Simulation and Design of Intravenous Infusion Dripping Rate Detection based on Infrared Ray

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Abstract. The main problem for an automatic Intravenous (IV) infusion process control system is the measurement of dripping rate in the drip chamber. This paper utilizes an optical sensor as a solution to this problem. The waveform of the receiver is forecasted by a simple simulation experiment which calculates each path of discrete directional light sources on the transmitter respectively, and then accumulates the number of rays which can reach the receiver. The converting circuit is designed to convert the analog signal into digital one and used as an interrupt signal to a CPU. The ultimate dripping rate is calculated in the corresponding interrupt service routine.

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Keywords: Intravenous infusion system • Dripping rate detection • Simulation of light intensity

1 Introduction

Intravenous infusion is a common medical procedure in the hospital. The pressure generated by the liquid level transfuses the liquid into vein which also affects the dripping rate of infusion. For a long time, the dripping rate is adjusted manually by nurses. However, the dripping rate would change in many situations such as the change of liquid level, the patient's movement, the change of medicine state and so on. It requires nurses to monitor the rate in case of dripping too fast and the rest of medicine all the time. To reduce their workload, it is necessary to develop an automatic intravenous infusion control system.

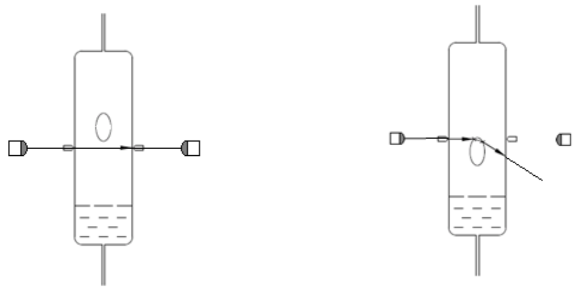
The measurement of the dripping rate is a crucial section if the control system functions as a dripping rate regulator. Methods to detect the dripping rate and the remaining drug have been proposed in literature, including detecting electrical impedance [1] and microwave reflectometry [2]. However, detectors of these types are limited by the shape and size of the drug bottle, so they are not convenience to use. Moreover, they cannot detect the dripping rate directly, which make the system short of real-time performance. Optical sensors are used as well [3, 4, 5, 6].

In section II of this article, we calculate the light intensity change of the receiver when a drip falls by simulation method. In section III, we design the detection and convertion circuit to process the signal generated by optical sensor.

2 Simulation Experiment of Light Intensity

2.1 The Principle of Dripping Detection

The optical sensors are mounted at both sides of the drip chamber, as shown in Fig.1. The light is emitted from the infrared emitting diode and straightly forwards the phototriode when the drip has not come down. When the drip falls down, it will change the path of the light, i.e. an interruption. So the light intensity received by phototriode is changed as well. So dripping rate could be represented by the reciprocal of time interval between two consecutive interruptions.

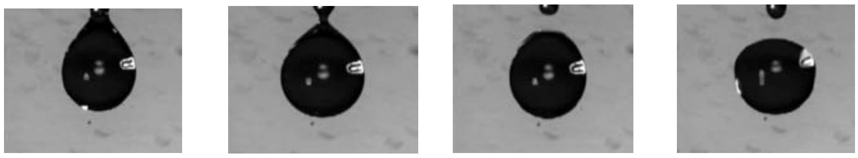


(a) infrared ray is not affected (b) infrared ray is affected

Fig. 1 The principle of optical detection

2.2 Model of Actual Drip

The first step to analyze infusion dripping rate detection is to figure out the shape of a drip. By utilizing a high-speed video camera the process of a drip falling down from a tube was observed clearly [7], as shown in Fig.2, where it was concluded that the outer shape of a falling drip could be represented by a circle approximately. Fig.2(a) to (d) shows several snapshots of a process consisted of drip formation, separation, and falling down sequentially.



(a) snapshot 1 (b) snapshot 2 (c) snapshot 3 (d) snapshot 4

Fig. 2 Shapes of a falling drip at several snapshots of a falling process

2.3 The Method of Light Intensity Simulation

Simulation is carried out by digitize the optical source into discrete rays that are emitted from the infrared emitting diode and calculate their paths towards the vertical plane at which the phototriode locates. Each ray can reach the sensor when the drip is not in its original path. The path changes when the ray goes through the falling drip because of the refraction that the ray may not reach the sensor. By counting the final received rays, we can get the approximate light intensity of which the drip at a certain location. Furthermore, we can draw the curve of light intensity when a drip is falling down. The main steps of simulation are as follow:

Step1: Establish a rectangular coordinate system as shown in Fig.3. And then determine the drip's location (xr, yr) and radium r.

