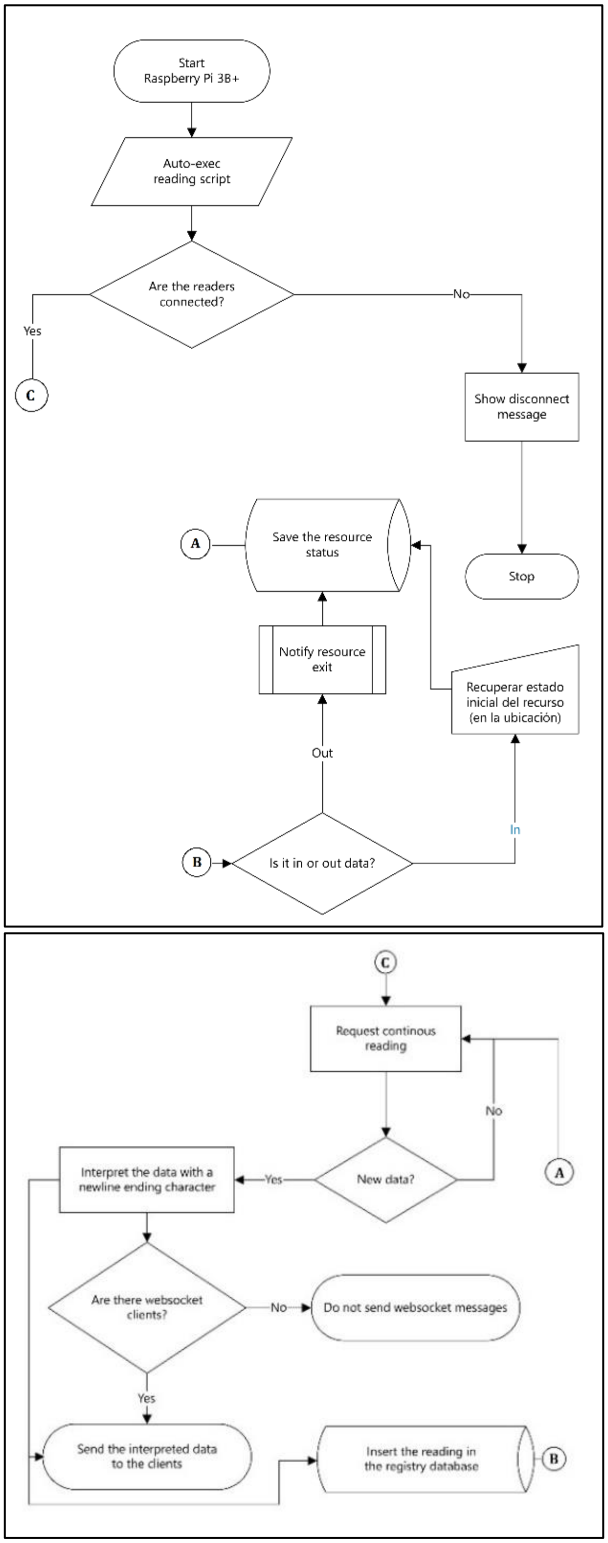

Figure 3. Flow chart of the reading algorithm.
Source: authors.

Similarly, the M6E Nano reader board needs to be adjusted to get readings from the external antenna rather than using the internal one, this adjustment consists of cutting the internal antenna trace in the board and closing the circuitto the UFL connector, as presented in Figure 4.

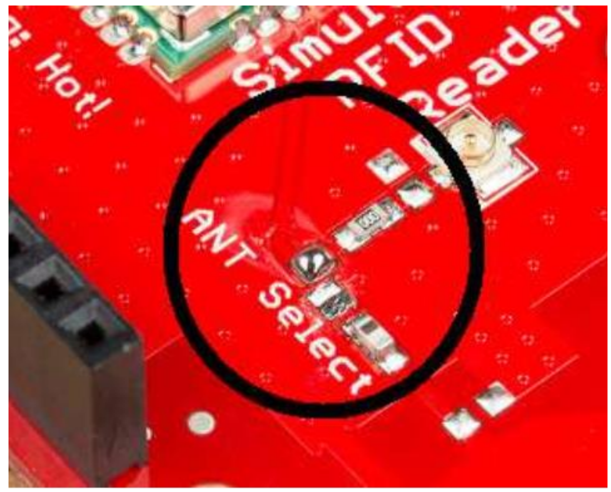

Figure 4. Adjustments (soldering) to the M6E Nano board to work with an external antenna, highlighted in a black circle. Source: [40].

