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An Automatic Cash Detector for PID Controller Based Self-service Petrol Dispenser

Tati Erlina[1, a)], Mohammad Andreanov[1, b)] and Rahmi Eka Putri[1, c)]

[1]*Computer Engineering Department, Faculty of Information Technology, Andalas University (Kampus Unand Limau Manis, Padang, Indonesia)*

[a)]Corresponding author: tatierlina@it.unand.ac.id
[b)]andreanov@gmail.com
[c)]rahmi@it.unand.ac.id

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Abstract. In this paper, we propose a design and implementation of an automatic self-service petrol dispenser that receives payment from a customer in the form of cash, instead of e-money of or credit card as those in many similar machines existing in Indonesia. Hence, the system can facilitate a vast majority of potential customers who have no access to any form of e-money, credit card, or simply because of personal preference of using cash. The experimental results show that every component can communicate smoothly; thus, relevant parts in the system received information as intended. Furthermore, the system is capable of recognizing the value and authenticity of the cash inserted to the machine using the template matching technique with an accuracy level of 95,83%. As equally important, the amount of petrol which is pumped out-flowing to the customer's tank using a PIC controller with an accuracy level of 98.22%.

INTRODUCTION

Self-service machines have increasingly become an indispensable part of modern society. In many developed countries, the machines are ubiquitous and offered to handle a variety of functions, from vending machines to automatic check-in machines. As opposed to those of the conventional method, the existence of self-service appliances provides many benefits to both business owners and customers [1]. From the industry point of view, the unattended machinery would raise efficiency, reduce costs and labor, while on the flip side, customers gain better control of their transactions.

One of the automatic and self-service instruments which have already been existing for some time in Indonesia is self-service petrol dispensers. Usually, they are located in big cities and still limited in numbers compared to the total number of gas stations demanded. Apparently, the number is not sufficient for serving the need of almost 14 million [2] number of vehicles in the country. Besides that, most of the self-service stations merely accept the non-cash payment such as credit card, debit card, or various platforms of e-money which for some reasons are barely accessible to a significant number of a variety of economic level of gas station customers.

Some previous research has attempted to build a non-conventional system to maximize the merits of such automatic systems. In [3] for example, the authors attempted to develop a QR-code based system that facilitates customers to buy petrol using a bar-coded voucher under their demand to cashiers in a counter. After a customer bought the voucher, they need to input the bar-code to an automatic transaction machine before the petrol is pumped to their tanks. Even though claimed as an autonomous, the existence of labors is still mandatory as a customer are demanded to buy the bar-coded voucher from cashiers. Other researchers in [4] developed a similar automatic system to regulate quota of petrol to be purchased by a customer based on the certain functionality type of registered vehicle. The amount of the quota is identified using Radio Frequency Identification (RFID) technology, while the payment is withdrawn from the account balance of the related ID in a database which can be accessed by every petrol station connected to the server. Unfortunately, the system has not optimally utilized the advantage of being automatic because it still needs a third party in the transaction process.

Therefore, we developed a system which facilitates a diverse background and preference of fuel station's customers to refuel the tanks of their vehicles from self-service petrol dispenser by providing a commonly recognized payment

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method, i.e. cash without the intervention of any labor in the process. The system is built by leveraging various components such as sensors and a single board computer as well as pattern matching and PID controller.

