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A REVIEW ON ELECTRICAL INSTRUMENTATION TECHNIQUES APPLIED IN GROUNDWATER LEVEL DETERMINATION

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ABSTRACT

Measuring groundwater level or depth-to-water is critically important for identifying long-term trends, including declining groundwater levels. To manage groundwater, there is need for timely and accurate data to assess groundwater conditions in order to manage and prevent adverse situations. The principal source of information about the hydrological stresses acting on aquifers and their impact on groundwater recharge, storage and discharge is groundwater level measurements. Systematic and accurate measurements of groundwater levels provide important data required to evaluate changes in groundwater resources condition overtime; to develop groundwater models used in forecasting trends; and also to design, implement, as well as monitor the effectiveness of groundwater management and protection programs. There are different electrical instruments that have been proposed and in use for determining water level with various degrees of efficiency. The application of these instruments in various columns differs. In this paper, the authors reviewed various instrumentation techniques applied in groundwater level determination. The advantages and limitation of these techniques are also discussed. This work can serve as an inspirational and informative tool to new and old researchers who are not (or adequately) grounded in this special area of research.

Keywords: Groundwater level, hydrological stresses, column.

1. INTRODUCTION

Groundwater reservoir also referred to as aquifer is a complex system that is exposed to both natural and artificial stresses in different chronological levels which result in fluctuation of groundwater level [1]. For instance, the increasing population density and major shift toward irrigation in agriculture (with extensive practice of irrigation in northern Nigeria) have increased the demand for groundwater usage which causes over-exploitation of the aquifer, and thereafter drought. Hence, efficient monitoring of groundwater level is necessary for proper management. The principal source of information about the hydrological stresses acting on aquifers and their impact on groundwater recharge, storage and discharge is groundwater level measurements [2].

Level is a very important parameter that is measured in various industries and across an extremely wide range of applications. In simple terms, level measurement is the measurement of the height of particular content with respect to a reference point or the base of the containing vessel. Since there are many applications where level measurement is performed, applications could be measuring the level of solids or liquids. Some of the typical applications for liquid level measurement include lift stations in wastewater treatment systems, bore hole or well level measurement, level of a liquid in a tank, and so on. Some of the applications for solid level measurement include grain storage silos, dust collectors, pneumatic conveying receivers, and more. In any application, level measurement requires appropriate and functional sensing element called sensor incorporated with other signal conditioning units. Sensor is a device that responds to a physical stimulus such as heat, light, sound, pressure, magnetism, motion, temperature, et cetera and transmits the resulting impulse for measurement or for operating a control. Sensors applied in measuring fluid levels are referred to as level sensors. Level sensors are used to measure the level of free-flowing substances. Such substances include liquids like water, oil, slurries, as well as solids in granular or powder form (solids which can flow). Examples of sensors include pressure sensors, strain gauges, thermistors, thermocouples, photoresistors because they all give electrical signals when subjected to necessary stimulus [3]. Selection of an appropriate type of sensor suiting the application requirement is very important. Generally, the choice of level sensor for a specific application is based on a number of factors. They include the physical properties of the column, range of measurement, characteristics of the liquid, resolution [4],

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pressure on the liquid, temperature of the liquid, turbulence, volatility, corrosiveness, level of accuracy required, single point or continuous measurement, direct or indirect, and particulates in a liquid [5]. Another major consideration when selecting a level sensor is temperature [6]. This is because density and dielectric constants are affected by temperature, making indirect level measurements temperature-sensitive. In this case, level reading must be compensated. Temperature-sensitive sensors include capacitive, bubblers, displacers, ultrasonic, pressure and load cells.

According to ref. [7], level sensing devices can be classified into four major classes namely:

i. Direct sensing where the actual level is monitored;
ii. Indirect sensing where a property of the liquid, such as pressure is sensed in order to determine the liquid level;
iii. Single point measurement where it is only necessary to detect the presence or absence of a liquid at specific level(s);
iv. Continuous level sensing where the liquid level is continuously monitored.

Level measurement has seen considerable change over the past decades from purely mechanical level measurement through to complex electronic sensors using various measuring principles. The large number of different technologies for measuring level, as reported in literatures, offers the designer the possibility to choose the most suitable sensor technology for his individual application [8]. These include capacitive, ultrasonic, optical, hydrostatic pressure, float, radar, steel tape, electric tape, air line, and many more. Some of these technologies are discussed in the following sections. The principles of operations, merits, and demerits of each technology are juxtaposed.

