Water Conductivity Sensor based on Coils to Detect Illegal Dumpings in Smart Cities

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***Abstract*— Illegal dumpings in sewerage can cause problems in wastewater treatment plants, so it may become an environmental problem. In this paper, we propose a system for detecting these illegal dumpings. We use conductivity sensors for detecting a change in the conductivity of water because this change may appear due to a dump. The system is based on two coils. One of the coils is powered by a sinus-wave and the other coil is induced. To prevent damage from water in the copper we encapsulate the coils in a PVC tube. These coils are connected to a Flyport in order to send the values and generate alarms. We tested the prototype with different configurations of coils with encapsulation of 3 and 1 mm. When the encapsulation is of 3 mm, we do not observe differences in the induced voltage. The prototype selected has a difference of 4.10 Volts between the samples 0 and 40 g/l of the table salt. In the verification test this prototype has a relative error of 2.54%.**

Keywords— Coils, Conductivity, Smart cities, Illegal dumping, Flyport.

I. INTRODUCTION

Illegal discharges are an important problem in cities all over the world, because they can cause problems in water bodies [1]. Historically, people have thrown their waste to the rivers, to be washed down. Thus, it caused a handful of environmental issues in the surrounding area downstream. Nowadays, we have water treatment plants, which process the sewage water so it can be returned to a water stream. They are designed to operate for a calculated range of flow and concentration of pollutants. Therefore, if there is an illegal discharge, the water treatment plant will be unable to completely process the water. Moreover, this is very important because if the water is not processed correctly it will affect the ecosystem downstream [2]. These discharges contain pollutants such as nitrates, sulphates and in the worst cases even heavy metals and other pernicious compounds.

Nowadays, sensors are being included in the sewer system to detect possible irregularities. E.g., in the Netherlands there is a method that consists of distributed sensors to measure the temperature, along with a fiber-optic cable that is being used to detect illicit sewage connections. It uses the temperature difference from the storm drain water and the sewage water to detect it. The cable has high temporal (30 seconds) and spatial (2 meters) resolution, and it measures 1300 meters [3]. Although it is a very good device, it is difficult to operate with it, since it is so long. It also could present difficulties such as a portion of the cable could be torn. The usefulness of a smart wireless sensor network has been widely proven in [4].

The integration of technologies in these cities (Smart cities) can help to detect illegal dumps. A smart city is a city in which technologies are ingrained in every day's life [5]. This proves to be highly beneficial for the citizens, who have more available information, as well as better services. The services for smart cities do not only benefit the population directly using an app, but also provide energy efficiency and environmental management. Both factors affect the lives of the citizens, as well as the planet. A good smart city would be one that not only covered the citizens' main necessities, but also the environmental ones.

The aim of this paper is to design a system, which could be used in smart cities for the detection of illegal discharges. If we are able to determine the precise time and location of the discharge, we will be capable of mustering a better course of work than the standard one. Our sensor is based on two coils insulated with a PVC tube. One of them is powered by alternating current and the other is induced. The two coils are connected to a flyport node. If the system detects an unusual change in the conductivity, it will generate an alarm in order to take the appropriate actions.

The rest of the paper is structured as follows. Section II presents the published related works about the measurement of pollutants in water. A description of the sensor node is developed in Section III. Section IV shows the structure of the message flow between IoT devices. In Section V we explain how we have obtained the results. The results are explained in Section VI. Finally, Section VII presents the conclusion and future work.

II. RELATED WORK

In this section, we are going to discuss some recent papers related to our work. We will talk about how coils have been used for other water related analysis. Moreover, we will mention some methods for detecting sewage water in the storm drainage system.

Siregar et al. [4] proved the need of a low-cost smart environment system to analyze in real-time the wastewater quality. They developed a wireless sensor network to detect changes in pH, conductivity, temperature and dissolved oxygen. Besides, it was equipped with a notification feature that would send an alarm when the parameters exited specified thresholds.

Rocher et al. [6] showed the utility of sensors for water monitoring. They used coils to measure the concentration of solids in the mechanical dried in the Wastewater treatment plants. This sensor works in concentration between 0 and 20% of solids in water (200.000 mg/L). Their sensor alone work in high concentration of solids. These concentrations are not likely to occur in sewers. The developed sensor works at lower concentrations, suitable for wastewater control.