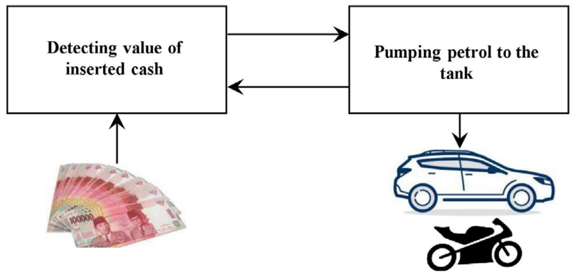

FIGURE 1. Top level view of system architecture

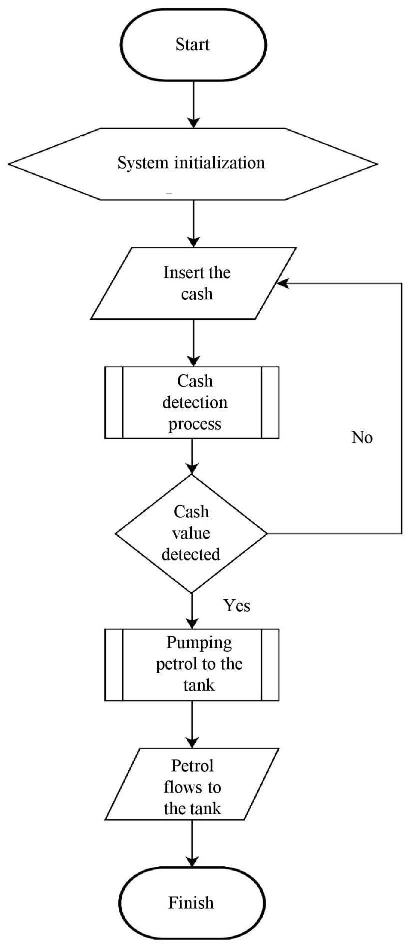

FIGURE 2. Top level view flowchart of the system

RESEARCH METHODS

This research is conducted in accordance with a certain research methodology starting by identifying problems (as it has already explained in section one, system requirement analysis, system design, testing, and analysis. The rest of

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section two would be dedicated to elaborate every remaining step except testing and analysis stage which is described in section three.

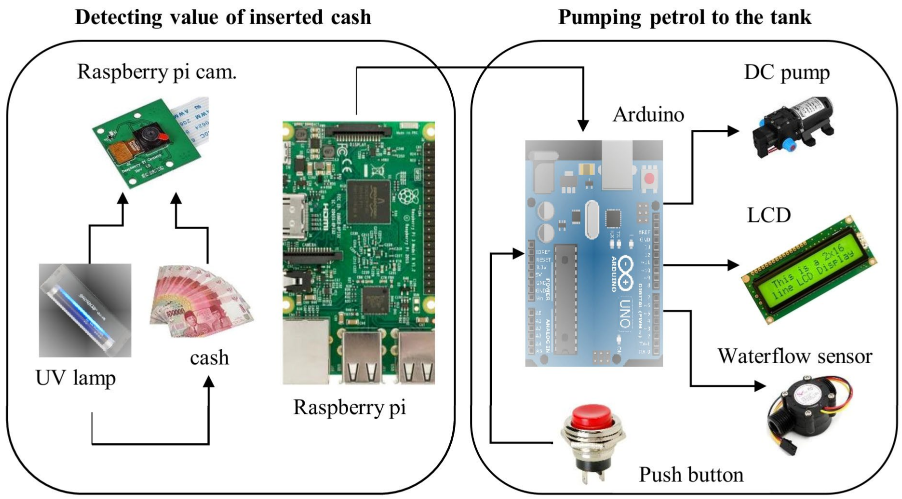

FIGURE 3. Hardware Design

System Requirement Analysis

First, we identify and determine what capability the system should provide in order to solve prior established problems. There are at least three functionality; including capturing image of invisible ink appeared on the surface of the inserted cash and extracting the features using image processing method, identifying the authenticity and value of the cash employing template matching, and converting the value recognized in the cash into the amount of petrol and pumping it out to the tank of customer's vehicle.

Beside requirements related to functionality, hardware, and software specification are also identified in this stage. Raspberry Pi, Camera, ultraviolet light, DC pump, and water-flow sensors are among the required hardware. While in term software, we utilize Raspberry OS, Arduino IDE, and phyton programming.