2. ULTRASONIC LEVEL SENSOR

Ultrasonic refers to sound above human hearing range. Ultrasonic frequencies are in the range above 20kHz. Ultrasonic devices are used in many fields of measurement, particularly for measuring fluid levels. Ultrasonic level sensor is a non-contacting continuous level measurement technology. The sensor works by the "time of flight" principle using speed of sound. It emits a high frequency pulse, generally in the range of 20kHz to 200kHz and then receives the echo. The pulse is transmitted in a cone, usually about 6^0 at the maximum [9]. The pulse hits the water surface and is reflected back to the sensor which now acts as a receiver as shown in figure 1.

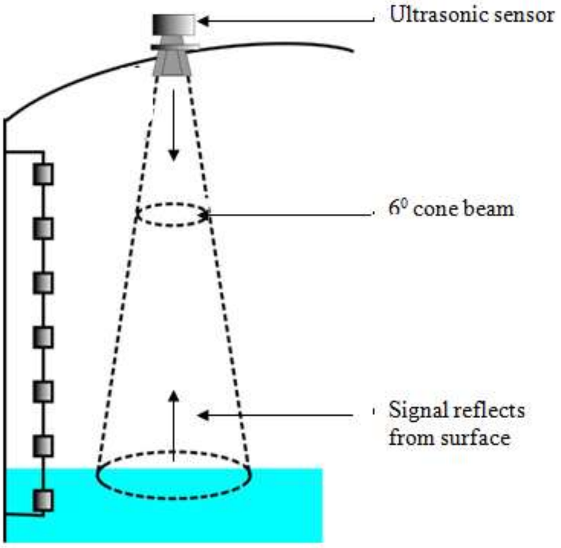

Figure 1: Ultrasonic Sensor sends pulses toward the water surface and receives echo pulses back

The complete return trip time between transmitted ultrasonic pulse and reflected echo is measured to determine water level. Lower frequency ultrasonic sensors are used for long level measurements, while higher frequency ones are used for short liquid level measurements. They can be used for single-point and continuous level measurements. The distance to water surface is calculated using equation 1.

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Distance = $V/_{2t}$ eq. 1

Where
V = the velocity of sound in the medium
t = time elapsed between transmitted pulse and reflected echo
Besides the time of flight principle, ultrasonic sensors use physical principles based on doppler effect and attenuation of sound waves [10]. Ultrasonic is affected by temperature changes because speed of sound varies with temperature changes, thereby necessitating the need for temperature compensation. Another major challenge with ultrasonic sensor is that irregular material surface and obstacles in the line of sight of the sensor can cause false echoes resulting in irregular readings. Ref. 11 developed a water level detection system using ultrasonic ping sensor. The system consists of a transmitter module and a receiver module. The transmitter module performs water level detection and transmits it to the receiver which collects the data and displays the data on a screen. Reasonably good performance was shown from the experimental result. They concluded that, since water level data was successfully displayed locally and remotely, the prototype can be used as part of a bigger system such as river flow management system that controls stream to minimize flood. The limitation of their work is that the sensor applied only covers a very short distance of 60cm. Ref. 12 developed a model for the estimation of multiple levels in tanks and reservoirs. They used ultrasonic sensors as the sensing device. They applied Wavelet Transform technique for signal filtering and detection in the presence of noise. In order to predict slope failure due to heavy rainfall, [13] used partially embedded and completely embedded ultrasonic detectors to monitor soil moisture and groundwater level. The ultrasonic sensor was set inside a 30cm long waveguide pipe that was open at the bottom and embedded in a shallow soil vertically with its bottom touching the underground soil. Their test results showed that the intensity of the reflected wave depends on the moisture state of the underground soil, and the propagation time of the reflected signal decreases with increase in groundwater level. Hence, they used propagation time to monitor increase in groundwater level while reflected intensity was used to monitor soil moisture. The range of coverage of their design was limited to just 30cm.

3. RADAR LEVEL SENSORS

Radar or Microwave level sensors operate on similar principles as ultrasonic level sensors with the only difference in the use of frequencies. Radar level measurement is also based on the principle of time of flight, that is, measurement of the time elapsed between transmission of a microwave pulse and reception of the reflected echo. Radars use a radiofrequency antenna pointing down to the surface of liquid. The radar antenna emits pulses downwards to measure the distance from the antenna to the liquid surface using the principle of time of flight. In this case, the radar emits an electromagnetic wave whose traveling speed is much higher than that of sound in air. The electronics involved in the process of measuring liquid height is more sophisticated than in the ultrasonic case [3]. Hence, the cost of implementation is considerably high. Also, these sensors are very sensitive to the buildup on sensors' surface, which in turn affects the efficiency.