Hoes et al. [3] observed the benefits of a system that could give data as often as possible. Moreover, they observed the need to find a method that does not need to be performed on private terrain. Moreover, they stablished how common illegal connections to storm water systems are and discussed the environmental impact they have. An impact that is lessened but not eradicated with a WWTP.

Irvine et al. [7] presented an interesting point of view. They sampled several locations, up to 64 outfalls. Then, they analyzed chemical parameters and the level of Escherichia coli. Those tests were run both on standard methods and low-cost methods, proving that the results were precise enough for the study to be a success. For the method they used it was necessary to take samples, which could not always be an easy endeavor.

Parra et al. [8] remarked the practicality of using sensors for monitoring places of difficult access parameters in smart cities. Two copper coils were used to measure conductivity, and with the result the salinity of groundwater resources was calculated. The usefulness and accuracy of the solenoid coils was widely proven in this paper. Besides, they showed the calibration of the sensor, which is similar to the one we use.

Panasiuk et al. [9] debated about the problematic of wastewater in stormwater sewers. Different reasons for this issue were explored in this paper. They discussed different methods and indicator parameters for the detection of these discharges. The chemical and microbiological factors were deemed vital for this process. They concluded that as of now, there is not a precise, fast and low-cost method for the detection of these discharges.

Rocher et al. [10] proved the usefulness of sensors for water monitoring. Different prototypes were tested for water level monitoring in pipes. All of them were composed of two coils and fed with a sine wave with an amplitude of 3.3V peak-to-peak. The most accurate prototype was the one with a voltage variation higher than 1 V. It was composed of two solenoidal coils of 0.4 mm of copper in form of half-circle with 55 spires. To broadcast the information, the sensor could be connected to a node as Arduino Uno.

As far as we know, a low-cost method for detecting illegal discharges in sewage water based on conductivity sensors is yet to be designed. We propose a sensor based on two coils that covers this matter and posits a possible solution for managing this issue in smart cities. Our system has the advantage that the sensor part (copper) does not directly contact in water. This allows a longer useful life because it avoids the effects of oxidation given by the water.

When an abnormal value of conductivity is detected in the water, the system generates an alarm.

III. Sensor Node Deployment

In order to deploy the sensor node for measuring water quality in the smart cities, we use the node Flyport [11]. It is a hardware designed and produced for Internet of Things (IoT). The hardware has OpenPicus, which is software open platform to speed up the development of IoT devices. Details of the scenario of deployment of the systematic hardware and the software algorithm are explained as follows.

A. Hardware and system description

Generally, the hardware part includes three main components; respectively, Coils to measure water quality for detecting illegal dumping, Flyport node to gather the measurement and collect data, and the router as intermediate, which has Internet access. The topology is illustrated in figure 1.

The Coil is designed to measure all the solutes in water. It takes analog measures. Therefore, the IoT sensor node generates the sine wave, which is used to feed the coils and from this measurement, the data can be obtained. The Flyport generates a pulse-width modulation (PWM) signal which is used to generate a sinusoidal signal in order to power the coils. The PWM signal needs to be filtered by a band pass filter (BPF) in order to obtain the sinusoidal signal [8]. Once PWM signal is generated by the integrated circuit Flyport, it is necessary to filter this signal by a BPF with the determined frequency.

The Flyport has a Certified Transceiver Wi-Fi IEEE 802.11g Microchip MRF24WG0MB. It allows the node to communicate to the wireless router.

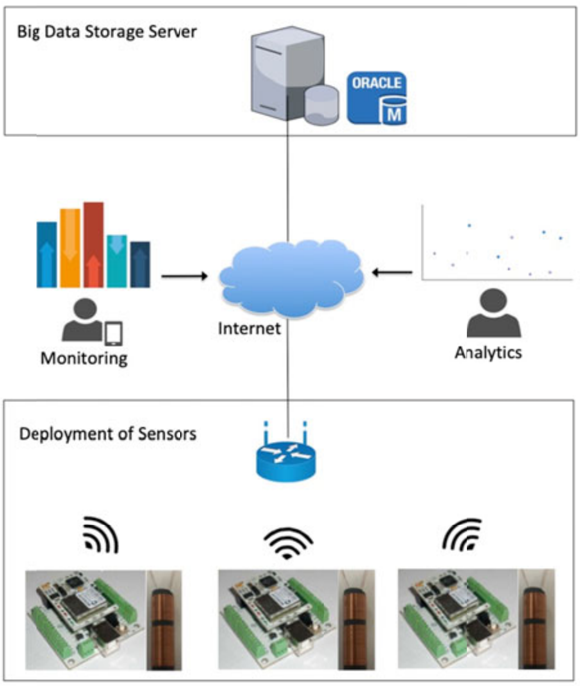

Fig 1. System description.

