IoUT device with inductive charging and wireless communications for freshwater fish tracking

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***Abstract*— This work focuses on the study, design, and implementation of a prototype IoUT Device intended for future underwater applications. The objective is to assess the feasibility of combining NFC and VLC wireless communication technologies to achieve a compact and durable solution as required.**

The prototype's implementation is based on data acquisition, transmission, and inductive recharging. However, during its study, it was also deemed necessary to design and develop a second prototype, named the "base station," which reads data from the first prototype, presents it to users, and transfers energy.

The second prototype or base station utilizes various development boards for control and NFC. The aim is to create a functional ecosystem that transfers data in a compact and straightforward manner. The acquired data is displayed on the user's console, and inductive recharging is implemented to maintain the IoUT device's operability and extended autonomy.

In summary, this thesis has successfully designed and developed two interconnected prototypes forming a functional IoUT system, contributing to the advancement of IoT, IoUT, and energy efficiency.

Index Terms – IoUT device, base station, LED, NFC, VLC, OWC, PCB, RF.

I. Introduction

In articles [1] and [2], the importance of the Internet of Things (IoT) is explored for both terrestrial and underwater monitoring, with a focus on the Internet of Underwater Things (IoUT) as a current revolutionary technology. This technology finds applications in oceanic exploration as well as biodiversity conservation. Within the context of Consumer Electronics (CE), IoUT technology is gaining attention, with intelligent underwater devices being integrated into IoUT networks, such as drones and autonomous cameras, enabling remote control and access.

The thesis project is dedicated to the study, design, and integration of a prototype IoUT device with multiple communication methods and a base station that facilitates wireless recharging of the device. A communication system via Visible Light Communication (VLC) is examined to establish underwater communication between the IoUT device and the land-based base station. Freshwater is chosen as the underwater medium due to its lower light attenuation. The objective is to evaluate the viability and potential applications of the system, as well as to utilize the technology to investigate communication between IoUT devices and the base station even outside of water, enabling inductive recharging of the device.

II. State of the Art

A. VLC

In [4], a comprehensive summary of visible light communication is available, discussing the revolution that has emerged from solid-state lighting and the appearance of LEDs, which stand out due to their extremely high energy efficiency.

Another benefit of LEDs is their capability to swiftly change light intensities. Consequently, they can be employed for high-speed data transfer, although this necessitates a receiver capable of converting light radiation into an electric current interpretable by existing electronics.

However, VLC technology necessitates a proper understanding of the properties of the physical layer of the visible light communication channel, possible modulation methods, and implementable communication techniques, among other knowledge.

In [5], the IEEE standard for visible light communication is provided. This standard defines a physical layer (PHY) and a medium access control sublayer (MAC) for short-range optical wireless communications (OWC) in optically transparent media, utilizing light wavelengths ranging from 10,000 nm to 190 nm.

B. NFC

Near Field Communication (NFC) was born as a specialized subset of the 13.56 MHz RFID technology during 2002.

Initially used for access control and payment cards in public transportation, its integration into other types of cards and smartphones is driving rapid growth not only in the realm of wireless payments but also as an always-active radio link for simple pairing, diagnostic reading, parameter programming, and other options.

In [5]–[9], along with the aforementioned references, several informative publications can be found, providing the necessary information to implement the NFC technology required for this project.

Furthermore, in [10], the company STMicroelectronics provides a comprehensive description of this technology and other freely available resources for anyone visiting their online platform.

C. *STMicroelectronics*

As introduced earlier, STMicroelectronics offers a wide variety of products designed for topics such as smart mobility, energy and power management, IoT, connectivity, design tools, and development tools.

In [11], the company's main platform window can be found. This provides information about the company, including its products, sustainability efforts, upcoming events, and job opportunities, among other resources.

For this project, several development platforms from STMicroelectronics will be used for control and communication tasks, among other resources for the provided software solution. The products used in the development of this work are described later.

In [12], all the information related to the STM32L053R8 can be found. This microcontroller is included in the NUCLEO-L053R8, available in [13]. This core is a development board used in this project to control the IoUT device.