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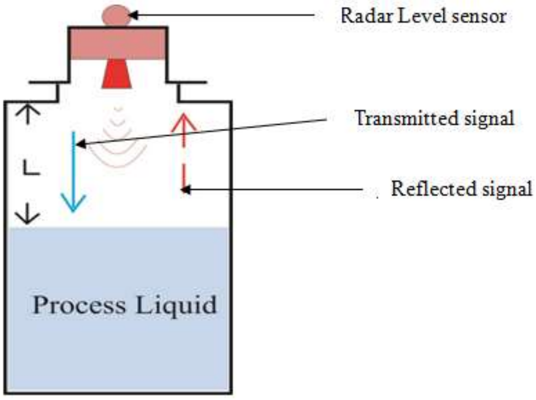

Figure 2: Water Level Measurement Using Radar Sensor

4. OPTICAL LEVEL SENSORS

An optical sensor is a device that converts light rays to electronic signals. Optical sensor has two points. One is the transmitting point (Infrared LED) where light is emitted and the other end is the receiving end (light receiver). The infrared light generated by an infrared LED is directed down to one face of a right angle prism, across the prism to the other face and then reflected up to an infrared receiver. A typical optical sensor used in water level detection is shown in the figure below. If there is no liquid present, the light from the LED is reflected within the prism and the receiver. When a liquid covers the external surface of the prism, the light is then deflected through the prisms face into the liquid and very little or no light is reflected back to the receiver. Sensing this change, the receiver actuates electronic switching within the unit to operate an external control circuit. The liquid level detection is at only one level and the output is either ON or OFF. For multilevel detection requirements, several optical level sensors need to be purchased and installed, thus increasing the cost. With multiple sensors, the connection to a control unit becomes more challenging. Today, there are many types of optical sensors; many based on the use of lasers, imaging systems, and/or fibers as discussed in [14].

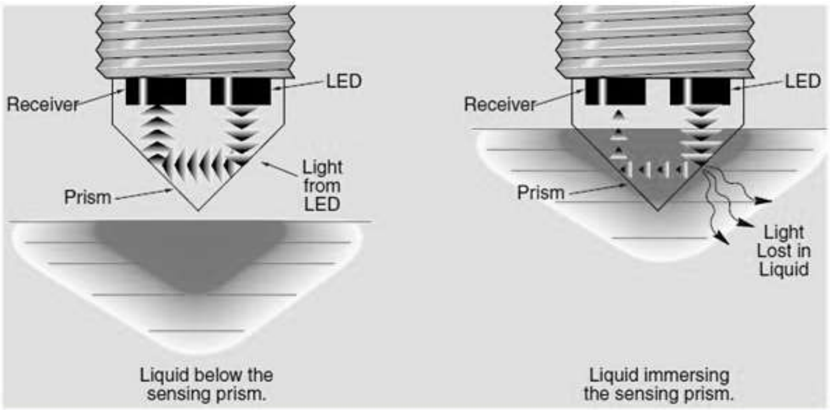

Figure 3: Water Level Measurement Using Optical Sensor

Applications of optical sensors in water level measurement have been reported in literatures. In [15], the application of plastic optical fibre for monitoring groundwater levels was described. They produced and tested two sensors with different groove depth ($^1/_2$ and $^1/_4$ of the core thickness) and a resolution of 20cm along 2m length of the optical fibre. They reported that the analysis of the optical signal's amplitude and its variations due to increase or decrease water level showed that both sensors presented appropriate performance and adequate sensitivity to groundwater level variations. They concluded that both sensors can be applied in groundwater level monitoring. Ref. [16] applied optical sensors for sea level prediction. The monitoring system was based on changes in optical spectra properties. Further applications of optical sensors for water level monitoring are discussed in [17] and [18]. The shortcomings of optical sensors are that they require complex monitoring

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system, high cost of implementation, and the configuration of the sensors does not allow its applications in harsh environments.

