SPEKTRA: Jurnal Fisika dan Aplikasinya
Volume 7, Issue 2, September 2022
Homepage: doi.org/10.21009/SPEKTRA

Check for updates

DOI: doi.org/10.21009/SPEKTRA.072.04

INTRAVENOUS INFUSION DOSING SYSTEM FOR VOLUME CONTROL BASED ON SIGNAL PERIODIC MEASUREMENT

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Received: 1 August 2022
Revised: 19 September 2022
Accepted: 22 September 2022
Online: 30 September 2022
Published: 30 September 2022

SPEKTRA: Jurnal Fisika dan Aplikasinya
p-ISSN: 2541-3384
e-ISSN: 2541-3392

ABSTRACT

Intravenous fluid therapy is a commonly used treatment modality that is used in the treatment of hospitalized patients. Intravenous flow rates are often controlled by counting the number of fluid drops in a drip chamber while adjusting the intravenous line with a watch. In this research, an intravenous infusion dosing system was designed based on periodic signal measurement using a pair of light couplers consisting of a transmitter and a receiver. The transmitter is built using an infrared LED (BPV10NF), while the receiver uses an infrared photodiode detector (BPW34). The infusion droplet will pass a slit between the two coupler components and interrupt the light transmission from the transmitter to the receiver, which will affect the current through the photodiode and change the output status of the circuits. The parameters obtained from this circuit signal are droplet frequency from 1 Hz to 10 Hz and droplet sizes 0.05 ml and 0.0167 ml. The resulting output signal is in the form of pulses due to the interruption of the droplet when it passes through the optocoupler. The droplet frequency is calculated based on the period between adjacent droplets, while the droplet size can be measured based on the width of the resulting pulse. For the droplet measurement process, variations of the droplet period and the number of droplets per ml were carried out. The droplet period is regulated by manually adjusting the aperture of the infusion droplet outlet faucet. In contrast, the droplet size is controlled by two types of infusion devices with 20 drops/ml and 60 drops/ml specifications. The experimental results can be used to develop a system response that detects changes in period and droplet size.

Keywords: intravenous infusion, dosing system, droplet sensor, photodiode, optocoupler

INTRODUCTION

In medical, infusion is a very important and a basic treatment for a patient in hospital. It is a method in medical purposes of supplying fluids or drugs into a body through an intravenous track or directly into a vein [1]. Supplying fluids or drugs through intravenous track is needed when patient requires drugs that must be received by the body soon or requires drugs or fluids at a certain flow rate. Unfortunately, it is often impossible for the patient to be supplied with normal medication, for example, when a patient disables because of highly need much fluids, has a nerve problem, brain cancer, or paralyzed, it is impossible for them to take meals. Furthermore, delivering fluids or medication through intravenous is also used in other purposes i.e., inserting anti-inflammation drugs, changing fluids concentration, and can also be used for sport needs.

When an infusion system is applied on patients, there are some parameters that should be considered to obtain good treatment to the patients. They are type of fluids, flow rate of the fluids or volume, and the amount of rest fluids in the infusion chamber. The amount of the medication given to the patients is determined by their physical condition, weight, sex, and age. The medication given to the patients should be appropriate to their needs. The lack or excess medication for patients can cause any serious problem to them. Therefore, care must be taken when dealing and designing drugs treatment to the patients. The patients like children and aged people are in high risk of mistreatment of medication. Medical personnel should pay more attention to check the infusion system regularly. This control cannot contain mistake as well as on the replacement of the infusion liquids.

On the traditional method, the insertion of intravenous fluids to the patients must be regularly watched and monitored by medical personnel. This method consumes much times and caused unpractical process during patients monitoring [2,3]. Dealing with this condition, many systems for monitoring and controlling intravenous fluids or drugs given to patients have been developed. From some prior studies, the level of intravenous fluids given to the patient was implemented using analytical models [4], microwave TDR [5], learning-based computer vision [6], electrodes, and optical sensors [1]. However, these studies have not yet provided the information about infusion system parameters needed for monitoring and controlling or alert method to the personnel in charge of the patient [7]. The Infusion Fluid Level Monitoring System has widely developed by many researchers. The developed system has succeeded in detecting a low level of IV fluids. They also developed the communication system for remote monitoring, but the use of the communication is mostly still limited to close distance and is not effective for large and multi-storey hospital environments. The development of an intravenous fluid monitoring and warning system using wireless communication has also been carried out [8]. The use of wireless communication or radio frequencies in the sending of information is very sensitive to interference because the low radio frequency waves are easily disturbed caused by any other EM waves. Previous studies have also developed a monitoring system for infusion fluid levels using a wireless communication system [9-11]. The disadvantage of using this wireless communication system is the installation of a system that requires high costs and the complexity of the system to be built. However, it offers high precision communication data and reliability.