Various resources about the STM32L476RG are available in [14]. This microcontroller is found in the NUCLEO-L476RG, available in [15]. This product is a development board required in this project to control the base station and its functions.

When designing the necessary base station for this work, it was first necessary to decide on the device used to implement the NFC reader. For this purpose, the ST25R3911B available in [16] has been selected. This device is oriented towards NFC system infrastructure, where users require optimal RF performance and flexibility combined with low power consumption.

The aforementioned device has been included in this project due to its ability to act as an NFC reader, among other aspects. Additionally, due to the need to incorporate the ST25R3911B into the project, the decision was made to use the STMicroelectronics X-NUCLEO-NFC05A1 expansion board available in [17], which integrates the necessary electronics for the NFC reader.

The chosen product from the ST25DVxxKC family for this work is the dynamic tag ST25DV64KC, whose documentation and other resources can be found in [18]. This is a low-power, high-performance NFC RFID device.

Therefore, the decision has been made to use the X-NUCLEO-NFC07A1, available along with multiple resources and documents about the platform in [19]. This expansion platform can be combined with the NUCLEO-L053R8 to provide the necessary NFC communication capability for it to act as a dynamic tag.

D. *SW4STM32*

The System Workbench toolchain, known as SW4STM32, is a free cross-platform software development environment based on Eclipse, supporting the entire range of STM32 microcontrollers and associated development boards or extensions.

This toolchain can be found along with various forums, blogs, and training resources for technical support at [20] and [21]. However, in order to download this development environment, users need to be registered on the OpenSTM32 website.

Once registered, any user can access the installation instructions provided on the website to proceed with the download of the free toolchain.

E. *KiCad 7.0*

For the completion of this project, the decision was made to utilize free printed circuit board design tools that provide the necessary features for the design objectives required in this work. After evaluating various available options, KiCad 7.0 was chosen for use.

The online platform of KiCad can be found at [22]. This company offers their free KiCad 7.0 software to the public for the design of electronic circuits and open-source printed circuit boards. It includes an integrated suite of tools for schematic creation, PCB design, library management, and more.

III. ADOPTED HARDWARE SOLUTION

The adopted solution consists of two independent prototypes arranged to be capable of communicating through different communication technologies.

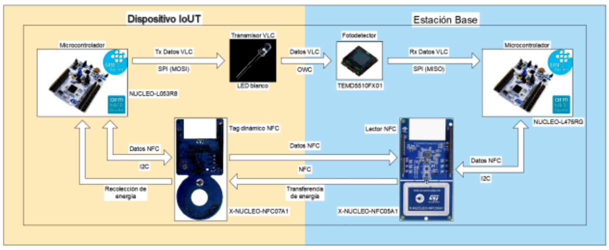

Figure 1. Scheme of the final prototypes

These prototypes are the IoUT device and the base station. Both include different internal data buses for controlling the devices proposed in this project.

A. *Hardware Solution for Prototipo de dispositivo IoUT*

The prototype of the IoUT device is conceived as an integration of the NUCLEO-L053R8 along with the X-NUCLEO-NFC07A1. Initially, the idea was to connect the output of the dynamic tag to a battery and measure the recharging.

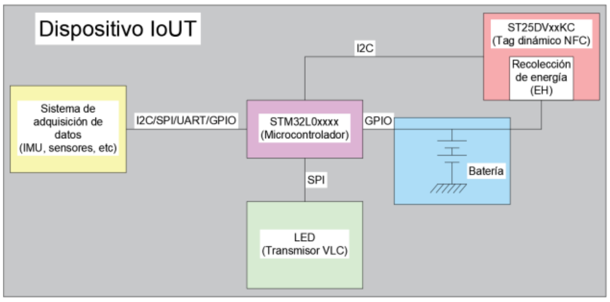

Figure 2. Block diagram of the IoUT device

However, the implemented prototype does not include any battery, as the intention is to measure the energy collected through the "EH" pin of the ST1 jumper on the NFC dynamic tag extension platform.