5. CAPACITIVE LEVEL SENSORS

Capacitive level sensors are operated by two electrodes forming a capacitor, often in the form of two parallel metal plates with insulating (non-conductive or dielectric) material separating them. In conventional capacitive-type level sensing system, two electrodes are used for non-metallic tank and one electrode for conducting tank [19]. These systems establish a capacitor as shown in Figures 4 and 5. Capacitive sensors exploit the variation of dielectric coefficient when water or other liquid rises and occupy the space between the sensor's plates that constitute a capacitor. Basically, capacitive sensor is made up of two parallel plates that are connected to a conditioning circuit that measures the capacitance. If the gap between the two electrodes is fixed, the capacitance becomes a function of the dielectric between the plates. The fluid level can be determined by measuring the capacitance between the conductors immersed in the liquid. Since capacitance is proportional to dielectric constant, change in the fluid level will change the effective dielectric constant and also the capacitance between the plates. Therefore, fluids rising or falling between the two parallel plates will increase or decrease the net capacitance of the measuring circuit as a function of fluid height.

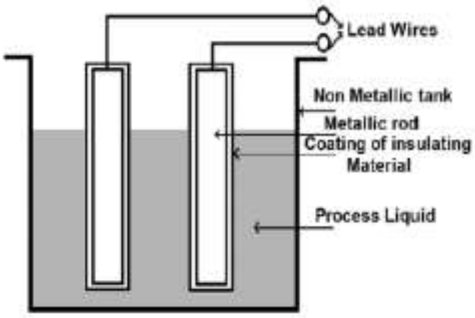

Figure 4: Capacitive Level Sensor with non-metallic tank

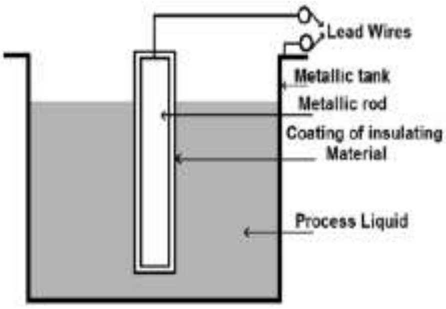

Figure 5: Capacitive Level Sensor with metallic tank

Ref. 20 proposed a four-electrode capacitive liquid level sensor which can be used for the measurement of liquid level, gradient direction, and gradient angle. Ref. 21 described the design and construction of a liquid level measurement system based on a remote grounded capacitive sensor. A rod of stainless steel and a polytetrafluoroethylene insulated wire were used for the electrodes of the capacitive sensor. Ref 22 designed capacitive sensor applied in water level measurement. In their experiments, the capacitive sensor was used to measure water level inside a container with 30cm of maximum depth. The result of the experiment showed that capacitance of the sensor varies proportionally with the level of water inside the container. They also stated that the sensor capacitance has non-zero initial value due to non-ideal condition of the experiment. Capacitive sensors are not practically applicable in applications where very high water column is to be monitored. This is because of the requirement that the length of the capacitor plates must be longer than maximum expected height of liquid in a monitoring column.

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6. FLOAT LEVEL SENSORS

The float-type level measuring device uses a float that rests on the water surface to measure water level changes. This type is usually installed in stilling wells where a float attached to a cable is wrapped around a pulley at the well head. As the float rises and lowers, the pulley turns a potentiometer, which outputs an electronic signal based on the water level. The float and pulley units described in [23] are custom-fabricated by reclamation using an inexpensive potentiometer with a 0–5 volt output and other commonly available parts. Also, float device may be attached to a drum pen recorder. A float device will measure water level continuously regardless of the frequency of the recording device to accept water level information [24]. The major concern here is that the float could become entangled and unable to move freely, especially in narrow wells like boreholes.

Ref. 25 proposed an edge-based water level detection scheme and image transmission technique using sparsely sampled images in time domain. The system consists of two sections. The first is called slave system. It collects image by a camera and converts the image to difference image, encodes the image and then transmits it to the second section called master system. Their work was tested in river Nakdong in Korea. Their experimental results showed that the performance of the proposed system is not deteriorated by changes in weather conditions. However, the cost of setting up the system is very high. Moreover, measurement accuracy is affected largely by lighting conditions, especially in the night. Ref. 26 designed and constructed a liquid measurement system using e-tape sensor. The system was designed to measure liquid level in a tank and used the measurement to control the states of motor pumping. Their system can only perform maximum level measurement of 25cm.