The decision matrix for the IoT protocols is presented in Table 6, with a highlight in the selected programming language and IoT protocol resulting in the selection of NodeJS with WebSockets weighting 53,9%, outperforming the other technologies having NodeJS with MQTT in 29,4%, Python with MQTT in 13,9% and Python with WebSockets with a 2,8% of the final score.

Table 6. Decision matrix for programminglanguage and IoT protocols

	A	**B**	**C**	**D**	**Sum**
Python WebSockets	0,0169	0,004	0,005	0,003	0,028
NodeJS WebSockets	0,358	0,124	0,001	0,056	0,539
Python MQTT	0,055	0,057	0,021	0,007	0,139
NodeJS MQTT	0,169	0,097	0,002	0,026	0,294

Source: authors.

The developed algorithm has the capacity of being completely asynchronous in its functions of reading from the serial ports. Asynchronous readings are described as non-blocking code, which is executed when available allowing other parts of the code to be executed, instead of traditional synchronous code which block other parts of the code to execute itself, allowing multiple readings of multiple devices at the same time. This asynchronous capability is built-in on NodeJS as demonstrated in its choosing using the PUGH method.

The final architecture of the device is presented on the Figure 5, from left to right: the tags are read either by the external or the internal antenna of the M6E Nano reader, this info is sent to the SparkFun RedBoard via software serial, which then sent this data through USB Serial to the Raspberry Pi and the RPi communicates with the database and emit this info to the connected clients.

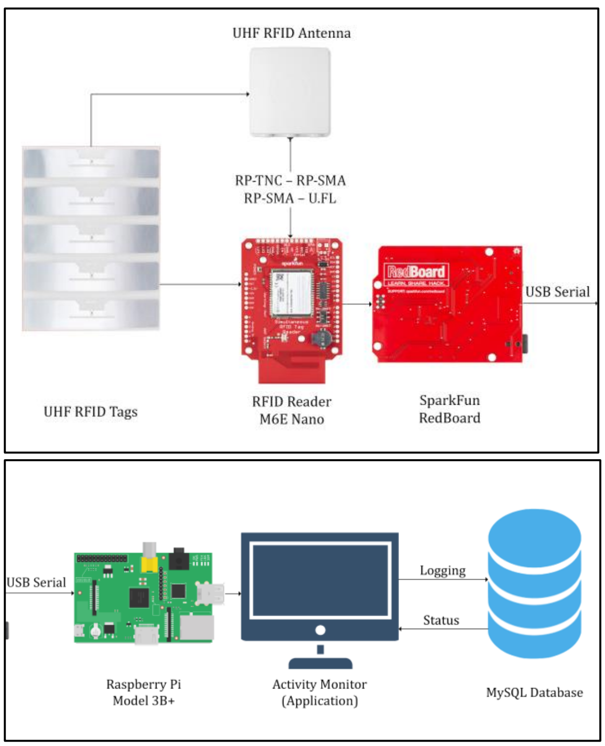

Figure 5. Architecture of the hardware / softwarehybrid UHF reading device. Source: The authors and SparkFun Electronics [41].

Likewise, a general overview or mockup design [42] of the implementation is presented on Figure 6 for better understanding of the intended configuration, indicating and referencing the previous figure to explain how it would work as an end device of, or as a product in a library management system, having tags in everypossible resource and allowing the user to request its loan and detect the tags in an exit.

