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RESEARCH ARTICLE

Serial Transmission Based on Pulse Width: Application to Water Bodies Monitoring

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ABSTRACT In this paper, a novel communications protocol, based on pulse width is presented, which is able to transmit data frames with bytes encoded in ASCII using a single transmission line. It is possible to transmit data between different embedded systems in the same electronic board or in different electronic boards. The computational cost is low and permits to transmit information in lengths up to 30 m. The protocol was tested in a system for measuring physichochemical parameters of water, composed of a floating body, a submerged probe to measure variables at different depths and a graphical user interface to receive and save data in a server. The floating body and the submerged probe are two independent embedded systems, interconnected with the proposed protocol; the system was implemented in a small water body, to cope with a relevant environment. The results show a good performance of the protocol in the transmission of data frames with high robustness, since in a period of 37 h the data were transmitted and received regularly, with a sample time of 5 minutes. The complexity of the algorithm was compared with other well-known protocols, resulting in fewer machine cycles, implemented in an eight-bit microcontroller.

INDEX TERMS Environmental monitoring, industrial communication, pulse width modulation, water pollution.

I. INTRODUCTION

Water pollution is a high-impact health problem, according to the World Health Organization, at least 2 billion people are supplied by a source of polluted drinking water. Water pollution in rural areas is an even higher danger, because in those locations there are no technological devices to monitor the quality of the water. There are several examples of the use of contaminated water for human consumption, irrigation and livestock [1], [2]. Therefore, it is necessary to develop technological tools to measure the water quality [3], [4]. A major problem in the monitoring of water quality is the measurement of physicochemical parameters, such as pH, dissolved oxygen, redox potential, temperature, color, turbidity, among others. Monitoring can be carried out using classical methods, an analyst goes to the water body to take samples, which are analyzed in a laboratory; this technique is complex, expensive and does not offer immediate results.

A. RELATED WORK

To avoid the related problems to the measurement of the water quality, it is possible to measure water parameters using sensors that are constantly immerged in the water. Several tools have been developed to measure the water quality, including applications to smart agriculture [5] and internet of things [6], [7]. To simplify the data acquisition in water bodies, some techniques can be applied, for example the use of a buoy [8], [9]. The buoys are installed to measure parameters in different types of water bodies [10], [11]. A main problem in these devices is the communication between the different elements when submerged probes are located at different depths.

The communications protocols are used to transmit data between different embedded systems [12], [13].

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Several protocols can be found in the literature with different characteristics, depending on the application [14], [15]. In recent years the serial protocols are preferred [16]. There are some well-known protocols, e. g., Serial interface protocol (SPI) [17] and Inter integrated circuits protocol (I2C) [18], both of them present high reliability, but are limited to short distances. To cope with the limitation in the transmission range, the Controller Area Network could be applied [19], this protocol requires at least two transmission lines and complex rules to perform the communication. Some approaches to enhance the CAN protocol can be found in the literature, see for example [20]. The transmission lines for the communication can be reduced using the One-wire protocol by Dallas Semiconductor [21], however, the transmission of one byte requires eight pulses, which could decrease the reliability, since some pulses could be lost in one or more packages. Although there are several serial protocols available, other techniques could be considered, to increase the flexibility in the transmission of different embedded systems, for example, increasing the transmission distance and the reliability, encoding the information during the transmission, as well as including several embedded systems.

B. MAIN CONTRIBUTION

In this paper, the Pulse-Width Protocol (PWP) is proposed as a novel communication protocol, which enables the data transfer between two or more embedded systems. The communication is achieved with a single transmission line in a stable way in lengths up to 30 m. The information is encoded with variable pulse-width, considering the ASCII code. With the proposed configuration, only three pulses are needed to send every byte. In this case, a half-duplex configuration with a single master transceiver and several slave transceivers is outlined that can be extended to several master transceivers and several slave transceivers. There are some highlights that must be underlined regarding the proposed scheme, to cope with the issues mentioned above:

- The limitations in the transmission distances in serial protocols, e. g., SPI and I2C, are avoided, by the used of the PWP, up to 30 m between embedded systems were obtained with the proposed scheme.
- The PWP has a few transmission rules, compared to CAN, then, it is easier to implement the PWP.
- The external Hardware required by the PWP and the One Wire is the same, however, the PWP require less pulses to send a single byte.
- The information is encoded in the PWP, considering a variable pulse-width in every pulse and the ASCII code.
- The hardware required to implement the PWP is simple, only an 8-bit microcontroller is required.
- The computational cost of the PWP is low, compared with other serial protocols, for example CAN.

In order to prove the effectiveness of the PWP, it was implemented in a system to measure physicochemical variables in water, the system is composed of two interconnected elements: a floating body and a submerged probe. Three cables were used for the connection, two to supply voltage and the other for communication. The floating body and submerged probe are independent embedded systems, each has its own microcontroller, the communication was made by using the PWP. The system can measure temperature, pH, conductivity, salinity and Total Suspended Solids (TSS) in real time with the sampling time defined by the user, the date and the time can be modified as well. The data acquired, including date and time, are sent to a server by using the Global System for Mobile communications (GSM). The server is a personal computer with an additional GSM module, this computer receives and save the data for future processing. An application for the server was developed in MATLAB with a Graphical User Interface (GUI). The system with the PWP was implemented in a small water body, the results show that the transmission between the floating body and the submerged probe was done without any problems and the data were sent to the server without interruptions or information loss.