System Design

A top-level view of the system shown in Fig. 1, consisting of components and programs related to the detection process of value and authenticity of the inserted cash in the payment stage and pumping a particular amount of petrol to customer's vehicles corresponding to the amount of money detected and the petrol price. Flowchart of the overall process in the system illustrated in Fig. 2. In a more detailed fashion, Fig. 3 depicts how every hardware element connected to each other in the two big stages of the overall process. First, the module which is responsible for cash detection comprises mainly of ultraviolet light, camera, and the Raspberry py. The light functions to illuminate the inserted cash in order to enable the camera to capture the invisible ink that appeared on the surface of the cash. While the raspberry pi processes the captured image to recognize the value and authenticity of the cash as well as serves as the controller of the overall cash detection process.

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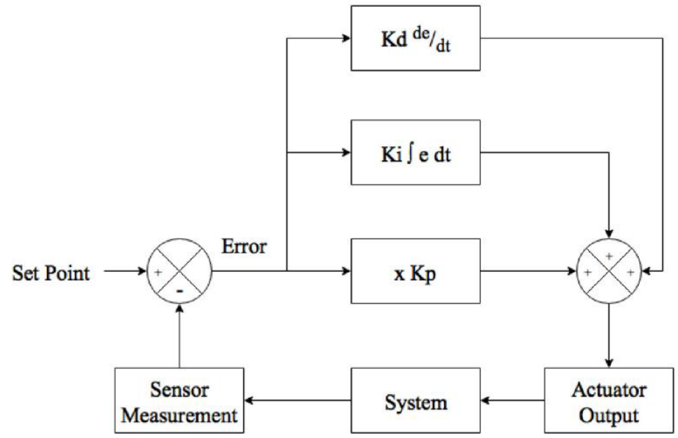

FIGURE 4. Block diagram of PID controller [5]

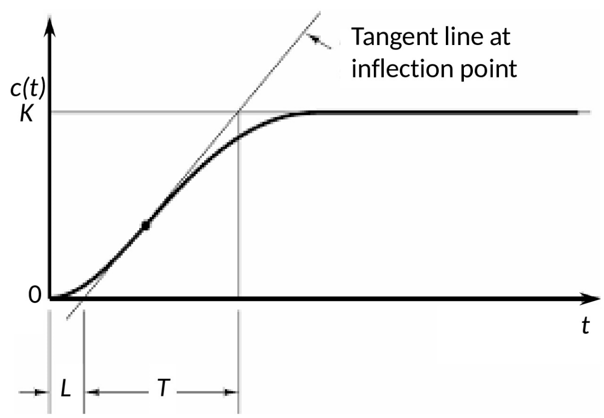

FIGURE 5. The response curve of Ziegler-Nichols [6]

The second major stage of the system handles the flow of petrol to the tank of the customers, constituting of dc pump, water-flow sensor, LCD, push-button and Arduino. As soon as the inserted cash validated by the system, a customer needs to push a button in order to signify the system that the customer's tank is ready to receive the petrol flow and to trigger the system to start pouring the petrol using a DC pump. An LCD displays the nominal of cash and the amount of petrol to be injected in liter. This amount is controlled by Arduino based on continuous data sent from sensor flow.

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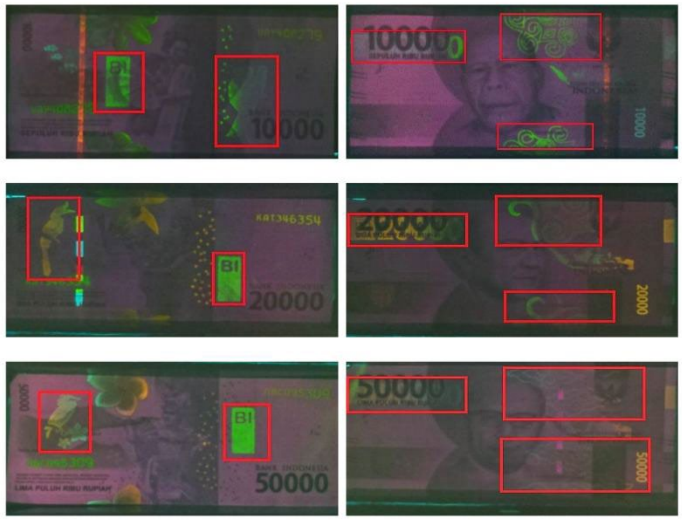

