www.ijaceeonline.com ISSN: 2456 - 3935

International Journal of Advances in Computer and Electronics Engineering
Volume: 2, Issue: 7, July 2017, pp. 21–28

IoT Embedded System Communications for Wireless Underwater Depth and Temperature Monitoring

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Abstract: *This paper presents an embedded wireless Internet of Things architecture, integrating real time embedded systems that communicate underwater through acoustic signals. The proposed architecture is based on an ultra-low-power Flash Micro-controller that manages communications with sensors, and synchronization between the whole system through wireless radio link. The developed system was tested with water depth and temperature sensors monitoring. Sensed data is gathered to the main station by means of wireless acoustic pulses, sent by transmitters through water. The transmitter and the receiver acoustic chains are based on a Digital Signal Processor. The receiver acoustic board is connected to a local server implemented on a RaspberryPI unit.*

Keyword: *IoT; wireless acoustic communication; underwater sensors; embedded systems.*

1. INTRODUCTION

Internet of Things (IoT) represents the interconnection, through the Internet, of a large number of things, uniquely identifiable physical objects with sensing, communication and actuation capabilities. The term has been introduced by Kevin Ashton in 1999 in the context of chain supply management [1]. In others words, IoT is considered as a network of devices that integrates a large number of physical objects that are connected to internet which enable these objects to collect and exchange data, in the aim to transform any object in the real-world into a computing device that has sensing, communication and control capabilities [2].

The majority of the earth's surface is covered by sea. The emergence of wireless underwater acoustic sensors provides new opportunities for the exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. Various systems have been studied in terrestrial IoT sensors, however, they cannot be applied directly to underwater sensor because of attenuation of Global Positioning System (GPS) and Radio Frequency (RF) signals underwater, which makes the IoT underwater particularly challenging.

This paper presents the design and experimentations of an IoT platform that integrates depth and water sensors, Digital signal processors, Flash micro-controllers, wireless radio link, RaspberryPI and acoustic transmitters and receiver chains. The rest of paper is organized as follows. Section 2 gives a review of literature on IoT, underwater sensor synchronization and water depth measurement. In Section 3,

Cite this paper:

R. Es-sadaoui, L. Azergui, M. Guermoud, J. Khallaayoune, S. Bouaazzaoui, T. Brizard, "IoT Embedded System Communications for Wireless Underwater Depth and Temperature Monitoring", International Journal of Advances in Computer and Electronics Engineering, Vol. 2, No. 7, pp. 21-28, July 2017.

the proposed architecture is described. In Section 4, we present the result of experiments. Finally, in Section 5, a conclusion is given.

2. LITERATURE REVIEW

2.1 IoT sensors

The number of IoT applications is growing in many areas including smart home, healthcare monitoring, smart city, utilities, smart agriculture, security, smart water, industrial control, environment monitoring, and more. The integration of things in the internet is challenging because they may have characteristics such as limited memory, processing capacity and energy resources [3] [4] [5].

In the paper [6], authors discussed architectures and technical aspect related to IoT. They gave a survey of IoT technologies, protocols and applications. a framework integrating different protocols was also given.

Paper [7] proposed a wireless temperature monitoring system based on ZigBee module. authors showed the capability of the system to solve wiring issues, limited adaptability, and others issues related to distributed wireless temperature monitoring system.

Vu Chien Thang proposed in [8] a solution for water factories in Vietnam using automatic meter reading technology. Author realized a prototype of water meters and water quality meters for water factories in Vietnam.

According to [9], [10], there are number of hardware IoT platforms. Table I lists the most popular brands of IoT boards and their characteristics.

2.2 Radio Synchronization

Paper [11] presented an acoustic based time synchronization method for underwater sensor networks to resolve problems related to messaging time stamping, node mobility and Doppler scale effect, where they compare many message time stamping algorithms in addition to different Doppler scale estimators. In time based systems, synchronization depends on message exchange between nodes to be synchronized.

In [12], authors took into account node's movement, basing on the DA-sync like protocol, by using first order kinematic equations, which tune Doppler scale factor estimation accuracy, and give a good synchronization performance. In this article, the authors propose to modify both time-stamping and Doppler scale estimation procedures. Many simulations and real tests are performed in a water test tank and a shallow-water test in the Mediterranean Sea.

