DESIGN OF SUBMERSIBLE WATER LEVEL MEASURING DEVICE

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Abstract

This paper presents an alternative design of water level measurement, which is aimed for flood warning and predicting applications. The depth of water can be calculated from underwater pressure using the formula $P = \rho gh$ where P is the differential water pressure, ρ is the density of water (1,000 kg/m^3), g is the acceleration due to gravity (9.81 m/s^2) and h is the depth of water. Due to the suspended sediment, which could be found in natural ground water, the calculated depth of water can be effected since the density of the mixture increases. The result of our study on the effect of suspended sediment to the calculated depth of water is presented in this paper and it is used for designing a submersible water level measuring device.

Keywords: Suspended Sediment, Water Level Measuring Device, Pressure Sensor

Introduction

Measuring of ground water level is an important procedure in order to acquire information used in prediction and prevention of flood. Water level measurement can be done using instruments such as staff gauge and automatic gauge recorder. Staff gauge is the simplest water level measuring instrument, but it requires on-site visit in order to read water level. The automatic gauge recorder is more complicated instrument, but it provides more features such as information of water level over period of time or remote reading of water level[1]. Automatic gauge recorder requires housing for permanent installation and protection of high-cost instruments.

These water level measuring instruments are installed above surface of water to be measured, therefore they require stationary place to hold them.

In this paper, we propose an alternative approach for measuring water level by sensing under water pressure and then convert it to height of water above. Our device is equipped with wireless communication module, which can transmit and receive information to form a network of water level measuring instruments. Our design eliminates the need for permanent installation of such instrument since it can be anchored and submerged under water which allow quick deployment.

The factor that effects on this concept is the density of water caused by suspended sediment which is commonly found in natural ground water.

In this paper, we present our experimental result of sediment effect on under water pressure and then use the conclusion obtained from this experiment in designing a prototype of submerged-type water level measuring device.

Pressure in the liquid

Pressure in liquid is the measure of force per unit area exerted by a liquid, acting perpendicularly to any surface it contacts.The standard SI unit for pressure measurement is the Pascal (Pa) or N/m^2[2]. There are three types of pressure in liquid:

(1) Absolute Pressure is difference between the pressure at a given point in a liquid and the absolute zero of pressure or a perfect vacuum

(2) Gage Pressure is difference between the absolute pressure and the local atmospheric pressure or vacuum pressure, depend on temperature, altitude, and the external environment.

(3) Differential pressure is different pressure between two references which is used to measure pressure drop in a liquid system. Figure 1 shows the relationship between absolute pressure, gage pressure and atmospheric pressure

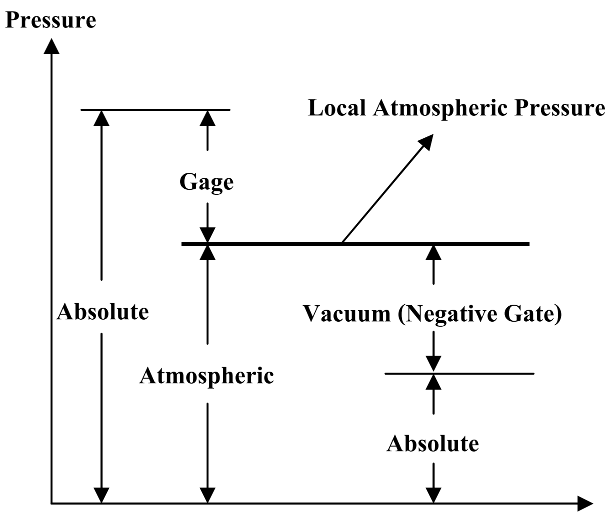

Figure 1 Pressure Term Relationships[2]

Calculation of pressure in the liquid

Pressure in liquid can be calculated from: $P_{abs} = P + \rho gh$

where

P_{abs} is the absolute pressure at depth h,

P is the external pressure at the top of the liquid (For most open system, this is atmospheric pressure),

ρ is the density of water (kg/m^3),

g is the acceleration due to gravity (9.81 m/sec^2) and

h is the depth of water (m)

Figure 2 shows two containers with the same liquid exposed to the external pressure. At the same depth, the pressure must be equal.

