MONITORING AND CONTROLLING NATURAL RESOURCES BY MEANS OF LOW COST COMMUNICATION PROTOCOL

Natan Rigailo Pytlowanciv 1, Conrado John Gehrmann 1, Arion dos Campos Júnior 1, Jonathan de Matos [1]
1 Department of Informatics – Ponta Grossa State University (UE PG) – Ponta Grossa – PR – Brazil
conrado_gehrmann@hotmail.com, natan.rigailo@outlook.com, arionjr@gmail.com, jonathan@uepg.br

Abstract. Natural resources are assets of humanity that require as much care with it's consumption as with it's administration. In times when excessive rains and prolonged drought affect the water supply of major center and small cities, such care become indispensable and critical. This paper investigates the implementation of a low cost system that allows the monitoring and control of the water consumption of a residence. The proposed system provides the consumer ways to keep the water consumption as low as possible, check for leakage, use the water in alternative periods, and avoid problems caused by maintenances such as air in the pipes being counted in the invoice. The relationship between concessionaires and consumers also has the potential to become narrower, with the easy interaction between the two, differentiated tariffs, consumption data exchange, and the comparison between measured and charged consumption.

1. INTRODUCTION

The constant grown of water supplies around the world makes humanity achieve a delicate situation. This situation is getting worse due to the demographic grown, polution and waste [Amorim 2011].

Another fact that must be taked into account is that the demographic grown tends to occur in more expressive way in places where the water resources has difficult access, is very demmanded and where sanitation access is not guaranteed [Camdessus 2005]. The metropolitan region of São Paulo is one of the most populous in Brazil, therefore it demands great amounts of clean water. A drought that stroke the southeast region of Brazil in the years of 2014 and 2015, but started in São Paulo earlier, in October of 2013 started an alert signed. The water reservoirs reached a point called dead volume, that required emergency maneuvers to change the region of water collection to explore parts of the reservoirs isolated from the capture pipes. The situation reached a critical point no only because of the lack of rain, but also because of the bad planning in providing and distributing policies. Another fact that can made the situation worse is the irregular occupation of the springs polluting and reducing the capitation in the main reservoirs [Sorianod et al. 2016].

Leakages that causes losses of treated water can involve large amounts of water, reflecting yet in financial cost due to the lost treatment. The preoccupation with the leakages are not only a Brazilian concern and extends from the companies that treat and distribute water to the final consumer. As the water is becoming more rare, its price increases, increasing the cost to the consumer [da Silva et al. 2008].

Urban expansion represents a great challenge in the natural resources management. The rain taxes can vary from year to year and are subject to global climate phenomenas. In the majority of cases the water consumed in a urban territory is collected in distant reservoirs and brought to population and treated by a large structure, making the cost of the process high.

Consumption and the management of a so precious resource must be done in an intelligent and controlled way. The advances in integrated circuit technologies brought a reduction in its costs and popularization. The utilization of this technologies and smart solutions for the management, monitoring and controlling can be profitable. The impact of the use of technologies can be important social and environmentally.

Considering a house where there is a regular and predictable water consumption, the house's owner can realize that there is or there was an irregular water consumption (likely to be a leakage), only on the next bill. This is a worrisome, because a leakage in a place with difficult access could be detected and fixed earlier, what would save water and money for the proprietary. Another factor to be taken into account is the erroneous billing. This error can occur when there is air in the pipes due to maintenances, rationing or even lack of water. The equipments that measure the water consumption in the house can account the air flowing through it. This considerations, social, environmental and financial, justify the utilization of sensors and microcontrolled systems to help the owner to monitor and control the water consumption in its house, reducing the water waste contributing in varied ways to the society. Data acquired by means of monitoring can induce decision making, as fill its local water reservoir in alternative hours, avoiding though hours where there is high demand over the water provider network. The primary water register can be close too when there is water shortage, avoiding air in the home pipes instead of water. The monitoring system can notify the owner when there is no water or when the water supply is working correctly.

Water supply network can have a non uniform use during the day, requiring high loads of treated water. The treatment station may not be large enough to provide water in peak hours, but if it is large enough, it will be almost unused in low consumption hours. This problem can affect the consumer when the treatment station is small and can affect the water company if the treatment station gets unused, meaning bad investment of monetary resources. The smart monitoring can help the company to stimulate users to use water in alternative hours for non urgent demands, like filling a swimming pool, fill in house water reservoirs, using washing machines. Thinking in a macro scenario, the company can detect leakage in public distribution pipes closing remotely for a brief period of time the registers of the consumers to isolate real water consumption from leakages.

Monitoring systems for this purpose must have some requirements taking into account its benefits. It must no be too expensive, because it would be applied in large scale, requiring large investment becoming almost prohibitive and unattractive depending on the costs. The technology must also be easy to install, requiring no big structure like data and power supply cables, slowing down the installation process and requiring more investment.

The objective of this study is to create a prototype of a low cost monitoring system that could provide to the user the data about water consumption and controlling over the water system.