II. PROPOSED PROTOCOL

As its initial approach, the PWP was developed to be applied in a system for monitoring physicochemical parameters in water, which was designed considering the problems identified to make the measurements in water bodies and the availability of the information. The monitoring system is composed of a floating body, placed on the water surface and a submerged probe. The complete system is depicted in Figure 1.

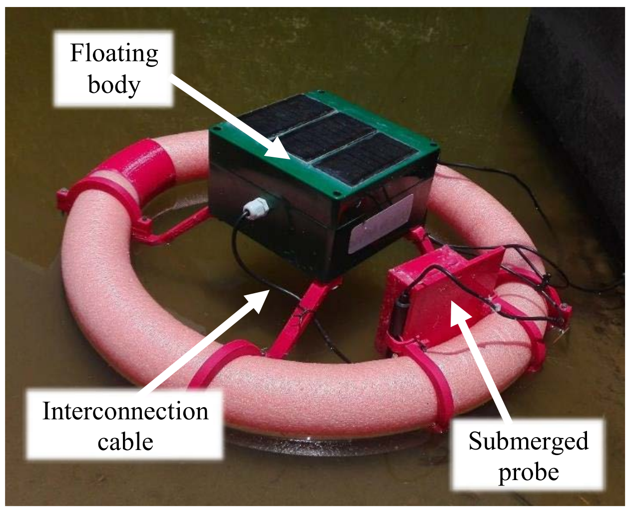

FIGURE 1. System for measuring parameters in water.

In order to apply the PWP, at least, some requirements must be fulfilled: an 8 bits microprocessor, a 16 bits timer and a general-purpose input output pin. Then, considering the minimum requirements, the PWP was applied in two microcontrollers PIC18F46K22, which meets the minimum requirements, one for a master transceiver in the floating body and the other for the slave transceiver in the submerged probe.

The floating body is a hermetic box that contains an electronic board with a microcontroller Microchip PIC18F46K22, a communication board, a power management board, a solar panel and a set of batteries. The length, width and height of the hermetic box are 16 cm, 16 cm and 10 cm, respectively. Since the system is designed to be installed in water bodies, without supervision and a fixed energy source, the floating body is feed with batteries and a solar panel, to guarantee an uninterrupted voltage source. The microcontroller manages the operations carried out in the process of taking measurements and transmitting the information to a server in a real time. The communication board transmits the data to the server through GSM, with Short Message Service (SMS), which permits no limitation in the transmission distance [22]. Every set of measurements is sent via a message to the server. It is possible to configure date, time and the sampling time by SMS with a defined syntax. The communication with the submerged probe is managed with the microcontroller, by means of the PWP. Each sampling time the microcontroller asks to the submerged probes the values of temperature, pH, TSS, conductivity and salinity. To manage the described tasks, an electronic board was developed, with the PIC18F46K22 as the core, which needs minimum requirements due to all the peripherals are embedded in the integrated circuit. Then, it is possible to achieve a compact design. Moreover, in spite of the microcontroller has a microprocessor of 8 bits only, it is capable to make the complete process with a maximum oscillator frequency of 64 Mhz and a machine cycle of four oscillator cycles. As a matter of fact, the microcontroller has several peripherals and general-purpose pins, in such a way that additional functions can be programmed.

On the other hand, the submerged probe is a hermetic box, with dimensions of 10 cm, 15 cm and 6 cm, for the length, width and height, respectively. The submerged probe is composed of an electric board with a microcontroller Microchip PIC18F46K22, as well as individual sensors to measure temperature, pH, TSS, conductivity and salinity; except for the temperature probe, every probe has an independent electronic signal conditioning card. The submerged probe is feed from the floating body, in this way only a single voltage source is needed for the complete system. The communication with the floating body is made with the microcontroller. When the submerged probe receives a request, all the parameters are measured, then, the microcontroller sends the values to the floating body by using the PWP. With the proposed configuration the resulting size of the system is small, including an external floating ring to stabilize the system, an external diameter of 40 cm was measured, with a height of 20 cm and a weight of 1.5 kg. It is worth mentioning that in Figure 1 the submerged probe that will be immersed it is shown near to the floating body, in such a way that the complete system can be visualized. Again, an electronic board based on the PIC18F46K22 was developed, taking advantage of the oscillator frequency of 64MHz, the machine cycle of four oscillator cycles and the embedded peripherals, to obtain a small size. With the proposed board several input/output pins are available, to apply additional functions, if they are needed.

The water parameters could vary depending on the measurement depth. Therefore, the proposed system was developed to position the submerged probe until 12 m under the water surface. Then, in order to reduce the weight and complexity, it is necessary to reduce the number of cables for the connection between the floating body and the submerged probe. The floating body and the submerged probe are connected through three cables, named V_{cc}, GND and COM, for the positive voltage, reference and communication, respectively. With the use of the PWP, it is possible to communicate the floating body and the submerged probe, as well as to supply with the suitable voltage the submerged probe. The interconnection between the floating body and the submerged is presented in Figure 2. Since the PWP is an important part of the system, a comprehensive description of the protocol is presented next.