FIGURE 6. The image of invisible ink on the surface of cash illuminated by ultraviolet light and captured by pi camera

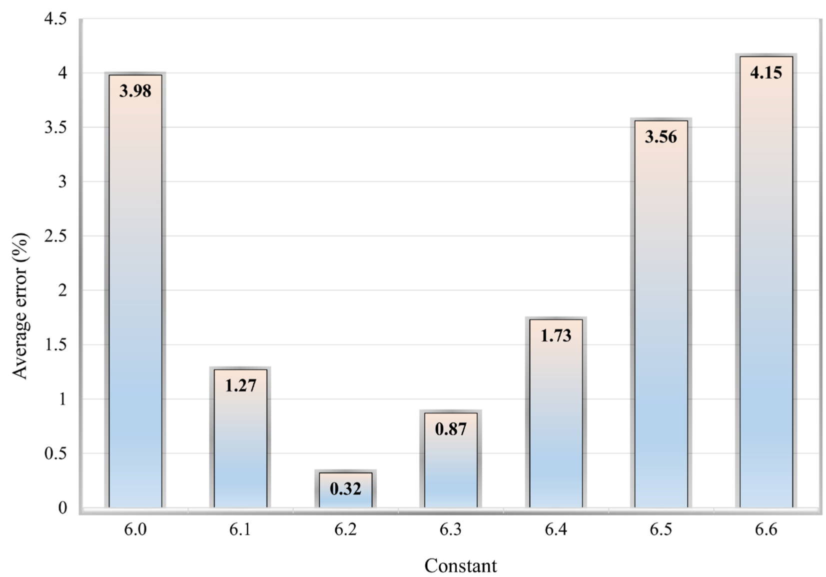

FIGURE 7. Water-flow constant value and related error

In accordance with the hardware design, two application software is also design to support the overall process in the system. A python-based application is built to run in the raspberry pi to support the cash detected system. While the Arduino in the petrol pumping process utilizes C programming based application.

Template Matching Algorithm

We use a template matching algorithm to recognize the value and the authenticity of the cash that would be inserted by a customer to the system. Template matching is one of the widely used image processing techniques by identifying the similarity of a particular area of a source image (I) with the available template (T) in a database [7]. The algorithm works by moving the template images to all areas of the source image, one pixel at a time [8][9]. A mathematical pattern is used to calculate the similarity in each location, aiming to find a particular area that has the highest similarity. For this research, we use *Normed Clustering Coefficient* [10], as shown in Eq. (1).

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$$R_{(x',y')} = \frac{\sum_{x',y'} (T'_{(x',y')} . I_{(x+x',y+y')}{}')}{\sqrt{\sum_{x',y'} T'_{(x',y')^2} \cdot \sum_{x',y'} I'_{(x+x',y+y')^2}}}. \tag{1}$$

where R_{xy} is the result of template matching on x,y coordinate, x' and y' are the coordinate width and coordinate height of template image pixel, x and y are the coordinate width and coordinate height of source image pixel, $T_{x'y'}$ is coordinate of template image pixel and $I_{x+x', y+y'}$ is the coordinate of input image pixel.

