World Wide Journal of Multidisciplinary Research and Development

WWJMRD 2017; 3(9): 287-294
www.wwjmrd.com
International Journal
Peer Reviewed Journal
Refereed Journal
Indexed Journal
UGC Approved Journal
Impact Factor MJIF: 4.25
e-ISSN: 2454-6615

Frederick Ehiagwina
Electrical and Electronics Engineering, Federal Polytechnic, Offa, Kwara State, Nigeria

Lateef Afolabi
Electrical and Electronics Engineering, Federal Polytechnic, Offa, Kwara State, Nigeria

Olufemi Kehinde
Electrical and Electronics Engineering, Federal Polytechnic, Offa, Kwara State, Nigeria

Abdulmutolib Olaoye
Physics Electronics, Federal Polytechnic, Offa, Kwara State, Nigeria

Anifowose Jamiu Jibola
Touchpoint Analytics Nigeria Ltd (MTN Connect Offa), Kwara State, Nigeria

Correspondence:
Frederick Ehiagwina
Electrical and Electronics Engineering, Federal Polytechnic, Offa, Kwara State, Nigeria

Overview of Liquid Level Detection Technologies with Performance Characteristics Assessment and Energy Cost Saving for Household Water Pumps

Frederick Ehiagwina, Lateef Afolabi, Olufemi Kehinde, Abdulmutolib Olaoye, Anifowose Jamiu Jibola

Abstract
Usually, the arises to measure liquid levels in containers, in large industries; where large volumes of liquids are stored, in small scale industries and residential buildings in developing countries that sees many households implementing their own domestic water supply system. Measurements by humans may be influenced by sentiments, fatigues, lack of concentration, and so on, which has led to economic losses due lost liquid and wasted electric power. Therefore, researches have been directed toward development of automatic liquid level sensing technologies. This paper thus attempts to review available current technologies in automatic liquid level detection systems published in reputable literature. The reviewed technologies are based on optical devices such as light emitting diode (LED), LASER, photocell, photodiode, light dependent resistor (LDR), fibre optics cable and ultrasonic sensors. Other liquid level detection schemes studied are bases on capacitance measurement, edge detection technique in a computer vision system for inspecting the over and under fill liquid level of bottles. This paper also compared the full scale length to resolution ratio of some of the proposals reviewed in a discussion of performance characteristics of liquid level sensors. Finally, evaluated energy cost savings possible when liquid level sensors are used in water pumping systems. This paper will assist instrumentation researchers to know the state of the art in level sensing technology, and practitioners in selecting the right kind of level sensors for a particular application.

Keywords: Capacitance measurement, edge detection, image processing, interferometer, liquid level, optical fibre, ultrasonic sensors

Introduction
The need usually arise to measure liquid levels in containers, both in large industries where large volumes of liquids are stored and in small scale industries, such as the vegetable oil processing plants, gas service station, and so on. Other areas where there are needs to measure liquid include public water supplies and treatment plants, fuel depots, even in residential water supplies. Also breweries and bottling company have critical need for liquid level sensing so as to maintain standard and minimize economic loss. These liquids may be inert or highly flammable, conductive or nonconductive[1,2]. Manual or mechanical measurements may be flawed, due to a multiplicity of factors such as human sentiments, fatigues, lack of concentration, instrument error and so on. Therefore, researches have been directed toward development of automatic liquid level sensing technologies.
Meanwhile, Zhou *et al.*[3] in doing a review of applications of plastic optical fibre (POF) displacement sensor, highlighted examples and applications of liquid level sensors (LLSs). However, the review was not comprehensive, since less than 20 literature were reviewed. In this paper, we reviewed literature discussing liquid level sensing techniques, such as optical, capacitive and ultrasonic sensors base liquid level technologies. Moreover, technologies based on edge detection, which is especially useful in bottling companies are highlighted. The rest of this article is arranged as follows: Section 2 presents a review of fibre optic, ultrasonic, capacitive and other miscellaneous technologies based systems. Section 3 presents a comparison of the obtained resolutions of various systems discussed. Finally, Section 4

presents the conclusion are reached and offers recommendations.

Review of Existing Technologies

There are several approaches reported in the literature for sensing the level of various kinds of liquid-volatile and non-volatile, hot or cold, etc. Level sensing technologies considered in this paper are classified in the taxonomy shown in fig. 1.

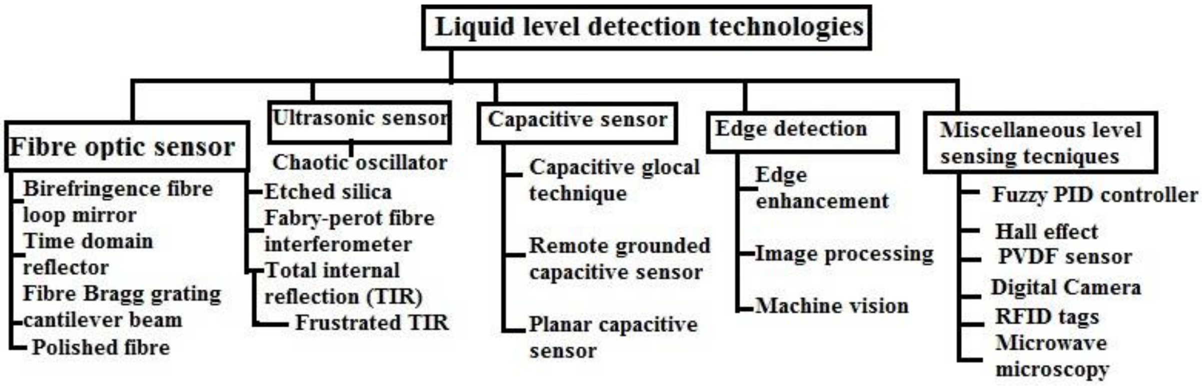

Fig. 1: Taxonomy of liquid detection technology

Optical Sensor Based Technology

Optical devices such as light emitting diodes (LEDs), LASERs, photocells, photodiodes, and light dependent resistors (LDRs) have variety of applications in electronic instrumentations. In addition, optical fibres are useful in implementing fibre based liquid level sensors, which are very useful in explosive environment due to their dielectric and immunity to electromagnetic interference[2]. This section of the paper examines trendy applications of optical fibre to liquid level detection.

