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Mechatronic System Design and Implementation for Liquid Level Measurement

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ABSTRACT

Liquid level measurement is used to determine the height or volumetric amount of liquid in a tank. The aim is to do maximum work using minimum energy. Different types of level measurement methods are used according to the places of use. The designed and implemented system is aimed to keep the liquid level in the tank constant at the desired value. The control of the system is provided by PID (Proportional Integral Derivative) control method using a microcontroller. 16F877A is used as the microcontroller. The software of the level control is written in C language. Updating the software and examining the effect of the desired parameters on the level control were carried out with microcontroller. The detection of the liquid level was made by means of optical sensors. The level control of the liquid in the tank was carried out by controlling the pump and valve with software. A mechanism has been placed that can be controlled manually in case of an emergency. Security control is provided both electrically and mechanically. The designed and implemented system is inexpensive and can be used easily in the industry. It will also provide great benefits in electrical, electronics and mechatronics education.

Sıvı Seviye Ölçümü için Mekatronik Sistem Tasarımı ve Uygulaması

ÖZ

Sıvı seviye ölçümü, bir depoda bulunan sıvının yüksekliğinin veya hacimsel miktarının belirlenmesi amacıyla kullanılır. Amaç minimum enerji kullanılarak maksimum iş yapmaktır. Kullanım yerlerine göre farklı tip seviye ölçüm metotları kullanılmaktadır. Tasarlanıp uygulanan sistem ile depodaki sıvı seviyesi istenilen değerde sabit tutmak hedeflenmektedir. Sistemin kontrolü mikrodenetleyici kullanılarak PID (oransal-integral-türevsel) kontrol metodu ile sağlanmıştır. Mikrodenetleyici olarak 16F877A kullanılmıştır. Seviye kontrolünün yazılımı C dilinde yazılmıştır. Yazılımın güncellenmesi ve istenilen parametrelerin seviye kontrolüne etkisinin incelenmesi mikrodenetleyici ile gerçekleştirilmiştir. Depo içindeki sıvı seviyesinin algılanması optik sensörler vasıtasıyla yapılmıştır. Depo içinde bulunan sıvının seviye kontrolü; yazılım sayesinde pompa ve valfin kontrol edilmesiyle gerçekleştirilmiştir. Herhangi bir acil durum anında manuel olarak kontrol edilebilecek düzenek yerleştirilmiştir. Güvenlik kontrolü hem elektriksel hem de mekaniksel olarak sağlanmıştır. Tasarımı ve uygulaması yapılan sistem ucuz ve endüstride kolaylıkla kullanılabilecek düzeydedir. Ayrıca, elektrik elektronik ve mekatronik eğitiminde büyük faydalar sağlayacaktır.

Anahtar Kelimeler: Mekatronik sistem tasarımı, PID kontrol, Sıvı seviye kontrolü, Mikrodenetleyici

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1. Introduction

In many areas of our lives, devices called tanks are used to store liquids. Especially, the measurement and control of the levels of solids or liquids in the tank are widely used in many areas of life. In general, the optimal level sensor selection for a particular application is based on requirements such as measuring range, liquid properties, resolution, accuracy and environment within the warehouse [1]. For example, when choosing high-accuracy level sensors in the pharmaceutical industry, there are also applications that only need an approximate level indicator, such as the water treatment system. This means that a wide range of instruments can be used according to the applications and criteria required by the user. E.g; storage of water and liquid fuel in apartment heating systems, reserve water tanks in homes. In addition, it is important that the liquids used in the industry are stored and kept ready for use. Examples such as storage of oil produced in the oil factory, storage of milk in milk storage centers, fuel tanks on ships and aircraft can be given [2]. It is also used in practice to keep the liquid at the desired temperature and level by using more than one tank [3]. It is important for safety in such systems that the liquids in the tanks are at appropriate levels. If the liquid levels in the tanks are not controlled, it can cause major accidents and waste. Level measurement in petroleum tanks is a very important issue especially in underground tanks. In addition, liquid level measurement in tanks located in places that are difficult to reach is of great importance.

The liquid level value in the tanks is generally specified in two ways as continuous level and intermittent level. At the continuous level, the level values of the tank between empty and full are indicated numerically. At the intermittent level, the liquid level in the tank is determined with the help of lighted indicators according to predetermined levels (such as empty, half, full). Liquid level control systems are execute by choosing one of these two options.