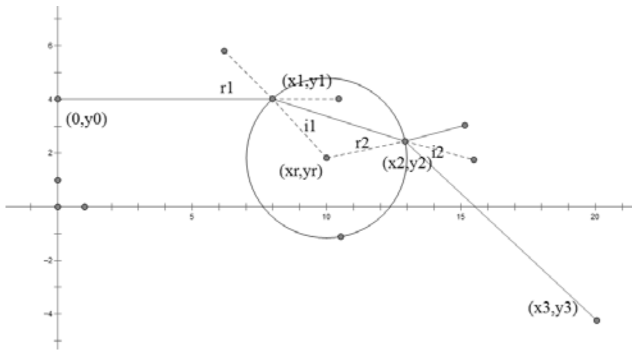


Fig. 3 Geometric analyze of the ray path

Step2: Digitize the optical source into discrete rays, represented by directional lines in the image. The more intensive of the ray, the more realistic the result will be, as well as a longer calculation time.

Step3: Calculate the path of each ray according to geometrical optics. First of all, assume one of the rays is emitted parallel to x-axis at (0, y0). If the drip has not reach the ray or has already passed, the ray will go straightly to the photo diode, where the end point's y = y0. Then we can figure out the first intersection (x1, y1) of the ray and the circle which represents the surface of the drip as follow:

$$x1 = -\sqrt{r^2 - (y0 - yr)^2} + xr \qquad (1.1)$$

$$y1 = y0 \quad (1.2)$$

Refraction occurs when the ray reaches the circle. The incident angle and the exit angle are

$$r1 = \tan^{-1}\left(\frac{yr - y1}{xr - x1}\right) \quad (1.3)$$

$$i1 = \sin^{-1}\left(\frac{n2}{n1}\sin r1\right) \quad (1.4)$$

respectively.

And then, using geometric and trigonometric relation, we can find out the second intersection (x2, y2) of the ray and the circle:

$$x2 = 2r\cos i1\cos(r1 - i1) + x1 \quad (1.5)$$

$$y2 = 2r\cos i1\sin(r1 - i1) + y1 \quad (1.6)$$

It's easy to know that the incident angle r2 at the second intersection is equal to the exit angle i1 at the first one. As a result, the exit angle at the second intersection is equal to r1. We can also deduce that the deviation angle of the exited part of ray is two times as the one of the part in the drip. So the slope of the exited ray is

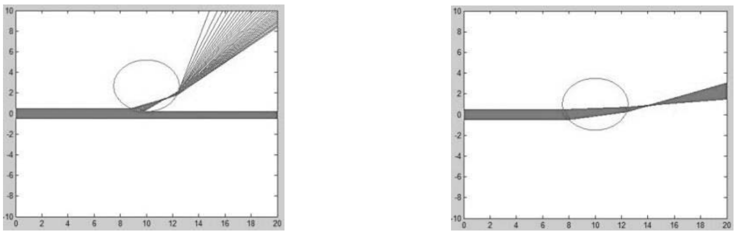
$$k = \tan[2(r1 - i1)] \quad (1.7)$$

Finally, we can figure out the end point (x3, y3) where its x3 squares 20.

$$y3 = k(x3 - x2) + y2 \quad (1.8)$$

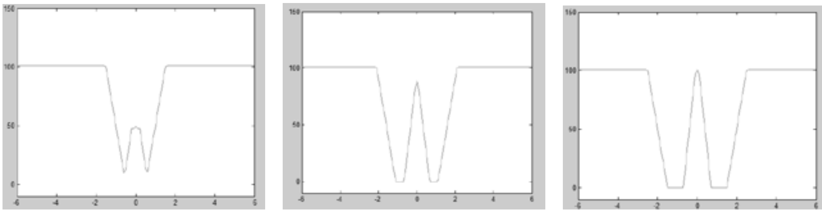
Step4: Change the place where the ray is emitted. In other words, we can vary y0 from -0.5 to 0.5 and at each emitting place we can get a specific y3. And then illustrate all the rays in the same figure, as shown in Fig.4. Count the number Y of the rays that reached the sensor area, which means its end point's y is in the range of -0.5 to 0.5. The number Y represents the relative light intensity.