Birefringence Fibre Loop Mirror and Time Domain Reflector Based Sensors

Bo *et al.*, in[4], who developed a system with a high birefringence-fibre loop mirror based on uniform-strength cantilever beam for liquid sensing. The system applied force at the end by using a hollow suspending pole. As the liquid level changes, the applied force varies, which consequently changes the transmission intensity of the laser light. Subsequently, the wavelength of the light is used to evaluate liquid level variations. Manik in[5] used an optosensor to continuously measure liquid level. Its approach was to establish an empirical relation for the attenuation of the light from the light emitting diode (LED) through a glass tube with varying distance. In its application to water level sensing, a photo-sensor and a light reflector in a glass tube floating on the water surface are used. The intensity of the reflected light detected depends on the distance between the sensor and the reflection, which changes with liquid level up to 80 cm to the nearest 0.5 mm. Additional aspect of this technology was shown by Yang in[6], who demonstrated a multiplexing of multiple liquid probes using an optical time domain reflectometer (OTDR) device for application in liquid level detection in cryogenic environment. The authors in[7] reported a system for detecting liquid height in tanks. The design was based on time-domain reflectometry and it uses two-wire probe fixed t the wall of the tank- conductive or nonconductive. Adaptability to container's shape is enhanced by the use of flexible wire.

Fibre Bragg Grating Based Sensor

A fibre Bragg grating (FBG) liquid sensor based on bending cantilever beam insensitive to temperature was demonstrated by Guo, *et al.* in[8] and, in Sohn and Shim[9]. As the liquid level change, there is a broadening of the FBG spectrum bandwidth and the consequent, reflection of optical power. Another FBG based sensor, though incorporating side- was reported in[10]. However, the FBG used in this case was polished at the side. It senses level variation of liquids of arbitrary refractive index, thus making it more flexible than that reported in[8]. In addition,[11] demonstrated and test liquid level and temperature sensor based on tilted fibre Bragg grating. It was reported that peak amplitude cladding modes and liquid level are inversely related. Another point to note, is the simplicity of the design.

Polished and Etched Silica Fibre Based Sensors

The bending losses of a partially polished polymer optical fibre was harnessed by Montero *et al.* in[12] in the development of a self-referencing optical intensity sensor designed for measuring liquid level in flammable environment, which is similar to that suggested in[13]. When a bend on a multimode fiber is incorporated, the higher order propagating modes in the fiber are refracted because the angle of incidence increases in the interface core-cladding, consequently leading to increase of the power losses in the receiver. The schematic of the scheme proposed by Montero *et al.* in[12] is shown in Fig. 2. If the core refractive index of the fibre, is equal to the cladding refractive index, it can be considered that the Fresnel transmission coefficient T, for the beams refracted in an optical fiber, is given[12] as shown in equation 2:

$$T = \frac{4\cos\theta\sqrt{\left(\cos^2\theta - \cos^2\theta_c\right)}}{\left[\cos\theta + \sqrt{\left(\cos^2\theta - \cos^2\theta_c\right)}\right]^2} \qquad (2)$$

Where:

θ = the angle of incidence for a certain beam with the normal to the core surface

θ_c = the critical angle, which is the arcsine of the ratio of cladding refractive index to core refractive index. When θ is less than or equal to θ_c, the beam will be refracted from the fiber core increasing the power losses

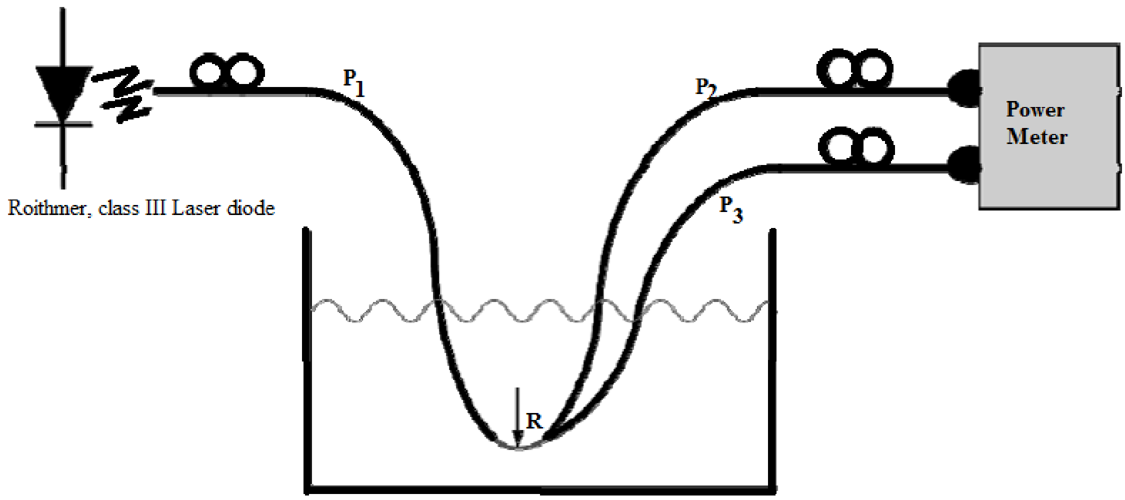

Fig. 2: Plastic optical fibre sensor arrangement for obtaining liquid level[12]

