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PROCEEDINGS

Time Division Multiplexing Fibre-Optic Liquid Level Sensors using a Nematic 1x2 Optical Switch

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1. INTRODUCTION

Polymer Optical Fibres (POF) are becoming an attractive medium in sensor networks, specially in flammable atmospheres because optical fibres are intrinsically safe in nature, with no risk of explosion even under malfunction operation, because they are inert materials [1-2]. Being the security a fundamental matter, it is important to have redundant paths and optical elements to switch between them.

Many kind of optical switches have been reported. Nowadays, Micro-Electro-Mechanical-Systems (MEMS) are quiet attractive due to its large scale integration, its fibre-to-fibre coupling, high crosstalk and speed, they use moving parts for switching. Switches based on Liquid Crystals (LC) cells [3-6] also cover the previous needs with no moving parts, low voltage driving, and low power consumption. Broadband LC switches are based on Nematic Liquid Crystals (NLC), simple prototypes based on NLC in combination with POF and operating at 650nm and 850nm simultaneously are reported in [6]. Those compact, broadband fibre optic 1x2 switches with low power consumption can be used in coarse WDM networks [7], POF LANs and sensor networks to allow redundant paths and time division multiplexing.

On the other hand, different laser and optical instrumentation devices have already been used in level measurement systems, as the level gauge described in [8] and the references included in this patent; but in any of them the laser, so the electronic driver, is in the sensor head. To avoid electronic presence in the measuring point, optical fibres should be used in the sensor head. This idea has been used in different optical sensors but for measuring short distances, as simple control level devices or in intrusive systems [9-11]. Remote sensor heads based on optical fibres for long distance are reported in [12, 13].

In this paper, time division multiplexing with optical switches in a multi-sensor system for level measurements with POF is reported. POF are used in the sensor heads and as the transmission media along the optical network. Optoelectronics and electronic circuits are developed to set up the laser output, the light reflected off the liquid surface and the control of the NLC switch. At least two sensor heads are placed in each tank and they are addressed by time division multiplexing using the same laser source. Level measurements on the system integrated by 2 sensor heads in a single tank and a 1x2 optical switch are reported.

2. PRINCIPLE OF OPERATION AND PROTOTYPES

The attenuation of the light transmitted from the sensor, reflected off the liquid surface and returned to the receiver fibre depends on the distance from the sensor head to the liquid surface.

A unique lens is used to collimate the incident beam and to focus the reflected beam (see Fig. 1). The emitter fibre is placed in the lens focal plane, near the focus, *f*. Therefore, behind the lens, there is a collimated beam that it is tilted a little angle, referred to the lens optical axis.

The beam is reflected by the liquid surface and comes back to the lens. Due to the mentioned angle, the beam suffers a lateral displacement depending on the distance between the lens and the liquid surface, *D*. Consequently, the lens collects only a part of the beam, whose image is formed on the focal plane, in a point symmetric to the emitter fibre in relation to the focus. The receptor fibre is placed in this position.

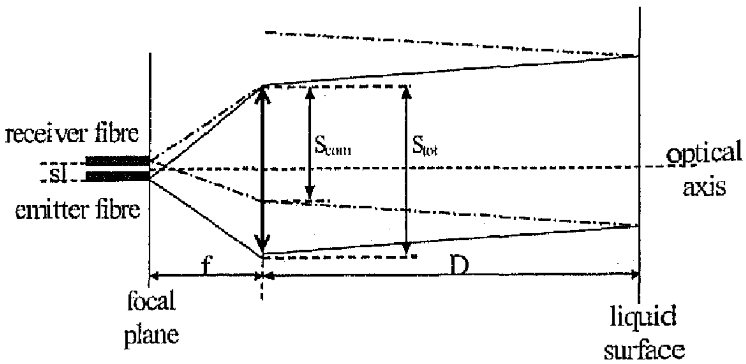

Fig. 1. Sensor heads: a schematic showing the incident (——) and reflected (-·-·-·-) beam path depending on the location of the lens and the emitter and receiver fibres.

The signal generated by the photodiode, which is placed behind the receptor fibre should be proportional to the rate of the common area between the reflected beam and the lens, S_{com}, to the total area of the reflected beam, S_{tot} (see Fig. 1). As the emitter fibre is very close to the lens focus, S_{com} could be calculated as the common area of two intersecting circles [13].