The microcontroller also controls the wireless protocol for the sensor's on-board radio frequency transmitter and receiver. The sensor node has 16 Bit low power microcontroller Processor under Microchip PIC24FJ256, with 16K Ram and 16Mips@32Mhz. These chips are used to upload data collected by the coils while keeping the coil sensor entirely encapsulated. On the other hand, using this sensor node with the technology of IEEE 802.11g standard makes fairly cost-effective. Moreover, it provides the smallest energy consumption.

B. Software System algorithm

The sensor software control is designed for three primary modes: user mode to configure the circuit Flyport, data collection to obtain data from the measurement, and transportation of the data over the wireless network. The programming language used in our system is C, which allows great adaptability in developing new applications and code schemes. The pseudo code 1 shows information about the configuration of the input and output ports and obtains data. Therefore, after receiving the data from the measurement nodes, the data is sent to the main server, therefore, if there is an abnormal measurement detected by the system for the quality of the water, the algorithm's system gives an alert about the case, for these cases where the maximum and minimum thresholds are defined in the system.

Psuedo code1, description of the system configuration and collection of data from the measurement

```
Begin
ADCAttach(); //Enable anolog input
Int MaxLevel, MinLevel;ADCValue
Float Level, Chart Msg
For ( i =0, i >1000000, i+10000) {
PWMInit(i);
PMWOn(p3out);
While (true){
for (Level = i; Level > minLev; Level--){
PWMDuty(Level, 1);
Delay(2); }
for (Level = i; Level > minLev; Level++){
PWMDuty(Level, 1);
Delay(2); } } }
While (true){
If (analog1){
ADCValue = ADCVal(1);
sprintf(Msg, "%d\r\n", ADCValue); }
Delay(2); }
```

IV. *MESSAGE FLOW BETWEEN IOT DEVICES*

The message flow protocol is explained between the IoT devices (Flyports) and the main server according to [12] as shown in figure 2. First, the IoT-Flyport device is ready to collect data by measuring water quality from the Coils. Second, the collected data sent to the main server over Internet using Transmission Control Protocol (TCP) and Hypertext Transfer Protocol (HTTP), the purpose of using this protocol is to guarantee received data in the communication and avoid losing important data in the transmission. In the scheme, the main IoT-server listens to receive requests from the Flyport nodes. The Flyports nodes initiate the conversation with the server by establishing TCP handshake. The measurement node has source host identification, the information of measuring water quality for detecting illegal dumping, and destination server information. The nodes send data to the server each two seconds, each node has a sleep for two seconds to send the obtained data from the coils to measure water quality therefore this is in order to reduce resource usage in system and network service. When the server receives the data from the IoT-nodes the server holds the data in the database, which is designed by using Oracle 11g as depicted in figure1. Using Oracle is to hold massive data of the measurement in the process. Therefore, the IoT data on the server can be used for the different purposes such as analytical or visual monitoring by other users.