In the literature, level measurement methods are grouped as mechanical and electrical. Especially in electrical level measurement, studies have been carried out using various sensors. Capacitive [4] and ultrasonic [5,6] sensors are widely used. Ultrasonic –based sensor [7] and magnetostrictive sensor [8] are also used for liquid level measurement. The measurement resolution of the magnetostrictive level meter is sensitive up to 0.1 mm. In addition, researchers have used a conductivity-based rapid level detection technique using a new type of digital sensor called a vibrating sensor [9] and studies in this area are continuing intensively. The sensitivity of optical sensors used in system designs depends on clear light in the environment and lossless reflection values. Fiber optic sensors are widely used for level control in tanks where flammable liquid materials are used [10].

The decisions made during the product design process directly affect the product cost. Therefore, cost reduction efforts should be incorporated into the design process. The target costing system considers the design process as part of the cost. For this reason, making the systems used at affordable costs causes the production and product to be cheaper [11]. Nowadays, automatic control systems are used in many places, from the simplest application areas to the most complex industrial applications. The purpose of these control systems is to control and keep all physical and chemical variables under control without being dependent on human power. Generally, automatic control systems are examined in two groups as open-loop control system and closed-loop system [12]. The most important unit for the control system is the controller. Programmable logic controllers (PLC) [13], microcontrollers [14], digital signal processors (DSP) [15] and compact proportional-integral-derivative (PID) controllers [16] are some of the control systems used in processes.

In addition, methods such as on-off, proportional (P), proportional-integral (PI), proportional-derivative (PD) and proportional-integral-derivative (PID), which are used as control methods, are used extensively in R&D studies and production. A more successful and responsive control method should be selected in the control of the system. Particularly, there is great interest in the proportional-integral-derivative control system. Because the desired results can be obtained in a shorter time in the control method. Methods such as proportional integral derivative (PID) plus feedback controller [17], self-adjusted PID controller [18], advanced PI controller [19] with hybrid genetic adaptation have been used in system controls.

In this study, simulation studies were carried out for liquid level measurement, and software was prepared to be loaded into the microcontroller according to the results obtained. The mechanical parts of the measurement system were prepared, the necessary equipment was added and the electrical connections were made. By performing many experiments, the most suitable control parameters were determined and the software loaded on the microcontroller was updated. Compared to other level measurement systems an easy-to-use and inexpensive level measurement system has been realized. In addition, it is thought that the study makes a great contribution to education.

2. Material and Method

In this study, 16F877A as microcontroller, optical sensors for liquid level determination, centrifugal pump as control element, solenoid valve and proportional integral derivative (PID) as control method are used. It is aimed that the elements to be used primarily in the mechatronic system design for liquid level measurement will benefit industrial and educational purposes. Centrifugal pumps are used to pressurize the liquid by converting the rotating kinetic energy of the liquid into hydrodynamic energy. The liquid enters the pump impeller along the axis of rotation, accelerates by the pump impeller and transfers the absorbed liquid to the desired section by centrifugal effect [20]. The pump is generally used to transfer liquid to the tank. Seleniod valve is the general name of the valves that are involved in the control of liquids that can be controlled (opened and closed) with an electrical signal. While the purpose of use is decisive in the valve selection, the solenoid valve should be selected according to the pressure and temperature of the fluid.

2.1. PID Control method

PID controllers are frequently used in industrial and R&D studies due to their powerful and effective performance. Each gain parameter (P, I and D) in the PID controller affects the operation of the system in which it is used. So each parameter has a different effect. Each of the blocks that make up the PID controller is managed with a gain parameter. These gain parameters receive different values for each system designed [21]. The basic control block diagram of the PID controller is given in Figure 1. In order to control any device, the output values must first be mathematically defined. The mathematical expression forms the basis of the PID controller. The output mathematical expression of the block diagram of the PID controller given in Figure 1 is given in Equation 1 [22].

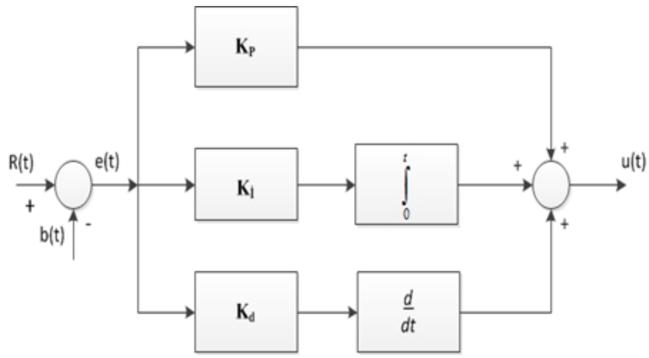

Figure 1. Block diagram of PID controller

$$u(t) = K_P\, e(t) + K_\text{i} \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \quad (1)$$

As shown in the block diagram in Figure 1, the PID calculates a continuous error value e(t). E(t) signal is the difference between the targeted state R(t) and the measured state b(t). The PID controller aims to minimize the error by making the necessary adjustments and setting the control variable u(t). In this way, the controller maintains the control system at the desired levels.