Paper [13], by Z. Guo et al., proposed a new frame synchronization approach based on Linear Frequency Modulation signal parameters estimation, considering the problem of false frame synchronization for underwater acoustic communication. The author's method showed its capability to locate the frames of the received signal efficiently, with no reduction of data rate, and it is low-computational cost because of algorithm simplicity. This paper addressed many simulation and experimental results to show the performance of the proposed method.

S. Kim and Y. Yoo suggested in [14] new time synchronization protocol called "SMP-sync" based on sea environment characteristics. To show the weakness of traditional time synchronization, authors defined error factors over linear regression and proposed a method to correct those errors. The effectiveness of this method is the exploitation of seawater features such the water movement, and node deployment. Also, this protocol removes channel access delay from the timestamp to add more time accuracy. The SMP-Sync is battery friendly; because it conducts time synchronization with smaller transmission and reception times compared with previous works.

F. Hong et al. described in the paper [15], a scalable synchronization protocol for multi-hop USWNs called MulSync, taking in consideration the acoustic communication limitations and restricted mobility of sensor nodes, and resolving many problems in existing time synchronization protocols. MulSync includes the synchronization communication scheme to exploit acoustic communication nature of broadcast. Simulation results demonstrated its high accuracy at low message overhead and time cost.

2.3 Water depth sensors

There are a wide variety of ways to produce a signal that tracks the depth of water in a specific part of the sea. Ultrasonic detectors find the distance between seabed to the surface of the water. To measure level, depth, with an ultrasonic range detector, the module is mounted at the bottom of the sea, seabed, looking up the surface. We must measure the time between the transmitted pulse and the echo received pulses. Since the ultrasonic signal is traveling at the speed of sound, the time between transmission and echo received is a measure of the distance to the surface, water depth.

Paper [16] presented an architecture of depth measurement based on the ultrasonic waves and a micro-controller. The micro-controller sends a pulse to the ultrasonic module then the modules start sending a wave for a short time and wait for the echo. The depth is estimated by using the difference between the time of sending pulse and that of receiving the echoes.

Paper titled "Real-Time Monitoring Method of Water Depth Using Oblique Incidence Sonar in Harbour Channel" [15] proposed a novel real-time monitoring method using the oblique incidence sonar to realize an in-situ measurement of water depth in harbour channel. By making the use of the multipath propagation structure of underwater acoustic channel, the method obtains the depth values by calculating the relative time delay of acoustic signals between the direct and the shortest bottom reflected paths.

3. PROPOSED ARCHITECTURE

3.1 Combined sensor architecture

The combined sensor architecture, presented in Figure 1, is based on an ultra-low-power consumption flash microcontroller (Flash MCU) that features a powerful 16-bit Reduced Instruction Set Computing "RISC" architecture, 16-bit registers, and constant generators that contribute to maximum code efficiency. The temperature sensor is immersed underwater to measure the temperature of the environment. The depth sensor measures the water depth based on the echoes received from the seafloor. The radio transceiver is used to communicate between systems on the surface. The sensed temperature and depth is transmitted through water to a distant receiver by means of an acoustic transmitter that incorporates a piezo-ceramic sensor (Acoustic transceiver antenna) to transform electrical signals to mechanical vibrations transmitting through water.

The Flash MCU manages the communication with the depth sensor, the temperature sensor, the radio transceiver and the acoustic transmitter.

