

## Review

## Fiber-optic liquid-level continuous gauge

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**Abstract**

An intensity-based fiber-optic liquid-level gauge for continuous measurement is described. The sensing principle is based on the total internal reflection of light within the fiber optic, and for this, a measurement is made of the power attenuation which occurs in the fiber optic immersed in the liquid tank when the liquid level varies. The light from a LED is modulated before being directed into the fiber to minimize measurement errors. The device contains an alarm programmable to signal any liquid level in the tank (high or low), and data can be sent via Internet in real time to a distant point.

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**Keywords:** Fiber optics; Liquid-level gauge; Optoelectronics; Electrical engineering and optics engineering**Contents**

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**1. Introduction**

Industry frequently needs to measure liquid levels in tanks and other large containers. This need arises not only in heavy industry where great volumes of liquids are often stored, but also in light industry, such as olive-oil pressing, as well as in other large-scale operations such as public water supplies and treatment plants, fuel storage for public-transport systems and service stations. These liquids may be inert (as in the case of water) or highly flammable (as in the case of many petroleum derivatives).

In the case of gasoline stations, a common measurement method is to plunge a measuring rod into the underground tank

to determine the level of fuel. This rudimentary method tends to be slow and inefficient.

In automobiles or ships, the fuel is measured by a float connected to a variable resistance, indicating the level of the liquid inside the tank. The main disadvantage of this system is that an electrical current (though weak) must be introduced into the flammable or simply conducting liquid.

The system that we have designed and manufactured has a great advantage over other methods because it is non-electrical and is also immune to electromagnetic interference. This is an intrinsic and intrusive measuring device for precise continual monitoring of liquid levels, perfecting the design of other systems already constructed [1,2].

Given that the optical fiber is the only part of the measuring device introduced into the tank – that is, only light and plastic or glass interacts with the liquid – the method becomes safe and

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corrosion free, without electrical sparks that could cause a fire or explosion of a tank. In addition, the measurement is highly sensitive, accurate and repeatable. There are no moveable parts (no wear and no problem with replacement pieces), there are no problems of hysteresis (repeatable), and the light is always guided in the same way within the fiber (repeatable and accurate). Moreover, for the characteristics of any fiber optics, any variation, no matter how small, in the cladding, is manifested as a great variation in the light that reaches the endface (accurate), i.e. great variation in light radiation (sensitive).

Most gauges of liquid levels are discrete or point-level sensors [3–5], while others allow continuous measurement [6–14]. In some cases, the sensor is a sensitive element which is submerged slightly in the liquid to indicate the presence of liquid [3–4,13]. This is a problem, given that the sensor rapidly deteriorates in permanent contact with a liquid. In other systems, the measurement is taken by the light reflection on the surface of the liquid [5,8,9,14], but this poses another problem because the light can undergo undesired reflections or refractions which can distort the measurements.

As shown below, our device, university patent [15] has solved all the technical problems surrounding gauges to date.

## 2. Operational principle

The scheme of the gauge is shown in Fig. 1. The device has a data-acquisition system (DAS) controlled by a PC

(which controls an emitter and a sensor) and a single optical fiber.

The light from a LED is directed into an optical fiber immersed in the liquid whose level we wish to measure. The light travels through the fiber and, when the fiber is completely surrounded by liquid, the liquid acts as a second cladding. Thus the total internal reflection occurs at the core–cladding interface, and the light reaches the receptor practically without loss except for absorption. When the tank is not completely full of liquid, one part of the fiber is surrounded by liquid and the other part is surrounded by air. In the submerged portion, total internal reflection occurs because the fiber has a cladding (cladding of the fiber plus the liquid), and the losses of light are very small because most of the rays are bounded. In the exposed portion of the fiber, less total internal reflection occurs because the fiber has only the cladding and there are more leaky rays. If we calibrate the gauge for the different liquid heights in the container, then simply by reading the outgoing signal of the detector we can determine the height of the liquid. The higher the level, the larger value in the reading of the photodiode.

According to the model of geometric optics, the number of reflections per unit of length in a step-profile fiber optics is

$$\frac{1}{N} = L \cos \theta_z = 2\rho \frac{\sin \theta_\phi}{\tan \theta_z} = 2\rho \bar{\beta} \frac{\sqrt{n_{co}^2 - \bar{\beta}^2 - l^2}}{n_{co}^2 - \bar{\beta}^2} \quad (1)$$