Suspended Sediment

Suspended sediment is created by erosion of soil because of rain and flow into natural water resources. Amount of suspended sediment depends on many factors such as amount of rain, types of soil, gradient and increasing water from community [3].

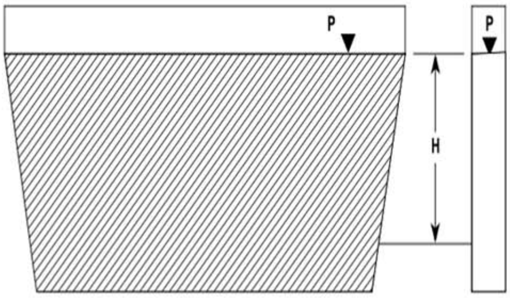

Figure 2 Pressure Measurement at a Depth in a Liquid[2]

To study the effect of suspended sediment on underwater pressure, we used suspended sediment whose specific gravity is about 2.65[4]. The suspended sediment data we used in our experiment was taken from the Department of Water Resources[5]. Table 1 shows data of suspended sediment measured from Chi River, Ban Chod, Amphoe Mancha Khiri, Khon Kaen.

Table 1 Sample of suspended sediment and flow rate of the water in Chi River at Amphoe Mancha Khiri, Khon Kaen, on 31 October – 9 November, 2001[5]

Date	Suspended sediment (*tons*)	Flow rate of the water (m^3/s)
31-Oct-01	1,280	185
1-Nov-01	1,290	187
2-Nov-01	1,270	184
3-Nov-01	1,260	183
4-Nov-01	1,250	182
5-Nov-01	1,250	182
6-Nov-01	1,250	181
7-Nov-01	1,250	181
8-Nov-01	1,220	178
9-Nov-01	1,150	168

Methodology

In our work, we conducted two procedures: first, we studied on the effect of suspended sediment to water density and then we used the conclusion of our study to design the prototype of the water level measuring devices.

Suspended sediment and density of water

Given the amount of suspended sediment(by weight) and flow rate of river water as shown in Table 1, the concentration of suspended sediment(C_m) can be calculated from:

$$C_m = \frac{W_s}{f_r \times 8.64 \times 10^4}$$

where

W_s is the amount of suspended sediment (kg),

f_r is the flow rate of river water (m^3/s)

Hence, the concentration of suspended sediment on 31 October 2001 shown in Table 1 is equal to

$$\frac{1280 \times 1000}{185 \times 86400} = 0.80\, kg/m^3$$

We created artificial suspended sediment using fine-grain sand and then mixed with water at different ratio in order to create various mixture density to simulate natural ground water. The density of the mixture can be calculated[6] from:

$$\rho_{mix} = C_m + \rho(1 - (C_m / \rho_s))$$

where

ρ_{mix} is the density of mixture (kg/m^3),

C_m is the sediment concentration by mass in the mixture (kg/m^3),

ρ is the density of water (1,000 kg/m^3) and

ρ_s is the density of sediment(2,650 kg/m^3)