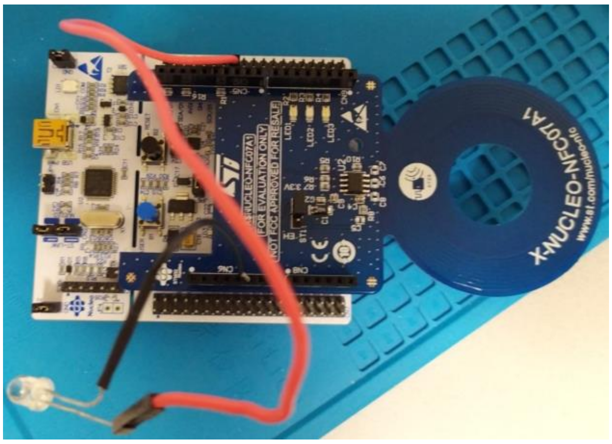

Figure 3. Proposed IoUT Device Prototype

On the other hand, the VLC technology integrated into this prototype is summarized in a white LED. Comprising various wavelengths, including that of the blue color, this LED is used for data transmissions through visible light. This color has been chosen to reduce signal absorption by the OWC channel. In freshwater environments, the visible spectrum wavelengths corresponding to green and blue colors are less absorbed by the medium.

Several internal communication interfaces are necessary in this prototype to implement the described operations. For VLC transmissions, an SPI interface is required, while an I2C interface is needed to control the NFC extension platform.

It is also possible to enable other interfaces of the NUCLEO-L053R8 to connect data acquisition devices or other devices of interest to the designer.

B. *Hardware Solution for Prototipo de estación base*

The prototype of the base station is conceived as an integration of the NUCLEO-L476RG along with the X-NUCLEO-NFC05A1, with the latter serving as the NFC reader.

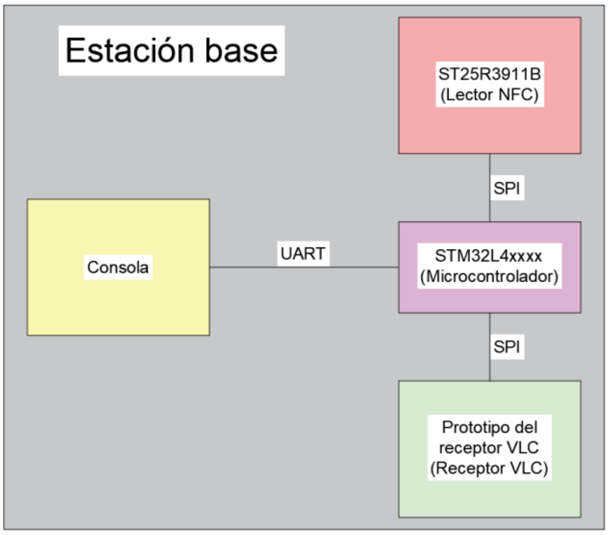

Figure 4. Block Diagram of the Base Station

The base station prototype is designed as an integration of the NUCLEO-L476RG along with the X-NUCLEO-NFC05A1, with the latter representing the NFC reader. Additionally, this prototype is intended to incorporate a specialized VLC receiver for 4 KHz signals, designed and developed by the student in the laboratory.

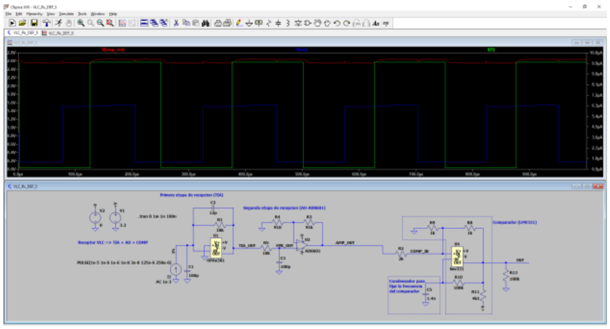

Figure 5. Simulation of the VLC receiver's response

This receiver features 3 reception stages aimed at capturing the light signal and converting it into an electrical signal. It filters and amplifies the received signal, and finally incorporates a comparator to ensure that the output signal of the receiver remains as a square wave.