7. STEEL TAPE

Water level measurement in wells can be obtained with a chalked steel tape. This method utilizes a graduated steel tape with a weight attached to its end. It is preferable for steel tape to have limited elasticity and sufficient weight in order to hang vertically in a well. The weight can be made of brass or stainless steel. The lower part of the tape is coated with carpenter's chalk, and the tape is lowered into the water until the lower part of the tape is submerged. For wells with deep water levels, it may be necessary to have an idea of depth to water or to make several measurement attempts to ensure that the tape is not submerged beyond its chalked length [27]. The tape shown in figure 6 is held at the reference point and the tape position is recorded. The depth to water below the reference point is determined by subtracting the length of wet tape (indicated by wet chalk) from the total length of tape lowered into the well. To lessen the possibility of computation errors, the measurement should be repeated to ensure its accuracy, and the measured water level must be static [27]. This method is very tedious, and not suitable for application in deep wells. Also, the weight could be entangled with the wiring in the well and could also cause damage to the submersible pump inside the well. Another drawback of steel tape is the uncertainty of how far to insert the tape down the hole, which could cause the tape to be inserted into the hole several times before hitting water [28].

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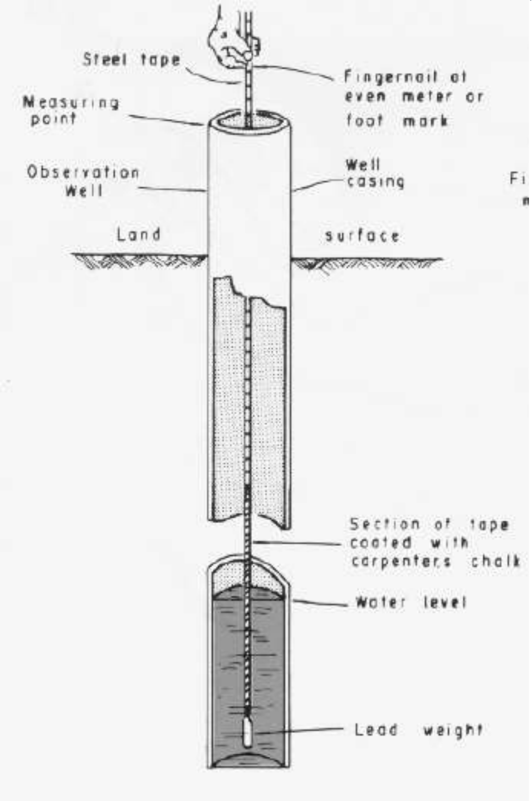

Figure 6: Using Steel Tape and Chalk Method For Groundwater Level Measurement [27]

8. ELECTRIC MEASURING TAPE (E-TAPE)

Electric groundwater level measurement tapes (e-tapes) are used to measure groundwater levels in wells. An electric measuring tape typically consists of a tape with two electrical conductors, marked in distance graduations, which is spooled onto the reel and connected to indicator circuit and power source. A probe with a pair of metal contacts separated by an air gap is connected to the naked end of the tape. E-tapes indicate on the indicator when an electrical connection is completed by the well water bridging two electrical contacts on the probe [27]. The challenge of having to insert measuring tape into the well several times experienced with chalked steel tape is overcome in e-tape since the indicator gives a signal immediately the probe touches water. Measurement is more easily and accurately made with an electric tape if water levels are affected by nearby groundwater pumping or previous use of the well [27]. An example of e-tape is shown in figure 7.

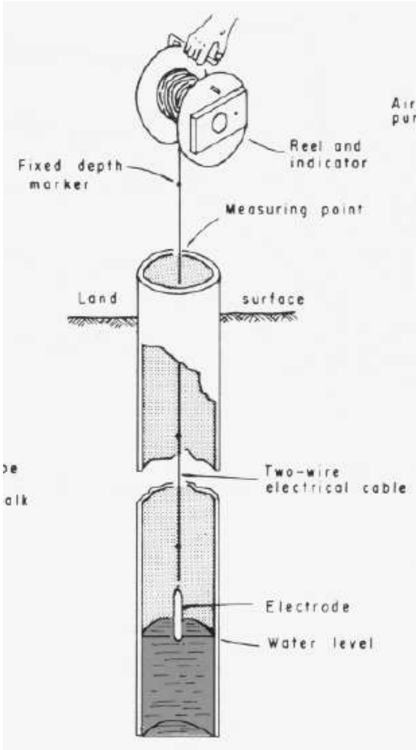

Figure 7: Using Electric Tape for Groundwater Level Measurement [27]

Ref. 29 conducted an experiment to measure the accuracy of electric groundwater tapes using six different models of electric groundwater tapes. The accuracy tests compared the length of each electric tape to a calibrated steel reference tape and measured each probe's activation accuracy and displacement volume. The tape-length accuracy combined with the probe-activation accuracy gave the overall measurement accuracy of the tape. The test data showed that the tape models in the study should give a water-level measurement that is accurate to roughly ±0.05 feet per 100 feet without additional calibration. They discovered that specific conductance plays a part in tape accuracy such that probes will not work in water with specific conductance values near zero, and the accuracy of one probe was unreliable in very high conductivity water. If the specific conductance of the well water is close to or greater than 10,000 µS/cm (microsiemens per centimeter), e-tape's probe should be checked to ensure that it operates properly.