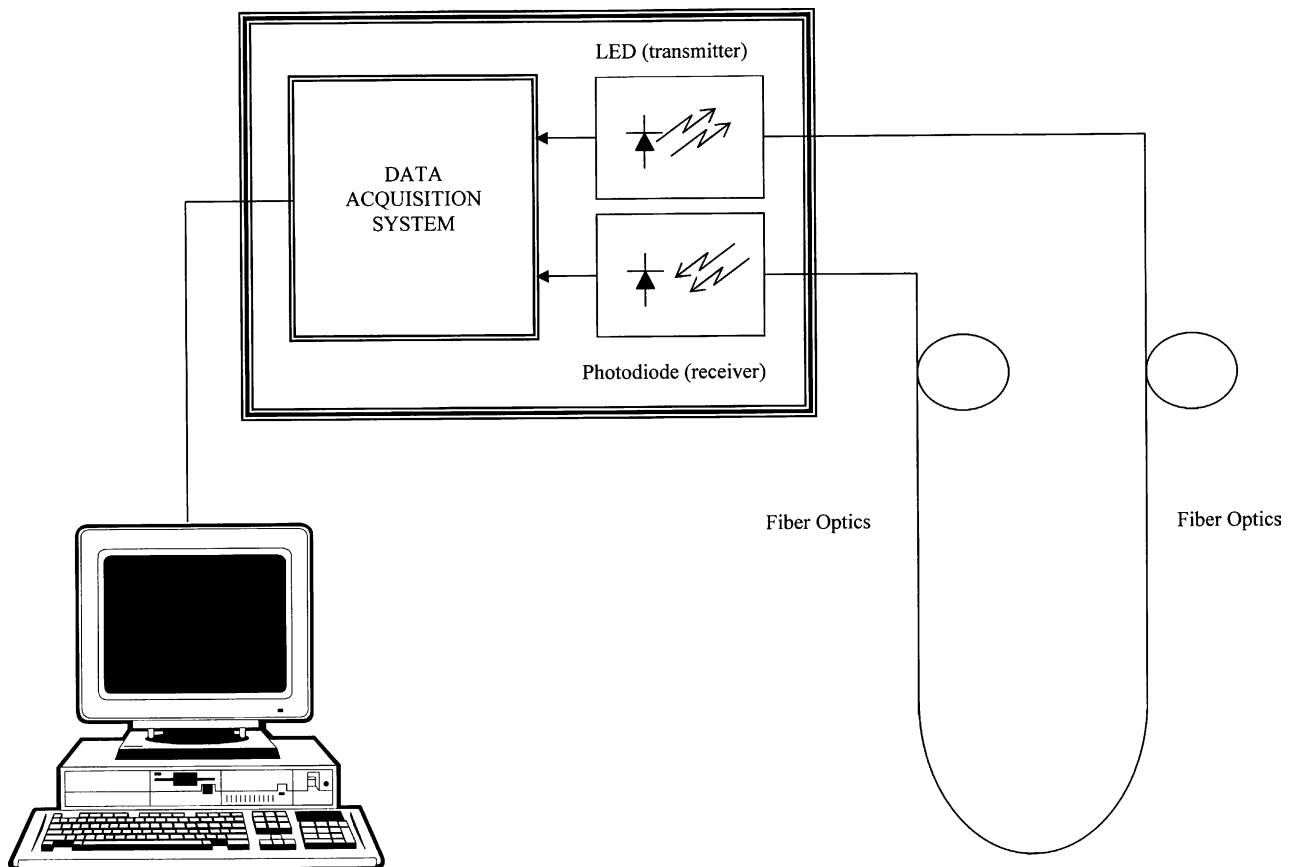


Fig. 1. General scheme of the gauge to measure the levels of liquids.