In addition, Lomer *et al.*[14] presented a multipoint level sensor based on lateral polishing bends in U-shapes in POF – with the resultant power loss. The polished bared surface is in direct contact with the liquid. Consequently, analysis is done on the variation in optical and geometric parameters of the multimode POF. Meanwhile, Linesh *et al.*[15] proposed a very sensitive level detection technique with a resolution of 100 mm, it was based on an optical source, silicon fibres etched with hydrofluoric acid and a detector.

Total Internal Reflection Based Sensing Technique

Furthermore, Li and Yu in[16] developed a system based frustrated total internal reflection (FTIR) based sensor combined with single chip computer controlled stepping motor for tracking and subsequently displaying liquid level. The sensor head is made from standard multi-mode communication silica fibre with a tapered tip. Another FTIR based sensor was reported by Nath, *et al.*, in[17]. The methodology involved polishing the end face of a step-index MMF to form a hemispherical tip, which allows part of the forward propagating modes to be reflected in reverse direction by the effect of TIR. When the tip of the fibre touched the liquid, the medium changes, the critical angle for the back reflected light, thus leading to a modulated power output. The system is able to detect the level of chemical liquids such as gasoline, diesel oil, and so on. Romo-Medrano and Khotiaintsev in[18] used optical sensors multiplexed using a matrix-type network of optical fibre using a robust level tracking algorithm for measuring the liquid level of nitrogen in large cryogenic systems. It reported a resolution of 5 mm for a full scale measurement of 1.6 m, which is higher than that reported by Description of a fibre optic liquid level sensor based on intensity modulation was presented by Golnabi in[19] and Pérez-Ocón, *et al.*, in[1]. The methodology used by Golnabi [19] involves liquid touching the 45^0 faces of the $45\text{-}90\text{-}45^0$ prism, leading the total internal reflection (TIR) to be disturbed and subsequent modulation of the reflected light. Whereas the approach used[1] involves the principle of TIR of light with the fibre optic. Power attenuation, which occurs in the fibre immersed in the liquid container is measured when there is variation in the liquid level. In order to minimize error in measurement, the LED light is modulated before feeding it into the fibre. Pérez-Ocón, *et al.* in[1] presented a system shown in fig. 2, and may incorporate an alarm configurable to alert the observer on any liquid level in the tank and a means of sending liquid level data via internet in real time to a distant observer.

Fabry-Perot Fibre and Interferometer Based Sensors

Meanwhile, Lü and Yang in[13] had earlier used an extrinsic fabry-perot (EFP) cavity comprising of the end of a single-mode optical fibre and elastic Silicon layer to sense liquid level. In this approach, liquid pressure change the cavity length through action on the mechanical construct that subsequently results in differential phase shifts observable in the form of signal intensity. The developed system has a resolution of 10 mm, with a linear range of 1.4 cm. Figure 3 shows the schematic diagram of the intensity based gauge for liquid level measurement.

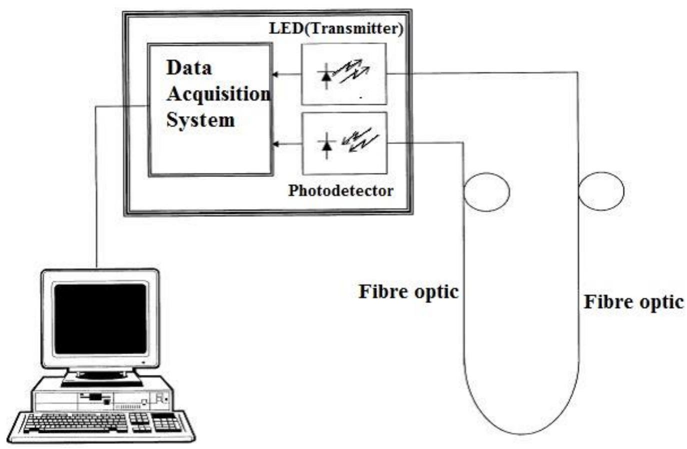

Fig. 3: Schematic diagram of the intensity based gauge for liquid level measurement[1]

Meanwhile, an extrinsic fabry-perot optical fibre interferometer with an all fused-silica structure and carbon (IV) oxide laser heating fusion bonding technology, which can be applied in optical fibre liquid level detection was reported by Wang and Li in[20]. The developed sensor have a resolution of 0.7 mm on a full length scale of 5 m, which is an improved result when compared with the 2 mm resolution over a range of 3.5 m reported in[13]. Another fabry-perot cavity structure based system is reported in 21. It is a white-light interferometric optical fibre sensor. It was based on sensitivity to pressure, which is a function of liquid depth. The reported sensitivity of the the system is 830,mmV per 10^6 N/m^2 for up to a pressure of $6{\times}10^6$ N/m^2

Hence, it is suitable for liquid level detection in environment containing flammable or explosive substances. Moreover, in[22], the authors reported a level sensor, which consists of elliptical multilayer-core fibre having one end silver coated. Due to the establishment of a Michelson interferometer, interference shifts related to liquid level can be observed.