TABLE I. IOT PLATFORMS SURVEY

Features	**Raspberry Pi 3**	**BeagleBone Black**	**Arduino Yun**	**UDOO**
SoC/ CPU	roadcom BCM2837 and ARM Cortex-A53 64-b Quad Core	AM335x ARM Cortex-A8	ATmega32U4+Atheros AR9331	ARM Cortex-A9 and Atmel SAM3X8E ARM Cortex-M3
Clock speed	1.2 GHz	1 GHz	16 MHz and 400 MHz	1 GHz
GPU	BCM VideoCore IV 400 Mhz	BCM VideoCore IV 400 Mhz	no	Vivante GC 2000 for 3-D + GC 355 for 2-D (vector graphics) + GC 320 for 2-D
RAM	1 GB LPDDR2	512 MB DDR3	64 MB DDR2	1 GB DDR3
Storage	Micro SD	4 GB 8-b eMMC, micro-SD	32 KB and 16 MB + micro-SD	Micro SD
USB Ports	4	1	1	2
Ethernet	IEEE 802.3 10/100 Mb/s	IEEE 802.3 10/100 Mb/s	IEEE 802.3 10/100 Mb/s	IEEE 802.3 10/100 Mb/s
WiFi	IEEE 802.11 b/g/n	no	IEEE 802.11 b/g/n	IEEE 802.11 b/g/n
Bluetooth	Bluetooth 4.1 LE	no	no	no
HDMI	yes	yes	no	yes
OS Supported	Raspbian, Windows 10 IoT Core, OpenELEC, OSMC, Pidora, Arch Linux, RISC OS, Ubuntu	Debian, Android, Ubuntu	OpenWrt-Yun (based on GNU/Linux)	UDOObuntu, Android, XMBC, Yocto, Arch Linux, OMV
communication	4xUART, 2x SPI,2x I2C, 2x CAN BUS	1x SPI, 2x I2C, PCM/I2S, 1xUART	I2C, UART	SPI, I2C, UART, CAN BUS
Price	$35	$49	$58	$135

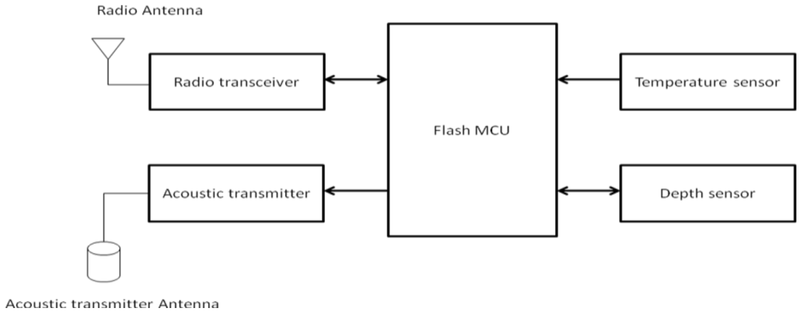

Figure 1 Diagram block showing the combined sensor components

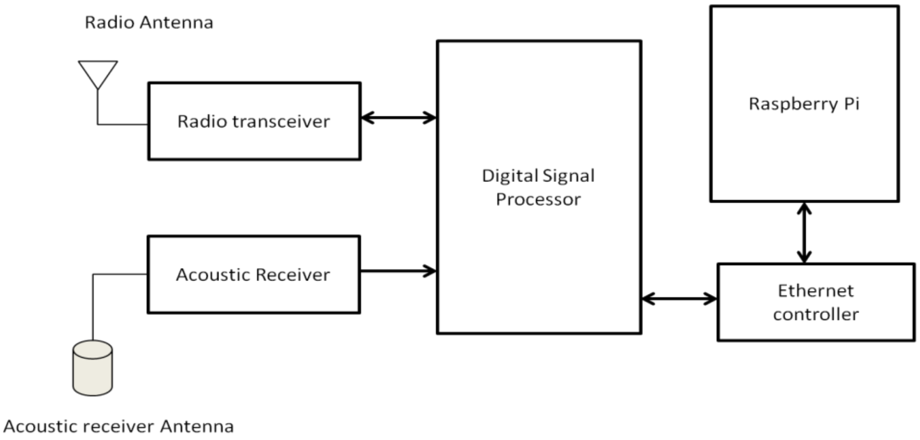

Figure 2 Diagram block showing the host component

3.2 Host Architecture

The host architecture, presented in Figure 2, incorporates a fixed-point digital signal processor (DSP) based on an advanced modified Harvard architecture which provides an arithmetic logic unit (ALU) with a high degree of parallelism, application-specific hardware logic, on-chip memory, and additional on-chip peripherals.

The radio transceiver is installed to communicate with combined sensors on the surface. Once immersed, the acoustic pulses coming from the combined sensors are received through the acoustic receiver chain. When a pulse is detected, the DSP computes the Time of Arrival (ToA) of received pulses and interprets the values of temperature and depth sent by each combined sensor. computed data is communicated via Ethernet port to the RaspberryPI local server.

