Proceedings of the Pakistan Academy of Sciences:
A. Physical and Computational Sciences: 58(S): 65-72 (2021)

ISSN (Print): 2518-4245; ISSN (Online): 2518-4253
http://doi.org/10.53560/PPASA(58-sp1)734

Pakistan Academy of Sciences

Research Article

A Novel Approach of Controlling Stoppage of Drip Infusion Using Image Processing on Raspberry PI Platform

Hartono Pranjoto[1*], Lanny Agustine[1], Diana Lestariningsih[1], Yesiana Dwi Wahyu Werdani[2], Widya Andyardja[1], Jose Maria Leao Filipe[1], Manar Fayiz Mousa Atoum[3] and Abubakar Yaro[4,5]

[1]Department of Electrical Engineering, Faculty of Engineering, Widya Mandala Catholic University, Jl. Kalisari Selatan No.1, Surabaya 60112, Indonesia, Surabaya, Indonesia
[2]Faculty of Nursing, Widya Mandala Catholic University Surabaya, Indonesia
[3]Department of Medical Laboratory Science, Faculty of Applied Health Science, The Hashemite University, PO Box 330127, 13133 Zarqa, Jordan
[4]Strathclyde Institute of Pharmacy & Biomedical Sciences (SIPBS), University of Strathclyde, SPBBS, 161 Cathedral St, Glasgow G4 0RE, Scotland, United Kingdom
[5]Dr Yaro Laboratory & AHRO Institute of Health Sciences and Research, 272 Bath Street, Glasgow, Scotland, G2 4JR, United Kingdom

Abstract: Intravenous drip diffusion is a common practice to treat patients in hospitals. During treatment, nurses must check the condition of the infusion bag frequently before running out of fluid. This research proposes a novel method of checking the infusion bag using an image processing technique on a compact Raspberry PI platform. The infusion monitoring system proposed here is based solely on capturing the image of the infusion bag and the accompanying bag/ tube. When the infusion fluid enters the patient, the surface of the liquid will decrease, and at the end will reach the bottom of the infusion bag. When the image of the fluid surface touches the bottom of the infusion bag, a mechanism will trigger a relay, and then activate a pinch valve to stop the flow of the infusion fluid before it runs out. The entire system incorporates a digital camera and Raspberry as the image processor. The surface of the liquid is determined using the Canny Edge Detection algorithm, and its relative position in the tube is determined using the Hough Line Transform. The raw picture of the infusion bag and the processed image are then sent via a wireless network to become part of a larger system and can be monitored via a simple smartphone equipped with the proper application, thus becoming an Internet of Things (IoT). With this approach, nurses can carry on other tasks in caring for the patients while this system substitutes some work on checking the infusion fluid.

Keywords: Canny Edge Detection, Health Care, Hough Line Transform, Infusion Control, Internet of Things

1. INTRODUCTION

Intravenous therapy in patients is one of the most widely used treatments in hospitals for the healing process of a patient. There are two methods of doing so, namely using an infusion pump and using drip IV (intravenous) delivery that has been used since 1944 [1]. Since the first use, there are many methods implemented to monitor the flow of the infusion fluid by measuring the weight, counting the number of drops, using ultrasonic wave TDR, infrared detection, and RFID [2–10].

Ogawa *et al.* [2] and Amano *et al.* [3] used three pieces of electrodes to form capacitors then compare the impedance to detect the fluid droplets. The same group then extended the work with a BlueTooth network for the reporting method. Every drip infusion set must be equipped with three electrodes before the system can be used for patients in this system. Baros and dos Santos [4] used an optical sensor and motor actuator to detect the

Received: March 2021; Accepted: July 2021
*Corresponding Author: Hartono Pranjoto <pranjoto@ukwms.ac.id>

infusion fluid's droplets and then regulate the flow with the motor. The fluid regulation flow utilized an integrated design of software and hardware developed within their research group.

Cataldo *et al.* [5] used time-domain reflectometry to detect the amount of infusion fluid inside the infusion tube by attaching a two-stip probe to the infusion tube's surface. This method had good results, but every infusion tube requires a two-stip probe attached to the surface, and the position of the probe will significantly determine the accuracy of the result. Huang and Lin [6] used a similar RF (radio frequency) approach to detect the level of infusion fluid by attaching an RFID (radio frequency identification) tag. When an infusion tube containing liquid is full, the RFID tag will not respond to the signal sent by the RFID reader. However, when the fluid level inside the bag is below the RFID tag, it worked as usual and echoes the signal to the RFID reader.