Multimode Interference Effect Based Sensor Furthermore, Antonio-Lopez, et al., in[24] demonstrated a fibre optic liquid sensing scheme whose functionality depends on multimode interference effect. The demonstration involved fabrication of a single discrete level detection, using a 105/125 step-index multimode fibre, which possesses the ability of discriminating the refractive index of the liquid during the level detection. The light source for the system is tunable laser with wavelength of 1460 to 1580 nm. In addition, Antonio-Lopez, et al.[23] used the liquid around the MMF to modify the self-imaging properties of the MMI device, thus, detecting liquid level. When the effective refractive index and the diameter of the fundamental mode of MMF is n_{MMF} and d_{MMF}, with total length L, then the free space wavelength is given as equation (1)[23] as:

$$\lambda_0 = \frac{4n_{MMFn}d^2_{MMFn}}{L}\left(\frac{L_n}{L}\right) + \frac{4n_{MMF}d^2_{MMF}}{L}\left(\frac{L_0}{L}\right) \quad (1)$$

n_{MMFn} And d_{MMFn} are the effective refractive index of the section with liquid and the diameter of the fundamental mode of MMF section with liquid respectively. Figure 4 shows a fibre sensor, with section covered by liquid L_n and other sections not touching the liquid L_0.

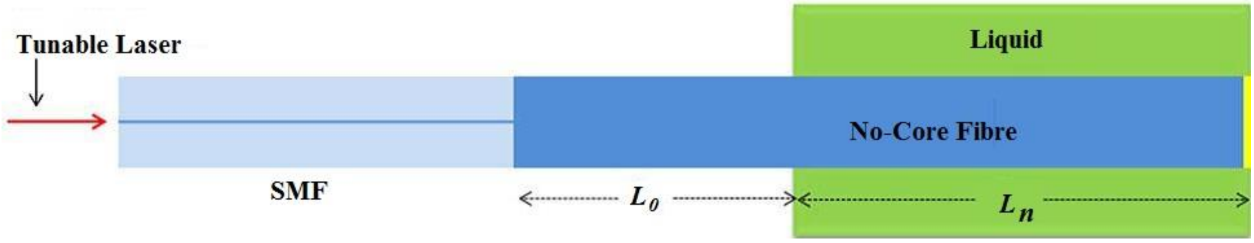

Fig. 4: Schematic of the fiber-optic liquid level sensor[23]

Ultrasonic Based Technology

The use of ultrasonic to detect liquid level, with LM567 as the ultrasonic detecting integrated circuit was presented by Jian-long[25]. The methodology involved measuring the ultrasonic velocity and the time delay in the detection by LM567. Later, Ling[26] evaluated several ultrasonic liquid level measurement methods, pointed out that with appropriate modification of the ultrasonic speed table, the liquid level of various liquids at various temperature can be determined. He went on to develop a system of ultrasonic liquid level measurement on ektesine of seal vessel.

Gao *et al.*[27] presented an ultrasonic based liquid level detection device. The authors further proposed the observation of weak signals based on chaotic oscillator, with the aim of enhancing the system's stability against noise disturbance. Due to the improved accuracy, the proposed device may be deployed in the measurement of oil rig. However, Sakharov *et al.*[28] presented a system based on ultrasonic lamb waves for the detection of liquid level in an enclosed metallic tank under high pressure. It is a non-invasive measurement technique. The developed system uses two sets of wedge transducer to generate and receive ultrasonic lamb waves along the circumference of the tank. Properties of the wave is dependent on the availability of liquid in the tank, thickness of the wall and the constituent of the tank wall.

Capacitive Based Technology

Planar Capacitive Sensor

A sensor consisting of planar electrode structure, a microcontroller and a capacitance controlled oscillator was presented by Toth, *et al.*[29]. Resolution of 0.1 mm over 4 m range within 0.2s was obtained. Reverter and Meijer[30] developed a remote grounded capacitive sensor. It used a stainless steel rod and a PTFE-insulated wire. It incorporated a cable with active shielding to connect the sensor to an interface circuit which relies on a relaxation oscillation and a microcontroller. It was used to measure the level of water in a grounded metallic container with a resolution of 0.10 mm over a range of 70 cm for a measuring time of 0.02 s. Ref.[31] uses a mutual calibrated output function along with taking new fluid as an on-line reference to develop a multifunctional sensor for monitoring liquid level and water content of brake fluid using capacitive method.

Capacitive Glocal Technique

Khan *et al.*[32] demonstrated the concept of continuous level monitoring through the development of a capacitive electric field methods for different fluids. Consequently, finite element method analysis in the process examining the sensitivity of the developed sensor in various liquid.

Capacitive Type Differential Sensor

Moreover, a hydrostatic pressure based level detection device using a very sensitive pulsating capacitive type differential sensor incorporating a customized oil manometer aimed at overcoming bubbling effect by air movements, spurious information of measured level occasioned by ambient temperature variation, etc. was presented by Pozo, *et al.*[33]. Owing to high cost of commercially available water level sensor and limited scope of existing system, Loizou and Koutroulis[34] presented the simulated performance characteristics of a new capacitive-type water level sensor, comparable to commercially available ultrasonic based water level detection schemes, with a much lower cost of production.