9. AIR LINE METHOD

It may be difficult or impossible to measure water levels in water supply wells using steel or electric tapes if an access port is not present or the well cap cannot be easily removed [27]. Such wells, particularly high-capacity industrial and municipal well use an air line for measurement. Air lines are commonly used in wells equipped with large power pumps, such as public supply wells to determine drawdown during pumping as well as fluctuations in static water level [28]. This method involves the installation of a small-diameter flexible plastic pipe or tube (the air line) from the top of the well to a known depth below the water level. The bottom of the tube is usually fastened to the base of the pump inside the well, and the top tube fitted with a valve and suitable connections so that an air pump and pressure gauge can be attached as shown in figure 8. The water level in this pipe is the same as that in the well. The principle used by air line is based on a law of physics where 1.0 pound per square inch (PSI) of pressure displaces water 2.31 feet [30]. This allows air lines to be applied in measuring the depth to water.

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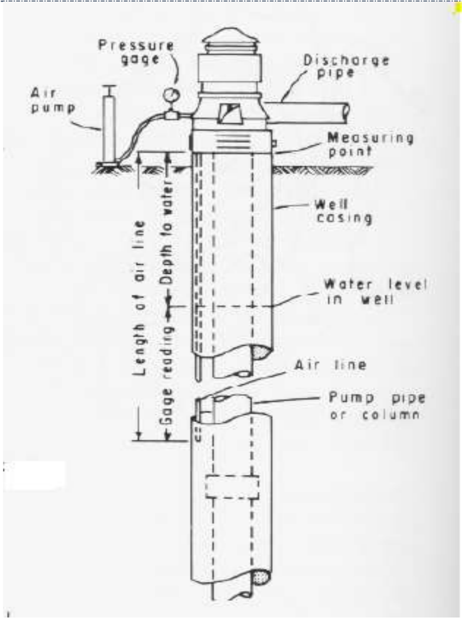

Figure 8: Using Air Line Method for Groundwater Level Measurement [27]

To determine the depth to water, air is pumped into the line using the air pump attached to the top of the air line at a noted reference point until all the water is displaced. This happens when the pressure indicated on the pressure gauge remains fairly constant. The amount of water displaced in feet is obtained by multiplying the PSI reading on the gauge by 2.31 to get the length of submerged air line. Subtracting this value from the total length of the air line gives the depth to water below the measuring point [30]. The level of accuracy of air line readings is the same whether water table is at its static level or pumping is taking place because it responds quickly to changes [30]. The expression for calculating water level in air line method is shown in equation 2.

$$WL = L - (P * 2.31) \quad \text{Eq. 2}$$

Where:
WL = water level in feet
L = length of air line in feet
P = pressure on gauge in PSI

Measurements by the air line method are not very accurate and are better for representing trends in water levels [28]. In fact, error in reporting the length of the line and holes that develop due to corrosion below the water level could cause greater measurement errors. Air lines generally are accurate to about ± 1 ft [27].

10. HYDROSTATIC DEPTH METHOD

In continuous, long-term, uninterrupted, real-time water level monitoring, hydrostatic pressure sensor (also known as hydrostatic level measurement) is the principal sensor technology and measuring principle applied in the determination of groundwater level. This technique requires a pressure sensor to be submerged at a fixed and known distance. They can either be submersed with borehole pump or directly suspended by their cable into the well, borehole, or monitoring well to a known height. Pressure sensor measures the equivalent hydrostatic pressure of the water above the sensor diaphragm and output a corresponding signal to the surface via the cable which can be converted to level. The signal can then be taken off to a data processing and control system which can be used to trigger a relay and turn the pump off if the level is too low. The measurement of groundwater level may be logged locally or transmitted depending on the design objective. Hydrostatic pressure sensors determine water level in a well using the hydrostatic effect of non-flowing fluids. This physical principle describes the effect of the weight force of a non-flowing liquid on a measuring point. This weight force is usually described as "hydrostatic pressure". The most important condition for hydrostatic level measurement is what is called the "hydrostatic paradox". Hydrostatic paradox states that the fluid pressure at a measuring point of a column is proportional to the filling height regardless of the shape and volume of the column. That is, the fluid pressure at a given depth does not depend on the total mass or total volume of the liquid, but on the depth of the liquid, the density of the liquid, and the acceleration of gravity as expressed in equation 3.