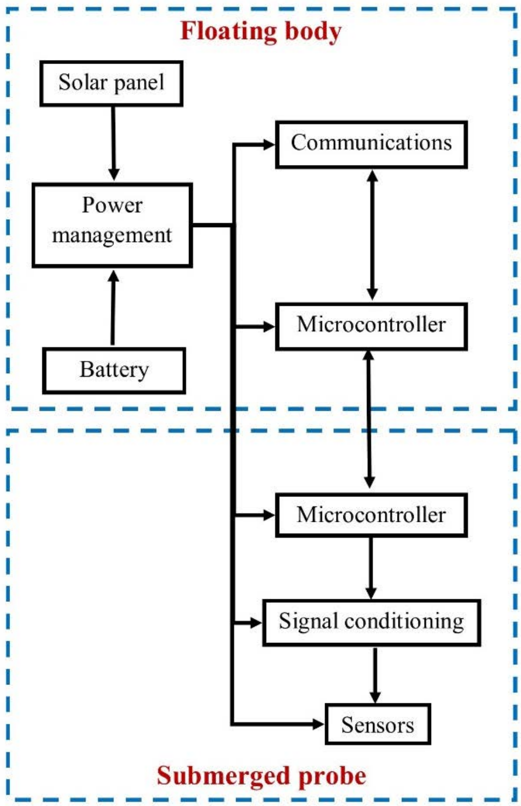

FIGURE 2. Interconnection between the floating body and submerged probe.

A. PWP DEFINITION

In this section, the proposed protocol is defined in generic terms, to show the generality of the approach.

The PWP was developed to transmit digital data between transceivers in different embedded systems. The transceivers can transmit and receive information, are based on an embedded system with a microcontroller and the components required for their operation. Every transceiver is composed of the following elements: a) Microprocessor, b) oscillator, c) transmission module, containing a transmission timer, transmission buffer, and encoder, and d) reception module, with an external interrupt module, reception timer, decoder and reception buffer.

The PWP considers a single master transceiver and several slave transceivers. With transmission and reception buffers of eight bits, it is possible to have until 256 slave transceivers with a defined single direction. The data transmitted are organized in a data frame, consisting in a series of bytes in a row of n positions. The master transceiver begins the communications with a slave transceiver by sending the first encoded byte that corresponds to the direction of the slave transceiver, in such a way that only the transceiver with the corresponding direction attends the message. The slave transceiver receives and saves in a sequential way the data in the reception buffer to compose a data frame. Then, the data frame is sent to the decoder, to obtain the information transferred from the master transceiver. In this case, the data frame can contain several bytes, according to the transmission needs. Moreover, a set of three pulses is defined as the end of transmission, to have a clear indicator of the end of data frame. The bytes are transmitted by using the PWP protocol, which encodes the byte through the pulse width. The PWP is a half-duplex protocol, which enables the communication between transceivers through a single wire. The data are sent by a square signal, with a constant low state period, named T_{off} and, a variable high state period. Ten different high values are needed. Three pulses are required to encode a byte, considering the ASCII code, as follows: a) The first pulse represents the hundreds, b) the second pulse represents the tens and c) the third pulse represents the units.

Every encoded byte is separated by a constant period, called T_s. The pulse-width of every pulse in an encoded byte depends on the information to transmit. In this way, a well-defined pulse-width is considered for the zero value, another pulse width for a value of one and so on. The complete data frame to be transmitted is organized in a chain of n bytes, where n is the number of characters in the data frame. The transmission begins with the byte in the position one, then the byte in the position two is transmitted and so on, until the character n. Finally, a particular combination of three pulses with defined pulse-width is sent to indicate the end of transmission.

In order to illustrate the use of the protocol, consider that transmission of the word "Test". The corresponding decimal values in the ASCII code for the word "Test" are presented in the Table 1, considering the character EOT to finalize the transmission.

Moreover, as it was stated above, ten different pulse-width value must be defined, in this example, consider an increment of 1 ms for each level, in such a way that the Table 2 is obtained.

TABLE 1. Decimal values in the ASCII code for the word "Test."

Character	T	e	s	T	End of transmission (EOT)
Decimal ASCII value	084	101	115	116	004

TABLE 2. Example of pulse-width for the values from 1 to 0.

Value	1	2	3	4	5	6	7	8	9	0
Pulse-width (ms)	1	2	3	4	5	6	7	8	9	10

Then, in the case of the example, the data frame sent from the microprocessor to the transmission buffer will be:

T-e-s-t-EOT

or, equivalently, in the ASCII code:

084-101-115-116-004

In addition, consider $T_s = 2\ ms$ and $T_{off} = 1\ ms$. Furthermore, taking into account that every character is encoded with three pulses, which corresponds to the decimal value in the ASCII code, the pulse-train that will be transmitted after the encoding process, is presented in Figure 3.

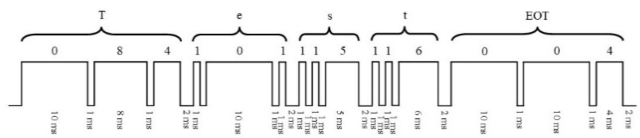

FIGURE 3. Pulse-train for the transmission of the word "Test."

It is worth mention that due to the communication is carried out by a single transmission line, a single communication pin is needed, in this case an input/output pin of the microprocessor, which must be commutated between output for transmission and input for reception.

The processes carried out for the transceivers, to transmit and receive, are presented next.

1) MASTER TRANSCEIVER

The communication begins in the master transceiver by using the transmission module. The microprocessor enables the transmission module and sets the communication pin as output. An auxiliary variable, $i = 1$, is defined. The microprocessor sends the data frame to the transmission buffer, which includes in the first byte the address of the desired slave transceiver, moreover, at the end of the data frame the end of transmission byte is included. The encoder module takes the i^{th} value of the data frame from the transmission buffer and assigns three pulses with a defined pulse-width, which represents the i^{th} byte. Next, the timer module generates the first pulse with the duration defined by the encoder module that is sent by means of the communication pin, then, the second pulse is generated and, finally, the third pulse is sent;

a low-state value with duration T_{off} is sent between two pulses. If the end of transmission byte was sent, the transmission concludes, otherwise, when more data are required to be sent, the microprocessor increments the auxiliary variable, i, to transmit the next byte in the data frame, until the end of transmission byte appears to indicate the finish of the communication. To conclude the transmission process, the microprocessor clears the transmission buffer, inhibits the transmission module and set the communication pin as input to be ready for the reception.