Edge Detection Based Technology

Pithadiya, *et al.*[35] discusses optimal and template based edge detection technique in a computer vision system for inspecting the over and underfill liquid level of bottle. It reported that Shen-Castan's ISEF optimal edge detection algorithm results were better than results from methods like Roberts, Prewitt, Sobel, Marr-Hilderth LoG algorithm and Canny algorithm. Upon review of existing techniques of bottle inspection in terms of cap closure, overfilling or under-filling, The authors in [36] proposed a feature extraction algorithm for achieving the aforementioned three tasks optimally.

Huang, *et al.*[37] proposed a system with a field rod for automatically detecting liquid level in a transparent bottle. The system, which is based on computer vision, incorporates positioning techniques used in determining the rod's position, which seems broken at the liquid surface due to the phenomenon of refraction.

Miscellaneous Technologies

Some other techniques are based on acoustic signal generated by mechanical impact but received by a piezoelectric polyvinylidene fluoride sensor attached to the liquid container[38]; PTC thermistor[39]. Meanwhile, a mmWave radar sensor incorporating stepped frequency radar methodology operating at 29,720 to 37,700 MHz. used among other things to observe continuously varying liquid level in a container[40,41].

Gu *et al.*[42] presented a system that is sensitive to microscopic variations in liquid level. The proposed system was based on near-field microwave microscopy platform based on an evanescent microwave coaxial probe electromagnetically coupled with the liquid and Network analyzer. The electromagnetic coupling was achieved by means of a tunable broadband matching network placed between the probe and the test port of the analyzer operating at about 0.86GHz. An earlier but similar system based on fibre optic micro displacement sensor was reported in[43]. Moreover, the authors in[44] demonstrated a level to frequency converter used for monitoring intravenous drip liquid level. A merit of this system is its small dimension, which is 1.96 mm by 2.00mm. This methodology was different from technique used in[45] for observing the liquid level in infusion bottle. In addition, the authors in[46] highlighted some techniques and steps such as edge detection, binarization, filtering, image projection and motion detection. In a yet another image processing-based measure, Wang *et al.*[47] used a digital camera and a circular float to observe more precisely and accurately liquid level in tank using the pixel counts of the uniquely coloured float in the image captured by the camera and the photographing distance.

Meanwhile, the authors in[48] proposed a contactless liquid level monitoring device, by measuring the phase shift and attenuation of the wave reflected from the surface of the liquid. Due to being contactless, it can be used to detect level of fluid inside automotive engine. While, the authors in[49] presented a prototype of a density independent and non-contact technique for observing liquid level. It was based on Hough transform and image normalisation. A merit of this system is that there is no need to recalibrate it, in detection of the level of different liquid. However Atojoko *et al.*[50] uses energy efficient passive UHF RFID tags as liquid level detectors. The RFID reader is made as part of the tank in close proximity to the tags. Liquid level is deduced by observing variation of the tag reading fed to a computer database. An earlier related work is a low cost application to restaurant beverage glass as seen in[51] and[52], where a wireless glassware was developed for sensing liquid level. Other contactless liquid level sensors are based on hall effect[53], capacitance measurement[52], optical effect.[54]

Furthermore, the authors in[55] designed a piezoelectric-exited millimetre-sized cantilever for sensing liquid level and subsequently evaluated the dynamic characteristics of the device for various depth of tip immersion scenarios using Euler-Bernoulli beam theory. Meanwhile, the device can observe a level difference of 8um. Furthermore, the authors in[56] reported a liquid level detection mechanism that can help in estimating the height of liquid in a blast furnace hearth. The basis for the system is theoretical hot metal and slag generation rate observed from both specific oxygen and calculated drainage rates. Many of the available methods will fail because of the high temperature and pressure inside hearth. Liang in[57] worked on fuzzy PID control for a coupled-tank liquid level control system having lumping lag and characteristics that are not linear. Meanwhile, a trend in liquid quantification is the integration of several sensors in a silicon bases CMOS for monitoring various parameters of fluid including liquid level[44,58].

Discussion

Liquid level sensor are instrumentation system so they are assessed by the following performance characteristics: reliability, speed of measurement, accuracy, resolution, full scale range, cost, simplicity of design, and so on. We next present in Table 1 a discussion of the resolution of some of the technologies reviewed in this paper.

Table 1: Comparing the resolution of optical and capacitance sensors liquid level detection technology

Author	Technology	Full Scale Length (mm)	Resolution (mm)	% resolution (mm) over full scale length
[5]	Optical sensor	800	0.5	0.0625
[18]	Optical sensor	1600	5	0.3125
[13]	Optical sensor	3500	2	0.0571
[20]	Optical sensor	5000	0.7	0.0140
[29]	Capacitive sensor	4000	0.1	0.0025
[30]	Capacitive sensor	700	0.1	0.0143
[59]	Optical sensor	750	9	0.012
[4]	Optical sensor	140	10	

The capacitive sensor based device reported in[29] have a lower full scale length to resolution ratio of 0.000025. But Wang and Li[20] reported a scheme with the highest full scale length of 5 m.

A Case for Applications of Liquid Level Sensor to Water Pump Control

How to provide and sustain available water resource in several countries of the World has been a subject of several discourses. This problem is related to poor water allocation, inefficient use, and lack of adequate and integrated water management. Therefore, efficient use and water monitoring, have necessitated research into various water level sensing technologies, and collection methods. To prevent or minimize water wastage during pumping and to care for future need for large volumes of water, the concept of automatic pumping machine with microcontroller based water level controller was developed in our previous work[60] based on the conductivity of a copper wire, as shown in Fig. 4.