This study aims the precision infusion flow rate measurement with the developed measurement system, which required in the precision treatment. The system is built with standard optical method [12] but with improved measuring capability with drops volume measurement. The infrared sensor used to measure height functions using the reflection response caused by fluids in the infusion tube. When fluid is established in the tube, light that has currently flowed through a slit and is reflected into the tube wall will refract and enter the liquid. As a result, the light that is reflected by the tube wall is reduced, which in turn affects the output response of the infrared receiving sensor. The precision data then can be developed for wireless recording and monitoring at a nurse station. The results obtained in this study have shown an ability to distinguish drops volume to measure further function such as flow measurements.

METHOD

To be able to detect the infusion system parameters, there should be a monitoring system that provides all the information needed [13]. The monitoring system could be built based on the drops measurements which consist of drops rate and volume. These two parameters could give information about flow rate and the kind of fluids used for the infusion. The rate can easily be measured by drops counting in a certain time. The drops counting can utilize infrared obstacle detector which works as a digital sensor. This function does not care about signal amplitude or pulse width, since it only measures the number of occurrences for a certain time. Different with rate detection, volume detection involves can be realized with droplets shadow area measurement on a photodiode. This area measurement utilizes analog output of the photodiode detector, since there is correlation between the area of the shadow and the analog output. The diagram of the method is shown in FIGURE 1.

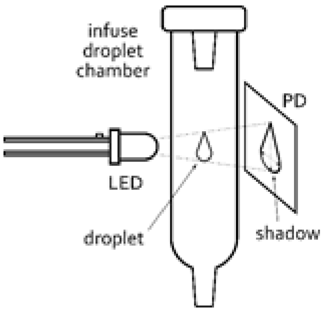

FIGURE 1. Infusion droplets detection using infrared sensor

The area consists of two dimensions which are height and width. The height measurement can easily be measured through digital pulse output, where the height affects the starting and ending point of the pulse due to falling drops. Different with height measurement, the width measurement needs intensity measurement of the photodiode because the width affects the area covered by the drops which determine the current resulted from the photodiode.

Sensor System

The drops rate measurement is similar to digital counting where it only measures the number of pulses per second. Therefore, all it needs is the pulse generated from the detector. It does not care about the pulse width. The rate measurement must be fast in order to avoid error due to delay pulse caused by electronic system. At least it should be faster ten times of the maximum rate of the falling drops.

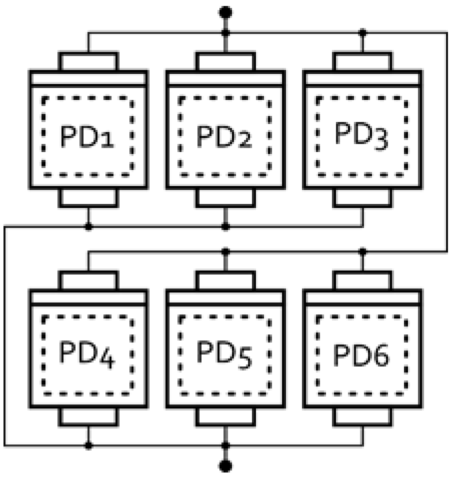

FIGURE 2. Photodiode array connection.

To be able to measure droplets shadow area, the photodiode detector should be wide enough, so that the droplets size can be distinguishable for different nozzle size and infusion solution. This becoming a challenge since only a few photodiodes that have large sensitive area. To deal with this situation, a large sensitive area photodiode can be made by building a photodiode array. These photodiodes can be connected in parallel connection to add current generated from all photodiodes. The connection can be made like arrangement in FIGURE 2.

Rate and Volume Detection

Rate and volume detection of Infusion droplets can be carried out in one process. The rate detection utilizes digital pulse resulted from the detection system, while the volume can be determined using the rate and the pulse width due to the droplets heights which can also be resulted from the detection system. The rate is counted using occurrence counter from a digital counter, while the pulse width is calculated using timer of a digital timer. Therefore, for these tasks a microcontroller like Arduino Uno can handle the processes.

The rate measurement only considers whether there is pulse or not and it will work with any pulse width. Therefore, the care must be taken only in electronic design of the signal processing to provide time delay as low as possible to avoid thin pulse failed to appear. The response of the electronic should be set to ten times faster than the maximum drops rate. The same case should be applied on the volume measurement. The electronic response must be able to detect the smallest volume wanted to be measured.