In the implemented system, the light signal used to measure the level is emitted by the generation unit, switched between the emitter fibres of the 2 sensor heads, transmitted to the tank and collected once it is reflected off the liquid surface by the receiver fibre of the excited sensor head. The receiver fibres of the 2 sensor heads are combined in a single POF by a passive component (a 1X2 POF combiner).

The output optical signal is converted to the electrical domain by the processing unit to extract the desired information and to fit up the signals to the microcontroller. These signals are sent to the Personal Computer (PC), via RS232 port (Fig. 2).

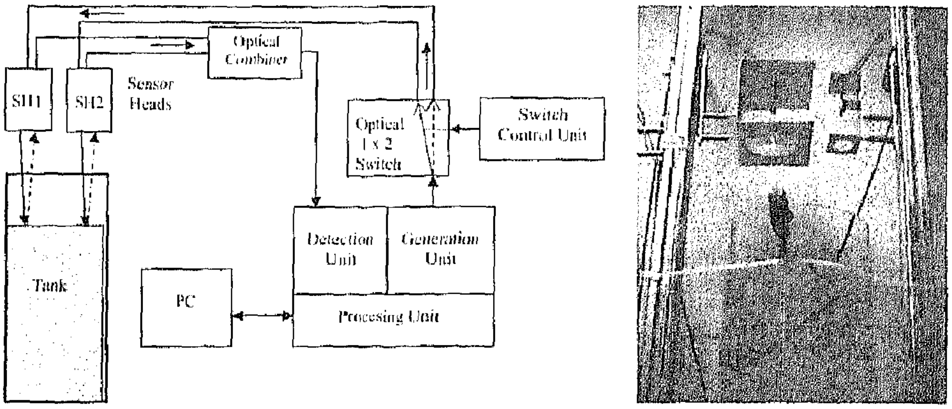

Fig. 2. System architecture and photograph of the two sensor heads at the top of the tank.

The emitter and receiver fibres of the sensor heads are made of POF with a 1mm diameter, a 0.47 numerical aperture and an attenuation of 0.24dB/m at 650nm. The sensor heads also include the collimating/focusing lens and the mechanical parts to align the sensors perpendicular to the liquid surface. The lens determines the range and sensitivity of each sensor. The photograph of two sensors heads are shown in Fig. 2. These sensors have lenses with different focal length and diameter and are made of different materials.

The optical 1x2 switch [6] is made of a Polarizing Beam Splitter (PBS), 2 nematic liquid crystals (NLC polarization switches PS1 and PS2 on Fig. 3) and polarizers. Focusing/collimating lenses are mandatory interfaces between the POF and the switch.

A schematic of the 1x2 switch can be seen in Fig. 3, with a photograph of the switch under operation, when the input signal (PORT1) is directed to one of the output (PORT3). The switch control unit drives the NLC polarization switches PS1 and PS2 (see Fig. 3), with voltage levels of 12 V_p and a frequency of 8 kHz. A low frequency clock is used to control the switch operation and time multiplexing the optical signal which excites the receiver fibre of each sensor head.

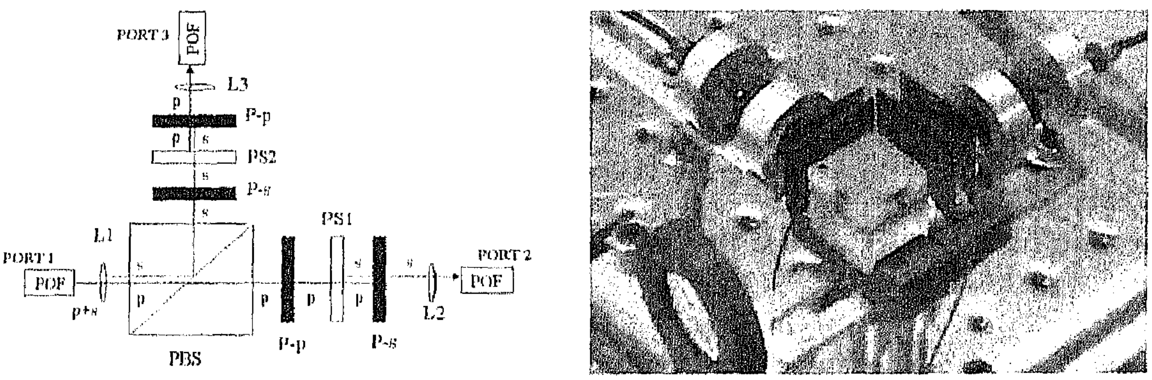

Fig. 3. Scheme and photograph of the implemented optical switch. POF: polymer optical fibres; PS: NLC polarization switch, PBS: polarizing beam splitter; P: polarizer; L: focusing/collimating lens.