If a slave transceiver sends information to the master transceiver as a part of the communication process, the master transceiver must receive and decode the information. When a rising edge is detected in the communication pin, the microprocessor enables the reception module, it remains active until the end of transmission bit is detected. In every rising edge detected by the external interrupt module, the reception timer module is turned on and turned off in the falling edge. The reception timer measures the time between the rising edge and the falling edge in the communication bit, this measurement is carried out for the three pulses in a byte. A validation on T_{off} and T_s is accomplished, if the values do not correspond to those defined in the protocol, an error message is generated, otherwise, the pulse-widths of the three pulses are sent to the decoder module. The decoder module interprets the three pulses, to generate the i^{th} byte in the received data frame that is sent to the reception buffer, and integrate the complete data frame. The sets of three pulses are decoded sequentially, until the end of transmission byte is received. At the end of the transmission, the microprocessor saves the data frame, clears the reception buffer and inhibits the reception module. Figure 4 presents the interconnection between the different elements in the master and slave transceivers. Figures 5 and 6 show the flow charts for the operation of the master transceiver for transmission and reception respectively.

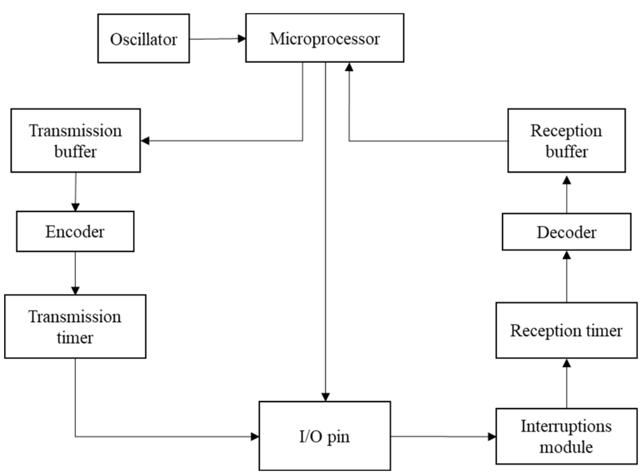

FIGURE 4. Schematic diagram of the master and slave transceivers.

2) SLAVE TRANSCEIVER

The operation of every slave transceiver is similar to the master transceiver. The communication process begins in the master transceiver. The reception is performed by the reception module of the slave transceiver, where the microprocessor set the communication pin in the slave transceiver as input and wait until the master transceiver makes a transmission. When a rising edge is detected in the communication pin, the microprocessor enables the reception module, this element remains active until the end of transmission byte is detected. In every rising edge detected by the external interrupt module, the reception timer module is turned on and turned off in the falling edge.

The reception timer measures the time between the rising edge and the falling edge in the communication bit. This step is carried out for the three pulses in a byte. If T_{off} or T_s do not corresponds to the values defined in the protocol an error is generated, otherwise, the pulse-widths of the three pulses are sent to the decoder module. The decoder module interprets the value of the three pulses, to generate the first byte that corresponds to the address and sent this value to the reception buffer. The microprocessor takes the byte received, which is compared with the address designated for the slave transceiver. If the received address and the slave transceiver address do not match, the reception procedure finish; the microprocessor inhibits the reception module and waits for the next transmission, otherwise, the reception procedure continues. The decoder module interprets the value of the sets of three pulses, to generate the i^{th} byte. The i^{th} byte is sent to the reception buffer to integrate the data frame. The pulses are received, decoded, and saved sequentially, until the end of transmission byte is received. Then, the microprocessor saves the data frame, contained in the reception buffer, clears the reception buffer and inhibits the reception module.

If the data frame contains a particular command or instruction, the microprocessor makes the corresponding actions. If the instructions received require a transmission between the slave transceiver and the master transceiver, the procedure sends the corresponding data, with the same procedure of the master transceiver. The microprocessor enables the transmission module, sets the communication pin as output and sends the data frame to the transmission buffer. An auxiliary variable i is defined. The encoder module takes de i^{th} byte in the data frame and defines the pulse-width for the three pulses that represents the i^{th} byte. The timer generates the three pulses with the required pulse-width. The pulses are sent by using the communication pin, a low-state with duration T_{off} is maintained between two pulses. If there are no more data to transmit the procedure concludes, the end of transmission byte is sent, the microprocessor inhibits the transmission module and set the communication pin as input, to be ready for the next reception, otherwise, the transmission continues encoding and transmitting the remaining bytes sequentially. At the end of the transmission, the microprocessor clears the transmission buffer and inhibits the reception module.