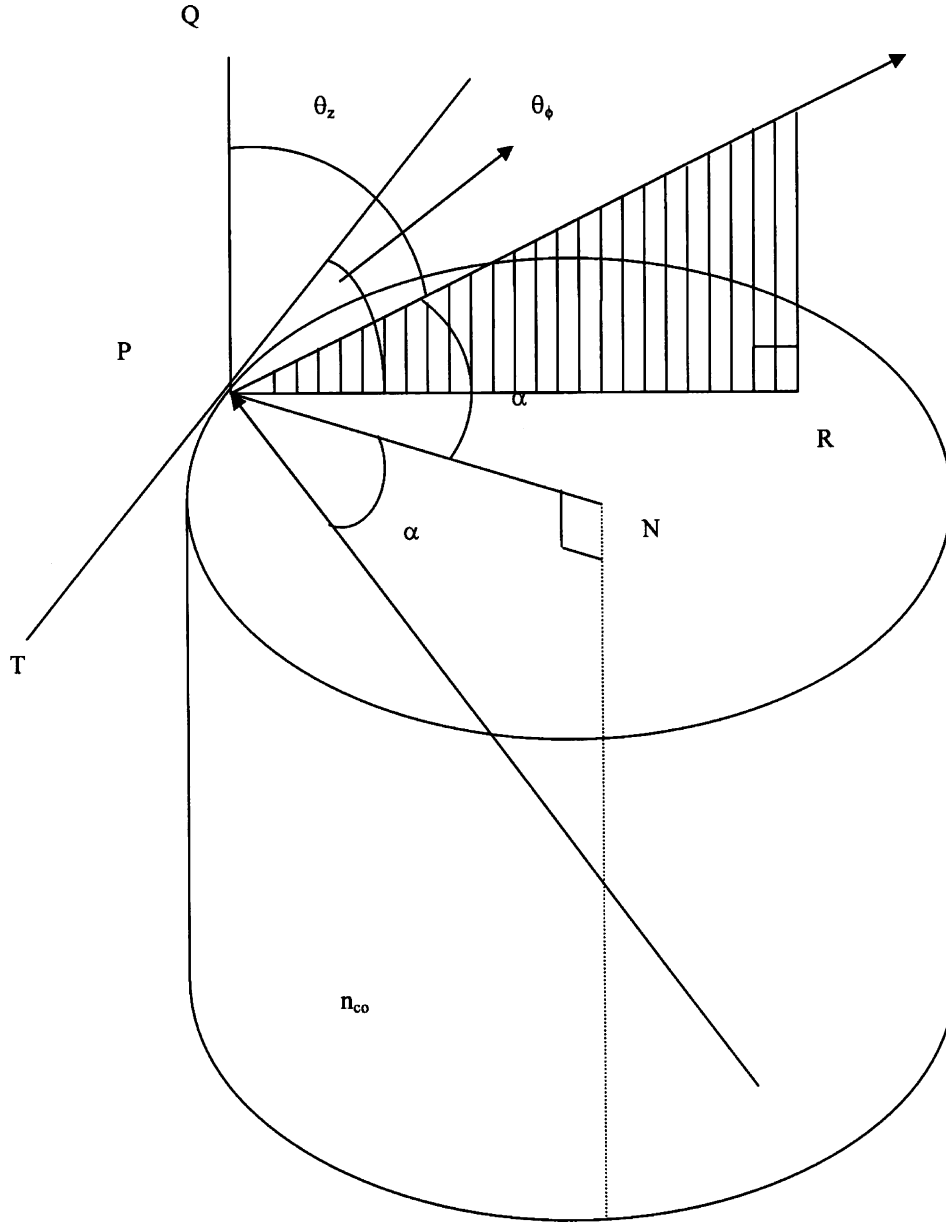


Fig. 2. Angles representing the reflection of an incident ray P at the cladding–core interface of the optical fiber used in our device.

where  $L$  is the path length of the light within the fiber, and  $\theta_z$  is the angle between the ray and the fiber axis. Fig. 2 shows a scheme of the total reflection of a ray within a radio fiber  $\rho$ ,  $n_{co}$  is the refractive index of the core. The normal direction is PN and the angle of incidence and reflection is  $\alpha$ . Both rays form an angle  $\theta_z$  with the axial direction PQ and an angle  $\theta_\phi$  with the straight section between the tangent PT and the projection of the trajectory—that is, with PP (reflected ray). Finally,  $\beta$  and  $l$  are the invariants of the rays, defined by

$$\bar{\beta} = n_{co} \cos \theta_z, \quad \bar{l} = n_{co} \sin \theta_\phi \cos \theta_\phi \quad (2)$$

The power of the ray along a distance  $z$  is

$$P(z) = P(0) e^{-\gamma z} \quad (3)$$

where  $P(0)$  is the power injected by the source in the fiber and  $\gamma$  is the power attenuation coefficient of the ray, defined as

$$\gamma = NT \quad (4)$$

where  $T$  is the power transmission coefficient or simply the loss coefficient, introduced to describe the loss due to the absorption in the cladding in the following way:

$$T = 1 - \frac{\text{power in the reflected ray}}{\text{power in the incident ray}} \quad (5)$$

thus a fraction of  $T$  of the ray is lost in each reflection.

### 3. Gauge construction

According to the scheme in Fig. 1, the sensor is composed of four main parts, i.e. the light source (LED), the

fiber, the photodiode (PIN) and the data-acquisition system (DAS).

The LED does not require special characteristics. The one used in our device is GaAsP (therefore red, and specifically emits with a peak at 640 nm). The device emits a light modulated at a frequency of 100 Hz to avoid illumination errors. Light entering the container for any reason could enter the fiber at the correct angle and could cause erroneous measurements because the photodiode would receive more light than emitted by the device. As a solution to this problem, the LED is turned off and a measurement is made in darkness; thus, if the tank is transparent, translucent or if light reaches the fiber for any other reason, we subtract this measurement from the one made with the LED turned on—that is, we make a reading at zero or in darkness. The final result is due to the circulation of light from the LED within the fiber after the subtraction of the signals. As we are modulating the light emitted by the LED, the emitter measures the light and darkness (100 measurements per second, 50 light, 50 darkness) and thus we eliminate the effects caused by any other illumination. During measurements, we have tested power and temperature fluctuations, and we have varied the external lighting conditions, subjecting the device to sunlight, darkness, incandescent and fluorescent lamp light. Through all these alterations, the modulation explained above guards against any effect in the final measurement.

The light does not have to be collimated because we do not send specific propagation modes, but rather the light directed into the fiber is simply compared with the light received by the photodiode. As the diameter of the fiber is relatively large (3 mm), condenser lenses are not needed, nor must the light emitted by the LED be focused as in other cases [6,8,10,14].