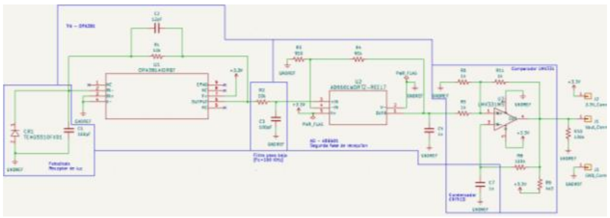

Figure 6. Schematic of the VLC receiver in KiCad 7.0

After designing the proposed VLC receiver in KiCad 7.0, the fabrication process was carried out. This process resulted in an additional prototype representing this receiver.

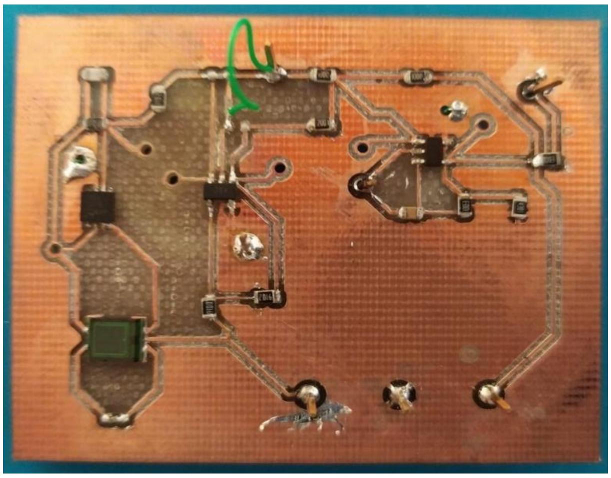

Figure 7. Fabricated VLC Receiver Prototype

When fabricating the VLC receiver proposed in this project, it's important to consider that it should be connected to one of the SPI interfaces of the NUCLEO-L476RG configured as an exclusive receiving interface.

Additionally, it's necessary to synchronize the clocks of the SPI interfaces related to the VLC technology integrated into the IoUT device and the base station at 4 KHz to avoid errors in visible light communication.

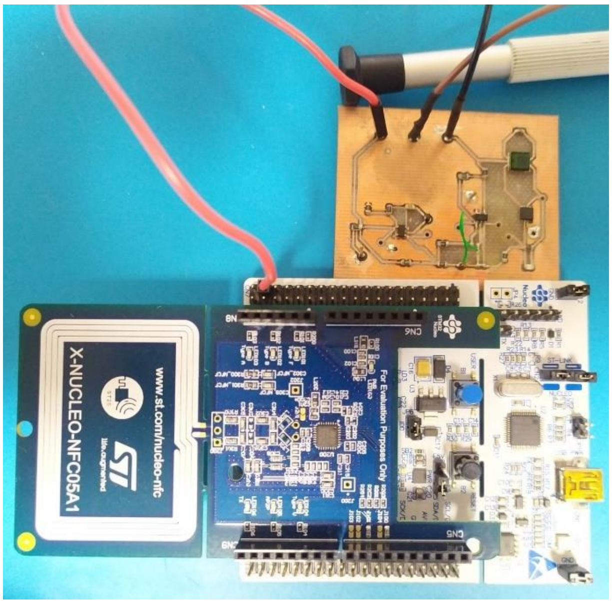

Figure 8. Proposed Base Station Prototype

Similarly to the first prototype, several internal communication interfaces are required to implement the described operations for the base station.

As mentioned earlier, an SPI interface is used for VLC reception, and an additional SPI interface is needed for controlling the NFC extension platform.

Fortunately, the NUCLEO-L476RG has the necessary interfaces, and it even provides the option to enable other communication interfaces to connect more peripherals.

IV. ADOPTED SOFTWARE SOLUTION

The software solution of this project is based on the C programming language and the development environments of STM32CubeMx, STM32CubeIDE, and SW4STM32. With these tools, the study and implementation of the necessary code to achieve the objectives of this project are planned.

A. *Software Solution for IoUT Device Prototype*

The IoUT device must be capable of communicating with the base station to transfer the acquired data and collect the energy transferred by the base station for recharging.