Further, Ting *et al.* [7] studied the electrical characteristics of how the RFID tag is suitable to echo the signal from the RFID reader and how the reader should detect the signal. They use two different modes of application, one for the low fluid warning and the other for the inventory control. This approach required an attachment process of the RFID tag to the infusion fluid, and the placement can be crucial in determining the low-level detection.

Gupta *et al.* [8] utilized four LED (light-emitting diodes) to detect the number of fluid droplets inside the drip chamber. The LEDs are attached outside the drip chamber at different levels, accompanied by four light detectors. This work showed promises, but when the drip chamber wall has some droplet splash, then the LED cannot detect the infusion droplet correctly. A study by Gil *et al.* [9] also utilized a light source and light sensor to detect the droplet inside the drip chamber and then report the result to the nurse station using a wireless local area network. Other more straightforward system development uses a simple optical sensor, a digital counter with reset, and two seven-segment displays to show the flow rate of the infusion fluid.

Tharian *et al.* [11] controlled the infusion fluid flow using a DC motor and disk-spring mechanism. The result of the work shows minimal effectiveness in regulating the infusion fluid while Rashid *et al.* [12] used an optical sensor to detect the infusion droplets and a servo motor valve to control the flow. The result showed that the system is working, although it is sensitive.

The above review indicates that the infusion set (infusion tube with the infusion set) requires some modification for use. This method proposed here requires no change at all to the system. Nurses only need to place the infusion tube onto the stand, set the roller clamp according to the requirement, and hang it as usual.

Figure 1 shows the gravity drip infusion set. The set consists of four main components, namely, a vented spike to connect it to the infusion tube, an IV drip chamber to see the droplets of liquid entering the patient's body, the infusion line to drain fluid, and a roller clamp to regulate the fluid infusion. The end is the IV catheter to connect to the catheter in the patient. The infusion tube that provides intravenous fluids is hung on the infusion pole

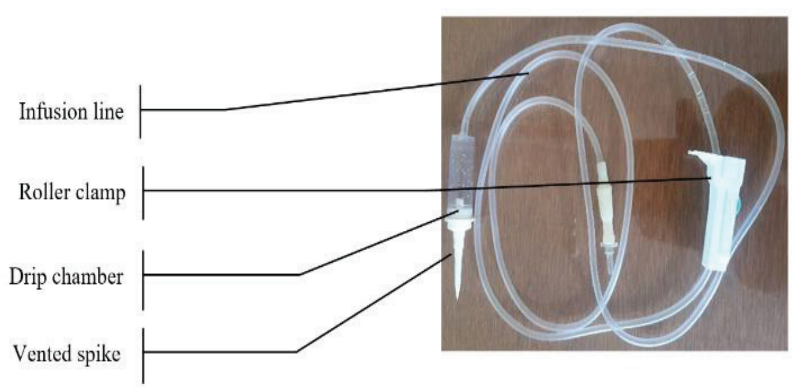

Fig. 1. Gravity drip infusion set.

In this drip system, the infusion liquid will drip from the vented spike output into the IV drip chamber slowly, depending on the position of the roller clamp. The liquid droplet volume based on the infusion set is 20 drops mL^{-1}. Therefore, the droplet count can be used to monitor the amount of fluid entering the patient's body.

In this study, monitoring the amount of fluid that comes out of the IV tube by using an image processing technique by detecting the surface of the liquid. As the amount of liquid decreases, the surface will go down until it reaches the bottom of the infusion tube. At this time, then the computer that processes the image will execute a pinch mechanism to stop the flow of liquid. As the infusion fluid is delivered to the patient, the surface level of it will go lower will reach the bottom of the tube when it runs out. As the surface level reaches the bottom of the infusion tube, the computer will trigger a mechanism to stop the delivery of the fluid to the patient similar to [8], and at the same time will trigger an alert to the nurse station to take action of the infusion tube.