2. BACKGROUND

2.1. Power line communication

The Power Line Communication (PLC) technology involves the introduction of a modulated signal carrier over the an existing power network. This signal can provide a two way communication platform with a non intrusive system [Usman and Shami 2013].

The PLC divides in two categories based in the band of working frequency, the narrow and wide band. Companies around the world are using this technologies for decades the communication over the power lines for remote measuring and load control. Most of the uses involves the narrow band systems, around the kHz frequencies, with bandwidth of some kilobytes [Galli et al. 2010]. This uses are a bit restrict to their purposes and not open for the home users.

The narrow band PLC has some common and accessible solutions, for example, X10, Home Plug, PRIME, UPB and others. This work uses the the X10 protocol. X10 is a protocol for low bandwidth that uses the moments where the sine wave of the alternate current present in the house electric system is equal by zero volts also called zero crossing. A pulse with duration of one millisecond and with a frequency around 125 kHz is inserted in the power line at this moment. Figure 1 shows an example of the protocol transmission technique.

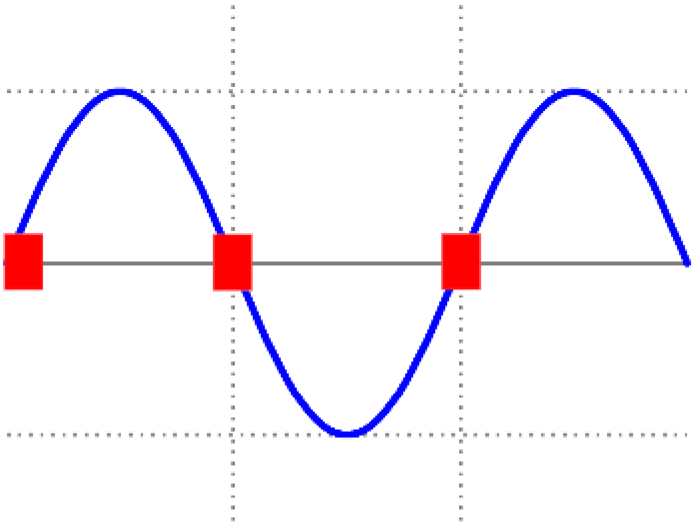

Figure 1: Zero-crossing, where the X10 signal is sent

The presence of a pulse in the X10 protocol represents a high signal, or one. The absence of the pulse of 125 kHz represents a zero. The specification of the protocol dictates a technique to avoid incorrect bits during the transmission. Every time the sender wants to signalize a zero, it first leave the zero crossing with no pulse, but in the next zero crossing it transmits a one, so every absence of pulse must have a pulse in the next zero crossing. The same occurs when the sender wants to signalize a one, it will send put a pulse on the line and an absence in the next zero crossing.

2.2. Low cost solutions

The objective of this work is to reach a great amount of consumers and generate a reduction in the water consumption. Besides that, the consumer also will have the advantage of detect a leakage and reduce the financial cost of it.

The aggregated cost of the system must not be high, if it is high, the advantages for the consumer will not be attractive causing a low adherence to it. Low costs can be achieved in the system starting by the choose of the communication protocol. The X10 protocol needs no extra cabling, using only a power plug close to the house's water intake.

The costs of the electronic components must be considered. High specialized CPUs or microcontrollers can be an oversize for a simple project like this. They are easy to program, have lots of features but increases the overall cost. Small processors or cheap components can compromise the processing capacity in the project and the reliability. The Brazilian market of electronic components is also restricted, becoming difficult to find some components. All the components must be correctly dimensioned to provide a reasonable cost/benefit relation.

2.3. The X10 operation

The utilization of the X10 protocol requires a microcontroler that act as a central unit controller and fulfill three functions: the zero crossing detection, the detection of the signal carrier and the signal generation.

We decided to use a single direction communication on this project. This decision decreases the size of the circuits, reduces the costs and the capability requirements of the microcontroller. In the domotic applications, it is a common scenario the implementation of a single direction communication, where a controller sends signals to activate multiple devices. The procedure of the communication on the X10 protocol is demonstrated in the flowchart in Figure 2. A transmission starts at the sender side when it detects a zero-crossing. After the detection, a square pulse with the frequency around 125 kHz with the duration of 1 ms is imposed in the power line when a bit 1 is needed to be sent. The receptor keeps waiting in a busy wait, every time the power line reaches a low level, it pools the power line for a high frequency pulse.