Figure 3 shows density measurement of the mixture using hydrometer

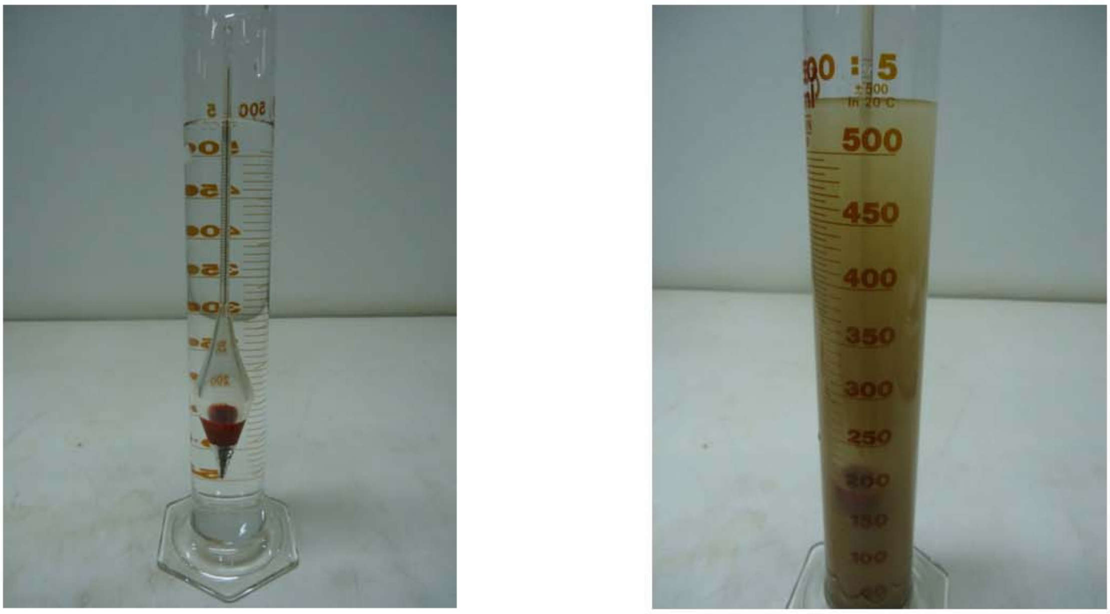

Figure 3 Hydrometer is used for measuring density of water. Pure water(left) and water mixed with sediment(right).

Experimental result

We setup testbench as shown in Fiqure 4. We poured the mixture of water and fine-grain sand in the water tub and then measured the pressure of air locked up in the PVC pipe. The result is shown in Table 2, we have tested different values of concentration from pure water up to 16.060g of suspended sediment per 1 litre of water. The measured values of pressure varied with the concentration of suspended sediment are 0.25% in average, which is significantly low.

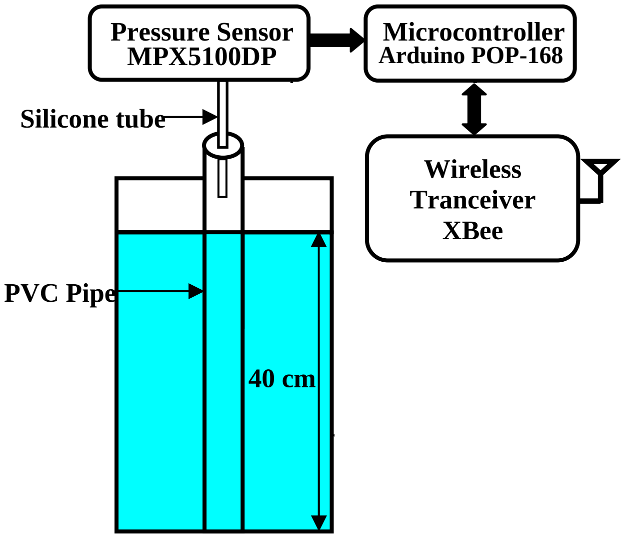

Figure 4 Concept and testing of water level measuring device

Table 2 Result of experiment pressure

Sediment concentration (C_m,(kg/m^3))	**Density of mixture (ρ_{mix},(kg/m^3))**	**Calculated pressure (kPa)**
0	1000	4.232
1.606	1001	4.236
3.212	1002	4.240
4.818	1003	4.244
6.424	1004	4.248
8.030	1005	4.252
9.636	1006	4.256
11.242	1007	4.260
12.848	1008	4.264
14.454	1009	4.268
16.060	1010	4.272

We have compared the actual sediment concentration taken from Chi River as shown in Table 3. It can be seen that the maximum concentration we used in our experiment is about 200 times greater than the typical concentration found in the river. This leads to our conclusion that suspended sediment found in natural ground water has significantly low effect on the underwater pressure.