2. MATERIALS AND METHODS

The experimental setup comprises a digital camera to capture the image of the infusion tube together with the infusion fluid, a Raspberry PI computer to process the image, and a wireless network to send the data. The implementation of the system will include two infusion tubes running at the same time with one unit detecting both infusion fluids. Figure 2a is the photograph of the setup with the infusion pole standing at the center of the picture. Two infusion bags are hanging on top of the pole, similar to a traditional infusion with two infusion lines going to the patient. Instead of going directly to the patient, the infusion line is inserted into the unit that will stop the flow of the fluid when it is almost out. There are two buttons to start the process of monitoring the infusion for the left and right sets. There are two LED indicators to track the status of the monitoring also for the two infusions. At the bottom are the power button and also a button to shut down the system gracefully since it is a Raspberry PI running Linux operating system. The digital camera is a standard USB camera compatible with the Raspberry PI and is mounted in front of the infusion set. Figure 2b shows the photograph of the setup from the side to provide clarity. Figure 2c is the inside of the Raspberry PI control box which consists of the single-board computer.

Figure 3 describes the functional block diagram of the system. The camera captures the image of the infusion tube with the fluid and then sends the data into the Raspberry PI via the USB data connection.

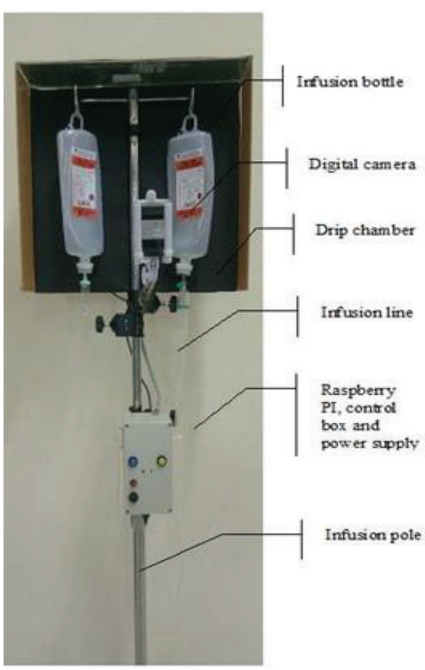

Fig. 2a. Experimental setup front view

Fig. 2b. Side view with the digital camera

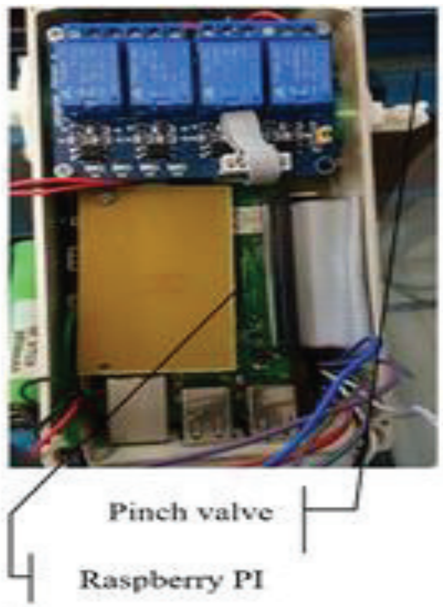

Fig. 2c. Control box with Raspberry PI, pinch valve, and relay

The Raspberry PI processes the data, determines the position of the surface of the fluid, computes the estimated volume of the remaining liquid. When the liquid is about to run out (determined/ calculated less than 20 mL) then it will activate the pinch valve to stop the flow and raise the alarm. During the process of monitoring, the Raspberry PI also updates the data of the fluid condition to a web server nearby using a wireless connection every minute. An operator can monitor the situation continuously either via a workstation located at the nurse station or using a smartphone connected to the server either via a local wireless connection or via the Internet.

Figure 3 illustrates the entire set, which consists of a Raspberry PI computer, a camera, and a web/ database server. The process starts when the nurse presses the start button after setting the infusion tube on the infusion pole. The USB camera captures the image from the infusion set and then sends the image to the Raspberry PI computer via a USB connection. The Raspberry PI computer processes the image the using Canny Edge Detection algorithm along with Hugh Line Transform to detect the surface of the liquid and then computes the amount of volume already transferred to the patient and at the same time determines the remaining fluid left in the tube. When there is less than 20 mL of fluid left, the computer will activate the pinch valve to stop the flow of infusion to the patient. The process described above is repeated every minute.