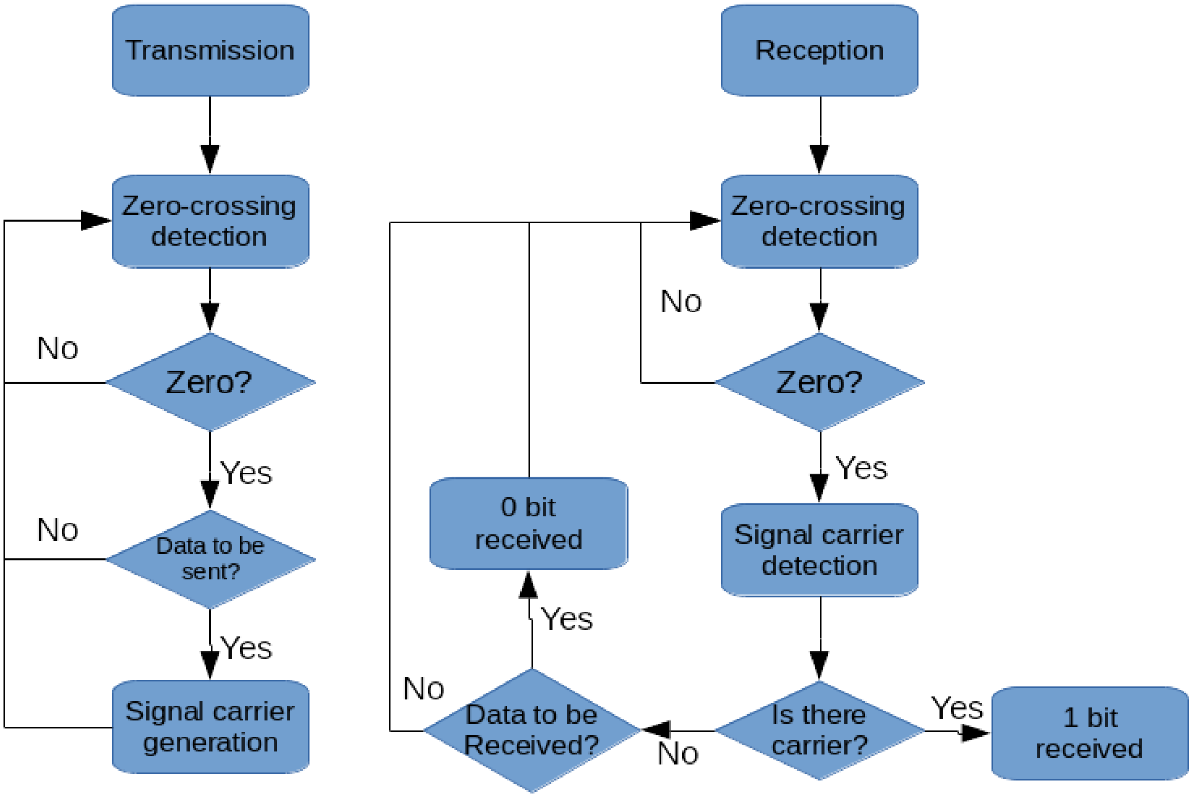

Figure 2: Flowchart of the X10 communication procedure

3. MATERIALS AND METHODS

3.1. Protocol modification

The X10 protocol is a has a protocol for sending the data over the line and a messaging protocol. The message protocol provide standard addresses and data format to communicate with multiple receptors. This protocol sends simple data, like messages meaning “on”, “off, “dim”, “bright”. There is no need of real data, carrying integers or so on. This is the base of the protocol, to be simple. Besides that, X10 does not worries with the resilience of the signal, it is only verified with the complementary bit schema at every bit.

The physical link provided by the power line can be full of noise, increasing the possibility of errors in the transmission. It is no possible to predict whether an error will occur in a transmission, but is possible to verify whether the data received is correct.

We introduce modifications in the original X10 protocol, removing the fixed address and data idea and enabling a simple data check. The needs of this project made necessary to transfer integer values representing the water consumption, so we decided to insert a verification strategy in the transmission. The idea is to ignore data that may be wrong or corrupted, as this data can impact negatively in the consumption record. A way to improve the results even with the discard of some data, is to increase the transmission rate. Water consumption for our problem does not need to be measured with a high rate, considering high as various transmissions per second. A rate of few transmissions in a minute is enough. Considering a consumption of $20m^3$ in a month with a continuous flow (that is only true if there is a leakage), the volume measured will be 0.46 l/min, even smal if measured by second. This means that a per second measure is exaggerated and per minute measure is sufficient. Values measured by the sensors can even be sent in a 5 minute basis. Considering this calculation, same measurement can be sent, for example, 3 times sequentially with a small interval between them. This would increase the possibility of the correct data receiving.

Our data is obtained from a flow sensor, described in section X, that measures values which fit in a 6 bit value (ranging from 0 to 64). The message sent containing water flow value is preceded with a one bit (start bit) and terminated with an extra one bit (stop bit), so the entire message has a length of 8 bits. We opted to not use the complementary bit at each bit sent. This technique described will no warranty a correct byte, but will improve the start and end control of the data. This mechanism also facilitates the reception algorithm, using only one byte, consequently only one register in the sender and receiver microcontroller. Figure 3 illustrates the steps from the data collected through the sender and the receiver.