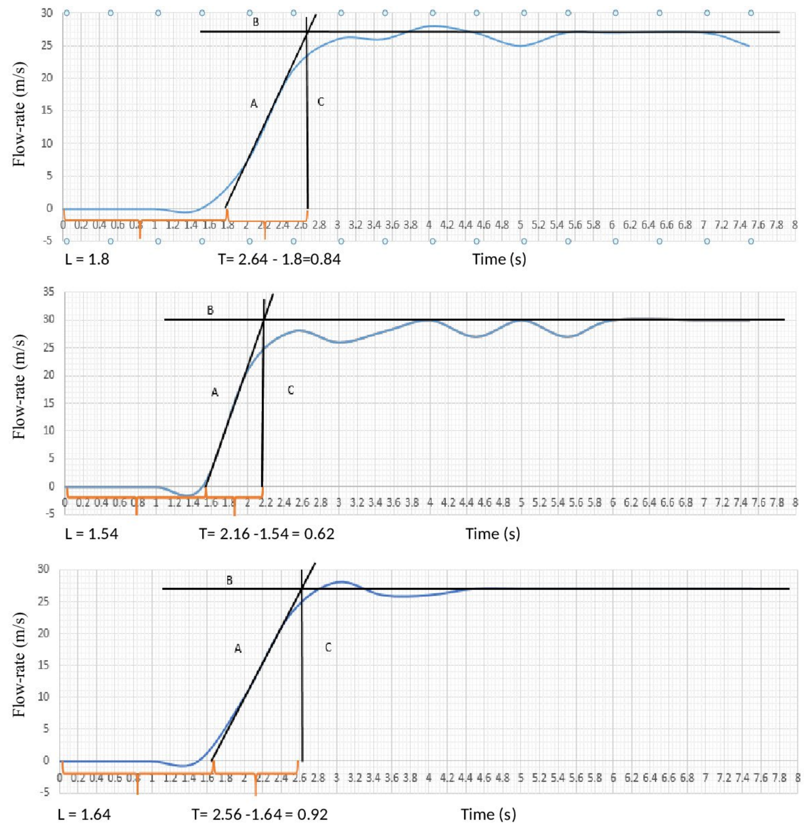

FIGURE 8. Some Reaction Curve in Determining the PID constant

The template images in this research are collected by cropping invisible ink part of sample images which is captured using the pi camera beforehand. Every banknote that would be accommodated by the system has some invisible ink part on both sides which is unique to the particular notes. Examples of invisible ink can be seen in Fig. 4.

For convenience reason, we use template matching technique which is available in the OpenCV, a library produced by Intel that aims to be utilized in processing a dynamic image in real-time. The library is free under a BSD license and can be used along with a diverse programming language like C++, Python etc [11].

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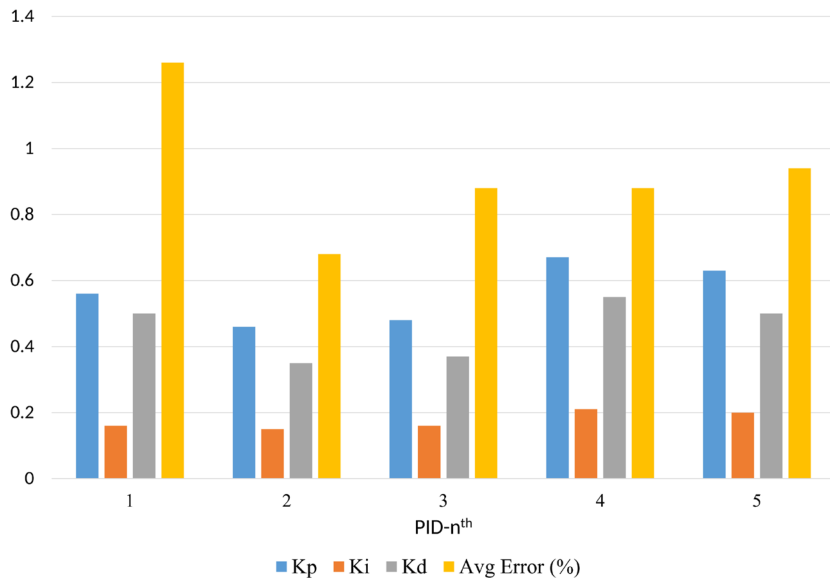

FIGURE 9. The experiment result in Determining PID constant

Proportional-Integral-Derivative (PID) Controller

PID controller is an instrument used as a mechanism to control loop feedback of a system that is expected to be accurate, responsive and stable. As the name implied, the controller is a combination of three basic controllers consisting of proportional (P), integral (I) and derivative (D) which aim to speed up the reaction of a system, eliminated offset and produce a significant early adjustment, respectively [12] [13]. Relation between the three parameters and their interaction with the system as a whole can be seen in Fig. 5.