The Generation, Detection and Processing unit (GDP unit) controlling the multi-sensor system for measuring liquid level is described in [2].

3. MEASUREMENTS AND RESULTS

Five series of measurements are developed in order to characterize the system described in Fig. 2. These measurements calibrate each sensor head individually, with and without connecting the optical switch and the calibration of the full system with the two sensor heads and the optical switch.

In the calibration of each sensor head individually, the liquid level varies from 1.90 m to 1.46 m, and the detection unit have been adjusted for having output digital words of 0 and 255 at those levels (see Fig. 4)

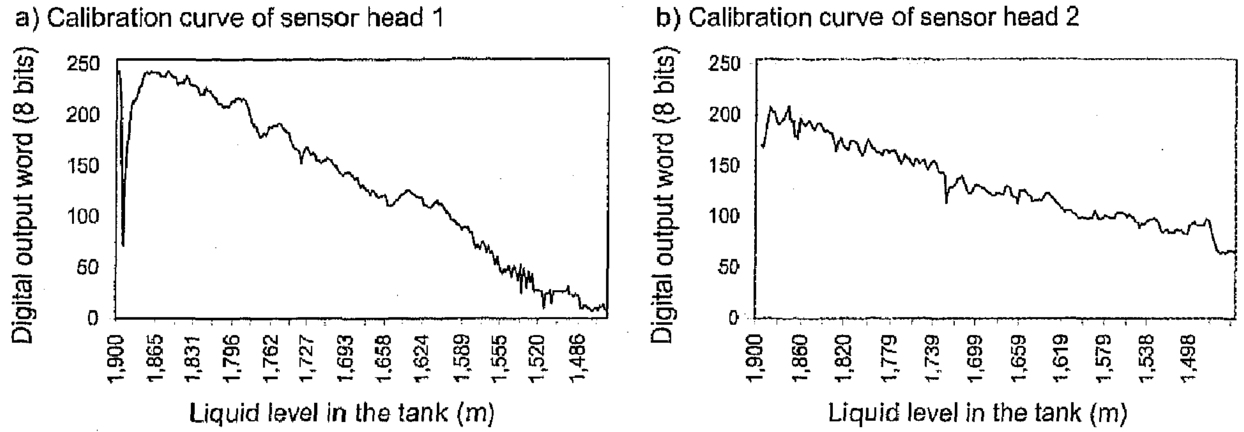

Fig. 4. Calibration curves of each sensor head individually.

Fig. 4a shows the calibration curve of sensor head 1, a sensitivity (defined as the ratio between output magnitude increment to input magnitude increment) is in the order of magnitude of 5/cm. On the other hand the sensor head 2 (see Fig. 4b), has a sensitivity of 2/cm.

The tank is emptied at a constant flow with a drainage pump, but this pump causes liquid level surface fluctuations when starting its operation. Those fluctuations cause the instability in the initial level measurements that are reported in Fig. 4.

Calibration curves of each sensor head individually, integrating the optical switch in the system, can be seen in Fig. 5. Liquid level variations are the same ones that were used in the previous calibrations.

The losses of the optical switch cause a decrement in the output voltage which has been partially readjusted in the electronic domain, through the GDP unit. The new sensitivity values are of 1/cm and of 1.5/cm for sensor head 1 and sensor head 2 respectively.

Full system calibration, with the 2 sensor heads simultaneously and the optical switch, is reported in Fig. 6a for a liquid level variation between 1.90 m and 1.78 m. Optical switch configuration is fixed so that the measurements are taken from each sensor every 1.5 s, or with a switching frequency of 2/3 Hz.