2.2. Design of mechatronic system

In this study, the control of the level in the tanks with liquid was carried out using a microcontroller, electronic circuits and software. In the designed and implemented mechatronic system, there is a liquid tank, level control elements used to determine the amount of liquid in the tank, and a microcontroller that controls the system. The block diagram of the system is shown in Figure 2. The liquid level system works with the software prepared and installed according to the desired criteria to the microcontroller. The important thing is that the software installed in the microcontroller is prepared accordingly to the needs. In addition, it is important that the control values can be changed via the display and keypad if desired. The regular and synchronous operation of the software and hardware in the system is of great importance in terms of security. In case of any problem, the system automatically switches to protection. The liquid level is fixed at the desired level and the inputs and outputs to the tank are stopped.

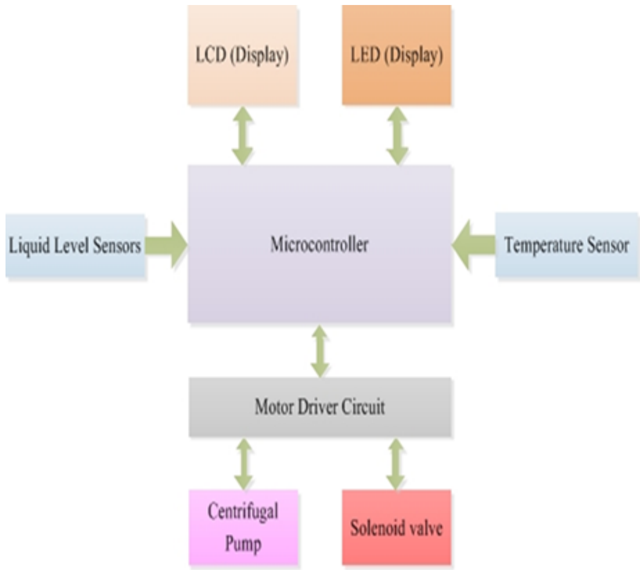

Figure 2. Block diagram of the mechatronic liquid level measurement system

The operation of the implemented system consists of two steps. In the first step, parameters such as the liquid level value and temperature in the tank are detected by sensors and sent to the microcontroller. Optical sensors are used for level determination. The measurement accuracy of optical sensors depends on the clear and good reflection of the light in the environment in which it is used. In the second step, the microcontroller controls the centrifuge and solenoid valve through control relays in order to bring the liquid level in the tank to a predetermined level according to this incoming data. The system operates in a loop by constantly controlling the liquid level with the software installed on the microcontroller. The schematic representation of the liquid measuring system is shown in Figure 3.

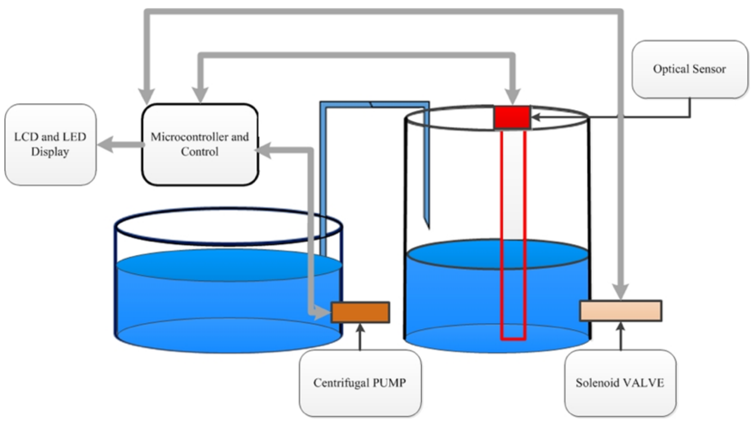

Figure 3. Schematic representation of the liquid level measurement system

2.3. Liquid level determination method of the system

To determine the level of the liquid in any tank, the amount of liquid entering and exiting the tank should be expressed mathematically. The mathematical equation is used in software that allows the system to be controlled. In addition, it is used to obtain the transfer function required for the control of the system. If the height of the liquid in the tank is h and the base area of the tank is determined as A;