$$P_{static\ liquid} = \rho g h \qquad \text{Eq. 3}$$

Where
ρ = liquid density
g = acceleration of gravity
h = depth or filling height of liquid

Pressure transducers offer an alternative measurement method that avoids many problems associated with other measurement techniques described earlier in this write-up. Ref. 31 described a pressure sensor that is inexpensive and easy to construct. The sensor was placed below the expected low water level in a shallow well and, when connected to a datalogger, was used to detect groundwater elevations. They stated in their report that the pressure sensor has linear response to changing water levels. Also, measurement errors resulting from temperature fluctuations are shown to be about 4 cm over a 35°C temperature range, but are minimal when the sensors are installed in groundwater wells where temperatures are less variable. They concluded that greater accuracy may be obtained by incorporating water temperature data into the initial calibration. Ref. 32 proposed a telemetry system for sensing groundwater level data in real-time using Field Programmable Gate Arrays and Wireless Local Area Networks. They used hydrostatic pressure sensor as the sensing device. The major disadvantage of the system is the very high cost of its implementation.

11. CONCLUSION

Manual measurement of water levels can provide information at many sites, but does not provide continuous data, and may miss short-term changes. The data may be inadequate for modeling groundwater hydrology or understanding the effects of hydrologic regime on groundwater. In addition, such manual measurements are labour intensive and time-consuming, especially if the wells or boreholes are located in remote areas and frequent measurements are required. Other sensor technologies such as ultrasonic, radar, capacitive and optical sensors have been used, but each of them has limitations when it comes to application in groundwater level monitoring. Pressure sensors offer an alternative measurement method that avoids many problems associated with other methods. They can be connected to conditioning circuits programmed for measurement intervals ranging from hours to days or longer, or to record measurements only when water levels change. Advancements in the field of control and instrumentation can be explored to take advantage of the varieties of sensor technologies to perform automatic determination and logging of groundwater level data.

REFERENCES

[1] Lohani, A. K. and Krishan, G., “Application of Artificial Neural Network for Groundwater Level Simulation in Amritsar and Gurdaspur Districts of Punjab, India.”, J Earth Sci Clim Change, Volume 6, issue 4, 2015.
[2] C. J. Taylor and W. M. alley, “Groundwater Level Monitoring and the Importance of Long-term Water Level Data”, U.S. Geological survey Circular 1217, 2001.
[3] Dardo Oscar Guaraglia and Jorge Lorenzo Pouza, “Introduction to Modern Instrumentation”, De Gruyter Open Ltd. Warsaw, Berlin, 2014.
[4] Alan S, Morris and Reza Langari, “Measurement and Instrumentation: Theory and Application”, Academic Press, Elsevier, U.S A., 2012.
[5] Paul B. O., “Seventeen Level sensing Methods. Chemical Processing”, 1999.
[6] William C. Dun, “Introduction to Instrumentation, Sensors, and Process Control”, Artech House Inc., USA, 2006.
[7] Vass G., “The Principles of Level Measurement”, Sensors Magazine, Volume 17, No. 10, 2000.
[8] Enrico Bossart, “Trade Article on Fundamentals of Hydrostatic Level Measurement”.
[9] Walt Boyes, “Understanding How Ultrasonic Continuous Level Measurement Works”, 2013.
[10] Michal Kelemen, Ivan Virgala, Tatiana Kelemenova, lubica Mikova, Peter Frankovsky, Tomas Liptak and Milan Lorinc, “Distance Measurement via Using of Ultrasonic Sensor”, Journal of Automation and Control, Vol. 3, no. 3, pp. 71-74, 2015.
[11] S. Jatmiko, A. B. Mutiara and M. Idriati, “Prototype of Water Level Detection System with Wireless”, Journal of Theoretical and Applied information Technology, Volume 37, no. 1, pp. 52-59, 2012.
[12] Karolie Nobre Dantas Grassi, Raimundo Carlos Silverio Freire and Juan Moises Maurico Villanueva, “Evaluation of Wavelet Analysis Performance in Multiphase Level Measurement Using Ultrasonic Sensors”, Instrumentation and Measurement Technology Conference proceedings, Montevideo, Uruguay, 2014.