Sensor	
Value	28
Binary	11100
Shift left <<	111000
OR 10000001	10111001
Sending	10111001

Receiving	10111001
Data	10111001
XOR 1000001	111000
Shift right >>	11100
Value	28

Figure 3: Data transformations scheme for the communication

3.2. Zero crossing detection

The zero crossing detection is a procedure necessary by both sender and receiver devices. The zero cross is the moment when the sender will put the 125 kHz pulse on the power line and the moment when the receiver will try to find a pulse representing a start bit of the data. PIC microcontrollers make this task easier because of their internal port circuit. They have two zener diodes connected on each pin of its ports. These diodes have the limiting voltage of 5V, so if a voltage greater than this is connected to one of its ports, the zener diode makes it flows excess flow to ground or power supply depending on the polarity. A zener diodes can burn if the current passing through it is to high, so a current limiter resistor is placed in series with the pin port. The voltage inside the microcontroller will no exceed 5V even if the supplied voltage is around 200V. Figure 4 exemplifies the port connection.

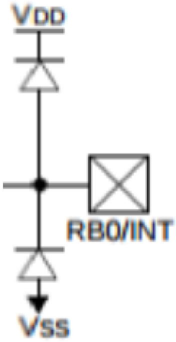

Figure 4: Block diagram of PIC16F628's PORT B

Whether a 127V AC current supply is connected to the microcontroller and a limiting resistor is used, the internal voltage will not reach the 180V of voltage peak of the AC supply. As the AC current is a sine wave, when its voltage drops from 180V to around 5 V, for example, the voltage inside the microcontroller keeps close to 5V, but when the AC voltage drops from 5V to 2V, it also drops the same inside the microcontroller. When the AC voltage reaches around 0.6V, the internal binary logic of the microcontroller considers a 0 value on the input pin. Figure 5 exemplifies voltage value in the microcontroller's port. This characteristics permits the zero-crossing detection in a binary form, allowing the association of the zero-crossing with a interrupt. The current that will flow through the zener diode must be very low to implements this circuit. According to the application note 236B [Burroughs 2010], a 5.6 MOmhs generates a secure current of 30 µA at the peak of 180V.

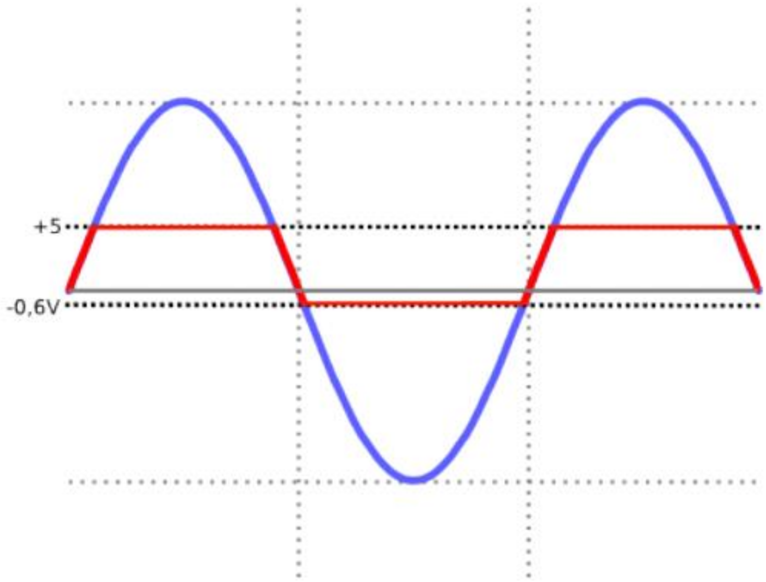

Figure 5: Voltage level present in input pin due to protection circuits

3.3. Signal carrier detection

A carrier of 125 kHz is used in X10 protocol. This frequency must be separated from the 60 Hz frequency of AC line and converted from a pulse of a high frequency to a high level, representing the bit one for the microcontroller. We constructed a modified version of the detection circuit proposed in [Burroughs 2010] composed of five steps: a decoupling capacitor, a high pass filter, a tunned amplifier, a envelope detector and a comparator. The literature proposes only the four first stages but empirical tests demonstrated that the output signal from the tunned amplifier is not compliant with signal level from the microcontroller, so we added a a last stage to make it compliant (Figure 6)