The LED used in the device has a maximum output power of 1 mW, which is more than adequate for the signal to reach the detector after having flowed through the optical fiber, even with an empty tank and even for containers of large heights. The intensity of the excitation is between 20 and 200 mA, the maximum working temperature is 60 °C and the duration time is 10<sup>6</sup> h. The injection of the light of the LED into the fiber, and the exit of the fiber to the detector, are made with a connector SMA 906, which for this type of device gives the most suitable results. The ferrule of this connector is 3 mm in diameter (the same as the fiber) and thus the alignment is very precise. The ferrule is of a special ceramic material that resists great changes in temperature without dilation, and therefore the optical fiber does not undergo movements (misalignment).

The detector used is a PIN photodiode. This device is of flat silicon technology, of InGaAs, of low noise, of a theoretic

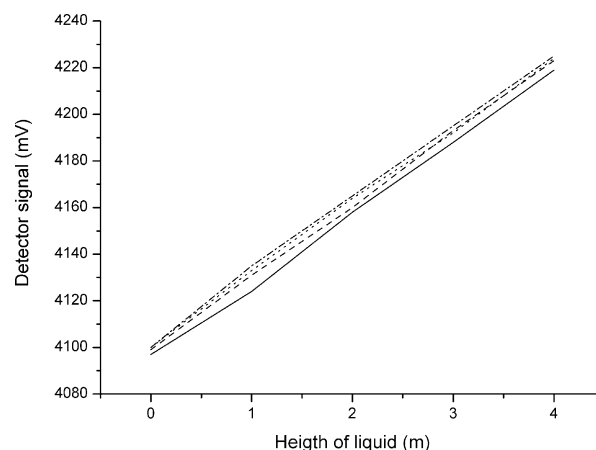


Fig. 3. Graph of the exit emission of the LED for different liquid heights at different temperatures for the case of gasoline: temperature −20 °C at 0, 1, 2, 3, 4 and 5 m of liquid height, solid line; temperature 0 °C at 0, 1, 2, 3, 4 and 5 m liquid height, dashed line; temperature 25 °C at 0, 1, 2, 3, 4 and 5 m liquid height, dotted line; temperature 50 °C at 0, 1, 2, 3, 4 and 5 m liquid height, dashed and dotted line.

cal working temperature from −55 to 125 °C, high impedance (2000 pF to 0 V/1 kHz), very low response time (1000 ns to 0 V/50 Ω), and low darkness current (2 pA at 25 °C). The spectral-response range is from 350 to 1100 nm, the response being very flat in the visible wavelengths. If at any moment the LED were to vary its emission within these ranges, the PIN would continue to detect the light and would continue to give a response. In fact, we have worked with different LEDs at different wavelengths within the operating range of the PIN and we have found no difference in the final results.

We have subjected the entire device to extreme working conditions. As shown in Fig. 3, we varied the temperature from −20 to 50 °C and the response was practically the same, as can be appreciated. The tests were made with gasoline, given that the temperature range for this compound is −150 °C (fusion point) to 200 °C (boiling point), whereas at these extreme temperatures the other liquids with which we have worked become solids or gases. The fusion point and boiling point, respectively, are −94 and 56.5 °C for acetone, −5 and 175 °C for diesel, −130 and 78.4 °C for alcohol and −3.5 and 300 °C for olive and sunflower oil (0 and 100 °C for water) [16].

Therefore, we can state that both the emitter and the receptor behaved reliably with respect to environmental temperature. As shown in Table 1, the results are very similar and linear.

This indicates that the LED emission is constant given that it behaves well in extreme temperatures. These types of

Table 1

Parameters for the adjustment curves (gasoline and diesel oil) corresponding to a straight line of the form  $y = a + bx$  in different temperatures

Temperature (°C)	Coefficient $a$	Coefficient $b$	Error of the coefficient $a$ , $\Delta a$	Error of the coefficient $b$ , $\Delta b$	Linear regression coefficient $R$	Standard deviation S.D.	$p$ -Value
−20	4095.6	30.8	1.3	0.5	0.9997	1.67	<0.0001
0	4099.2	31.0	0.7	0.3	0.9999	0.97	<0.0001
25	4101.2	30.7	1.1	0.5	0.9997	1.45	<0.0001
50	4102.0	31.0	1.4	0.6	0.9995	1.83	<0.0001

measurements have been made periodically since 1997. During the entire period and during the temperature variation, radiometric measurements of the LED were made. Measurements of the emission curve i.e. wavelength versus radiance, were made, with a spectroradiometer Spectra Scan PR 704 (PHOTO RESEARCH®). The measurement results did not significantly differ over time or with temperature changes.

All of these characteristics exceed the requirements of our design. In fact, given the qualities of the measuring device, real measuring conditions will never reach or surpass the limits of the photodiode and LED characteristics. The detector has a half time of 115 years, similar to that of the LED.