4. SYSTEM DEVELOPPEMENT AND EXPERIMENTS

3.1 Temperature monitoring

Figure 3 illustrates a block diagram of the temperature monitoring module. The Flash MCU collects the surrounding environment sensed data from the temperature sensor, then sends measurements to RaspberryPI server through Wi-Fi. Figure 4 shows the plot of some real measurements stored by the server.

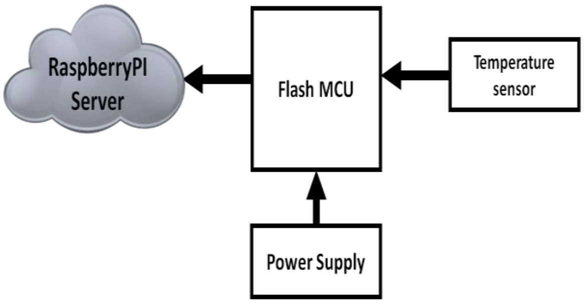

Figure 3 Performance value against input parameter

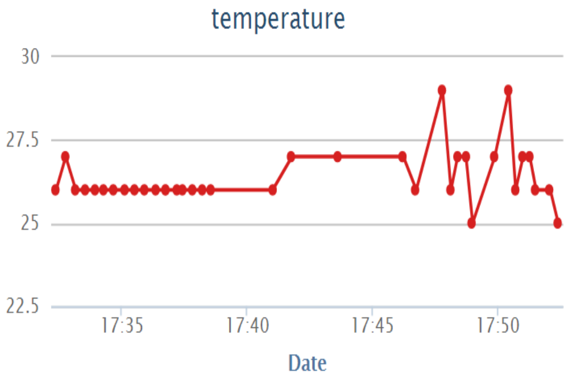

Figure 4 Performance value against input parameter

3.2 Water depth measurement

Figure 5 shows a simplified block diagram of the water depth sensor chain. In order to perform water depth measurement, the Flash MCU triggers the transmission of an ultrasonic wave by setting a control command to the echo sounder electronic board. When the echo pulse is received, the Flash MCU processes the time difference between the transmitted pulse and the echo pulse and computes the distance to the seabed.

The depth measurement is repeated many times in order to get an accurate depth values. In the first stage, the obtained measurements are buffered into Flash MCU memory.

4.2 Radio Communications

The RF hardware structure is typically based on Flash MCU and a RF module as shown in Figure 6. Our design is mainly composed of two parts: The Flash MCU and the radio transceiver. The Flash MCU manages the interface to the radio transceiver. The wireless link is ensured by a low-cost RF module with built in stack management and full support for low power mode, it can communicate with the Flash MCU through Serial Protocol Interface (SPI). During our tests, we used batteries to provide a stable power supply to the RF module. Figure 7 describes the different level of the software developed on the Flash MCU for radio communication. Many considerations have been taken into consideration in order to build our module, such as:

- How many connected objects will participate the wireless network?
- What is the maximum range between connected objects?
- Is the RF module has any low power features?