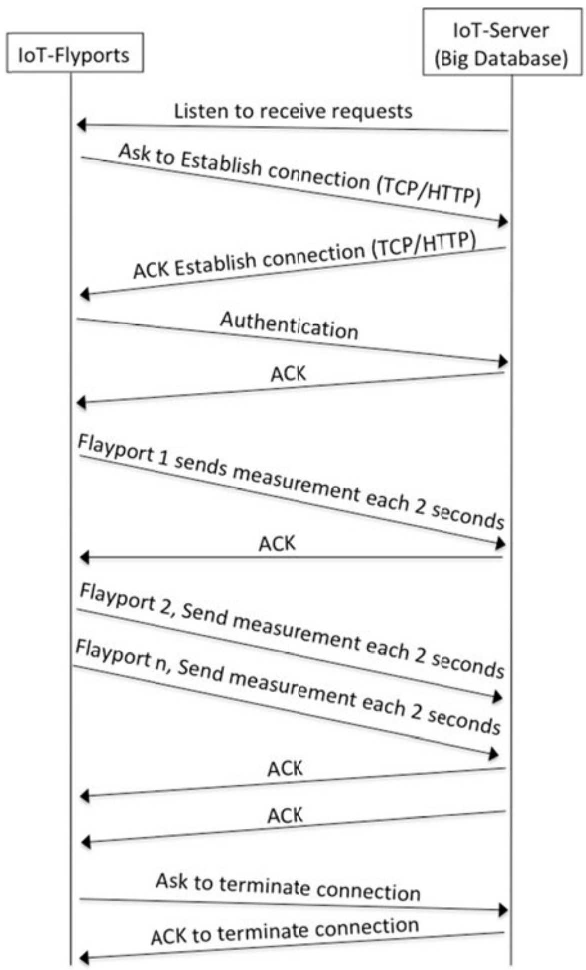

Fig 2. Flow message conversation.

V. TEST BENCH

In this section, we explain the materials and methods used in the tests.

We tested different prototypes based on two coils (a powered coil (PC) and an induced coil (IC)). These prototypes are represented in Table 3. The firstpart of the coil is powered with a wave generator model AFG1022. This generates a sinus-wave current with a voltage of 3.3 V peak-to-peak. In addition, we used an oscilloscope model TBS1104 to measure the current induced. The powered coil has a resistance of 47 Ω in the positive cable. The induced coil has a capacitor of 10 nF in parallel.

The prototypes are manufactured on a PVC pipe of 25 mm with a thickness of 3 mm.. The copper used is enameled and it has 0.4 mm to the diameter. The different prototypes are encapsulated in PVC pipes. We used PVC pipes of 32 mm for prototypes P1, P2, P3 and P4. The prototypes P5, P6, and P7 are encapsulated in PVC pipes of 40 mm because they do not fit in 32mm pipes. In addition, we use hot melt adhesive to ensure that the coil is not in contact with the water. The PVC pipes have a thickness of 3 mm. However, we sand these pipes to 1 mm of thickness for some tests.

The different samples are prepared with table salt (NaCl) and drinking water. The conductivity of these samples is measured with a conductometer Basic-30. We use plastic cups with 500ml of samples to test the prototypes.

For all prototypes, we need to find the working frequency. This frequency is the frequency that has a significant difference between the different samples and is adapted to a mathematical model. We search the working frequency between 0 to 1000 kHz with 10 kHz jumps.

The following tests are carried out:

(I) Firstly, the prototypes P1, P2, P3, and P4 are tested with the samples of 0 and 45 mg/l of table salt with encapsulation of 3 mm thickness.

(II) In the second test, we tested the same prototypes but with encapsulation of 1 mm of thickness.

(III) In the third test, we select the best prototypes from the first and second tests and change the number of layers when the copper is distributed. In this case we tested with encapsulation of 1 mm of thickness. This test is performed with the samples of 0 and 45 mg/l of table salt.

(IV) We test the better prototypes from the third test. We use the concentration of table salt of table 1. We related the value of induced voltage with a mathematical model.

(V) Finally, we verified the operation of the prototypes with the concentration of table salt of table 2.

Table 1. Samples prepared for deve

Table salt (g/l)	**Conductivity (mS/cm)**	**Table salt (g/l)**	**Conductivity (mS/cm)**
0	0.487	5	9.04
10	15.49	20	27.3
35	47.1	45	56.4

Table 2. Conductivity and salt concentration of the samples of verification

Table salt (g/l)	Conductivity (mS/cm)	Table salt (g/l)	Conductivity (mS/cm)	Table salt (g/l)	Conductivity (mS/cm)
1	2.89	2	3.83	4	6.62
7	11.02	9	14.36	12	17.9
15	22.3	18	25.5	22	30.3
30	41.2				