The  $\text{OH}^-$  ions to a large extent affect light absorption in the infrared range (far and near) as well as in long wavelengths of the visible spectrum. Absorption in this region, due only to the OH is more than 10 dB/km. These hydroxide groups are introduced into the structure of the  $\text{SiO}_2$  molecules, fundamentally, due to the breakdown of  $\text{H}_2\text{O}$ . Water, being present in many fluids and in the form of vapor in many environments, undoubtedly affects all fibers [12]. We have used plastic fiber and therefore this problem does not appreciably affect this device.

Since the material is acrylic plastic, the emission of 640 nm is favorable instead of 680 nm. The window of the 650 nm between two resonance C–H is very small and therefore the effective absorption is between 0.3 and 0.4 dB/m. In our case, the absorption is much lower for using 640 nm. The only mechanical requirement that the fiber must fulfill is that it must be weighted down so that it reaches the bottom of the container, to ensure complete measurements from the bottom to the lip of the container.

The theoretical operational range of the light guide used is from  $-55$  to  $55^\circ\text{C}$ , and thus even with extreme temperatures the dilation or contraction would not affect the measurements, either. In fact, the above tests demonstrate that the characteristics of the fiber remain unaltered. With regard to the curvature of the fiber, the calibration does not appreciably change until the radius of the curvature reaches 20-fold the diameter of the entire fiber. The diameter of the fiber used in our device was 3 mm—that is, the curvature radius allowed for the fiber is 30 cm, which is an extraordinarily large curvature radius. This means that in the set-up and maintenance the fiber curvature within the tank does not influence the measurements, nor of course the calibration.

If the microbendings persist over the entire measuring process, they are not affected by the way the device is calibrated, as we shall see below. Measurements can be performed on any liquid that does not chemically attack the type of fiber being used. Many liquids exist (e.g. acids) which could destroy the fiber while others, although are not acid (e.g. NaOH) could corrode it too. Examples of acids that attack the fiber include sulfuric acid ( $\text{H}_2\text{SO}_4$ ), hydrochloric acid (HCl), and nitric acid ( $\text{HNO}_3$ ), even diluted in water, ascorbic acid, although damages the fiber very slowly, forcing the operator to change the fiber frequently and to calibrate the device with each change.

Another of the specifications that make this device unique is that the plastic fiber has no special requirement as in the case of other devices. The fiber has a core and a cladding. In other

devices, it is essential that the fiber be only a core while the liquid serves as the cladding. In our case, when the fiber is submerged, the core is jointly the core and the cladding of the fiber. This simplifies the device, since there is no need to demand special characteristics of the fiber, and almost any plastic fiber will serve for design and manufacturing.

The resolution of the instrument is currently 2 mm, greater than most of the commercial instruments. To date, the level gauge with the smallest resolution was 4 mm [2,12].

The device was designed and constructed in December 1997 and patented in 2001. Since 1997 to the present, the fibers have been in 24 h daily contact with seven different liquids, respectively, with which we have worked. We have made periodic calibrations as a method of testing the reliability of the device. All the calibrations have proved that the components remain in excellent condition.

In any case, if the measurement accuracy was deteriorated by dirtiness or deposits on the fiber, then, being plastic and having no special curvature requirements, the fiber would simply have to be cleaned and returned to the tank or removed and replaced with a new fiber. Since a complete calibration must be made, we propose replacing the fiber with a new one of similar characteristics.

When we subjected the device to strong electromagnetic fields, given that the entire electronic system is separate from the optical system and enclosed in a Faraday cage, there was no notable interaction and the device continued to function normally and without variations.

The outgoing signal of the photodiode goes to the DAS and from there to the computer, where the signal is processed and the measuring device is controlled. The software, produced entirely in our laboratories, makes it possible for the computer to activate an alarm when the liquid levels pass either of two prefixed heights (minimum or maximum) chosen by the operator. This warns undesired overflow or emptying of the container. The alarms can be both heard and seen, so that the gauge can serve for any situation where either seeing or hearing the alarm is not possible, and the operator can be alerted to an undesirable or dangerous situation. In addition, the data can be sent in real time via Internet to a distant point and be monitored regardless of where the container is located (on a mountain summit, underground, etc.).

In essence, the data-acquisition system (DAS) consists of a signal conditioner, a digital/analogical converter (DAC), a microcontroller (PIC) and a computer (PC) [17]. The first part of the DAS is the transducer in which the light intensity is converted to electric current. After this transducer (photodiode), the next stage is a current/voltage converter because in the rest of the stages we will work with voltages. The current/voltage converter is a precision operational amplifier, given that the photodiode output intensity is very small, especially when the tank is empty. The following stage is the amplification of the signal with the amplifier in the inverter configuration. The technology is FET of very high impedance, and thus it does not affect the previous stage. The gain of this stage is variable, although in our case a gain of 10 has proved sufficient. The last stage is the subtraction amplifier (subtracts the light and darkness measurement), it is