Design of submersible water level measuring device

Our prototype of submersible water level measuring device consists of 3 major components: pressure sensor, microcontroller and wireless tranceiver. Figure 5 illustrates the component of water level measuring device. We used MPX5100DP, a linear, differential air pressure sensor from Freescale Semiconductor to measured the air pressure created by the depth of water. An Arduino microcontroller board is used for receiving and converting analog signal from pressure sensor. The wireless transceiver is used for transmiting information of water level to receiver station. Figure 6 illustrates the internal layout of the prototype. The PVC tube, whose diameter is 2 inches and 7.5 inches long, is used as housing.

Table 3 Calculated for sediment concentration in Chi River at Amphoe Mancha Khiri, Khon Kaen, on 31 October – 9 November, 2001[5]

Sediment concentration (kg/m^3)	Density of water (kg/m^3)
0.0800	1000.0499
0.0798	1000.0497
0.0798	1000.0497
0.0796	1000.0496
0.0794	1000.0495
0.0794	1000.0495
0.0800	1000.0498
0.0800	1000.0498
0.0794	1000.0494
0.0792	1000.0493

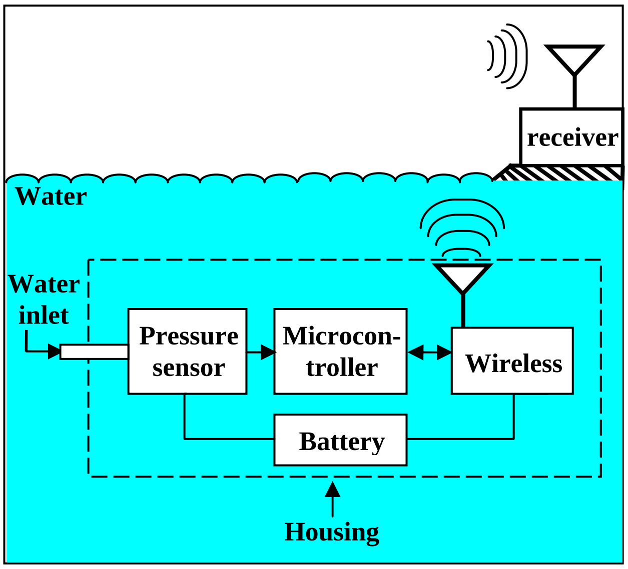

Figure 5 Components of water level measuring device

Performance of submersible water level measuring device

We tested the prototype in a swimmimg pool. We tied the prototype with a rope with marking scale on it. The prototype was dipped in the water starting from surface of water to depth of 2.4 m. The pressure was recorded every 0.2 m as shown in Table 4. We compared the measured pressure against the theoretical pressure foe each depth ang then calculated the error.Note that we use ρ = 998 kg/m^3 and g = 9.7842 m/s^2 in theoretical pressure calculation.

