THE RESEARCH OF DROPS SENSORS OF PERISTALTIC PUMPS

V. Markevicius, D. Navikas, D. Andriukaitis, A. Valinevicius, N. Dubauskiene

Department of Electronics Engineering, Kaunas University of Technology,
Studentu St. 50-418, LT-51368 Kaunas, Lithuania
T. +370 37 300518; E: vytautas.markevicius@ktu.lt

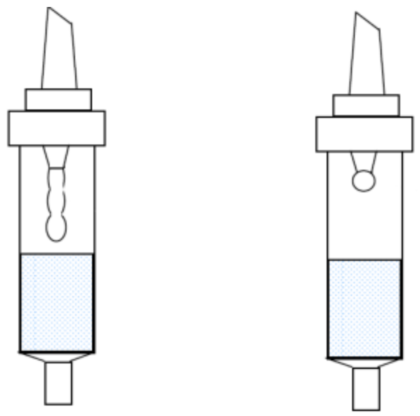
Abstract

Due to its simplicity and efficiency peristaltic drips [1] are widely used in a wide variety of treatments in medical practice [2]. Drip sensors used along with the drips provide step-infusion of medications and reduce the influence of the human factor. Infusion rate of medication plays one of the key roles in the treatment process [3], [4], so it is necessary to ensure that the drops sensor adequately detects the state of the drip camera when dripping speed is from a few ml/h to a few hundred ml/h. Three types of drop detectors are examined. Their main advantages and disadvantages are given.

1. INTRODUCTION

Drops sensors are used as a protective measure for peristaltic drips to reduce the likelihood of termination of the infusion, drug overdose, or infusion into a human circulatory system acceleration or slowdown due to external (e.g., suppressed drug supply hose) and internal (e.g. peristaltic pump failure) causes. These sensors capture the dripping fact, but do not count the drops.

Modern peristaltic pumps can administer medication at very different speeds - from a few ml/h to a few hundred ml/h [1]. The speed depends on the design of the pump and the size of the drops camera, and drops sensors have to be versatile and be able to detect infusions at any speed. It should be noted that the higher the infusion rate, the more difficult it is to capture the drops due to the transition of a dripping on to a weak continuous stream of flowing fluid (Fig. 1).



a) b)

Figure 1. a) High drip rate; b) low drip rate

This paper presents analysis of several drop sensors of different manufacturers and patents related, identifying their strengths and weaknesses.

2. DROP SENSORS

Drop sensors of peristaltic pumps are designed to protect patients from drug overdose or accidental drug supply disruptions and help doctors timely find deviations from the norm in the level of medicine in drug containers.

Currently the market is dominated by three types of drop sensors with IR LEDs and IR sensors. In general, the sensors can be classified as:

1. Operating on the basis of optical lenses;
2. Without specialized optics;
3. Operating on the basis of mirror optics.

Drops sensors of the first type are made with a sophisticated optical system of lenses. Such a sensor typically consists of one IR LED, which is covered by a complex lens, focusing rays and directing them straight to the IR sensor, which is often also covered with a focusing lens.

Drops sensor of the second type does not have any complex optical systems. In it the IR LEDs and IR sensors are covered with a simple protective filter, which does not focus rays and performs as a simple safety feature, to keep out dust, liquids, and so on. In these, only electronics-based drops sensors, comparators, repeaters and pulse generators are commonly used, but not all drops sensors have all of these microchips.

Drops sensors of the third type have a complex optical system based on mirrors. These drops sensors are quite difficult to produce because mirror calibration and adjusting means is a complex process. Without optics electronic parts are also required in such systems. Therefore, in order to produce such accurate drops sensors require precise mechanics, optics and electronics.

2.1. Lens Optics based Drop Sensors

Optical sensor based drops sensor LED directivity diagram study was carried out in the horizontal (Fig. 2) and the vertical (Fig. 3) planes, with IR-sensor ФД 263-01, and built-in IR sensor.