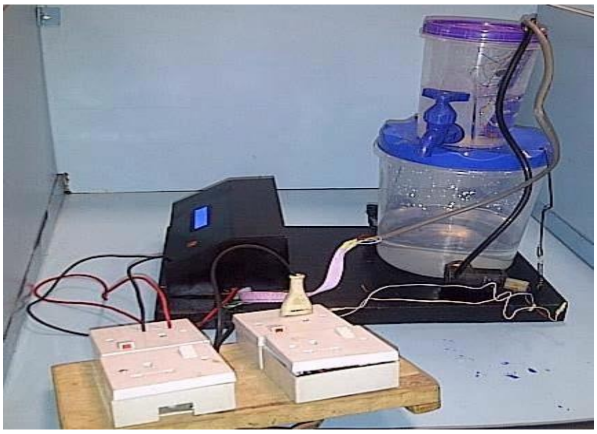

Fig. 4: Hardware prototype of the automatic water level controller[60]

We show in this section of the paper that energy can be saved when motorized boreholes pumps in most cities in Nigeria incorporates liquid level sensor. The quantity of energy consumed by a water pump is a product of the pump power rating and the time of operation in pumping up water to a collection tank. P_{hp} is the number of horse power of the pump. The quantity of energy (kWh) per minute, Q of operation is as shown in equation (2).

$$Q = P_{hp} \times \frac{3}{4}\ (kW) \times t/60 \qquad (2)$$

At cost of ₦23.5 ($0.0642) per unit (1 kWh), the cost of energy usage in a minute will be as shown in equation (3).

$$Q = P_{hp} \times \frac{3 \times 23.5\,(₦/kWh)}{4 \times 60}\ (kW) \qquad (3)$$

With the assumption of a household pump up water three times per week, and the average rating of the pump is 1.5 horse power, Figure 5 shows the cost of energy that could be save for 1000 motorized pumps, if a water pump is not allowed to stay ON for an extra minute after the collection tank is filled to capacity.

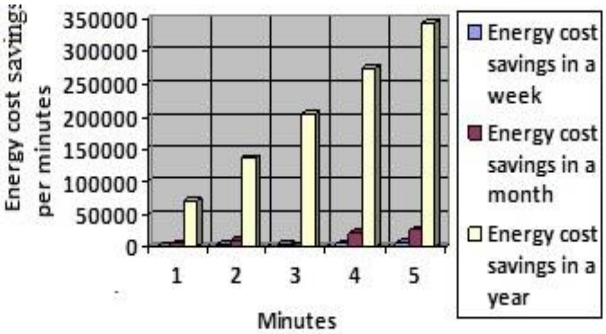

Fig. 5: Estimated energy cost savings for incorporating liquid level detector in boreholes pumps

Conclusion

This paper have shown that liquid level detection technology have drawn the attention of researchers. In this regard, trendy technologies are based on the following: fibre optics sensors, ultrasonic sensors and edge detection. There are ongoing efforts to improve the accuracy, resolution and dynamic range of operation of the liquid level sensor instrumentation. Other efforts are directed towards development of level sensors that be used in harsh environment such as the compartment of an internal combustion engine and the blast furnace of an iron processor.

Cost of energy per household with private borehole based water scheme would be reduced, if a liquid level detector based water pump controller is implemented with every water pump system. In addition, water resource would be conserved. Meanwhile, much still needed to be done in terms of integrating liquid level sensors in small scale liquid storage facilities in developing nations as typified by Nigeria, where a lot of facilities still rely on deep-sticks and other crude methods of observing liquid levels.

References

1. Pérez-Ocón F, Rubiño M, Abril JM, Casanova P, Martínez JA. Fiber-optic liquid-level continuous gauge. Sensors Actuators, A Phys. 2006;125(2):124-132. doi:10.1016/j.sna.2005.07.019.
2. Guo T, Zhao Q, Dou Q, et al. Temperature-insensitive fiber Bragg grating liquid-level sensor based on bending cantilever beam. Photonics Technol Lett IEEE. 2005;17(11):2400-2402.
3. Zhou H, Guang X, Luo D, Sing K, Chong W. A review of recent developed and applications of plastic fiber optic displacement sensors. Measurement. 2014;48:333-345. doi:10.1016/j.measurement.2013.11.007.
4. Bo D, Qida Z, Feng L, et al. Liquid-level sensor with a high-birefringence-fiber loop mirror. Appl Opt. 2006;45(30):7767-7771.
5. Manik NB, Mukherjee SC, Basu AN. Studies on the propagation of light from a light-emitting diode through a glass tube and development of an optosensor for the continuous detection of liquid level. Opt Eng. 2001;40(12):2830-2836.
6. Yang C, Chen S, Yang G. Fiber optical liquid level sensor under cryogenic environment. Sensors Actuators A Phys. 2001;94(1):69-75.
7. Cataldo A, Piuzzi E, De Benedetto E, Cannazza G. Experimental characterization and performance evaluation of flexible two-wire probes for TDR monitoring of liquid level. IEEE Trans Instrum Meas. 2014;63(12):2779-2788.
8. Guo T, Zhao Q, Dou Q, et al. Temperature-Insensitive Fiber Bragg Grating Cantilever Beam. 2005;17(11):2400-2402.
9. Sohn K-R, Shim J-H. Liquid-level monitoring sensor systems using fiber Bragg grating embedded in cantilever. Sensors Actuators A Phys. 2009;152(2):248-251. doi:10.1016/j.sna.2009.04.003.
10. Xiaowei D, Ruifeng Z. Detection of liquid-level variation using a side-polished fiber Bragg grating. Opt laser Technol. 2010;42(1):214-218.
11. Osuch T, Jurek T, Markowski K, Jędrzejewski K. A dual-parameter tilted fiber Bragg grating-based sensor