System Design

The system is built with an implementation of an opto-coupler, which can employ the drops as the detected object to disturb the light transmission between transmitter and receiver. An optocoupler, which is an LED and a phototransistor in a single package, is usually used to provide the feedback signal [14]. The wavelength characteristics of the light transmitted by the transmitter and the light received by the photodiode should be the same to obtain high sensitivity response for transparent object like water or infusion solution. Therefore, an infrared LED BPV10NF and an infrared photodiode BPW34 are used, since they have match wavelength characteristics.

The system is designed by considering the noise and the ringing of the digital signal from the photodiode detector. This should be taken into account unless the processes result in error result of rate and volume detection. The first signal processing usually uses standard current to voltage converter with transimpedance circuit which converts the current from the photodiode to an adequate output voltage level. Then it is followed by a comparator to detect transition and change it to sharp pulse. Since it only involves digital signal, a digital processor is then implemented such as a microcontroller for better compact and integrated system due to its complete features. The measurement results further can be connected to a PC or a wireless communication for remote real-time monitoring from a central station in a hospital. The general block diagram of the infusion system is shown in FIGURE 3.

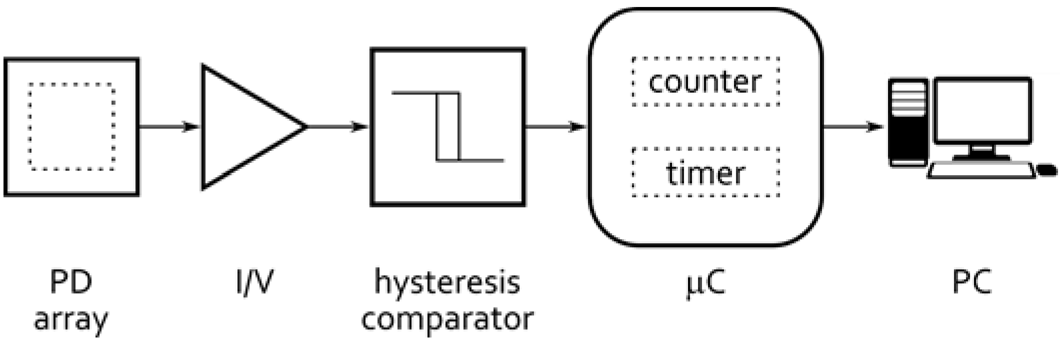

FIGURE 3. System design of drops detection.

To eliminate the noise and ringing pulses, a hysteresis comparator has been used. This comparator prevents direct comparation using two level reference voltages. It creates a window where the noise cannot make an instant change on the comparator output [15]. This window can be adjusted depending on the noise level of the photodiode output. It is very useful in a precision time measurement like pulse width measurement in this application.

The pulse rate and width were measured using digital method by a standard microcontroller. The measurement implements interrupt feature in the microcontroller to ensure fast pulse edge detection. The pulse rate measurement involves only positive or negative pulse edge, since it only measures pulse number per unit time. Inversely, pulse width measurement involves both edges of the pulse, since it measures time difference between them. Therefore, interrupt should be activated for both edges, but later can be check whether it is positive or negative for corresponding measurement.

RESULT AND DISCUSSION

The experiments of rate and volume detections have been conducted and provide reliable results which show the effectivity of the detection system method. The first experiment is the general system functionality test, which aims to see the basic response of the detection system. The system is run at an arbitrary droplet rate and volume. The response is shown in FIGURE 4.

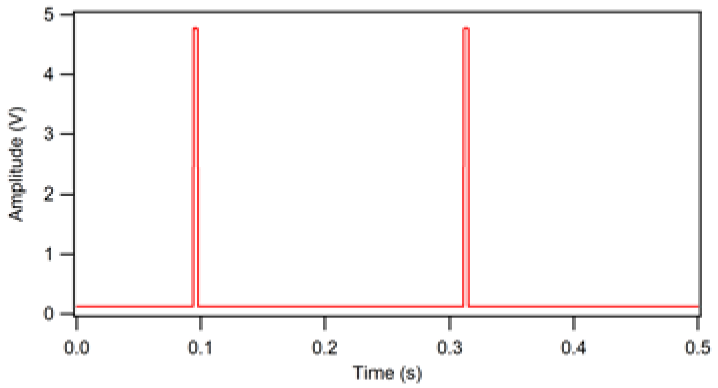

FIGURE 4. Detection system response to droplets.