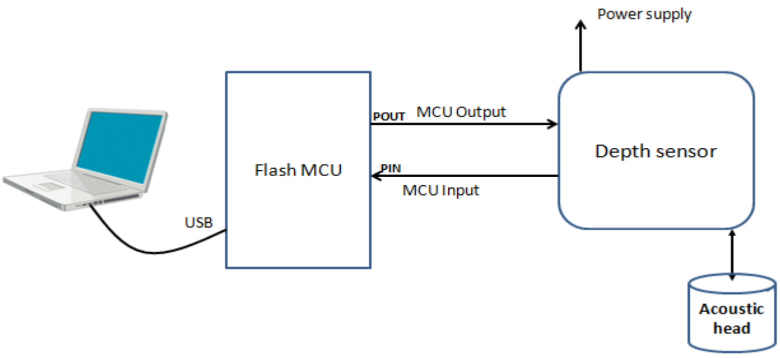

Figure 5 Waster depth measurement setup

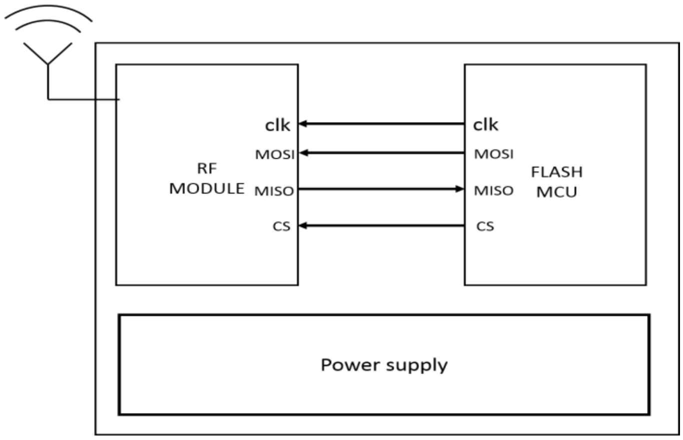

Figure 6 Radio Interface to MCU

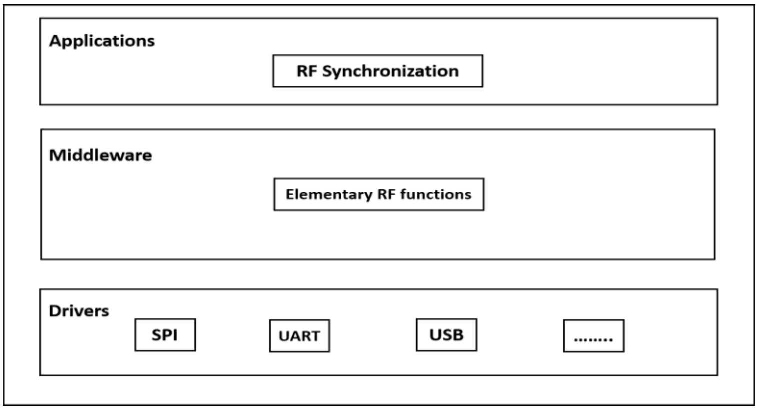

Figure 7 Radio Development levels

4.3 Power management

It is essential to have an IoT low power application, in order to maximize the power supply autonomy of the actual system. This section discusses the result of the study and experiments realized on the improvement of the system power consumption by integrating a sleep mode in order to save energy. Table II depicts the estimated current consumption of the MCU running a firmware to read data sensed by the temperature sensor and to transmit the measurement to the Raspberry Pi server.

TABLE II. CURRENT CONSUMPTION MODES SUPPORTED INTO FLASH MCU

MCU mode	*Current consumption*
Busy mode	100 mA
Sleep mode	0.001 mA
Duty mode	20 mA

Experiments have been performed in order to evaluate the performance of the system in terms of power consumption: The first experiment consists of a busy mode configuration that set the Flash MCU running continuously in active state. In the second experiment, the duty mode is enabled by using a duty cycle between the busy and the sleep states. Figure 8 give a comparison between the busy and the sleep mode. The duty mode is then selected for the actual system. Figure 9 shows a real measurement obtained a 4.5Volts Alkaline battery. The batteries autonomy is estimated depending the transmission cycle that corresponds to the frequency of reading data from sensor and transmit it to the server through wifi. refer to Figure 10.

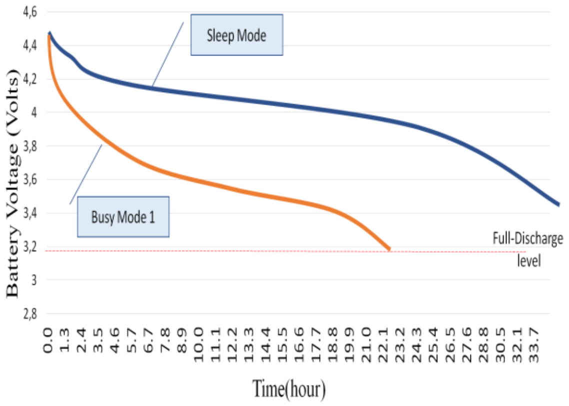

Figure 8 Estimation of Battery discharge rate depending the two MCU mode: Busy mode and Sleep mode 1.

4.4 Power management

The developed system was tested during sea trials, performed in BOUREGREG MARINA, located at the mouth of the Bouregreg River, on the shore of SALE, Morocco. This location provides an easy-to-access environment for experimental tests (Figure 11). The combined sensor and the host receiver were spaced with a maximum range of 500 meters. The sea experiments have been conducted successfully and showed the ability of the combined sensor to transmit the sensed data to the acoustic receiver.