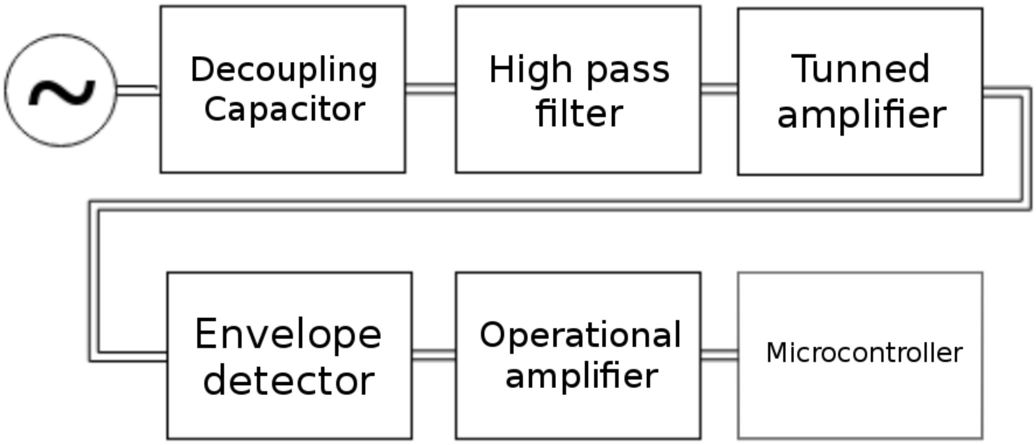

Figure 6: Block diagram of signal carrier detection

The first stage (Figure 7) is the decoupling circuit that acts connected to the AC line. its impedance for 60 Hz sine wave can be calculated by Equation 1. A 0.1 µF capacitor have a low impedance for 125 kHz, around 13 Ohms , and a high impedance for 60 Hz, around 26.5 KOhms. This stage can separate signal fom AC frequency.

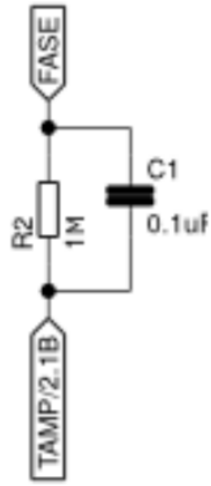

Figure 7: Decoupling capacitor circuit

The second stage (Figure 8) is the high pass filter. As the first stage only imposes a high impedance to 60Hz frequency, not eliminating it, a filter is necessary after it. This filter allows high frequency to pass over it and attenuates low frequency in a threshold calculated by Equation 2. The frequencies involved in this situation are very different so the filter can be easily calculated. The values present int Figure 8 were obtained for a cutting frequency of 32 Khz.

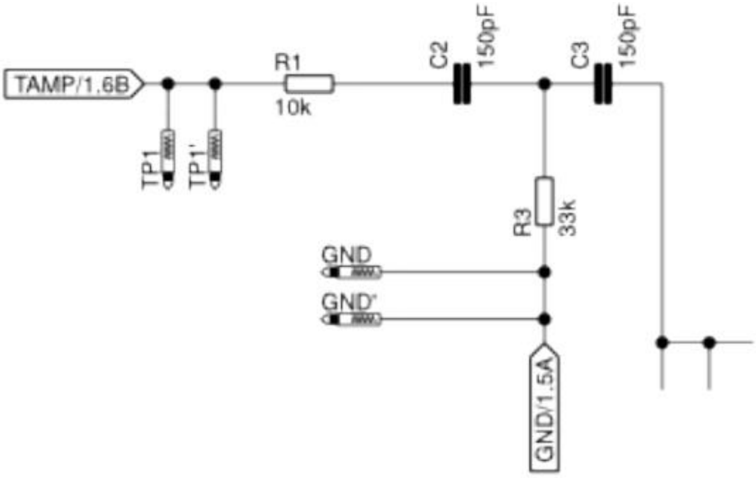

Figure 8: High pass filter circuit

After high pass filter stage there are a tunned amplifier (Figure 9). This amplifier were obtained from the literature described by Burroughs 2010. It amplifies a signal with a frequency around to 125 kHz. A envelope filter is placed after the amplifier and it have the purpose of converting the pulse of 125 kHz in a single pulse with approximately 1 ms.