The characteristics of the PID controller are highly dependent on the contribution of its basic P, I and D controller. The tuning of constant value of Kp, Ki and Kd would determine the strength of each element of the parameters. One of the three parameters can be set much higher than the others, thus, becoming the dominantly affects the overall behavior of the system. Since every parameters are not independent of each other, the change of constant value in one parameter could cause the system to react differently from expected. Mathematically, the control action of a PID controller is expressed as Eq. 2

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \tag{2}$$

where *u(t)* is the controller input, *MV* is the manipulative variable, K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain, *e(t)* is the error, *t* is the instantaneous time and is the τ variable integration.

The proportional controller K_p reduces the rise time of the system but would not eliminate errors continuously. The integral controller K_i could shrink the error repeatedly but would reduce the transient response of the system. The derivative controller would improve system stability, reduce the maximum overshot and increase transfer function. The effect of each controller in a closed loop system is depicted in Table 1.

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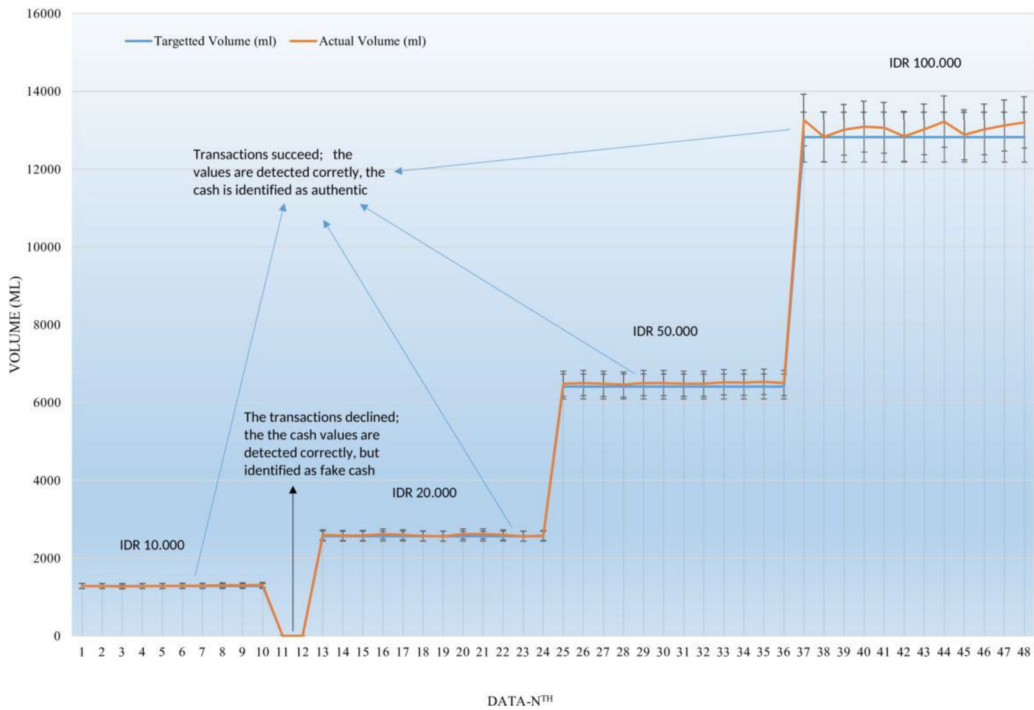

FIGURE 11. Validation of Overall System Functionality

The most commonly used method in PID parameter tuning is Ziegler-Nichols method, that can be performed in two ways, namely reaction curve method and oscillation method for open loop system and closed loop system, respectively.