for liquid level and temperature monitoring. In: Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2016. International Society for Optics and Photonics; 2016:100311I-100311I.
12. Montero DS, Vázquez C, Möllers I, Arrúe J, Jäger D. A self-referencing intensity based polymer optical fiber sensor for liquid detection. Sensors. 2009;9(8):6446-6455. doi:10.3390/s90806446.
13. Lü T, Yang S. Extrinsic Fabry-Perot cavity optical fiber liquid-level sensor. Appl Opt. 2007;46(18):3682-3687.
14. Lomer M, Arrue J, Jauregui C, Aiestaran P, Zubia J, López-Higuera JM. Lateral polishing of bends in plastic optical fibres applied to a multipoint liquid-level measurement sensor. Sensors Actuators A Phys. 2007;137(1):68-73. doi:10.1016/j.sna.2007.02.043.
15. Linesh J, Sudeesh K, Radhakrishnan P, Nampoori VPN. Liquid level sensor using etched silica fiber. Microw Opt Technol Lett. 2010;52(4):883-886. doi:10.1002/mop.25037.
16. Li GZ, Yu QX. Optical Fiber Frustrated-total-internal-reflection Based on High Accuracy Liquid Level Sensor. J Instrum Tech Sens. 2004;2(22).
17. Nath P, Datta P, Ch Sarma K. All fiber-optic sensor for liquid level measurement. Microw Opt Technol. 2008;50(7):1982-1984.
18. Romo-Medrano KE, Khotiaintsev SN. An optical-fibre refractometric liquid-level sensor for liquid nitrogen. Meas Sci Technol. 2006;17(5):998.
19. Golnabi H. Design and operation of a fiber optic sensor for liquid level detection. Opt Lasers Eng. 2004;41(5):801-812.
20. Wang W, Li F. Large-range liquid level sensor based on an optical fibre extrinsic Fabry–Perot interferometer. Opt Lasers Eng. 2014;52:201-205.
21. Zhao J, Xu L, Luo M, Hua J. White-light interferometric fiber optic liquid sensor based on MEMS fabry-perot cavity. In: Photonics and Optoelectronic (SOPO), 2010 Symposium on. IEEE; 2010. doi:10.1109/SOPO.2010.5504424.
22. Liang X, Ren G, Li Y, Liu Z, Wei H, Jian S. In-fiber liquid-level probe based on Michelson interferometer via dual-mode elliptical multilayer-core fiber. J Mod Opt. 2016;63(13):1254-1259.
23. Antonio-Lopez JE, Sanchez-Mondragon JJ, Likamwa P, May-Arrioja DA. Fiber-optic sensor for liquid level measurement. Opt Lett. 2011;36(17):3425-3427. doi:10.1364/OL.36.003425.
24. Antonio-lopez JE, May-arrioja DA, Likamwa P, Member S. Fiber-Optic Liquid Level Sensor. 2011;23(23):1826-1828.
25. Jian-long LEI. Meter Based on Ultrasonic to Measure the Liquid-level. Instrum Tech Sens. 2004;6(4).
26. Ling HZDWZ. Study on Ultrasonic Liquid Level Measurement on the Ektexine of Seal Vessel. J Electron Meas Instrument, 4, 010. 2007;4(10).
27. Gao B, Zhang C, Yang F, Bi H. High accuracy chaotic oscillators ultrasonic wave liquid level detection. In: Measurement, Information and Control (MIC), 2012 International Conference on. Vol 2. IEEE; 2012:735-739.
28. Sakharov VE, Kuznetsov SA, Zaitsev BD, Kuznetsova IE, Joshi SG. Liquid level sensor using ultrasonic Lamb waves. Ultrasonics. 2002.
29. Toth FN, Meijer G, van der Lee M. A planar capacitive precision gauge for liquid-level and leakage detection. Instrum Meas IEEE Trans. 1997;46(2):644-646.
30. Reverter F, Li X, Meijer GC. Liquid-level measurement system based on a remote grounded capacitive sensor. Sensors Actuators A Phys. 2007;138(1):1-8.
31. Wang C, Shida K. A multifunctional self-calibrated sensor for brake fluid condition monitoring. In: 2006 5th IEEE Conference on Sensors. IEEE; 2006:815-818.
32. Khan FA, Yousaf A, Reindl LM. Build-up detection and level monitoring by using capacitive glocal technique. In: 2016 European Frequency and Time Forum (EFTF). IEEE; 2016:1-4.
33. Pozo AM, Pérez-Ocón F, Rabaza O. A Continuous Liquid-Level Sensor for Fuel Tanks Based on Surface Plasmon Resonance. Sensors. 2016;16(5):724.
34. Loizou K, Koutroulis E. Water level sensing: State of the art review and performance evaluation of a low-cost measurement system. Measurement. 2016;89:204-214.
35. Pithadiya KJ, Modi CK, Chauhan JD. Selecting the Most Favourable Edge Detection Technique for Liquid Level Inspection in Bottles. Int J Comput Inf Syst Ind Manag Appl. 2011.
36. Karasfi B, Hong TS, Jalalian A, Nakhaeinia D. Speedup Robust Features based unsupervised place recognition for assistive mobile robot. Pattern Anal Intell Robot (ICPAIR), 2011 Int Conf. 2011;1:97-102. doi:10.1109/ICPAIR.2011.5976919.
37. Huang L, Zhang YL, Hu B, Ma ZM. Automatic detection of liquid level in transparent bottle based on machine vision. Zidonghuayu Yibiao/ Autom Instrum. 2012;27(2):57-60.
38. Sanchez-Galicia ER, Stitt EH, Jackson P, York TA. Acoustic-Based Liquid Level Determination in Process Vessels using PVDF Sensors. In: 2006 IEEE Instrumentation and Measurement Technology Conference Proceedings. IEEE; 2006:1770-1773.
39. Horn M, Umar L, Ruser H. Self-controlled PTC sensor for reliable overfill protection of liquids. In: Instrumentation and Measurement Technology Conference, 2002. IMTC/2002. Proceedings of the 19th IEEE. Vol 1. IEEE; 2002:415-419.
40. Park J, Nguyen C. A Ka-band stepped-frequency radar sensor for surface and subsurface sensing. In: 2007 IEEE Antennas and Propagation Society International Symposium. IEEE; 2007:4921-4924.
41. Park J, Nguyen C. Development of a new millimeter-wave integrated-circuit sensor for surface and subsurface sensing. IEEE Sens J. 2006;6(3):650-
42. Gu S, Haddadi K, Lasri T. Near-field microwave microscopy for liquid characterization. In: Microwave Conference (EuMC), 2014 44th European. IEEE; 2014:628-631.
43. Sengupta D, Shankar MS, Reddy PS, SaiPrasad RLN, Narayana KS, Kishore P. A real time fiber optic micro displacement level sensor. In: Sensing Technology (ICST), 2011 Fifth International Conference on. IEEE; 2011:358-361.
44. Chiang C-T, Tsai P-C. A CMOS liquid level to frequency converter with calibration circuits for