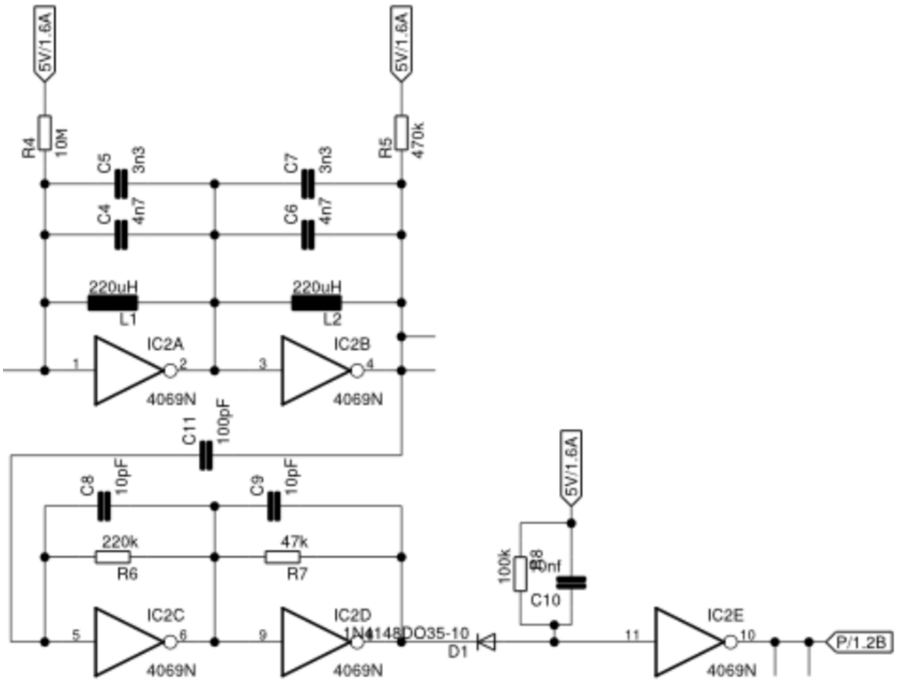

Figure 9: Tunned amplifier and envelope detector

The output of the circuit until this stage is not high enough to activate the microcontroller logic levels. We added another stage composed by a LM358 operational amplifier. This component contains two OpAmp circuits and booth of them were used. The first one was used as a non-inverting amplifier and the second as a comparator to eliminate the DC bias created by the amplification of the first (Figure 10).

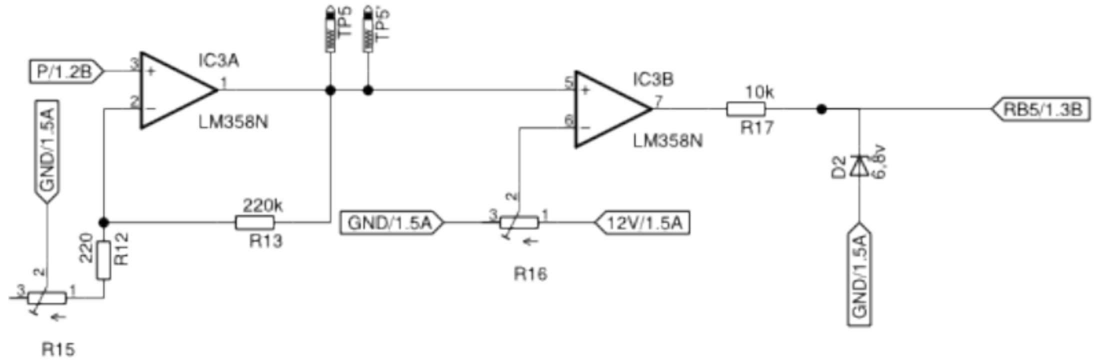

Figure 10: Operational amplifiers

This circuit makes possible for the microcontroller to inspect the output of the last stage at each zero-crossing, detecting the presence or not of bits, creating the byte of data.

3.4. Signal carrier generation

Signal generation involves the modulation of a carrier on power line. This modulation of 125 kHz is created using the PWM peripheral. This peripheral generates a pulse of a defined frequency, but with a diferent ratio of high and low state. It can be used in conjunction with filters to generate analog voltage values [Barr 2001]. We used it with a equal ratio between high and low voltage values, generating a regular square wave. The output of the PWM peripheral is connected with bipolar transistors to amplify the power and current of the pulse and insert it on AC line. Normally the PWM peripheral when disabled keeps the pin of microcontroller in the low level. The PWM peripheral is only used in the zero-crossing and only when a one bit must be sent. Whether a low low level is inserted in the base of a bipolar NPN transistor, it produces a high level in the power line. The signal needs to be inverted to be inserted in another transistor generating the correct signalization. Figure 11 shows the connection between the microcontroller and the power line. The same decoupling circuit present in the stage one of the carrier detector must be used between the transistor collector and the power line. It causes a high impedance to the AC current of 60 Hz, preventing it from damaging the DC circuit.

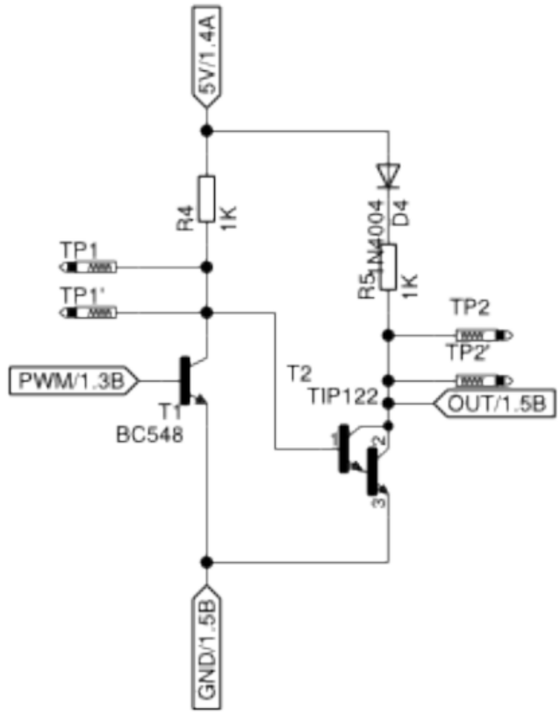

Figure 11: Signal generation circuit

3.5. Water flow sensor

There are two situations that need to be measured, the absence of water and the fluid flow through the pipes. The presence or not of water can be measured in lot of ways, in this project we choose a resistive sensor. The method consists in inserting two electrodes apart from each other inside a pipe. Measuring the resistance between them will result in the resistance of the material they are in. Water and air have different electrical resistance, so evaluating the values with and without water in the pipe it is simple to detect its presence.