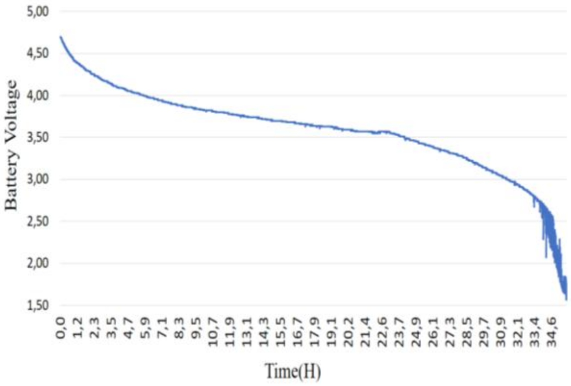

Figure 9 Real measurements of battery discharge rate

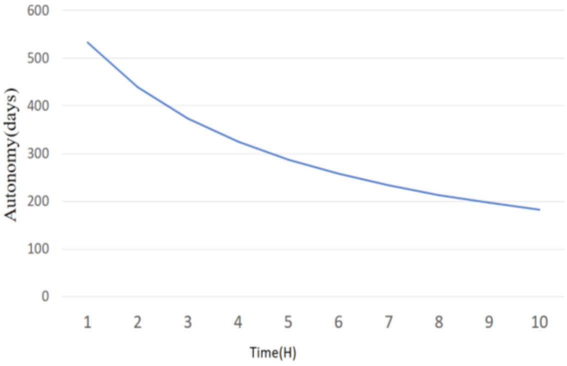

Figure 10 Real Estimated battery autonomy

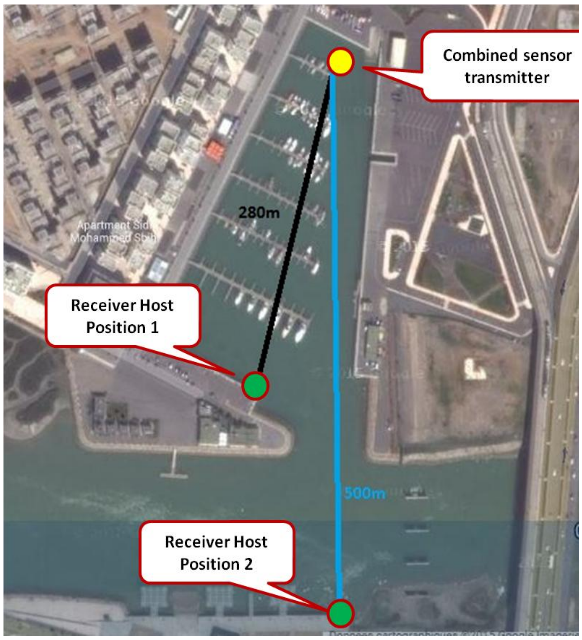

Figure 11 Marina bouregrag map showing the location of the experimental setup

5. CONCLUSION

In this paper, we addressed some of the most important points of IoT platforms and sensor networks applied in underwater environment: Water depth and temperature sensing, synchronization between sensors, power management and acoustic communication. The developed system integrates an ultrasonic ranging module for water depth measurement and a temperature sensor.

A novel method was proposed to synchronize sensors through radio link. The Laboratory and sea water tests results illustrated the ability of the system to gather the sensed depth and temperature measurements to a local host server, installed on Raspberry PI unit.

In order to reduce the power consumption of the actual system, a duty mode that alternates between active and sleep mode was tested and qualified depending the frequency of transmission. The presented platform will be improved in the future by including algorithms to localize sensors underwater in reference to GPS coordinates and add more sensors to the actual system.

6. ACKNOWLEDGEMENTS

We would like to thank the Bouregrag Marina staff, for giving us permission and support to perform sea trials.

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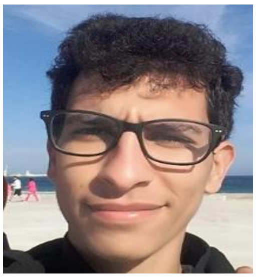

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Cite this paper:

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