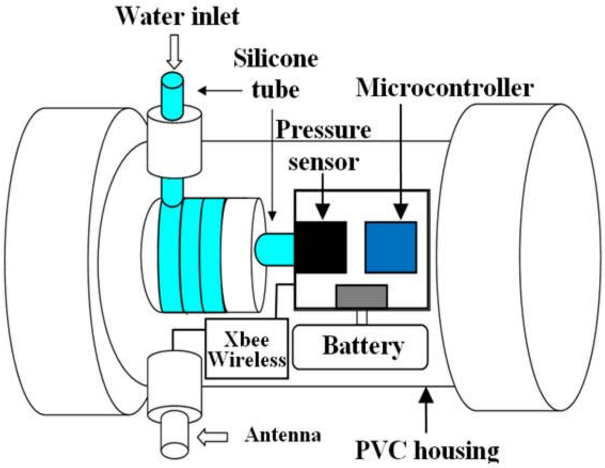

Figure 6 Internal layout of the prototype

Table 4 Result of depth measurement

Water Level actual depth (*cm*)	Measured pressure (*kPa*)	Theoretical pressure (*kPa*)	Error %
20	1.953	1.953	0.01
40	3.906	3.906	0.01
60	5.859	5.859	0.01
80	7.813	7.812	0.01
100	9.766	9.765	0.01
120	11.610	11.718	0.92
140	13.455	13.670	1.58
160	15.299	15.623	2.07
180	17.144	17.576	2.46
200	18.989	19.529	2.77
220	20.833	21.482	3.02
240	22.678	23.435	3.23

The measured depth can be estimated using a linear equation $h = 10.541p - 2.94085$. as shown in Figure 7.

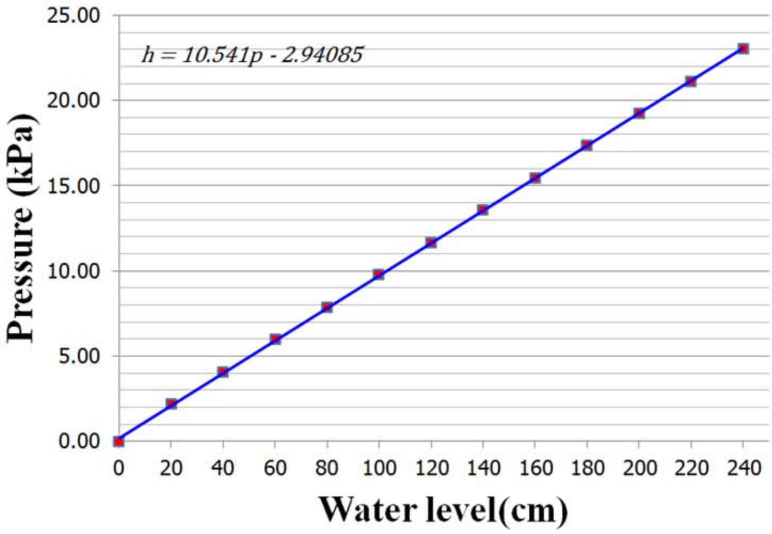

Figure 7 Relationship between the pressure and the water level.

Figure 8 shows the prototype is being tested and calibrated.

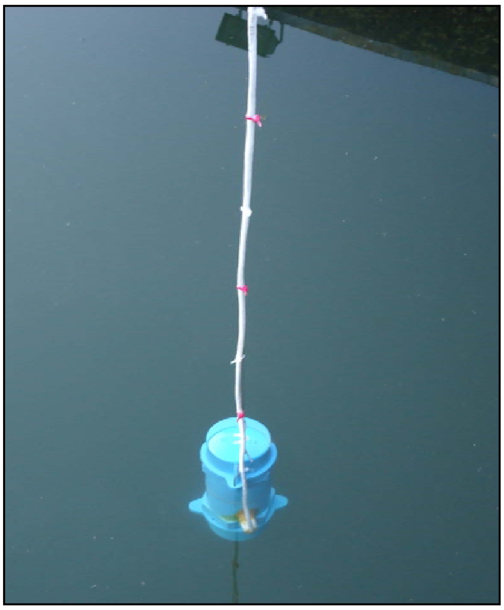

Figure 8 Testing and calibrating of the prototype

Conclusion and future work

In this paper, we have designed and built a prototype of submersible water level measuring device. We have showed that suspeded sediment normally found in natural ground water does not effect the underwater pressure that we used to calculate depth of water. The prototype was tested and we founded that the average accuracy of the device is 1.34%. We are working on designing firmware in order to create wireless sensor network capability for this device.

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