Another situation that needs to be measured is the amount of water passing through the pipe that conducts water to the house. This measure can be made with a flow sensor. We used the model YF-S201 (Figure 12) which consists of a rotative encoder activated by the flowing of water inside it through pads connected to the encoder. The encoder generates pulses proportionally to the water that passes through it.

Figure 12: Water flow sensor model YF-S201

3.6. Encoder measure validation

Encoder validation was accomplished using an Atmega328 microcontroller, a container to store water, two electrodes and a graduated cup. The encoder (flow sensor) was connected to the water tap using a tube with two electrodes. The output of the flow sensor was connected to a water container. This container was used to store temporally the water to pour it on the graduated cup for measuring purpose.

The method for measuring consist of opening the water tap and with water flow through the pipe, the microcontroller detected water presence and started to count the time. When the water tap was closed, the microcontroller detects no water in the pipe, finishing the counting. While the water was flowing through the flow sensor, the pulses generates by it were counted by the microcontroller. The time and pulses (flow) counted by the microcontroller were used to construct the Table 1. Flow sensor manufacturer specifies that the volume of water that flowed through it has a ratio of 7.5 times the number of pulses it counted. Table 1 compares the amount of water that flowed through the sensor and was measured by the graduated cup with the theoretical value based on the number of pulses the microcontroller counted multiplied by 7.5. It can be noted that the greatest error was 4.35%.

Table 1: Encoder values and validation

	Volume (ml)	Time (s)	Pulses	Frequency (Hz)	Flow (real) (l/min)	Flow (encoder) (l/min)	Error (%)
1	460	3.667	217	0.986	7.527	7.397	1.720
2	340	2.744	160	0.972	7.434	7.289	1.960
3	530	4.296	245	0.951	7.402	7.129	3.690
4	470	3.967	225	0.945	7.109	7.090	0.260
5	535	4.150	250	1.004	7.735	7.530	2.640
6	365	3.423	180	0.876	6.398	6.573	2.730
7	340	2.821	161	0.951	7.232	7.134	1.340
8	465	3.942	225	0.951	7.078	7.135	0.800
9	460	3.709	212	0.953	7.441	7.145	3.980

10	440	3.543	202	0.950	7.451	7.127	4.350

3.7. Data provider

Once the water flow was measured, transmitted using the power line to the in house device, this last device needs to provide this data to the consumer. The microcontroller used in this project, PIC16F628, has two pins used for serial communication (one more pin for the common ground). Asynchronous serial communication is compatible with lots of devices as other microcontrollers or computers (using RS-232 protocol). The data output of the measuring system, thanks to the serial protocol, is very flexible and is part of future works to implement a user friendly way to show the results.

3.8. Power Supply

Both the sides of the system, sender and receiver, needs a power supply. Sender can use a 5 V power supply and it is recommended a switched one to reduce the size and improve energy efficiency. The same applies to the receiver, but this one requires a 12 V power supply for operational amplifiers supplying, taking into account that they have some losses internally not being able to provide 5 V in their output using a 5 V supply. Power is not a problem in this circuit, because they need to be connected to the power line to send data.

3.9. Electric power risks

Electric power provided by domestic power lines can reach peaks of 280 V in alternate current, causing from light to severe injuries depending on the form of contact with the human body and the time of exposure. Some procedures need to be followed before start testings using domestic power lines.

A device called residual current device (RCD) or residual current circuit breaker is highly recommended when working with domestic power lines. This device is effective in protecting life and property. It monitors the residual current in the circuit it is connected. Residual current is the sum of all instant current values passing by all the active conductors in a circuit in a given electric system. RCD breaks the circuit when a residual current above its nominal value is detected [Daviu and Alfonso 2014].

When prototyping circuits that deals directly with power lines, it can be used a insulation transformer. This device isolates the ground of the power line from the earth, reducing the risks of touching electrical conductors. Insulation transformers are used, for example, in medical equipments to reduce the risks of electrical shock. In the prototyping process the insulation transformer can even apply a reducing factor of 2, for example, reducing the voltage and the lethality of electric power. Another important measure is the correct dimensioning of the protection circuit, using a low current fuse. The maximum current allowed by this component must be very close to the real current consumption of the circuit. When a problem, like a electrical shock, occurs the RCD must be enough, but if it does not break the circuit the insulating transformer with reduction factor will not cause a great injury and if the current that is passing through the human body is large, the fuse will break, improving the security.