Step5: Illustrate the changes in light intensity. Considering the distance for the drip through the rays is short, we approximately take the falling process of the drip as a uniform motion. As consequence, we vary the yr from 6 to -6 by 0.1 to simulate the falling process and figure out each relative intensity Y at specific yr. Illustrate the yr-Y curve, which is the result of the simulation experiment. Fig.5 shows different results for the drips with different radium.



(a) parts of rays pass through (b) all rays pass through

Fig. 4 Simulation of light scattering



(a) r = 1 (b) r = 1.6 (c) r =2

Fig. 5 Change of light intensity

3 Detection Circuit and Signal Processing

The optical sensor is composed with an infrared emitting diode and a phototriode. The detection circuit is shown in Fig.6. The emitting diode works at emitting state with 5mA of current. The received light intensity is week since the distance between emitting diode and phototriode is a bit far (about 2cm), which make the current of the phototriode branch low. In order to provide a sufficient voltage drip, it needs to cascade a large resistance. After several test, we pick a 200K resistance to provide the voltage drip. When the phototriode receives the light, the generated low current will make the voltage of Signal In terminal close to zero.

The change of voltage of Signal In terminal, whose typical wave forms are observed in an oscilloscope and shown as the lower curves in Fig.7, is related to the light intensity which the phototriode received. It is clear they are similar to the curves in Fig.5 if reversed. For the convenience of signal processing by CPU, we should convert the analog signal into a digital one. We use a Schmitt trigger composed of a 555 multivibrator to achieve the conversion. The converted signals are shown as the upper curves in Fig.7. When the drip has not fall down, the trigger will output a high level signal to the CPU. And when a drip comes, the trigger will output one or two low-level pulses.

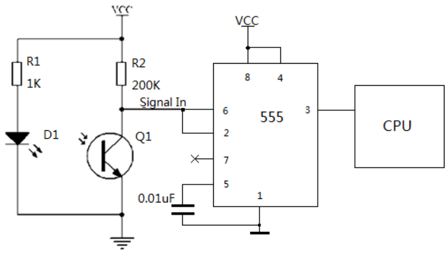
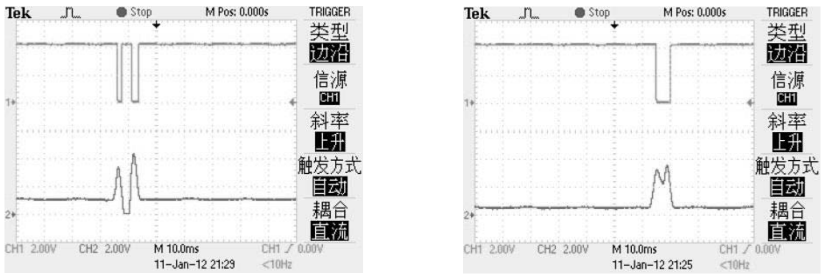


Fig. 6 Detection circuit



(a) wave form 1

(b) wave form 2

Fig. 7 The originally detected and converted wave forms

To count the drips and calculate the dripping rate, the output terminal of 555 is connected directly to an I/O terminal of the CPU. When the CPU received a pulse, a GPIO interrupt is generated. If it is the first drip, it will start and load the timer in the interrupt service routine and wait for the next pulse. When the time interval between two pulses is less than 20ms, we do nothing and wait for the next pulse. When the interval is bigger than 20ms, reload the timer and calculate the rate according to the interval. The rate would be zero if it cannot detect the drip in the loaded time.

4 Conclusion

This paper uses a ray path simulation for the received light intensity of optical sensor in order to explain how and why the change of light intensity is, which affects the detected signal directly. The actual circuit experiment provides a similar result to the simulation. We convert the analog signals into digital signals with a Schmitt trigger, then a CPU can finally calculate the real-time dripping rate.

To provide a satisfactory result of dripping rate control, effective algorithm of control and accurate actuator should be added to the system, which will be the next task for us.

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