Level sensor for hydrodynamics experiments

Horacio Munguía Aguilar
Departamento de Física, Universidad de Sonora, Hermosillo, Sonora 83000, Mexico
E-mail: hmunguia@correo.fisica.uson.mx

Abstract
An electronic system for the conversion of a liquid level into voltage is shown. This allows the student to carry out basic hydrodynamic experiments where fast liquid level changes occur. The use of this system is illustrated with the classic draining tank experiment.

Introduction
The traditional way to measure the level of liquid in basic hydrodynamic experiments is by using a chronometer and graduated containers. Electronic sensors are not used in this experiment due to their complexity and cost. We present an electronic level sensor for conductive liquids such as water, that is simple, economical and will allow the application of basic knowledge in electronic instrumentation.

This device is an economical variant of the capacitive sensor used in industrial measurements [1]. It consists of a stretched enamel magnet wire placed vertically and partially immersed in the liquid to be measured. This forms a cylindrical capacitor which has two ‘plates’: one is the interior of the wire (usually copper); the other plate is the conductive liquid surrounding the wire. The insulating enamel of the wire forms the capacitor’s dielectric.

The capacity of this system is proportional to the length of the immersed part of the wire. To measure it, an electrode is connected to the uncovered end of the wire and another electrode is placed in the liquid by using a metal rod or a plain wire touching the bottom of the container. See figure 1.

One of the advantages of this type of sensor, besides its simplicity, is that its calibration does not depend on the liquid’s conductivity. However, it has the drawback that the capacitance to voltage conversion is not straightforward.

Level–voltage conversion
In order to obtain the liquid level information from the sensor’s capacitance we first translate this capacitance into a squarewave signal using the multivibrator circuit [2] shown in figure 2.

In this circuit the relationship between the period $T$ of the squarewave and the sensor’s
Level sensor for hydrodynamics experiments

The capacitance is given by

\[ T = 2R3C \ln \left( 1 + 2 \frac{R1}{R2} \right). \quad (1) \]

Since the capacitance is proportional to the liquid level plus some residual capacitance \( C_0 \), we conclude that

\[ C = K_1N_L + C_0, \quad (2) \]

where \( N_L \) is the liquid’s level and \( K_1 \) is a constant. Combining both equations, we obtain

\[ T = K_2N_L + T_0. \quad (3) \]

In this expression, the constants \( K_2 \) and \( T_0 \) can be empirically found.

Figure 3 shows this relation for a wire that is 40 cm long and 2 mm in diameter in a container with plain water, where its level has been adjusted to obtain the calibration curve shown in figure 3.

Figure 2. A stable multivibrator circuit.

Figure 3. The calibration curve.

It is now clear that knowing the signal’s period and the calibration constants \( K_2 \) and \( T_0 \) would let us find the liquid level in the container. If a data acquisition system with a frequency or period measurement facility is not available, we should then convert the wave’s period into DC voltage. In this way, the voltage can be metered and saved by a conventional data acquisition system such as a digital oscilloscope.

The period to voltage conversion can be made through a simple RC filter such as the one shown in figure 4.

The AC analysis for this circuit leads us to the next expression for the output amplitude:

\[ V_o = \frac{V_e}{\sqrt{1 + (\omega RC)^2}}. \quad (4) \]

where \( V_e \) is the input amplitude and \( \omega \) is the frequency in rad s\(^{-1}\).

If \( \omega RC \gg 1 \) equation (4) becomes

\[ V_o \approx \frac{V_e}{\omega RC}. \quad (5) \]

Since \( \omega = 2\pi/T \), we get the relationship

\[ V_e \approx \frac{V_o}{2\pi RC}T. \quad (6) \]

This means that if we apply a sinusoidal wave to the input filter the output amplitude will be proportional to the period if we take care that \( \omega RC \gg 1 \). Even though the input is a square wave, this is an acceptable approximation for output voltage much less than the input voltage level.

Finally, the AC output from the filter needs to be converted into DC voltage. This can easily be done with a rectifier circuit. But there is the problem that the \( V_o \) levels are too small for a conventional rectifier and the losses in the diodes would be too large, so a precision rectifier is
needed. We found that this can be made in a simple way by using an Analog Devices [3] AD735 RMS converter. This is an integrated circuit which converts the RMS value of a signal into a DC voltage. This circuit includes a precision rectifier, an RMS averager and a low pass filter. It only needs two external capacitors for proper operation. This circuit together with the RC filter is shown in figure 5, with the component values used in the hydrodynamics experiment described later.

The AD736 gives a maximum voltage level of 200 mV. This voltage should be amplified in order to have a more manageable voltage range capable of fitting the data acquisition system (DAQ) used. For a 0–5 V range the circuit in figure 6 can be used. This circuit has an adjustable gain of up to 30.

**Experiment**

The use of this sensor is illustrated with the classic tank draining experiment [4]. Figure 7 shows a 40 cm high vessel with the level sensor immersed in a straight vertical position. The multivibrator circuit is located on the sensor support on the top of the tank. In this way parasitic capacitance is minimized between the wire and the circuit itself. From this circuit the signal is carried out to the RMS converter (on the table) and applied to an Agilent Technologies DSO3062A oscilloscope. The container is initially filled with water and the experiment starts by opening the output cap. The signal is monitored until the vessel is empty. The corresponding graph can be seen in figure 8.

Although this sensor has limitations in its stability and response speed, it can be used in non-critical experiments. The sensor’s resolution depends on the gauge of the wire used. In our case, with a piece of enameled copper wire 2 mm diameter and 35 cm long we have an approximate resolution of 1 mm and a response time of approximately 0.2 s. Stability could be improved with the use of a PTFE wire. However, such wire is not easily available and is more expensive.

**Conclusion**

We have presented a level transducer for conductive liquids that can be used in hydrodynamic experiments. Of particular interest is the period to
Level sensor for hydrodynamics experiments

**Figure 7.** Level sensor circuit on top of the vessel.

**Figure 8.** Water level changes in draining vessel.
H M Aguilar

voltage conversion circuit that allows the use of a standard DAQ for water level measurement. From this kind of experiment students can get a twofold benefit: its use allows them to develop adequate electronic instrumentation for a specific experiment; furthermore, they acquire new tools for the development of basic laboratory measurements in a very accessible way.

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References

Horacio Munguía Aguilar holds an MSc in Electronics from INAOE, México. Since 1978 he has been working at the Departamento de Física of the Universidad de Sonora in Hermosillo, México. He has been involved in teaching electronic instrumentation and developing equipment and systems for measurement and control. He is also engaged in developing physics education materials.