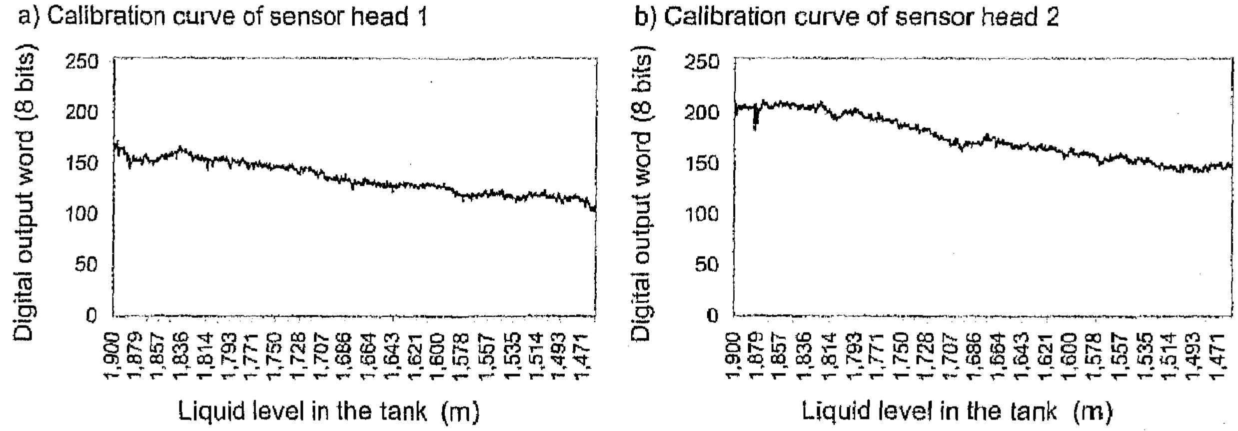

Fig. 5. Calibration curves of the 2 sensor heads individually with the optical switch.

The different sensitivity observed for both sensor heads implies an output signal variation within a certain range (see Fig. 6a). Output data post-processing is developed for separating the measurements of each sensor (or channel), and the results of the sensor head 1 can be seen in Fig. 6b. In that figure we see that the output values fluctuate with a certain periodicity between the two output levels which can be related to each sensor head. The reason is that there is no synchronization between the clock that excites the optical switch and the timers of the GDP unit, which select the values of the measurement samples of each sensor.

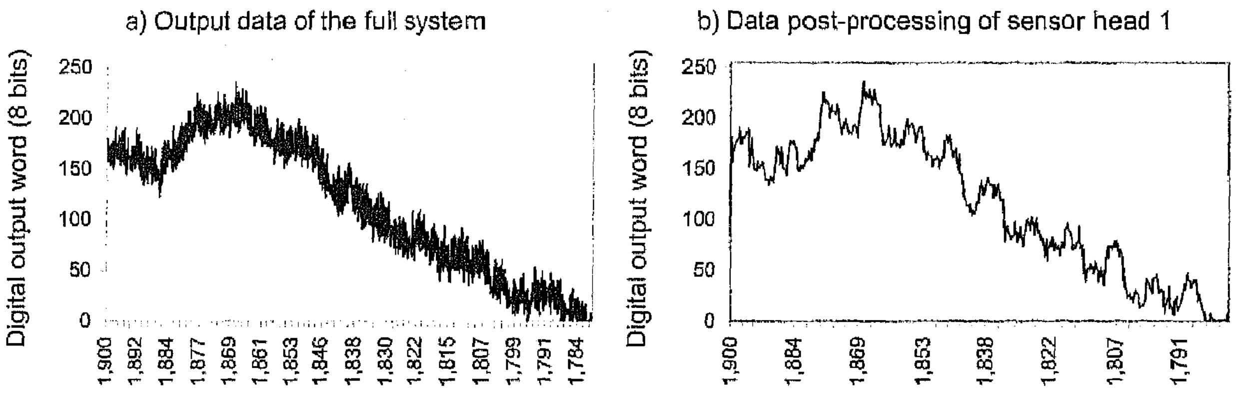

Fig. 6. Calibration curves of the full system

We can conclude that we have shown the feasibility of time multiplexing in POF networks using switches based on liquid crystals. A practical implementation is developed, with a simple optical switch that time multiplex two sensor heads of a level multi-sensor system. The main drawback is the optical loss introduced by the optical switch but it can be overcome using lasers with higher output powers or improving the electronic gain of the reception stage. Synchronization will be improved using adequate timing signals. This application is relevant in systems using lasers that cannot be internally modulated, lasers whose properties can be deteriorated if they are internally modulated or for updating networks without altering the laser source among others.

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