[13] Katsuhiko Tanaka, Nobutaka Hiraoka, Takeshi Mishina, Kazunari Sako, Ryoichi Fukagawa, Asako Togari, Hiroyuki Morishima and Makoto Shimamura, "Monitoring of Soil Moisture and Groundwater Level Using Partially Embedded and Completely Embedded Ultrasonic Detectors to Predict Slope Failure", Procedia Engineering 25, pp. 371-374, 2011.
[14] Dhiraj Ahuja and Deepa Parande, "Optical Sensors and Their Applications", Journal of Scientific Research and Reviews, Vol. 1(5), pp. 60-68, 2012.
[15] Esequiel Mesquita, Tiago Paixao, Paulo Antunes, Francisco Coelho, Pedro Ferreira, Paulo Andre and Humberto Varum, "Groundwater Level Monitoring Using a Plastic Optical Fibre", Sensors and Actuators Ai Physical, 240, pp. 138-144, 2016.
[16] L. F. Ferreira, P. Antunes, F. Domingues, P. A. Silva and P. S. Andre, "Monitoring of Sea Bed Level Changes in Near Shore Regions Using Fibre Optic Sensors", Measurement, 45, pp. 1527-1533, 2012.
[17] M. Lomer, J. Arrue, C. Jauregui, P. Aiestaran, J. Zubia and J. M. Lopez-Higuera, "Lateral Polishing of Bends in Plastic Optical Fibres Applied to a Multi-point Liquid level Measurement Sensor", Sensors and Actuators A, 137(1), pp. 68-73, 2007.
[18] Chun Liang yang, Hui-Tzu Jung, Hong-Sing Lee and San-Liang Lee, "Optic Fibre Sensor Employing Soaking Discolouration Ink for Water Immersion Detection", IEEE International Symposium on Intelligent Signal Processing and Communication Systems, Taipei, Taiwan, pp. 880-882, 2012.
[19] Brajesh Kumar, G. Rajita and Nirupama Mandal, "A Review on Capacitive-Type Sensor for Measurement of Height of Liquid Level", Measurement and Control, Vol. 47(7), pp. 219-224, 2014.
[20] Guirong L. and Shuyue C., "A Capacitive Liquid Level Sensor With Four Electrodes", 3rd IEEE International Conference on Computer Science and Information Technology, Chengdu, China, pp. 628-632, 2010.
[21] Ferran Reverter, Xiujun Li and Gerard C. M. Meijer, "Liquid-Level Measurement System Based on a Remote Grounded Capacitive Sensor", Sensors and Actuators A: Physical, Vol. 138, pp. 1-8, 2007.
[22] A. Quathobi, R. F. Iskandar, A. Krisnatal and Weldzikarvina, "Design of capacitive Sensor for Water Level Measurement", Journal of Physics: Conference Series 776, 2016.
[23] Bryan J. Heiner and Thomas W. Gill, "Water Level Sensors, What Works?" 4th International Junior Researcher and Engineer Workshop on Hydraulic Structures. USA, 2012.
[24] Joseph D. Ritchey, "Electronic Sensing Devices Used for In Situ Groundwater Monitoring", Groundwater Monitoring and Remediation, Vol. 6(2), pp. 108-113, 1986.
[25] Jaehyoung Yu and Hernsoo Hahn, "Remote Detection and Monitoring of a Water Level Using Narrow Band Channel", Journal of Information Science and Engineering 26, pp. 71-82, 2009.
[26] [K. A. Mohd Annuar, N. A. AbHadi, I. M. Saadon and M. H. Harun, "Design and construction of Liquid Level Measurement System", Journal of advanced Research in Applied Mechanics, Vol. 12, no. 1, pp. 8-15, 2015.
[27] United States Geological Survey, "Measuring and Mapping Groundwater Levels in Wells", 2005.
[28] Janie Hopkins P. G. and Bryan Anderson, "A Field Manual for Groundwater Level Monitoring at the Texas Water Development Board", 2016.
[29] Jelinski J., Clayton C. S. and Fulford J. M., "Accuracy Testing of Electric Groundwater Level Measurement Tapes", U.S. Geological Survey Open-File Report 2014-1236, 27p., 2015.
[30] Joe Henggeler, "Installing and Inexpensive Air Line to Measure Water Depths in Wells".
[31] B. D. Keeland, J. F. Dowd and W. S. Hardegree, "Use of Inexpensive Pressure Transducers for Measuring Water levels in Wells", Wetlands Ecology and Management 5, pp. 121-129, 1997.
[32] Srikanth Anumalla, "Groundwater Monitoring Using Smart Sensors", 2004. Unpublished.

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