The computer will send the data from the image processing result to the web/ database server every 5 min via a wireless connection, which is already embedded in the Raspberry PI. The picture of the infusion tube, along with the data of the amount of fluid remaining, a marker of the edge of the tube, and surface-level via a smartphone connected to the server or via a workstation. Figure 4 shows the result of the image processing together with the marker that is available for viewing via a smartphone.

3. RESULTS

The experimental setup uses an actual infusion tube used in a typical hospital which is normal saline NaCl 500 mL. The experiment uses the same material, although they are from different batch numbers and dates of expiration. The volume of the fluid leaving the tube is measured using a graduated cylinder while – at the same time – the Canny Edge detection and Hough Line Transform determines the location of the surface of the liquid in the picture [13–17]. This work is carried out using Open CV with Raspberry PI model 3B+. At the start of measurement after the infusion tube is placed at the infusion stand, the top surface levels are set at pixel coordinate 550, and the bottom of the tube is at pixel coordinate133. When the surface level of the fluid goes down due to the decrease of the volume, the volume is measured. Figure 5 is the correlation graph of the amount of fluid leaving the tube and the surface level of the fluid in the picture.

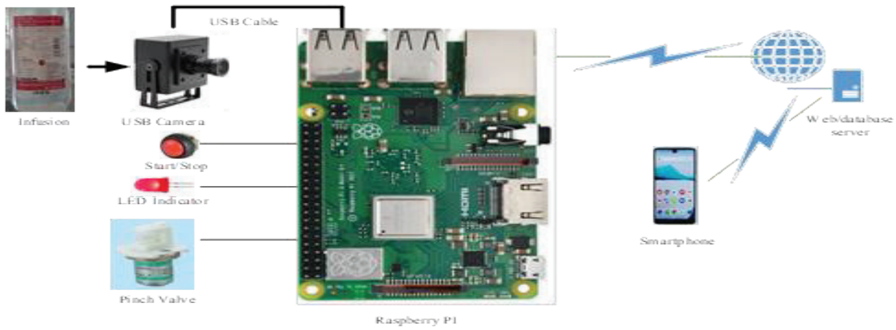

Fig. 3. System setup with USB camera, Raspberry PI, pinch valve, and webserver

The digital camera captures the entire infusion bottles and then crops the picture into a height of 650 pixels for image processing. There are two methods used for image processing. The edges of the infusion bottle and the surface of the liquid use the Canny Edge detection algorithm and Hough Line transform algorithm to detect the straight line of the surface of the liquid.

Figure 4a to Figure 4f depicts the process of image processing to locate the surface of the liquid. The start of the fluid surface detection uses the standard Canny Edge Detection method, which involves six distinct steps starting from the original image (Fig 4a) as follows:

i. Grayscale conversion from color image (Fig 4b);
ii. Noise reduction of the image using a simple smoothing technique with Gaussian filter (Fig 4c.);
iii. Normalization to extract the intensity gradient of the grayscale image;
iv. Removing spurious response of the edge detection using non-maximum suppression;
v. Determining the potential edges using a double threshold (Fig 4d.);
vi. Tracking the edges using hysteresis and remove the weak and the non-connected.

Line detection of the surface of the fluid is performed by the Hough line transform, which is a technique of image analysis to find straight edges in conjunction with the method mentioned above. Figure 4e is the inverse of Figure 4d for easy observation. After the line transformation, as shown in Figure 4f (at the point of the arrow), the surface of the infusion fluid is detected, and the marker is superimposed to the first image.

In Figure 4f, on the left-hand side of the tube, there is a long line (green in color), which shows the edge of the infusion tube. This line is the reference line to determine the location of the fluid level since the surface level will be located 25 pixels to the right of the line. The horizontal line (red) is the processed indicator of the surface of the fluid. This red line is the parameter to determine the amount of