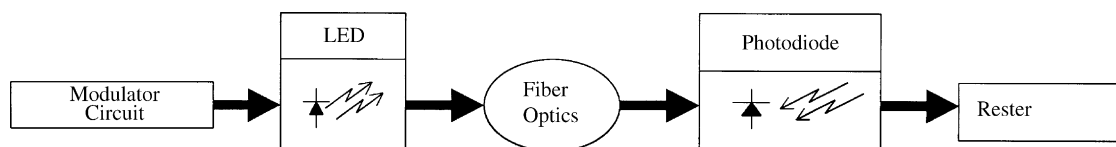


Fig. 4. Block scheme of the liquid-level gauge.

in charge to provide the relation of the measure of the voltage and the liquid level. We have used a double amplifier of very low output impedance because this stage would attack the following one, which is the DAC. The DAC is integrated into the microcontroller PIC which includes an USART to send the data directly to the PC. The communication with the PC is via an RS-232 interface, which is more than adequate for our purposes [14].

For the control program, considering the objectives of the design, we chose an object-oriented programming language, specifically Visual Basic of Microsoft. The minimum requirements of the control computer are a Pentium processor at 166 MHz with 16 MB of RAM, Windows 95 operating system, 2 MB free hard disk and a VGA graphics card.

The block scheme of the parts of the complete device is detailed in Fig. 4.

After installation, the instrument should be calibrated. This consists of taking a series of measurements with the device, both with the tank empty and with various levels of liquid inside. This gives a calibrated curve and indicates the response of the photodiode according to the height of the liquid inside the container. As the calibration in reality takes the amplitude of the light emission that travels through the fiber into account, this can be changed over time due to the variations in the LED, fiber, connectors, and any other component of the device; however, this problem is not important as the calibration only takes values of liquid height in the tank and the outgoing electric signal of the complete system, rather than intermediate measurements; therefore, the procedure is uncomplicated and the calibration is simple.

As stated above, the device makes 100 measurements per sec and the processing time is short. The above mentioned characteristics of the PC are more than adequate for the measurements and later processes, showing that our device has no special PC requirements.

#### 4. Experiment and discussion

A great number of experiments were made to verify the validity of the device. For this, we made a series of quality tests using different types of liquids contained in transparent tanks where we also changed the artificial illumination to determine whether the system gave reliable measurements, even under adverse conditions. The liquids used were: fresh water, seawater, acetone, olive oil, gasoline, diesel and alcohol. The calibration graphs for the seven fluids are shown in Figs. 5–9. The curves corresponding to the two types of water were so similar that in practice they could be considered equal. The same was true for gasoline and diesel.

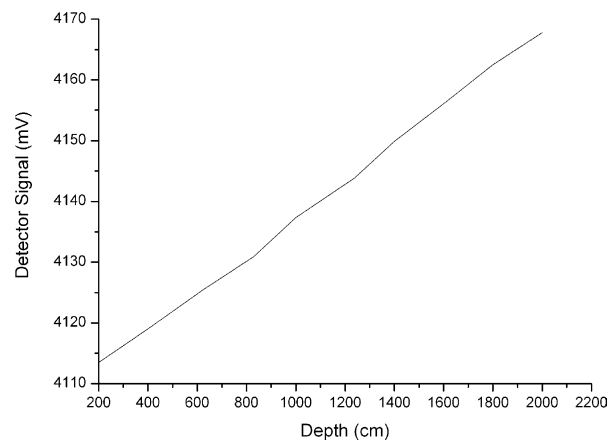


Fig. 5. Calibrated curve of fresh water and seawater. The outgoing signal of the gauge is shown according to the height of the liquid. The dotted line corresponds to the experimental values and the solid line to the theoretical fit.

Table 2 gives the parameters for the adjustment curves corresponding to a straight line of the form:  $y = a + bx$  ( $R$  is the linear regression coefficient, S.D. the standard deviation, and the  $p$ -value). The  $p$ -value, in our case, indicates the probability of committing an error in the adjustment of the experimental data to the theoretical curve that we present. The lower the  $p$ -value, the more certain we are of a good fit.

The results in the case of fresh water and seawater were so similar that these values are represented in a single row, as in the case of the olive and sunflower oil as well as the gasoline and diesel (Figs. 5, 7 and 8, Table 2). In any case, it should be emphasized that, considering only the regression coefficient of the acetone, this is the worst fit. The reason for such an uneven

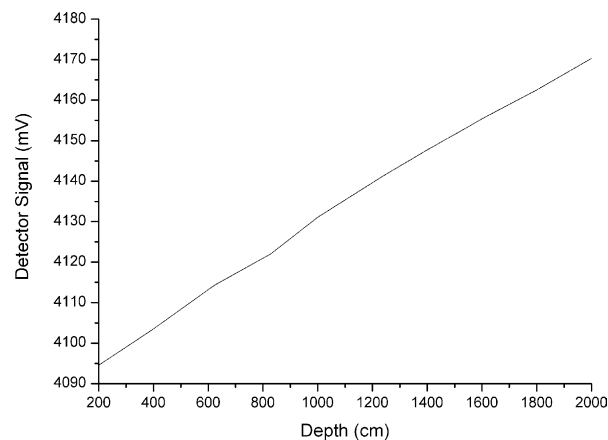


Fig. 6. Calibrated curve for acetone. The outgoing signal of the gauge is shown according to the height of the liquid. The dotted line corresponds to the experimental values and the solid line to the theoretical fit.