The parameters of the PID controller are gained based on a controlled characteristic from a particular plant. Every action in the plant needs to be identified by modeling the plant before determining the parameters. Since the arrangement of the mathematical model of a plant is quite challenging, the parameter tuning conducted experimentally. The method is based on the reaction of a plant when a parameter changes. The most commonly used method in PID parameter tuning is the Ziegler-Nichols method, which can be performed in two ways, namely the reaction curve method and the oscillation method for open-loop system and closed-loop system, respectively.

The reaction curve method is applied by looking at the response of a system when input is given. The system response is presented in the form of a reaction curve and is characterized by 2 parameters, namely L (delay time), and T (constant time). This parameter is obtained by drawing a line as shown in Fig. 6 and using the formula in Table 2.

TABLE 1. Effect of Changing PID Controller Parameter Independently [14] [15]

Parameter	Rise time	Overshoot	Settling Time	Steady-state error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminated	Degrade
K_d	Minor change	Decrease	Decrease	No effect	Improved if K_d is small

RESULT AND DISCUSSION

To verify that the proposed system functions as it is intended, a set of test has been conducted hierarchically, consisting of testing of every hardware component and overall operation of the systems.

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TABLE 2. DC Motor Driver Specification

The controller	Kp	Ki	Kd
P	(T/L)	-	-
PI	0.9 (T/L)	0.27 (T/L^2)	-
PID	1.2 (T/L)	0.6 (T/L^2)	0.6T

Camera and Ultraviolet Light

To conduct the test, both components are installed in a black box in order to minimize intervention of light from the environment which could affect the clarity of the invisible ink when the cash illuminated by the ultraviolet light. The camera, ultraviolet light and the cash are then placed in a way that enable the camera on top of the box to capture the invisible ink image appeared on the surface of the banknote as soon as it is illuminated by the light. Examples of invisible lights from both sides of various banknotes shown in Fig. 7, annotated by red rectangles in each examples.

Water-flow Sensor

Data from water flow sensor is received in the form of pulse with various frequency, depending on the speed of fluid flowing through the sensor. In order to measure the amount of petrol flowing in the pipe correctly, the data from the sensor need to be converted into flow-rate (the rate of petrol which pass the sensor per minute) using a particular constant value prior to conversion into volume in liter. Mathematically, the process can be expressed as follows:

$$flowrate = \frac{pulse}{constant}. \tag{3}$$

$$speed = (flowrate/60) * 1000;. \tag{4}$$

$$litervolume = litervolume + speed;. \tag{5}$$

According to information from the data-sheet of the sensor, recommended constant value is in the range of 4.5 to 7.5. Hence, the right value of the constant which will lead to the smallest difference between volume measured with sensor and that of measurement glass, a set of experiment need to be conducted. Based on the experimental result as shown in Fig. 8, the best constant value is 6.2 with 0.32\% average error rate. Using this constant, the sensor works consistently across some other experiment, proving that the sensor functions well as it is expected.

The Pump and Motor Driver

Motor driver testing is conducted by feeding a variety of PWM values into the motor driver L298N and measuring the output voltage of the motor driver to the dc pump using a multimeter. As illustrated in Table 3, the amount of PWM value on the driver would highly affect the voltage on the DC pump, which directly determines the flow rate of petrol pumped to the customer's tank proportionately. In other words, when the driver is given a maximum value of the PWM, i.e. 255, the voltage on the pump would also be the maximum amount of 11,52V (about the same as the supply voltage to the pump), causing the flow-sensor reads the highest flow rate of the pumping capability of the dc pump which is 83ml/sec. On the contrary, when the PWM value is too small (lower than 35), the resulting voltage on the pump can not afford to trigger the flow of petrol.

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The Parameter Tuning of PID Controller

In order to validate that the constant parameter of the PID controller has already set to a suitable value to our system's requirement, particularly in controlling the amount of petrol that would be pumped to the customer's tank, we perform two particular steps in the experiment, including the constant parameter tuning and constant parameter validation.