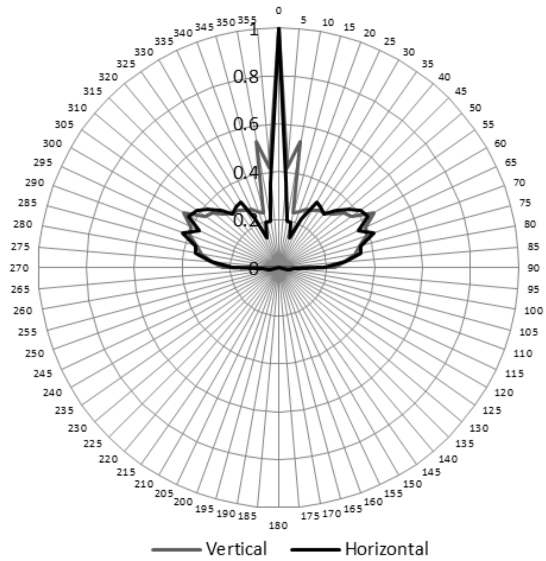


Figure 2. IVAC LED directivity diagram in the vertical and horizontal planes, measured with ФД-263-01 IR sensor (values normalized by the maximum value)

The study found that the directivity diagram width is about 5° (Fig. 2). After normalizing by the maximum voltage value it indicates that at small deviations (up to 5°) directivity diagrams have the same profile. At the higher (30°–90°) deviations similar shape of lateral leafs (Fig. 2 (b)) is obtained. The maximum directivity diagram discrepancies are observed in the measurements of the vertical plane at 10° deviations.

Figure 3 shows the directivity diagram obtained by measurements when the lens centre distance is 2.7 cm (which corresponds to the actual distance between the LEDs and the sensor in the IVAC drop detector), and 7.5 cm. This (Fig. 3) directivity diagram shows that the optics in the IVAC drop sensor is able to focus the IR beam into a narrow strip. During the measurements in the horizontal or vertical plane width of the directivity diagrams obtained is 10°–30°.

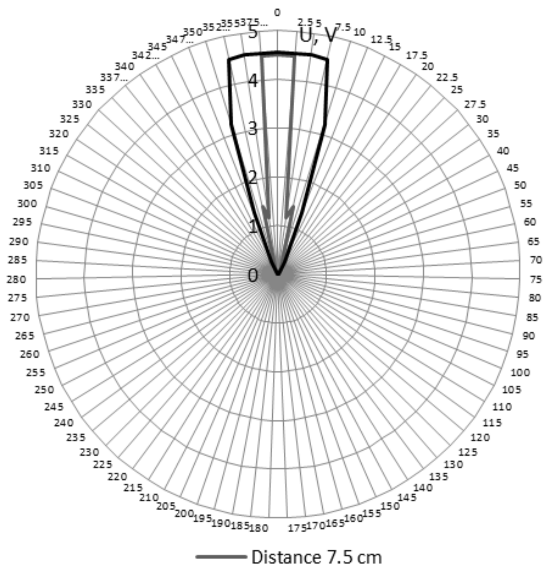


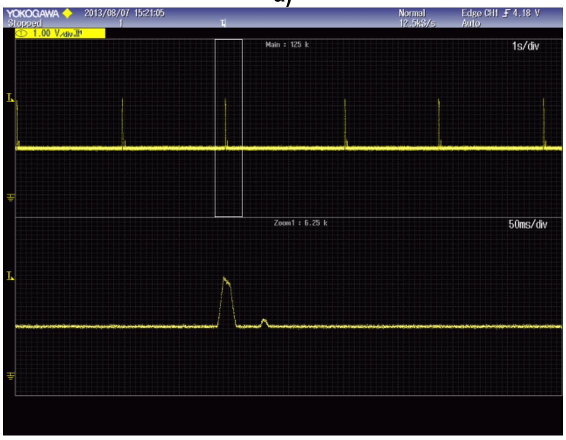
Figure 3. IVAC LED directivity diagram in the horizontal plane, measured with IVAC IR sensor when the distances between lens centres are 7.5 cm and 2.7 cm respectively

This directivity diagram shows the efficiency and accuracy of the lens optics based drop sensor, but it works effectively only in the horizontal plane. If the drop camera is not vertical or the drop sensor is not mounted at a horizontal plane, the drop sensor will not detected drops correctly or will not register them at all. This sensor ensures high accuracy only when the drops camera is strictly upright, and drop sensor is mounted in a horizontal position with a great precision.