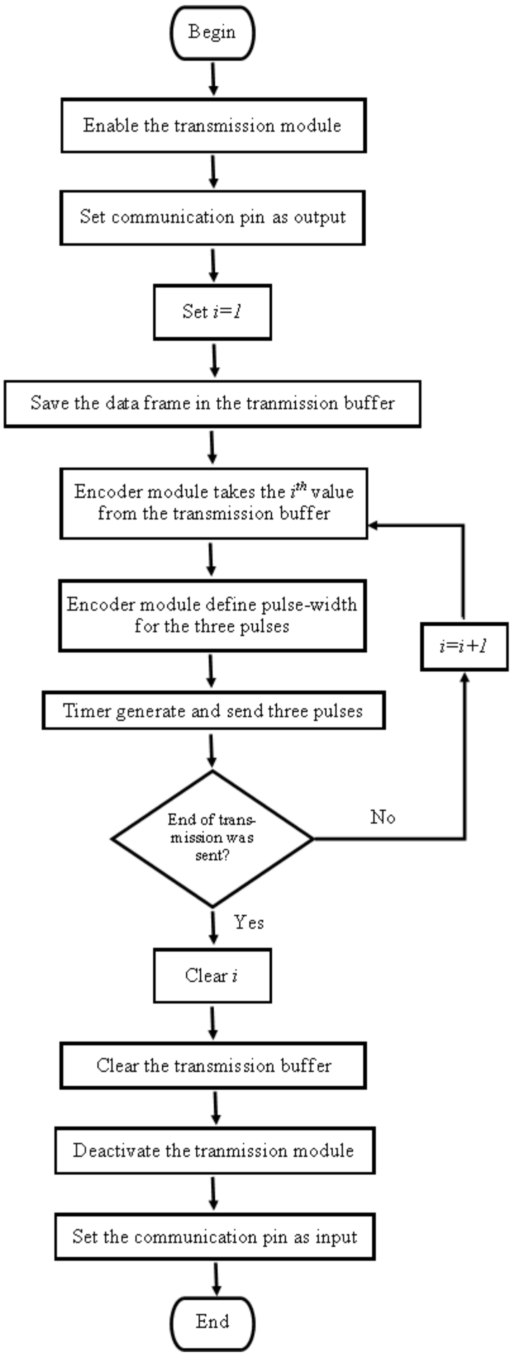

FIGURE 5. Master and slave transceivers, transmission process.

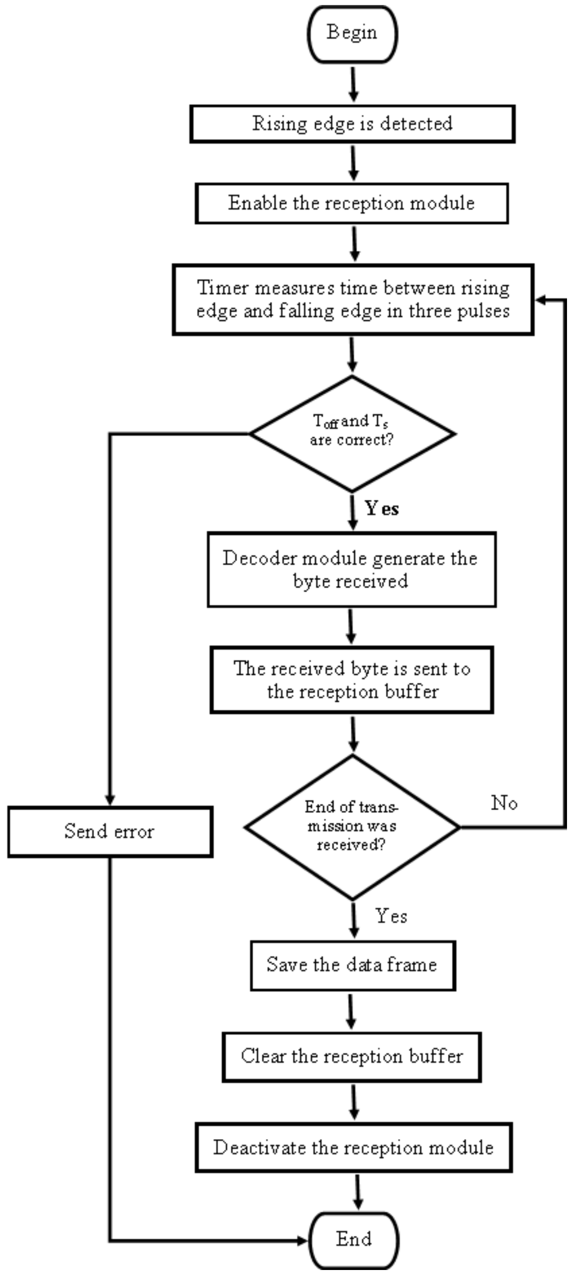

FIGURE 6. Master transceiver, reception process.

Figures 5 and 7 show the flow chart for the operation of the slave transceiver for transmission and reception. Note that the transmission flow chart of the slave transceiver can be presented as the flow chart for transmission in the master transceiver.

B. GRAPHICAL USER INTERFACE

To complete the scheme for measuring the physicochemical variables a GUI is included (see Figure 8). The messages from the floating body are sent to a server, in this case a personal computer that must have connected in a USB port a communication module to receive the messages via GSM. The GUI was implemented in MATLAB, taking advantage of the simplicity to access the computer ports, save the information and generate reports. The GUI has two buttons, to connect and disconnect the communication module, in a specific port. Moreover, the interface receives a set of data every sampling time, or a request can be sent to the floating body arbitrarily with a button. The sampling time, date and time in the floating body can be modified with two buttons. Finally, the current data received, including the date and time, are shown and saved in a comma-separated values file. The GUI was compiled in an executable file, in such a way that it is not necessary to have MATLAB installed in the server.