TABLE 3. DC Motor Driver Specification

No. The controller	Duty Cycle K_p	Vout (V) K_i	Debit (ml/s) K_d
1	255	11.52	83
2	240	11.52	83
3	235	11.52	83
4	215	11.42	71
5	195	11.19	65
6	175	11.02	60
7	155	10.71	60
8	135	10.35	51
9	115	9.94	52
10	95	9.53	20
11	75	9.04	11
12	55	8.52	9
13	35	7.92	5
14	15	7.23	0
15	0	1.51	0

Constant Parameter Tuning. This stage is performed using the reaction curve method of Ziegler-Nichols by activating the DC pump, measuring the flow-rate of the petrol, and then present the resulted flow-rate graphically. In the graphic, a new line is drawn on the existing line formed when the system is in a stable state (line a), then a tangent line is drawn on the curve turning point (line b) until the line intersects with the previous horizontal line. On the intersection point, a perpendicular line is drawn to the x-axis. While the value of T is calculated based on the distance between the intersection point (b and c) and x-axis, the L value is measured from the distance between zero and intersection between the b line and the x-axis. The experiment to determine the PID constant was conducted five times for five different values of K_p, K_i and K_d.

An example of the reaction curve of the experiment shown in Fig. 9. The curve derives from the number of pulse in the water-flow sensor measured every 30 seconds, starting from the moment the pump is ON to the point where the amount of petrol flown is stable. Based on the T and L value gained from the process and the Formula of the reaction curve of Ziegler-Nicols shown in Table 1, we calculate the PID constant.

Constant Parameter Validation. This stage aims to select the best PID constant among a variety of values from the previous stage by feeding the pump with various PWM value illustrated in Table 2, ranging from 35 to 255 (as proven previously, the system does not respond to the PWM value equal to or less than 35). After testing each set of constants for five times in controlling the pump of 1000ml of petrol in the system, we collect the data and select the constant that allows the system to produce the least average error in the process. Figure 10 illustrates the PID constant with $K_p = 0.46$, $K_i = 0.15$, and $K_d = 0.35$ allows the system to produce the minimum average error rate of 0.68%. Therefore, the values are the final constant that would be implemented in the final version of the system.

Validation of System Functionality

Following the completion of the test and data collection of every relevant component separately, we experiment with the higher level, involving every part in the system, which integrated as a whole. The procedure aims to reveal the overall performance, including communication among the subsystems. The assessment starts with transaction

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initiation by inserting cash to the machine until the transfer of petrol to the tank or container of the costumers is complete. It is found that data transfer from cash detection subsystem to the petrol dispenser subsystem are valid, proofing that the subsystems succeed to interact as predetermined. The main components of both subsystems, i.e., raspberry pi and Arduino Uno in cash detector and petrol dispenser, respectively, are connected using a serial cable.

The testing conducted employing four different banknotes of rupiah, 10.000, 20.000, 50.000, and 100.000, three samples for each value, and every sample, each side of the cash are evaluated for every possible perpendicular position of the cash with the horizontal line, resulting in 48 times of experiment. The validity of experiment illustrated in Figure 11 which plots the banknotes recognition which eventually determines the states of the transaction i.e., succeed and declined, for every n^{th} samples of the banknotes and the accuracy of the amount of the petrol transferred to the customer's tanks, with the succeeding level of 95.83% and accuracy 98.22% of accuracy level, respectively.

CONCLUSION

To sum up, we have designed and implement an automatic cash detector for PID controller based self-service petrol dispenser which is intended to receive payment in the form of cash. This system is capable of recognizing the value and authenticity of the cash inserted to the machine using the template matching method with an accuracy level of 95,83%. Every component can communicate smoothly thus relevant parts in the system received information as intended. Finally, the amount of petrol which is pumped out-flowing to the customer's tank using a PIC controller with an accuracy level of 98.22%.

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