Graphs in Fig. 4 illustrate the reliable IVAC 180 drop sensor (optical lens based) at the different drip-speed of 200 ml/h up to 1200 ml/h. Pulse amplitude and shape is stable, independent of the rate of infusion.

Oscilloscope graphs show that in many cases the drop causes a secondary voltage pulse, which is much smaller than the main one. We believe that it is due to the fact that a detached drop splits into two parts when falling, the main and the tiny drop formed from drop "tail". Additional pulses may be due to tiny droplets that eventually form on the inner walls of the drops chamber sides.

a)



b)

Figure 4. Oscillograms of IVAC 180 drop sensor:
a) the drip rate of 1200 ml/h (cell value in oscillogram is 500 ms), b) the drip rate of 200 ml/h (cell value in oscillogram is 1000 ms)

2.2. Electronics-based Drop Sensors

An electronic-based (without specialized optics) Daiwha drop sensor [5] LED's and IR sensor's directivity diagrams in the horizontal and vertical planes study is performed using ФД-263-01 IR sensor, and the built-in IR sensor.

The study was conducted with two different Daiwha drop sensors. The analysis evaluated the schematic diagrams, each differing slightly, but the sensor operating principle is identical. Both Daiwha drop sensors have the same IR LED sensors and IR sensors. In addition, they are symmetrical, so these sensor's LED's vertical and horizontal planes of the directivity diagram are the same and are suitable for both Daiwha drop sensors. Directivity diagrams normalized by the maximum value of the voltage (Fig. 5) are presented.

Directivity diagram width established is approximately 50° (with ФД-263-01 IR), and approximately 70° (with Daiwha IR). The resulting directivity diagram leads to the conclusion that LEDs in Daiwha drop sensors emit infrared beams in a much wider angle (Fig. 5) than the IVAC 180 (Fig. 2, Fig. 3) and IR sensor accepts IR beams in wide angle as well.

Daiwha drops sensor oscillograms captured monitoring the out signal of the operational amplifier of the drop sensor are presented Fig. 6.

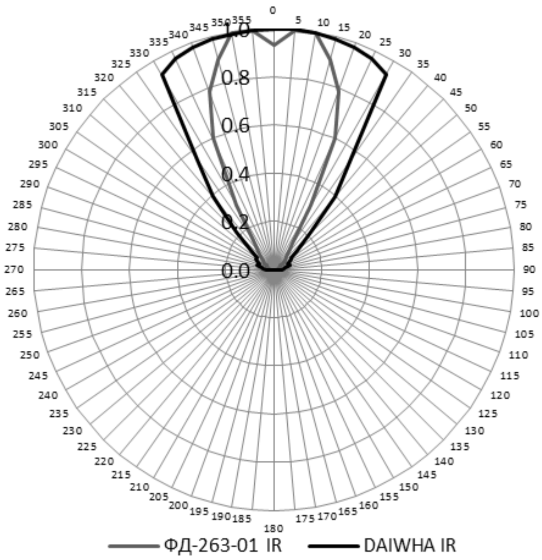


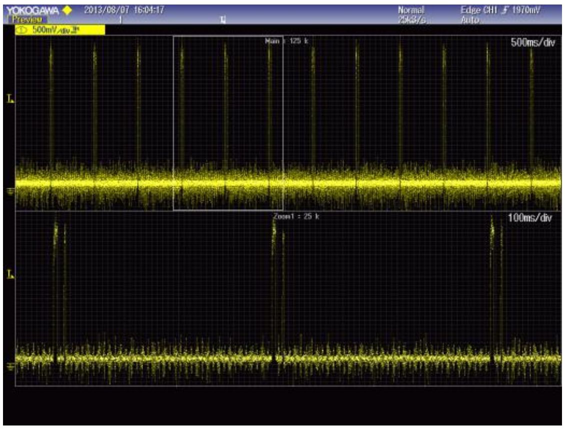
Figure 5. Daiwha LED directivity diagram measured with ФД-263-01 IR sensor and with Daiwha IR sensors in the horizontal plane (normalized values by the maximum value).