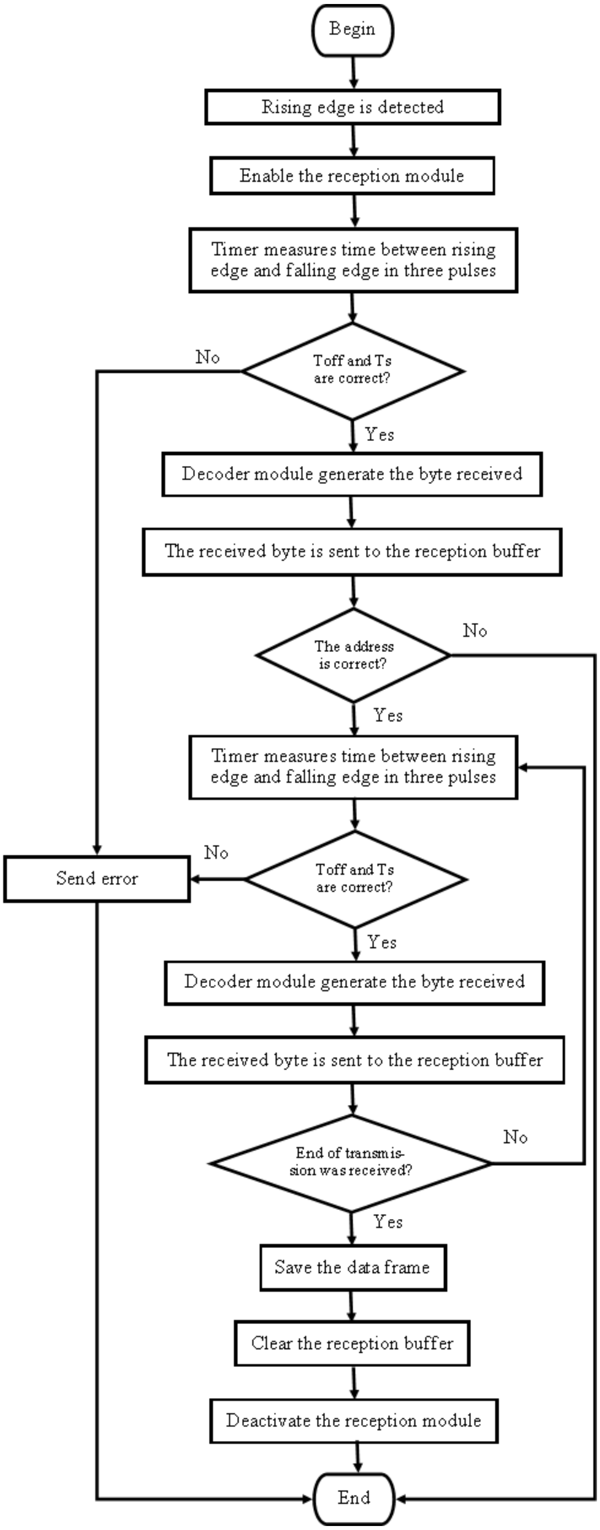

FIGURE 7. Slave transceiver, reception process.

III. RESULTS

The floating body and submerged probe were installed in a small water body, to cope with a relevant environment and test the robustness. The server was installed approximately 300 m from the body of water. The floating body was operating

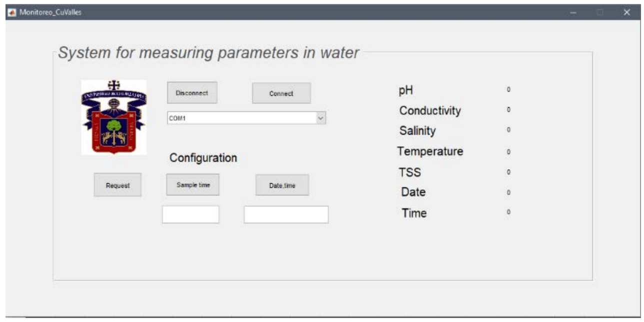

FIGURE 8. Graphical user interface.

TABLE 3. Pulse-width defined for the values in the tests.

Value	Pulse-width (ms)
1	1.29
2	2.17
3	3.20
4	4.20
5	5.20
6	6.27
7	7.30
8	8.20
9	9.20
0	10.27

continuously for a period longer that 37 h, which show the capability to work for long periods. This fact is important, due to the modern communication systems require high robustness. In the period of 37 h, all the data were received every sampling time without information loss, therefore, the reliability and effectiveness of the system was demonstrated. The variables measured were temperature, pH, TSS, conductivity and salinity. The pulse-width for the ten pulses required in the PWP were defined according to the characteristics of a timer in the PIC18F46K22 and are presented in the Table 3. Moreover, T_{off} and T_s were defined as 2 ms and 2.5 ms, respectively.

Figure 9 illustrates the pulse-train generated by the PWP, first the number 1, after the number 0, and finally the number 10. The first two pulses in the three cases of Figure 7 are the address. Note that in the cases a) and b) three pulses follow the address. For the case a), the number 1 is encoded with the character 049 ASCII, in this way, according to the Table 3, the corresponding pulse-widths are 10.25 ms, 4.2 ms and 9.2 ms. Then, for the case b), the value of 1 is encoded with the character 049 ASCII, to obtain the pulse-widths as 10.25 ms, 4.2 ms and 8.2 ms. In the case c), the number 10 is encoded, to show the interconnection of the values 1 and 0, therefore, six pulses are sent after the address.