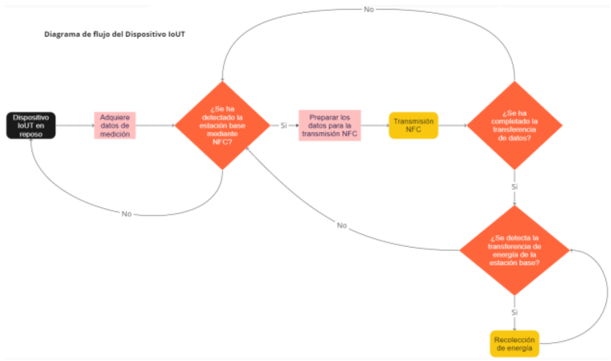

Figure 9. IoUT Device Flowchart

For this purpose, an example project provided by STMicroelectronics has been implemented to demonstrate the proper functionality of this device. This example includes the necessary functions to develop the various features that this prototype must include to fulfill the intended objectives.

B. Software Solution for Base Station Prototype

The software solution adopted for the base station enables it to read the data obtained through communication with the IoUT device, display this data on the user console, and transfer energy to facilitate the inductive recharging of the first prototype.

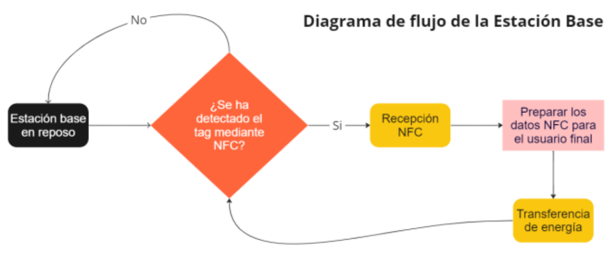

Figure 10. Base Station Flowchart

Similarly to the configuration of the IoUT device, an STMicroelectronics example project has been utilized to demonstrate the functionality of this station base. This example enables the achievement of the objectives required for this work and includes various information messages to indicate the properties of the tag detected by the reader.

V. Results

After conducting multiple experiments in the laboratory, it has been concluded that the VLC technology proposed in this project requires more study and design time for its development in future applications.

However, measurements taken so far indicate that it is a technology that could enable wireless communication between the project prototypes up to 15 cm in an OWC channel.

On the other hand, NFC technology has proven to be a robust solution that ensures communication between the prototypes. It even enables the inductive charging of the IoUT device when placed over the antenna of the base station.

VI. Conclusions and Future Work

A. Conclusions

This paper describes the study of integrating VLC and NFC technologies, exploring their applicability in IoUT. The implementation focused on a scalable, low-power, and adaptable design solution.

The provided solution includes various development platforms for the implementation of two prototypes: an IoUT device and a base station, achieving a robust communication system with NFC-based inductive charging.

Test results indicate maximum underwater communication distances of up to 15 cm via VLC, along with communication and energy harvesting outside of this medium using NFC. However, the development of underwater communications will require more time for future applications.

B. Future work:

The future work proposed to continue the study, design, and implementation presented in this document includes the following:

1) Compact Hardware Design for IoUT Device: It is considered that this prototype could be scaled down to achieve a more compact design. This would involve implementing a specific platform onto which the necessary elements for its particular application are integrated, while maintaining its role as an NFC dynamic tag.

2) Integration of an Inductive Charging System: The complexity of implementing an inductive charging system to add a battery to the IoUT Device is highlighted. Multiple criteria need to be considered for its development. Emphasis is placed on the need for meticulous design, testing, and prototyping to ensure the proper functioning and performance of the new device.

3) More Compact Design of the VLC Receiver: The possibility of a more compact design in the future is mentioned. This could involve rearranging components to reduce space between them and, if part of the future design, redistributing them across the faces of the board.

4) Design and Implementation of Custom Software: Improving the prototypes through the implementation of custom software is proposed. It is suggested to base this software on existing designs and adapt it to the required communication protocols. Additionally, resources provided by companies like STMicroelectronics and familiar development environments can be used to expedite the design and implementation process of the new software.

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