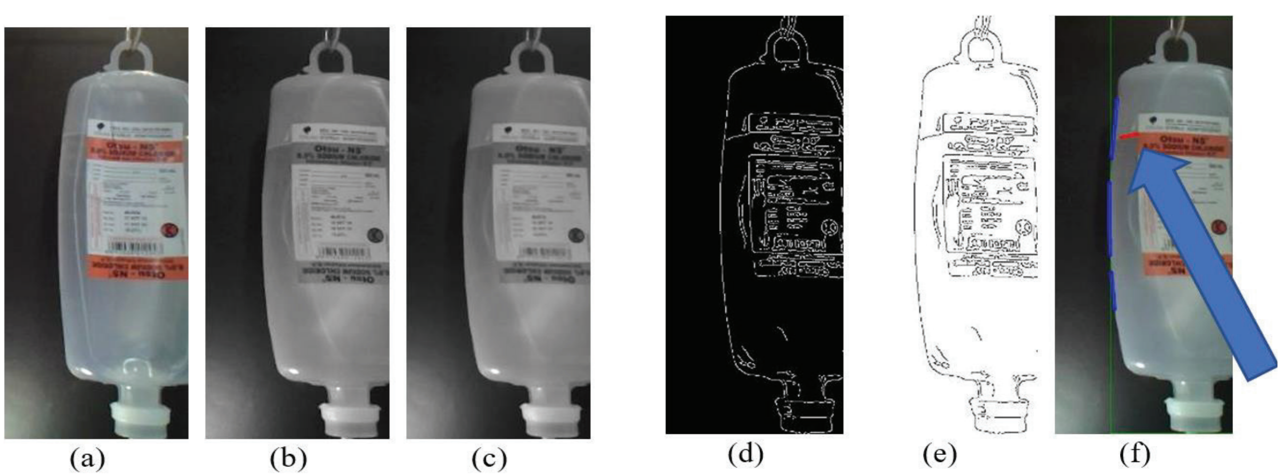

Fig. 4. The process of image liquid processing detection

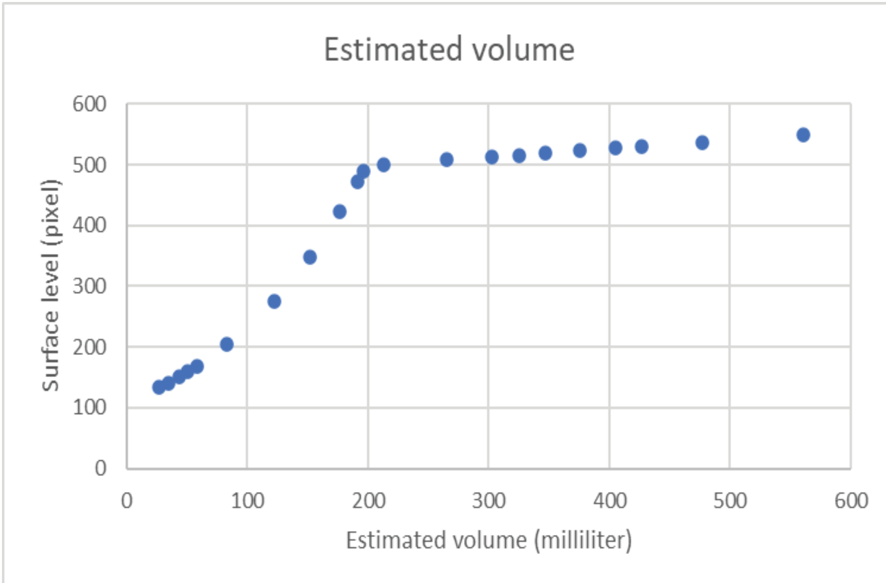

Fig. 5. Relationship of the surface level in pixel coordinate and the volume of the liquid.

volume left in the bottle as emphasized at the top of the arrow.

The amount of fluid leaving the tube will decrease the level of the surface of the fluid. The amount of liquid left in the tube is calculated by subtracting the initial volume of infusion fluid from the fluid, leaving the tube measured using a graduated cylinder.

4. DISCUSSION

Figure 5 shows the relationship between surface level in pixel coordinate as a function of leftover infusion fluid inside the tube. There are ten measurements conducted to obtain this figure. During the observation, the amount of infusion fluid left inside the tube and the surface level height are recorded. The plot is the average of the ten observations mentioned previously, and the most significant deviation is ± 20 pixels at a volume level of 270 mL. The change of pixel height is not proportional to the leftover volume because the infusion tube itself deforms due to the lack of fluid, and there is no air replacing it. Figure 5 clearly shows a clean break at 200 mL volume in the tube due to this condition.