Table 3. Prototypes tested

Prototype	**Picture**	**PC**	**IC**	**Prototype**	**Picture**	**PC**	**IC**	**Prototype**	**Picture**	**PC**	**IC**
P1		Nº Spires: 40 Nº layers: 1	Nº Spires: 100 Nº layers: 1	P2		Nº Spires: 40 Nº layers: 1	Nº Spires: 80 Nº layers: 1	P3		Nº Spires: 40 Nº layers: 1	Nº Spires: 60 Nº layers: 1
P4		Nº Spires: 40 Nº layers: 1	Nº Spires: 40 Nº layers: 1	P5		Nº Spires: 40 Nº layers: 2	Nº Spires: 80 Nº layers: 2	P6		Nº Spires: 40 Nº layers: 4	Nº Spires: 80 Nº layers: 4
P7		Nº Spires: 40 Nº layers: 8	Nº Spires: 80 Nº layers: 8								

VI. RESULTS

In this section, we are going to show the results of the different prototypes tested.

A. 3mm of tickness

In this subsection, we indicate the results of encapsulating the prototypes P1, P2, P3, and P4. We test with the samples 0 and 45 mg/l of table salt. We search if a difference exists between these samples.

In Table 4, we can observe the results of the prototypes P1, P2, P3 and P4 with an encapsulation of 3mm of PVC. The prototype 4 has the highest difference between 0 to 45 g/l of table salt with a value of 0.4V. The prototypes P2 and P3 have a difference of 0.28V and finally the prototype 1 has a difference of 0.08V. These differences are small which causes the sensor to have low sensibility. For this reason, we are going to test with a less thick encapsulation.

Table 4. Result of the prototype with 3 mm PVC encapsulation

Prototypes	Frequency (kHz)	Sample 0 g/l (V)	Sample 45 g/l (V)	Difference (V)
P1	150	8.88	8.80	0.08
P2	170	10.20	9.92	0.28
P3	210	5.24	4.96	0.28
P4	270	8.24	7.84	0.40

B. 1 mm of tickness

After trying with an encapsulation of 3 mm of PVC, we test with an encapsulation of 1 mm of PVC. In this subsection we show the results of this test.

The results of prototypes P1, P2, P3 and P4 are in Table 5. In Prototypes P1, P2, and P3 the difference of induced voltage is higher than in the ones whose thickness was of 3mm of PVC. Prototype P4 has the same difference of induced voltage. The working frequency is the same in the cases of P1 and P2. In the cases of P3 and P4 are 10 kHz less. Due to the large induced voltage difference of prototype 2 (6.06 against 1.28 of the second biggest difference). We take this prototype as a reference to distribute this coil in different layers

Table 5. Result of the prototype with 1 mm PVC encapsulation

Prototypes	Frequency (kHz)	Sample 0 g/l (V)	Sample 45 g/l (V)	Difference (V)
P1	150	8.48	8.16	0.32
P2	170	9.20	3.14	6.06
P3	200	9.44	7.76	1.68
P4	260	8.40	8.80	-0.40

C. Turns distributed in different levels 1 tickness

In this subsection, we test the prototypes P2, P5, P6 and P7. We test with the samples of 0 and 45 mg/l of NaCl to find the working frequency. After that, we test them with the samples of the Table 1. In the Table 6 we can observe that prototypes P2, and P5 have a good difference between the samples of 0 and 45 mg/l of table salt. The difference is 6.06 and 4.10 in the prototypes P2 and P5 respectively. We select the prototypes P2 and P5 because these will have a better precision.

Table 6. Result of the prototype with 3 mm PVC encapsulation

Prototypes	Frequency (kHz)	Sample 0 g/l (V)	Sample 45 g/l (V)	Difference (V)
P2	170	9.20	3.14	6.06
P5	130	8.56	9.76	1.20
P6	110	12.50	8.40	4.10
P7	110	12.60	12.80	0.20

With the prototypes P2 and P6 we test with the samples of Table 1 (the results can be seen in Fig 3). The different values of output voltage (current induced) are compared with the conductivity obtaining a mathematical model. The mathematical models that represent these prototypes are the equations 1, and 2 for the prototypes P2 and P6 respectively. The R^2 (this is a statistical parameter that indicates how the mathematical model can be adapted for the different points) are 0.9974, and 0.9706 respectively. Since the two prototypes have a good R^2, we perform the verification with both prototypes

$$\text{Vout (V)} = -1.297 * \ln(\text{conductivity (mS/cm)}) + 8.2589 \quad (1)$$