Based on FIGURE 4, it shows the pulses generated by the drops in the experiments. The pulses are seen smooth and very narrow with the peak at 5 V, which is set in accordance with the standard digital level. The good smoothness is supported by the implementation of the hysteresis comparator which eliminates the unwanted ringing pulses. The narrow width of the pulse is apparently caused by the low sensitivity setting of the photodiode. It can be increased depending on the requirement.

The drops rate measurements are carried out by varying the clamp of the infusion. In this experiment there are three openings were made i.e., small, medium, and large openings. The drops rate was also observed to ensure the rate change. Then, the output signal of these conditions was recorded for analysis. The measurement results are shown in FIGURE 5.

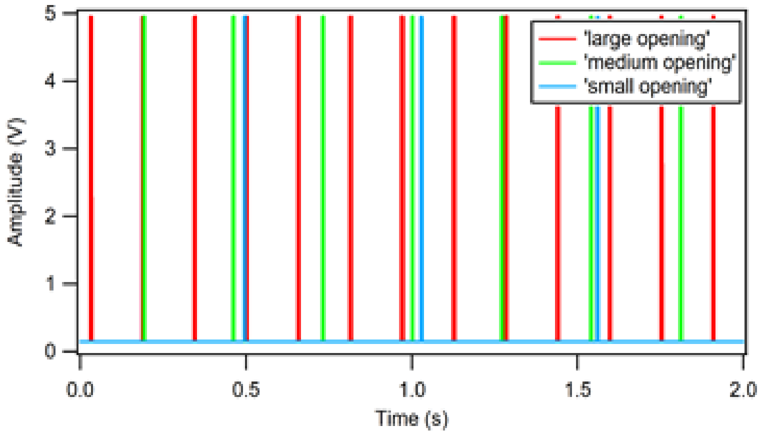

FIGURE 5. Rate variation detection due to valve opening.

The drops rate experiment results shown in FIGURE 5 describe the change of pulse period for changing clamp opening. The larger the opening, the higher the rate of the drops, and vice versa. From these pulses, it is seen that the smaller period is about 0.33 s and the larger period is about 0.5 s or 7 drops/s and 2 drops/s. Through this drops frequency and later combined with drops volume the drops flow can be determined.

The drops volume is measured by varying the infusion "number of drops per ml" type. Two type of drops volume were used i.e., 20 drops/ml and 60 drops/ml to created different volume drops. The pulse width of these drops was measured and the results are depicted in FIGURE 6.

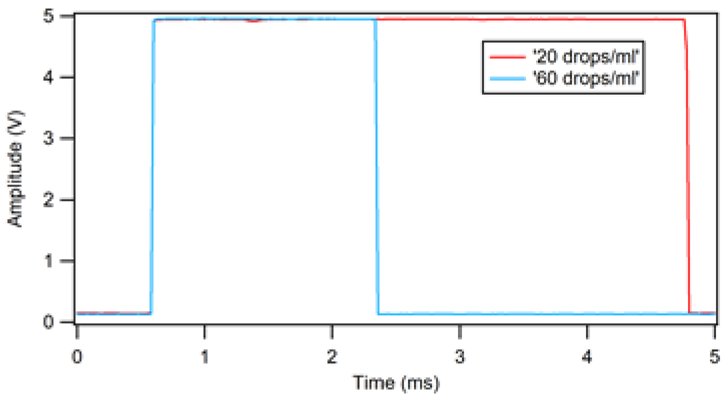

FIGURE 6. Pulse width variation based on drops volume.

The curves in FIGURE 6 shows the pulse width differences from two drops sizes of two standard infusion drop types. The pulse width for infusion type of "20 drops/ml" is seen larger than the infusion type of "60 drops/ml". Moore [16] conducted an objective assessment based on the variability in the number of drops per bottle for the treatment of glaucoma. The ratio obtained by size and volume was an average of 20.9 drops/ml to 40.8 drops/ml. This shows the agreement that the infusion with higher drops number per ml would yield smaller pulse width compared to the infusion with lower drops number per ml. This is true since the higher number of drops per ml will produce smaller drops volume due to smaller nozzle. This small volume shortens the starting and ending time of the shadow of the drops, and the opposite case is applied when the volume is larger.

CONCLUSION

It has been shown that the developed system works with the drops detection on the rate and volume. The rate has affected the number of pulses created during a period of time which calculated through the counter in the processor, while the volume has affected the light intensity received which is detected through the pulse width measured with timer in the processor. The results obtained agree with the theory and show good correlation between the quantities measured and the outputs. To increase the accuracy, an analog pulse peak can be considered to be measured.