Figure 6 shows that the Daiwha sensors able to capture drops dripping at different speeds: 400 ml/h ... 1200 ml/h. However, when the drip rate is high, it is clear that each drop falling causes two voltage pulses whose amplitude varies very little. The drop about to let splits into two parts when fallen, the main one, and the tiniest drop formed from drop "tail". Due to the sensor electronics features a small and a large drop evoke the same amplitude pulse, but with different pulse duration.

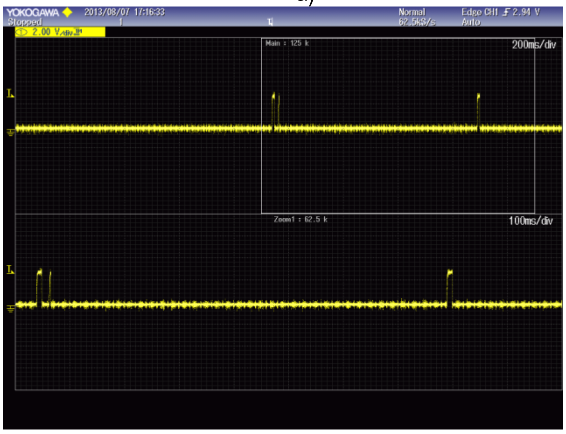
This problem disappears at low (<400 ml/h) drip speed. The study found that the operational amplifier signal is fed with noise (50 Hz and 120 kHz). The same noise (120 kHz) in the output signal is observed (Fig. 6). Possible cause may be the lack of filtered mains of voltage converter noise in the power supply.

2.3. IR Optical Pair without Electronics

Research showed that the drop sensor can operate in the absence of the electronic part. In this case IR sensor and IR LEDs are sufficient. The signals are obtained with the noise, but with proper selection of LEDs and IR sensor detection of the flow of fluid dripping are possible. (Fig. 7).



a)



b)

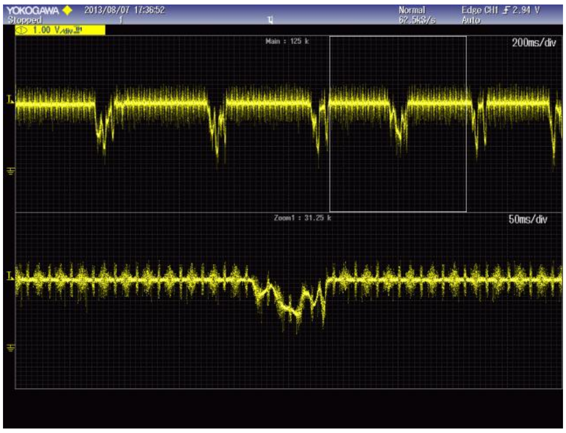
Figure 6. Daiwha drop sensor oscillograms: a – the drip rate of 1200 ml/h (cell value of 500 ms), b – drip rate of 400 ml/h (cell value of 200 ms)

Daiwha drop sensor LED on IR the couple signal is presented in Fig. 7.