$$\text{Vout (V)} = 12.28 * e^{-0.007 * \text{conductivity (mS/cm)}} \quad (2)$$

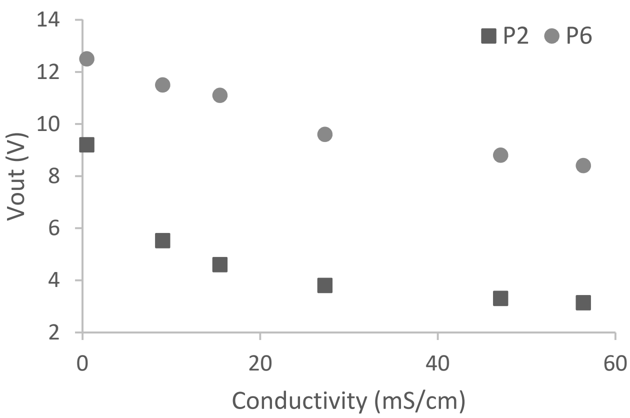

Fig 3. Induced voltage of the prototype 2, and 6.

D. Verification

Finally, in this subsection, we are going to perform the verification of the prototypes P2 and P6.

To verify the prototypes, we prepared different samples with a concentration of table salt and conductivity that are shown in Table 2.

The values of the output voltage in the verification of the prototypes 2 and 6 are in Table 7. The real value is the value of the induced voltage of the prototype in the lab. It is the theoretical value according to the model for a specific salinity. The absolute error is the difference between those values. The relative error is the absolute error divided the real value. The relative error of the prototype 6 is less than prototype 2. In the range of 1 to 9 mg/l the prototype 6 has the minor errors. In prototype 2 the minor errors are in the range of 2 to 15 mg/l. We decide to use the prototype 6 because it has more precision at the cost of sacrificing sensor sensitivity.

Table 7. Conductivity and salt concentration of the samples of verification

		Prototypes							
		P2		P6		P2	P6	P2	P6
Table salt (g/l)	Conductivity (mS/cm)	Real (V)	Model (V)	Real (V)	Model (V)	Absolutly error (V)		Relative error (%)	
1	2.89	7.73	6.88	12.07	12.05	0.86	0.01	11.08	0.11
2	3.83	6.84	6.51	11.97	11.97	0.33	0.01	4.79	0.07
4	6.62	6.01	5.81	11.77	11.74	0.21	0.02	3.46	0.20
7	11.02	5.37	5.15	11.40	11.39	0.23	0.01	4.23	0.12
9	14.36	4.77	4.80	11.27	11.12	0.03	0.14	0.64	1.27
12	17.9	4.45	4.52	10.23	10.85	0.07	0.62	1.47	6.04
15	22.3	4.00	4.23	10.10	10.52	0.23	0.42	5.87	4.18
18	25.5	3.81	4.06	9.79	10.29	0.25	0.50	6.50	5.14
22	30.3	3.37	3.84	9.33	9.95	0.47	0.62	14.01	6.60
30	41.2	3.03	3.44	9.07	9.22	0.41	0.15	13.44	1.67
					Media	0.31	0.25	6.55	2.54

VII. CONCLUSION AND FUTURE WORK

In this paper, we present a system for monitoring the conductivity in sewage. This parameter can be used to detect illegal dumpings in smart cities.

We determine that 3 mm of encapsulation has a low resolution and therefore a thinner encapsulation should be used. From the tested prototypes, we determined that the prototypes P2 and P6 are the ones that work best. Although the prototype P2 presents a greater difference between the sample of tap water and that containing 45 g / l of salt (which implies greater sensitivity). We choose the prototype P6 because in the verification phase it presented less error.

This sensor can be combined with other sensors as turbidity [13], colour, water level, etc. To improve the detection of illegal dumping.

In future works, we are going to determine the effect of the temperature, the water flow and the biofouling in the coils.

ACKNOWLEDGMENT

This work has also been partially supported by the European Union through the ERANETMED (Euromediterranean Cooperation through ERANET joint activ-ities and beyond) project ERANETMED3-227 SMARTWATIR by the “Ministerio de Educación, Cultura y Deporte”, through the “Ayudas para contratacion pre-doctoral de Formación del Profesorado Universitario FPU (Convocatoria 2016)”. Grant number FPU16/05540.

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