In the proposed system, every sampling time the microprocessor of the floating body request to the submerged probe the values of the variables in the water. The address is sent as

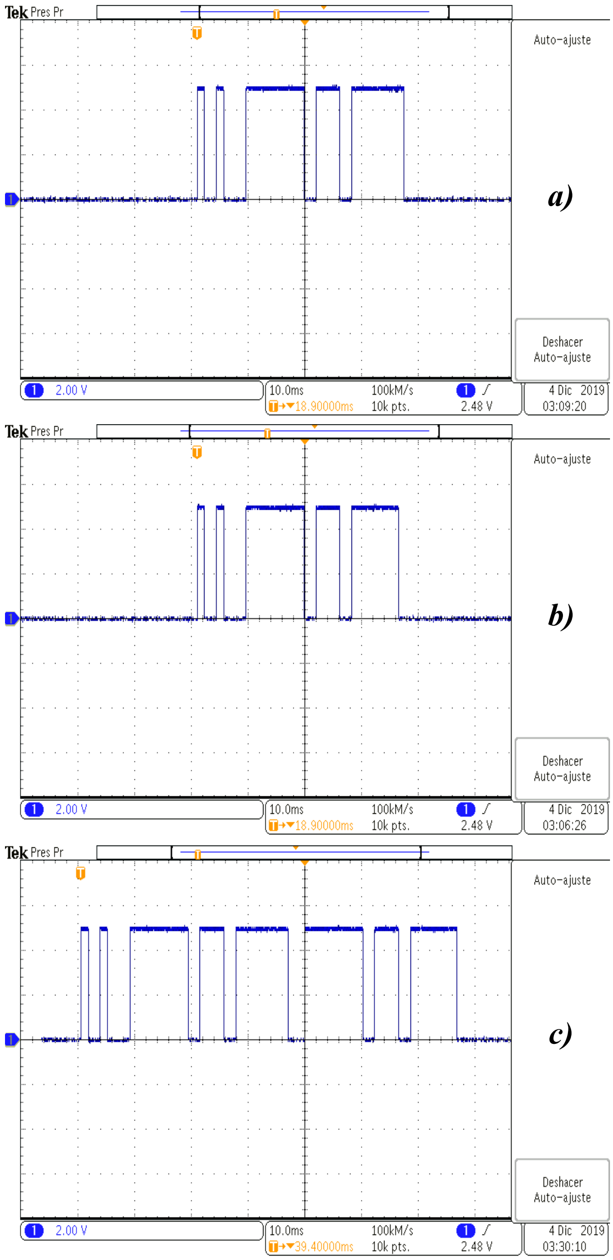

FIGURE 9. Examples of transmission of three value, a): 1, b): 0 and c): 10.

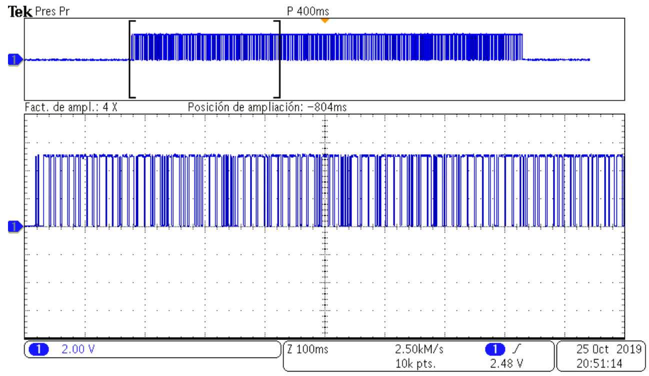

FIGURE 10. Example of data frame in the system for measuring parameters in water.

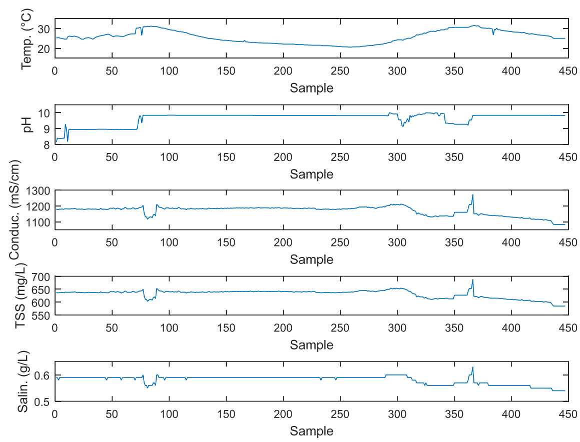

FIGURE 11. Results of the measured variables.

Figure 9 shows, that is, two pulses with pulse-width of 1 ms. Then, the microprocessor in the submerged probe makes the measurement of temperature, pH, conductivity, salinity and TSS and compose the data frame, which is transmitted to the floating body, the complete pulse-train is shown in Figure 10. Finally, the floating body sends the complete message to the server, in the following format:

CUValles, buoy 1: Conductivity 518.50, TSS 280.00, Salinity 0.25, Temperature 28.81, pH 10.80, Date: "19/07/10, 21:18:52"

The system was operating continuously since 10:37 h of june 19th, 2020, until 23:52 h of june 20th, 2020, to obtain 447 samples, with a sampling time of 5 min. The results for the five variables measured are depicted in Figure 11, which shows the effectiveness of the system. All the components were operating satisfactorily, including the floating body, the submerged probe and the GUI, during the testing period, showing good stability in the floating body and the submerged probe.