detecting liquid level of intravenous drip. In: 2014 IEEE International Conference on Mechatronics and Automation. IEEE; 2014:342-346.
45. Zhu H. New algorithm of liquid level of infusion bottle based on image processing. In: 2009 International Conference on Information Engineering and Computer Science. IEEE; 2009:1-4.
46. Pithadiya KJ, Modi CK, Chauhan JD. Comparison of optimal edge detection algorithms for liquid level inspection in bottles. In: 2009 Second International Conference on Emerging Trends in Engineering & Technology. IEEE; 2009:447-452.
47. Wang T, Lu M, Chen C. Liquid-level measurement using a single digital camera. 2009;(November 2016). doi:10.1016/j.measurement.2008.10.006.
48. Pelczar C, Meiners M, Gould D, Lang W, Benecke W. Contactless Liquid Level Sensing using Wave Damping Phenomena in Free-Space. In: TRANSDUCERS 2007-2007 International Solid-State Sensors, Actuators and Microsystems Conference. ; 2007.
49. Flores MA, Thome AC, Lima C, Cruz AJ. A dynamic fluid level monitoring application using Hough transform and edge enhancement. In: 2009 IEEE International Symposium on Industrial Electronics. IEEE; 2009:317-322.
50. Atojoko A, Abd-Alhameed RA, Tu Y, Elmegri F, See CH, Child MB. Automatic liquid level indication and control using passive UHF RFID tags. In: Antennas and Propagation Conference (LAPC), 2014 Loughborough. IEEE; 2014:136-140.
51. Bhattacharyya R, Floerkemeier C, Sarma S. RFID tag antenna based sensing: Does your beverage glass need a refill? 2010 IEEE Int Conf RFID (IEEE RFID 2010). 2010:126-133. doi:10.1109/RFID.2010.5467235.
52. Dietz PH, Leigh D, Yerazunis WS. Wireless liquid level sensing for restaurant applications. Sensors, 2002 Proc IEEE. 2002;1:715-720 vol.1. doi:10.1109/ICSENS.2002.1037191.
53. Pepka G. Position and Level Sensing Using Hall Effect Sensing Technology. Worcester, Massachusetts; 2007. www. allegromicro.com.
54. 54. Reza SA, Riza NA. Author â€™ s personal copy Agile lensing-based non-contact liquid level optical sensor for extreme environments. doi:10.1016/j.optcom.2010.03.043.
55. Maroufi M, Shamshirsaz M. Size effect on performance of Resonant Piezoelectric Millimeter-sized Cantilevers using as liquid level detection sensors. Des Test, Integr Packag MEMS/MOEMS (DTIP), 2012 Symp. 2012:42-46.
56. Agrawal A, Kor SC, Nandy U, Choudhary AR, Tripathi VR. Real-time blast furnace hearth liquid level monitoring system. Ironmak Steelmak. 2016:1-9.
57. Liang L. The application of fuzzy PID controller in coupled-tank liquid-level control system. In: Electronics, Communications and Control (ICECC), 2011 International Conference on IEEE. ; 2011:2894-2897.
58. Purrington HM, Puchades I, Baylav M, Fuller LF. A MEMS Universal Fluid Quality Interrogation Sensor. In: 2010 18th Biennial University/Government/Industry Micro/Nano Symposium. ; 2010.
59. Rizvi S, Showan N, Mitchell J. Analyzing the Integration of Cognitive Radio and Cloud Computing for Secure Networking. Procedia Comput Sci. 2015;61:206-212. doi:10.1016/j.procs.2015.09.195.
60. Kehinde OO, Bamigboye OO, Ehiagwina FO. Design and Implementation of an AT89C52 Microcontroller Based Water Pump Controller. IJISET -International J Innov Sci Eng Technol Impact Factor. 2016;3(7). www.ijiset.com.