ACKNOWLEDGEMENT

The authors acknowledge the Direktorat Jenderal Pendidikan Tinggi, Riset, dan Teknologi, Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi and Lembaga Pengelola Dana Pendidikan for the Research Funding with contract number: 015/E4.1/AK.04.RA/2021.

REFERENCES

[1] M. Safitri, H. Da Fonseca and E. Loniza, "Short text message based infusion fluid level monitoring system," *J. Robot Control*, vol. 2, no. 2, pp. 60-64, 2021, doi: 10.18196/jrc.2253.

[2] H. Firdaus *et al*., "Analysis of the Drop Sensors Accuracy in Central Peristaltic Infusion Monitoring Displayed on PC Based Wireless (TCRT5000 Drop Sensor)," *J. Electron. Electromed Eng. Med. Informatics*, vol. 4, no. 1, pp. 42-49, 2022, doi: 10.35882/jeeemi.v4i1.5.

[3] X. Wang, H. Zhou and Y. Song, "Infrared infusion monitor based on data dimensionality reduction and logistics classifier," *Processes*, vol. 8, no. 4, 2020, doi: 10.3390/PR8040437.

[4] F. Yang, K. Chen and Z. Feng, "Analytical model of initial fluid infusion by a microneedle drug delivery system," *in 2011 4th International Conference on Biomedical Engineering and Informatics (BMEI)*, vol. 2, pp. 913-917, 15-17 October 2011, doi: 10.1109/BMEI.2011.6098420.

[5] A. Cataldo *et al*., "Microwave TDR for Real-Time Control of Intravenous Drip Infusions," *IEEE Transactions on Instrumentation and Measurement*, vol. 61, no. 7, pp. 1866-1873, 2012, doi: 10.1109/tim.2012.2192346.

[6] N. Giaquinto *et al*., "Real-time drip infusion monitoring through a computer vision system," *in 2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*, pp. 1-5, July 2020, doi: 10.1109/MeMeA49120.2020.9137359.

[7] Syaifudin *et al*., "Analysis of Drop Sensor Accuracy in Central Infusion Peristaltic Monitoring Based on Computer Using Wireless Communication HC-11," *J. Electron. Electromed Eng. Med. Informatics*, vol. 4, no. 2 pp. 55-61, 2022.

[8] W. H. Tseng *et al.*, “Optical design and study of a wireless IV drip detection device,” *Microelectron. Reliab*, vol. 102, p. 113325, 2019, doi: 10.1016/j.microrel.2019.06.017.

[9] Y. Zhang *et al.*, “Wireless sensor network-enabled intravenous infusion monitoring,” *IET wireless sensor systems*, vol. 1, no. 4, pp. 241-247, 2011, doi: 10.1049/iet-wss.2011.0031.

[10] P. P. Ray and N. Thapa, “A systematic review on real-time automated measurement of IV fluid level: Status and challenges,” *Measurement*, vol. 129, pp. 343-348, 2018, doi: 10.1016/j.measurement.2018.07.046.

[11] M. V. Caya *et al*., “Design and Implementation of an Intravenous Infusion Control and Monitoring System,” *in 2019 IEEE International Conference on Consumer Electronics-Asia (ICCE-Asia)*, pp. 68-72, 12-14 June 2019, doi: 10.1109/ICCE-Asia46551.2019.8941599.

[12] S. Zheng, Z. Li and B. Li, “The design of liquid drip speed monitoring device system based on MCU,” *AIP Conf. Proc*, vol. 1864, 2017, doi: 10.1063/1.4992940.

[13] R. A. Peterfreund and J. H. Philip, “Critical parameters in drug delivery by intravenous infusion,” *Expert Opin. Drug Deliv*, vol. 10, no. 8, pp. 1095-1108, 2013, doi: 10.1517/17425247.2013.785519.

[14] M. Compton, “Safety issues,” *Cargo System*, vol. 30, no. 1, p. 16, 2003, doi: 10.3109/9781439811795.004.

[15] B. Dobkin and J. Williams, “Analog Circuit Design Immersion in the Black Art of Analog Design,” Elsevier, 2013, doi: doi.org/10.1016/C2012-0-00027-0

[16] D. B. Moore, J. Beck and R. J. Kryscio, “An objective assessment of the variability in number of drops per bottle of glaucoma medication,” *BMC Ophthalmology*, vol. 17, no. 1, pp. 1-7, 2017, doi: 10.1186/s12886-017-0473-8.