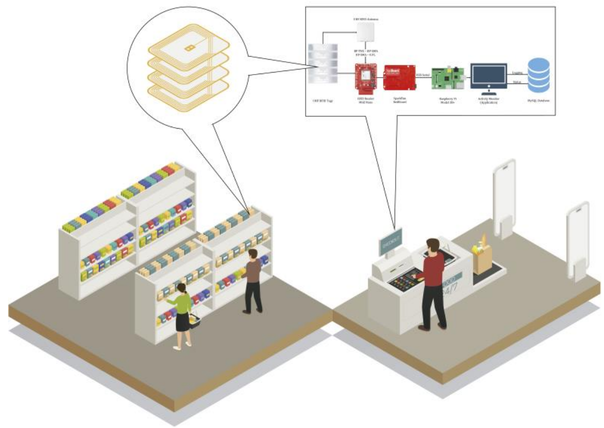

Figure 6. Mockup of the implementation of the UHF RFID reading device. Source: The authors and Macrovector (Freepik with Creative Commons Attribution).

Tests results for the device prototype are shown in Table 7 with the following characteristics (A) CPU Usage in Megabytes, (B) RAM Usage in Megabytes, (C) Timestamp of reading (D)Timestamp of MySQL Data Storage, demonstrating the best results for NodeJS with WebSockets.

Table 7. Test results of the device prototype. NR means No Response

Technology	A	B	C	D
Python WebSockets	53,7	122,9	NR	NR
NodeJS WebSockets	38,9	151,1	[…]7868	[…]7878
Python MQTT	20,9	43,5	NR	NR
NodeJS MQTT	35,6	144,7	NR	NR

Source: authors.

MQTT couldn’t handle simultaneous readings without crashing during testing, therefore producing no results. Results arebased on attempted readings from 5 different tags adhered to books and objects, individually and multiple at the same time.

Finally, A working prototype of this architecture is presented in Figure 7, highlighting in (1) and (2) the M6E Nano Reader and the RedBoard, antenna connectors RP-SMAto UFL and RP-TNC to RP-SMA in (3) and (4), externalantenna in (5) and the Raspberry Pi and main processingunit of the system in (6).

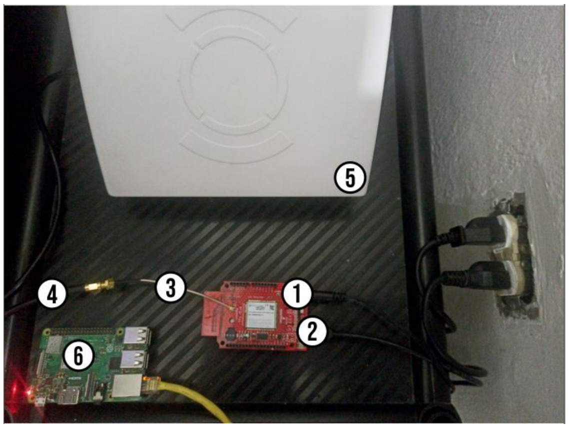

Figure 7. Designed and assembled prototype of the architecture of the device. Source: authors.

4. Conclusions

Long distance readings and readings with obstacles in a 1-2 meters range were doable with an external UHF RFID antenna, giving libraries supervisors and managers security in their implementations with a device like this ensuring that their resources are safe within their installations.

Asynchronous coding allows continuous and repetitive tasks such as USB serial reading without throttling the reading device thanks to its non-blocking nature and anti-data duplication measures, while also allowing multiple reads without data collision, permitting free moving and reading of the resources below the 50 milliseconds marks, by the users entering or exiting the libraries rooms or the library itself.

A built and working prototype as a result demonstrates that the proposed architecture is suitable to be implemented in a library management system, integrating Raspberry Pi and RedBoard as hardware and NodeJS, WebSockets and MySQL databases as open-source software technologies, granting a fast, low cost and open alternative to the UHF RFID implementations, giving the opportunity to build a modular device, letting diagnose failures easily in any part of the chain such as data corruption or USB serial collision, debuggable in the RedBoard and in the Raspberry Pi respectively, or data storage and socket broadcasting failures in the MySQL databases connections and IoT communication codes.

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Autor Contributions

J. Durán-Bayona: Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing. S. Quintero-Ayala: Investigation, Validation, Writing – review & editing. S. Castro-Casadiego: Investigation, Validation, Writing – review & editing. C. Niño-Rondon: Conceptualization, Methodology, Writing – review & editing. G. Sandoval-Martínez: Conceptualization, Methodology, Project administration, Supervision, Writing – original draft.

All authors have read an agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

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