Table 2

Parameters for the adjustment curves corresponding to a straight line of the form  $y = a + bx$  (calibrated curve)

Liquid	Coefficient $a$	Coefficient $b$	Error of the coefficient $a$ , $\Delta a$	Error of the coefficient $b$ , $\Delta b$	Linear regression coefficient $R$	Standard deviation S.D.	$p$ -Value
Water	4107.0	0.0307	0.3	0.0002	0.9998	0.38	<0.0001
Acetone	4090.9	0.0388	1.7	0.0014	0.9951	2.49	<0.0001
Olive and sunflower oil	4127.0	0.0053	0.1	0.0001	0.9979	0.22	<0.0001
Gasoline and diesel oil	4125.9	0.0108	0.2	0.0002	0.9990	0.31	<0.0001
Ethyl alcohol	4096.4	0.0359	0.5	0.0004	0.9994	0.80	<0.0001

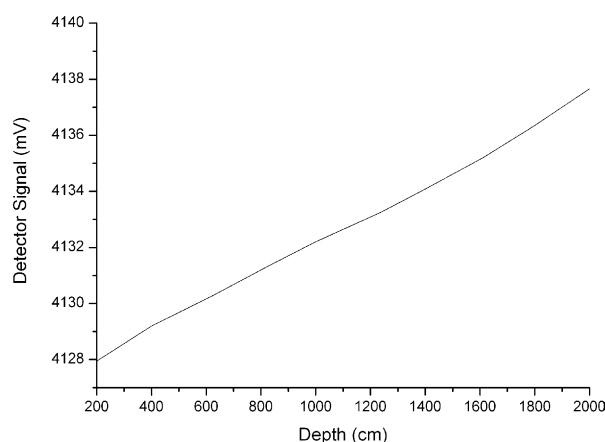


Fig. 7. Calibrated curve for olive oil. The outgoing signal of the gauge is shown according to the height of the liquid. The dotted line corresponds to the experimental values and the solid line to the theoretical fit.

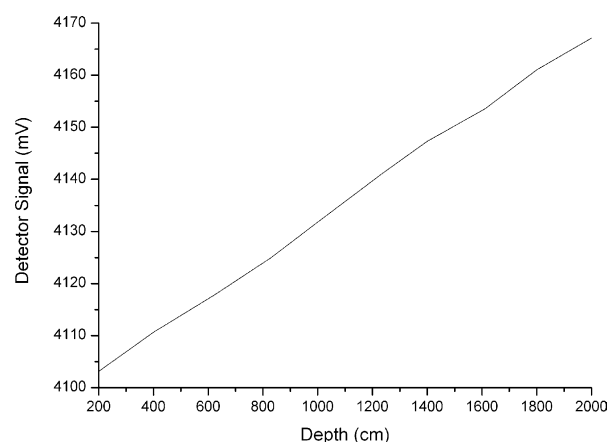


Fig. 9. Calibrated curve for ethyl alcohol. The outgoing signal of the gauge is shown according to the height of the liquid. The dotted line corresponds to the experimental values and the solid line to the theoretical fit.

fit (although not bad), compared to the foregoing ones, was perhaps due to the volatile nature of this liquid. The tests were made consistently under bad conditions: open container, changing exterior light, etc. Thus, it is possible that the acetone, being highly volatile, was evaporating and was condensing on the fiber, and therefore the measurer did not always detect the exact level. Furthermore, the evaporation surely was not constant, as the surface of the liquid was submitted to changing environmental conditions.

In the case of olive oil (Fig. 7), the results were better than those for acetone, as shown in Table 2. In this case, the great vis-

cosity of this liquid may have caused errors, since, with the fall in the liquid level, a film of oil remained on the fiber, apparently altering the experimental results.

Fig. 8 shows the results for calibration of the device measuring gasoline and diesel. The two sets of results, as in the case of fresh water and seawater, were so similar that they could be considered the same (see Table 2) indicating a good linear fit. Finally, for the results in Fig. 9 corresponding to ethyl alcohol, the regression coefficient of the straight line of the calibration again was strong (see Table 2), again signifying a good fit. The fit of the experimental data was linear with a regression index of 0.999 in most cases. The height of the liquids was verified by a measuring rod accurate to 1 mm. The bar was placed outside the container so as not to interfere with the measurements in the container. In no case did the relative difference between two measurements exceed 0.1%.