4. RESULTS AND CONSIDERATIONS

The proposed system was functional, showing that its construction and real use is possible. Potential befits involves the water waste prevention, from the environmental point of view, allowing the leakage detection. It can also benefits the consumer monetarily with early leakage detection and with detection of air accounting. Other possible use is in the billing differentiation in low consumption periods, optimizing the water treatment plants.

As the initial proposal of the project, the costs were kept low. The microcontroller cost is the key for the project, as the cost of it in the moment of the final edition of this document was R$ 14,13 [Soldafria, 2016]. This value is responsible for 61% and 75% of the total cost of receiver and sender respectively.

The decision of use only single direction communication was an important point in the project, as it reduced the costs and the complexity of the circuit to the microcontrollers. The complexity reduction made possible the use of a simpler microcontroller. The amount of total components were reduced too, impacting in the size and costs.

The receiver circuit did not behaved like the literature determined, requiring some modifications. The modifications increased the costs with the addition of components so there is a motivation to improve the circuit, using a clever and optimized solution. A new solution could involve the operational amplifier LM358 as the previous solution. The first two stages would be kept and its output would feed the op. amplifier. acting like a comparator (Figure 13). The next stage would involve a circuit to filter the 125 kHz frequency and finally a conditioner to put the signal in 5 V level.

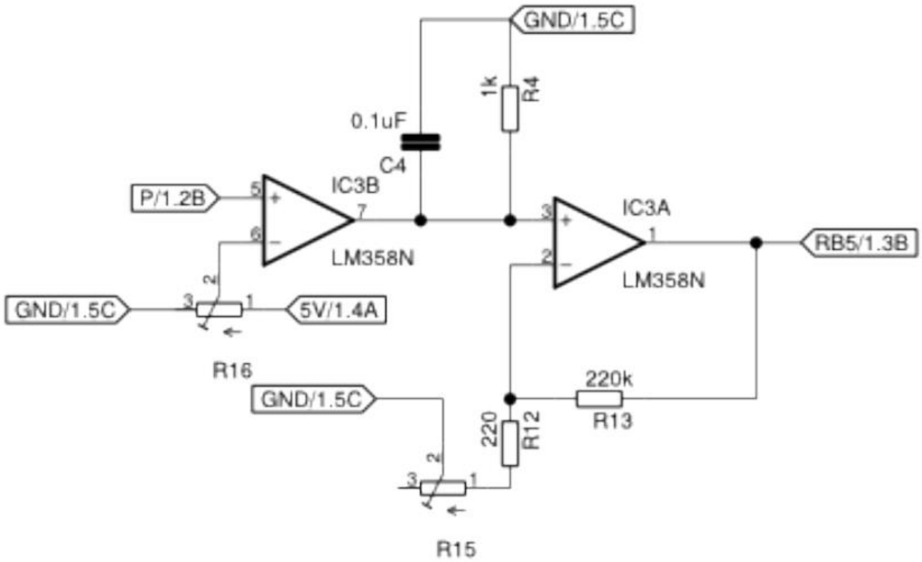

Figure 13: Improved circuit proposed

5. REFERENCES

Amorim, P. H. O. P. d. (2011). Água, cultura e crise: uma análise do discurso contemporâneo sobre recursos hídricos. Page 35.

Barr, M. (2001). Pulse width modulation. Embedded Systems Programming, 14(10):103–104.

Burroughs, J. (2010). X-10 R home automation using the pic16f877a. Lamp.

Camdessus, M. (2005). Água: oito milhões de mortos por ano: um escândalo mundial. Bertrand Brasil.

da Silva, G. S., Tamaki, H. O., Loureiro, R. S., and Gonçalves, O. M. (2008). Eliminação de vazamentos em redes externas no contexto de programas de uso racional da água estudo de caso: Universidade de são paulo. Ambiente Construído, 8(2):41–52.

Daviu, A. and Alfonso, J. (2014). Residual current devices.

Galli, S., Scaglione, A., and Wang, Z. (2010). Power line communications and the smart grid. In Smart Grid Communications (SmartGridComm), 2010 First IEEE International Conference on, pages 303–308. IEEE.

Instruments, T. Lm358 datasheet. Technical report, staženo 2014-02-27. http://www. ti.com/lit/ds/symlink/lm158-n. pdf.

Microchip. Pic16f627a/628a/648a datasheet. Technical report, 2007. http://ww1. microchip. com/downloads/en/DeviceDoc/40044F. Pdf.

Pertence Jr, A. (2003). Amplificadores Operacionais e Filtros Ativos. Bookman Editora.

Soldafria. Soldafria. http://www.soldafria.com.br/. Acesso: 15/10/2016.

Sorianod, É., Londe, L. d. R., Di Gregorio, L. T., Coutinho, M. P., and Santos, L. B. L.(2016). Crise hídrica em são paulo sob o ponto de vista dos desastres. Ambiente & Sociedade, 19(1):21–42.

Usman, A. and Shami, S. H. (2013). Evolution of communication technologies for smart grid applications. Renewable and Sustainable Energy Reviews, 19:191–199.