$$Liquid\ coming\ out\ of\ the\ tank\ (L_C) = m.\sqrt{2.g.h} \qquad (2)$$
$$A.h = Liquid\ filled\ into\ the\ tank\ (L_F) - (L_C)$$

$$A.h = L_F - m.\sqrt{2.g.h} \quad (3)$$
$$h = \frac{L_F}{A} - \frac{m}{A}.\sqrt{2.g.h} \quad (4)$$

statements are obtained. The transfer function of the system is required for PID control. The transfer function must be in the form of a single mathematical equation in terms of the input value of the output value. The transfer function obtained for liquid level measurement is given in Equation 4. The control of the system using the obtained transfer function is shown in Figure 4. The simulation of the transfer function has been done using the MATLAB program. Similar results were obtained when the simulation results were compared with the experimental results. When the simulation is run, the changes in the liquid level in the tank are observed with the aid of an oscilloscope. The responses of the system were examined and observed at the oscilloscope by changing the P, I and D (K_P, K_I and K_D) values. It is aimed to keep the liquid level constant at 50 cm in the mechatronic liquid level system. E.g; When K_P=3.8, K_I=1.2 and K_D=0.9 are taken, the liquid level reaches 50 cm in 20 seconds, and when K_P=3.4, K_I=0.6 and K_D=0.1 are selected, it reaches around 10 seconds. In Figure 5, oscilloscope images are given for different values of the PID parameters.

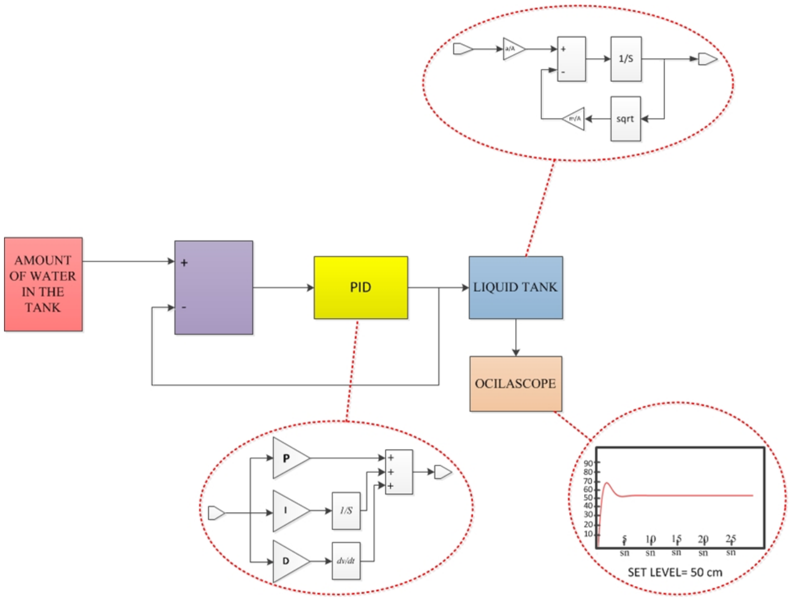

Figure 4. PID control of the liquid level measurement system

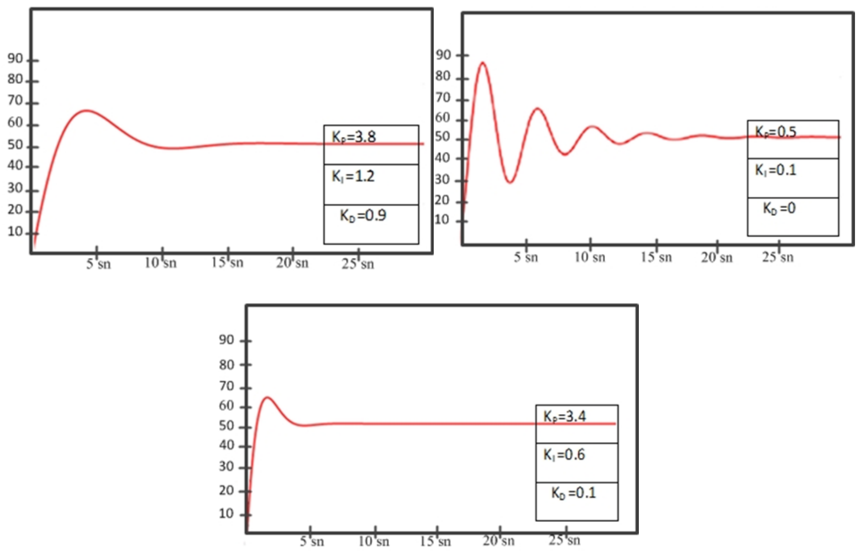

Figure 5. Simulation oscilloscope images for different K_P, K_I and K_D values

2.4. Control units of the system

The control of the mechatronic level measurement system consists of 3 units.