In addition to the calibration curves, we made a series of test measurements that were sent in real time by Internet to various distant points. In all cases, the time necessary to make the measurements and calculate the level was negligible compared with the delays of Internet itself. Thus, the measurements can be considered instantaneous so that, at any moment, updated information on the liquid levels in containers is available. This efficiency is also due to the fact that the calibration curves were all linear, and therefore the calculation process of the level performed by the control program was shorter, as it did not have to operate with powers.

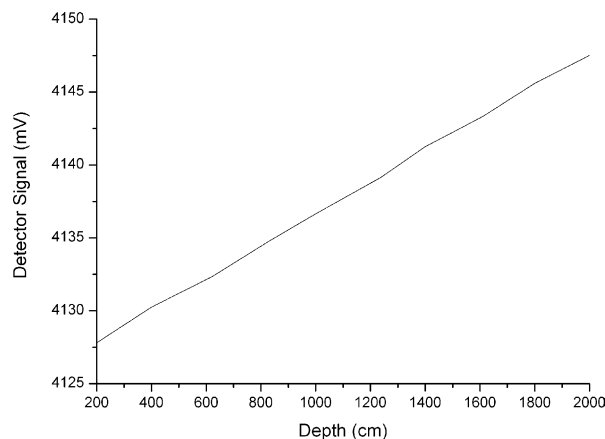


Fig. 8. Calibrated curve for gasoline and diesel. The outgoing signal of the gauge is shown according to the height of the liquid. The dotted line corresponds to the experimental values and the solid line to the theoretical fit.

The management and control of the device, as well as the automatic sending of data by Internet were developed entirely in our laboratories.

## 5. Conclusions

The measuring device presented in this study offers many advantages over gauges described by other authors [1,3,4,7,8].

Our gauge functions on an optical principle consisting of a single LED and only one photodiode. LEDs are much less expensive and much easier to replace than the ones in [1,2,7,13,14].

Also, it is based on the difference in the intensity of light circulating through an optical fiber, and thus the mechanism is very simple compared with far more complicated liquid-level sensor based on the refractive-index sensitivity of long-period fiber-optic gratings [3,11].

As we are modulating light emitted by the LED, the photodetector measures light and darkness (100 measurements per second), eliminating the effect of different kinds of illumination. The modulation is fundamental to avoid instability of the device and other related problems. The gauge has the ability of measuring the height of liquid in any container – opaque, translucent, or transparent – by modulating the LED to avoid errors. Only the work of Iwamoto and Kamata [8] has achieved this, although with another procedure and with the added problem that two LEDs are required instead of one, as in our case.

The spectral response range is from 350 to 1100 nm. The response is very flat in the visible wavelengths. If at some point the LED varied its emission within a visible range, the PIN would continue to detect the light and would continue to give a response. In fact, we have worked with different LEDs with different wavelengths within the visible spectrum and we found practically no differences in the final results.

In addition, it is capable of continually measuring the levels of all kinds of liquids which do not attack the optical fiber used. This fact is especially important given that it is the first liquid-level gauge that functions using an optical fiber with cladding.

Another specification that sets it apart is that the plastic fiber has no special requirement as in the case of other devices. The fiber has a core and cladding. In other devices, it is essential for the fiber to be only a core and for the liquid to act as the cladding. In our case, when the fiber is submerged, the core is jointly the core–cladding of the fiber. This greatly simplifies the device, as it avoids demanding a fiber with special characteristics, and thus almost any plastic fiber will serve in its design and manufacture.

Our device uses only one entry and exit (input, output in the tank) orifice and it is not necessary to have an upper and lower orifice as in the case of patent [6]. If the tank was underground, for example, the lower exit would be hampered. In addition, there is no need for bent curvatures, and it is a continuous measuring device and not restricted by presence or absence of fluid as in claim 1 of the USA patent. On the contrary, the optical fiber of our device, inserted into the tank, has no special requirement, but only has to reach the bottom of the tank. Reaching the bottom, it requires the curvature necessary to return to the entry orifice. The measurement of the liquid is continuous, not only of the presence or absence of the fluid.

The optical fiber constituting the gauge is characterized precisely for not having special requisites in the coating, apart from using one and only one, and the radiation directed into the fiber does not need to be collimated nor focused on any point of the fiber. For these reasons, problems of alignment can never arise. The fiber core is circular (standard fiber) instead of eccentric, which is more costly and delicate [11].

The overall system is equipped with a visual and audible alarm which can be regulated to any liquid height.

Another specification is that the gauge is controlled by a PC capable of storing the data in the memory, printing them or sending them in real time by Internet to distant points.

This calibration procedure, shown in Figs. 5–9, solves all the problems of intermediate calibrations of other devices. Although there are variations that affect the LED, fiber and connectors, etc., these variations are not a source of error as the measurement is read at the exit of the detector. The calibration of the device consists of knowing the output value of the PIN photodiode and the height of the liquid at the time of measurement, and no intermediate effects are taken into consideration. With recalibration, the intermediate changes (if there are any) would affect the final results, but the effect of each one would not be taken into account, as the overall effect would be the result in the value at the output value of the PIN.

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