The results show that with the application of the PWP in the proposed system it is possible to achieve the communication between two embedded systems, in this case two microcontrollers, which enables the transmission of the results of measuring physicochemical variables in water bodies. The transmission with only three cables was carried out satisfactorily, two of them for the power supply and the third to transmit data; this configuration enables the connection of two embedded systems in a single or different electronic board by using a single transmission line. Furthermore, the proposed PWP requires a low computation cost, the system presented is based on the microcontroller PIC18F46K22, with a microprocessor of eight bits, oscillator of 64MHz and a Harvard architecture. In spite of the limited processing characteristics, the transmission could be achieved adequately.

IV. DISCUSSION

From the results obtained with the proposed scheme, some features should be underlined. The PWP is an asynchronous protocol, i. e., an oscillator is not required to control the frequency of the carrier signals phase in the transmitted data. This feature enables to reduce the number of transmission lines, since a clock signal is not necessary, as occurs in other protocols, e. g., SPI or I2C.

With the proposed scheme the transmission is performed by two transmission lines, one for data and the other for the reference. This configuration of two lines can be used for any number of master or slave transceivers. The communication through the proposed PWP requires a reduced number of hardware elements, due to the simplicity of the protocol, resulting in compact transceivers. This feature simplifies and reduce the hardware required for the communication between two or more embedded systems, which is not possible in other protocols, for example SPI or I2C.

Since a clock signal is not necessary to synchronize two transceivers during the transmission process, a dedicated module for an additional oscillator is not required. Again, this fact enables to reduce the hardware in the PWP, which is possible for any number of transceivers connected.

Regarding the complexity of the algorithm, with the proposed scheme, 9 machine cycles are required to receive a single byte in the master transceiver, and 8 in the slave transceiver, with 8 machine cycles at the beginning of the reception, to validate the address. On the other hand, in the transmission process, the number of machine cycles is the same for the master and slave transceivers, that is, for a chain of n bytes, in the first and the last bytes 9 machine cycles are needed, for the second until the n-1 bytes only 5 machine cycles are required. Considering other well know protocols some direct comparisons can be identified. For example, to begin a transmission and send the first byte, CAN requires 20 machine cycles, while I2C, 18 machine cycles. To finalize the transmission, CAN and I2C need 25 and 11 machines cycles, respectively, to send the last byte. Then, the computational complexity is lower than other modern protocols, e. g., CAN and I2C. It is important to note that these comparisons are based on the procedure developed by a microprocessor directly, without considering external or embedded dedicated modules.

Compared to the classical PWM modulation, it is important to note that PWM requires a carrier signal and a modulation signal, to obtain the final signal. Again, the hardware needed in the PWP is lesser than PWM, since the signal is generated with a timer and the microprocessor.

Although in this paper the PWP is presented with a single master transceiver, the number could be increased, by assigning an address to every master transceiver and implementing the encoded address in the transmission procedure of the slave transceivers. Moreover, a master transceiver can be interconnected up to 256 slave transceivers, but the number of total transceivers could be augmented, increasing the number of bits used to encode the address. This flexibility is not presented in other well-known protocols, since they have a fixed communications structure.

The PWP enables a distributed communication system, since the transceivers could be located in the same electronic board, or in different electronic boards, or in the same system or in different systems, which adds a great flexibility to the communication system. This flexibility is not presented in other protocols, which, in general, are designed to operate with a well-defined structure.

After several tests, the transmission distance was up to 30 m, with a typical copper cable and without additional hardware, such as external resistors or shielded cable, as occurs in other protocols. In the different tests, the performance was the same, no matter the distance.

Due to the flexibility of the PWP, it is possible to transmit data frames with several characters, numbers or information, encoding in the same way. Then, the user has the flexibility to send different kind of information by using the same protocol. Furthermore, different requests can be transmitted from the master transceiver to the slave transceivers, in the form of commands. For example, a command can be applied to ask the slave transceiver to achieve a specific task in the microprocessor or to ask for data. This property is similar to the behavior shown in other protocols, for example, SPI, I2C or CAN.

In the case of the system to measure psychochemical variables, as stated above, the complete system is small compared with commercial systems, then, it is possible to install it in shallow waterbodies. Moreover, the sampling time, data and time can be configured remotely, by using the GUI or directly with a mobile device, sending a SMS with the desired configuration, in contrast to commercial buoys that must be configured before the installation. Moreover, although the variables are measured and sent to the server every sampling time, a request could be sent anytime, from the GUI in the server or from a mobile device. Finally, due to the configuration presented, the submerged probe could measure parameters at different depths, which is possible with the application of the PWP that requires only three cables between the floating body and the submerged probe; this characteristic is only presented in buoys of higher size, with a base of 1 m^2 and heights of 1 m.

V. CONCLUSION

In this paper a novel communication protocol was presented, which enables to transmit data frames between embedded systems. Every byte in a data frame is encoded with three pulses with different pulse-width. With the proposed configuration is possible to make the transmission with a single communication cable. The protocol can be applied in the same electronic board or different electronic boards with a low computational cost. In this work, a scheme with a single master transceiver and several slave transceivers was introduced, however, more master transceivers can be implemented. Compared to other well-known protocols, that is, I2C and CAN, some advantages were identified, for example, the protocol can be applied in the same or different electronic boards, transmission lengths up to 30 m, additional hardware not required, clock signal not necessary, and lower computational cost, shown by fewer machine cycles to transmit and receive data.

The proposed protocol was tested in a system for measuring parameters in water that includes a submerged probe to make the monitoring of variables in water bodies, a floating body to manage the measurement and communication process, as well as a graphical user interface for a server. The proposed system was tested in a small water body, with different depths, to cope with a relevant environment. The data measured were transmitted regularly, with a constant sampling time of 5 minutes, showing high robustness, for a period of around 37 h.

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