2.4.1. Control part

It is the card that provides information exchange between the input units and output units of the system. It activates or deactivates the control elements according to the values it receives from the input units through the sensors, via the pre-prepared and loaded software on the microcontroller. Through the LCD and sequential LED on it, instant information about the status of the system can be obtained. By means of the keys connected to the control unit, it is possible to select from the programs pre-loaded on the microcontroller. The RS-232 cable on the panel can be used when it is desired to make changes in the program. Program updates can be done by uploading new software to the microcontroller through RS-232 connection [23].

2.4.2. Sensor part

The sensors convert the physical or chemical information in their location into electrical signals and send them to the desired unit. In the liquid control system, the level data detected by the sensors connected to the tank are collected in a center and sent to the control unit by increasing the amplitude value. This unit is the unit the where data collection, transformation and sending process is done. The microcontroller uses these signals and performs the desired operations through the installed software. The microcontroller is insulated with optocoupler to protect it from electrical effects and damages. Data from both the sensors and the microcontroller memory are processed in this unit.

2.4.3. Relay part

Relays provide control of large values with small electrical signal values. In the relay card, the intended elements (such as pump and valve) are controlled according to the information sent from the microcontroller. That is, the operating voltages of the elements are activated. Each relay has been given the task of controlling a different element. In addition, alarm and security units are operated via relays.

3. Designed and Performed Mechatronic Liquid Level System

The aim of this study is to determine the level of the liquid in the tank and keep it at the desired level by controlling the liquid level according to the software previously written in C language and uploaded to the microcontroller. The designed and implemented mechatronic liquid level measurement system is shown in Figure 6.

Figure 6. Mechatronic liquid level measurement system

Optical sensors have been used as liquid level sensors. These sensors are placed in a transparent glass tube inside the tank. The signals leaving the sensor to determine the liquid level and returning to the sensor must be error-free. Therefore, a water buoy is used on the liquid in the glass tube. The signals from the sensor are returned by hitting the water buoy. In this way, signal loss is prevented. The sensor detects the changes in the liquid level and transmits electrical data to the sensor card. These signals are processed in the microprocessor and control and command operations are performed in the relevant units. In addition, in case of any error in the system, liquid inlets and outlets can be controlled mechanically. The power control unit of the system and the centrifugal pump section that sends the liquid to the tank are shown in Figure 7. The pressure gauge on the pump shows the pressure at which the pump pushes the liquid into the tank.

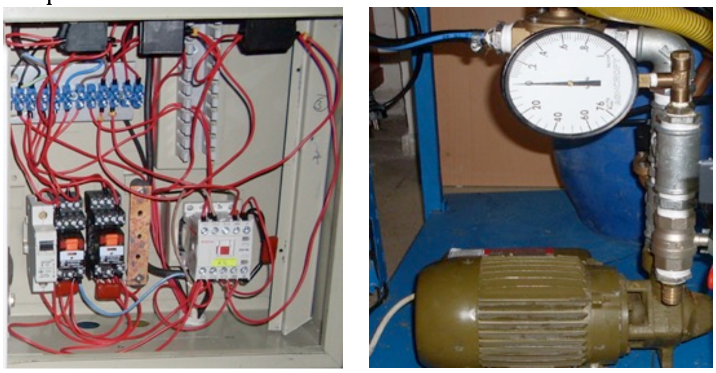

Figure 7. The power control unit of the system and the centrifugal pump

4. Results and Discussion

Mechatronic liquid level measurement system has been designed and implemented. The control of the system has been provided by PID control. The level status of the system can be brought to the desired levels at any time by changing the control parameters for PID control. In the liquid level measurement, the liquid level in the tank was determined as 50 cm. As a result of the simulations and measurements, it was seen that the most ideal values were K_P=3.4, K_I=0.6 and K_P=0.1. Since the design of the system requires knowledge of software, machinery and electronics, it is thought to be an example for mechatronics education and practice. It will also contribute to electrical and electronics education. It can be used easily and at a low cost in many processes in the industry.

Conflict of Interest Statement

The authors declare that there is no conflict of interest

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