The amount of fluid in the tube is estimated using two different empirical models for the upper part (from 200 to 550 pixel coordinate) and for the bottom part (from 25 to 200 pixel coordinate). The upper estimation of the fluid follows a linear equation using a curve fitting by Microsoft Excel with a correlation coefficient of 1, as stated in Equation (1). The bottom part of the data uses exponential curve fitting since the plot shows exponential curvature. Equation (2) results from arbitrary curve fitting provided by Microsoft Excel and is always consistent with the result. Estimation of the amount of fluid left in the bottle is within 10 mL – which is the essential part because the line must be stopped – uses this model. This model fits very well and will stop the fluid level consistently

Upper part:

$$y=0.1378x+47.3 \quad (1)$$

Bottom part:

$$y=107.8\exp(0.0077x) \quad (2)$$

Where:

y = the estimated volume left in the infusion tube
x = the pixel coordinate

The computer always monitors the level of the liquid with the technique mentioned above, and when the level reaches below 133-pixel coordinate, it triggers a signal to activate the pinch valve to stop the flow of the infusion liquid completely. At the same time, there is also a visual alarm via the LED to alert the nurse that the infusion process has stopped.

The picture similar to Figure 4f is available in the Raspberry PI computer controlling the system and also sent to a web server to be filed and also viewed remotely. There is no display monitor on the Raspberry PI at the infusion set. Therefore there is no means to see the picture of the processed image. Data send to the webserver uses JSON (Javascript Object Notation), which is lightweight in format. This feature allows the processed images monitored from anywhere as part of the Internet of Things.

Results of sending the image of the infusion bottle via a wireless network are not implemented just for one infusion set [18-21] (one infusion pole and two infusion bottles), but for the entire room comprising several beds. In this work, ten infusion poles are monitored at the same time, and the image data are sent with tags so that each picture is identified correctly based on the bed and in turn, based on the patient. Figure 6 is the implementation of the system viewed using a smartphone.

The health care people can observe the pictures obtained from the process. A web page monitor is available to view the images via a wireless local area network along with a detailed description of the infusion condition. The system mentioned above uses a Raspberry PI platform.

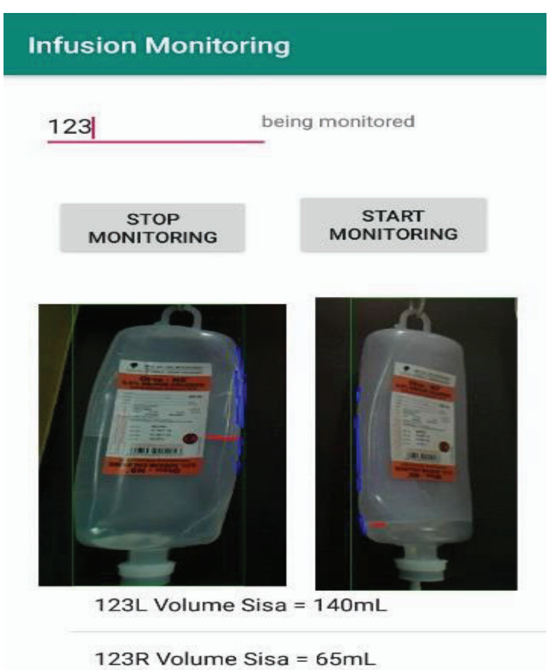

Fig. 6. Two infusion bottles viewed from a smartphone.

5. CONCLUSION

A novel approach of controlling the stoppage of drip infusion using image processing uses the Canny Edge Detection method and Hough Line Transform to find the edges of the image and then determine the surface of the liquid. The pixel position of the surface is then used to predict the amount of infusion volume left. This method has been shown to work correctly and reliably based on the image itself. Together with the Hough line transform, the Canny Edge detection can predict the amount of infusion fluid left in the infusion tube.

6. ACKNOWLEDGEMENTS

This work is funded by: Directorate of Research and Community ServicesDirectorate General of Research and Development Strengthening Ministry of Research, Technology and Higher Education by the Research Contract 2018 – 2019 Number: 200M/ WM01.5/ N/ 2019.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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