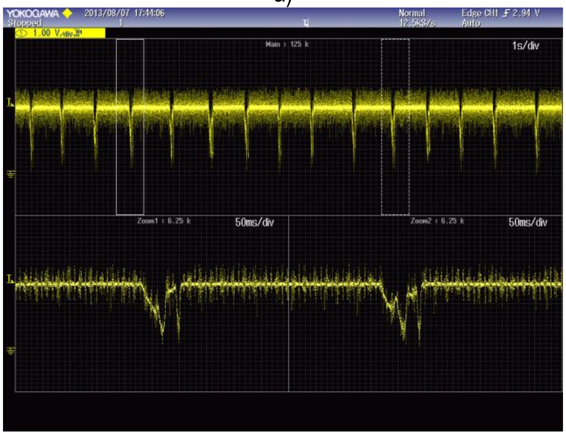
These oscillograms raise suspicion that the Daiwha [5] drops sensor scheme is misleading, or at least misspelled because after removing the electronic part from the sensor, and leaving only the IR LEDs and IR sensors, it still works. Signals are obtained with a very high noise level (from the power transformer) and one drop falling creates several voltage pulses (Fig. 7). Interestingly, even without the electronic part, the generated voltage pulse amplitude and duration is almost the same as with the electronic part and the peristaltic pump is operating normally.

3. PATENT ANALYSIS

Summarising the study carried out, analysis of patents associated with the drop sensors is presented (Table 1) [6] – [12], highlighting the principle of operation as well as the advantages and disadvantages.



a)



b)

Figure 7. Daiwha drops sensor oscillograms without electronics: a) – the dripping rate of 1200 ml/h (cell value of 200 ms), b) – the dripping rate of 600 ml/h (cell value of 1000 ms)

4. DISCUSSION

Usually each manufacturer adds a drops sensor at its peristaltic pump, which is designed specifically for that peristaltic pump model. The main problem is that most of these sensors operate reliably only when they are mounted precisely vertically. The sensors are usually not working in horizontal position or at an angle. Such sensors are not valuable in busy environments such as an ambulance, even though drops sensors would be very useful in such an environment, since it is often very difficult, if not impossible to administer the appropriate dose of the medication to the patients in such circumstances.

When the speed is very low (0.3 to 0.6 ml/h), the drops are also difficult to capture for the sensor because it is unable to distinguish whether the drops fall very slowly, or do not fall at all, so often at a slow dripping rate, drops sensors report an empty drops tank or discontinued supply of drugs, although this is not true.

Table 1. *Summary of patent analysis*

Patent No.	*Operating principle*	*Advantages and disadvantages*
US 4,181,130	Electronic based. There are five IR LEDs that illuminate phototransistors on the other side of the drops tank.	Production costs of such drops sensor are not small because an optical lens is required. Its accuracy is pretty good. Would not be able to capture drops in slow dripping rate.
US 4,583,975	Based on electronics. Piezoelectric sensors responsible for the drop detection feel the vibrations that occur when a single drop falls in the liquid of the drops chamber.	Such drops sensor production costs are high, but it is not very accurate, because the piezoelectric sensors detect vibrations caused by the drops when they fall, but those vibrations can easily be the result of many external stimuli. It is small and easily fixed.
US 4,680,977	Based on expensive optics. Lenses focus infrared light exactly in the centre of drops container and to the IR sensor. Only the width of the drop IR beam is allowed to enter the sensors.	Drops sensors described in this patent are highly accurate, but they are among the most expensive ones, because they are based on complex optics. The sensor is designed so that it can be mounted and removed very conveniently and simply. The only disadvantage of such drop sensors is that they are very expensive.
US 4,703,314	Operates on electronic basis. On one side of the drop sensor is the IR LED, which emits beams to the other side in the straight line to the IR sensor.	This drops sensor is quite simple. Its production costs are not high, but accuracy is also low. Daiwha drops sensors operate on this basis.
US 7,918,834	Operates on electronic basis. Contains a number of IR LED's and IR sensor layout options. The point is that one IR sensor captures the IR beam going through the drop, and the other reflected from the drop.	Drops sensors described in that patent can be placed on the number of drops containers. They are easy to make, simple in their construction, manufacturing costs are low. Accuracy is good enough due to the arrangement of IR LEDs and IR sensor described in the patent.
EP0198909 B1	Based on mirrors. On one side of the drops sensor is the IR LEDs and IR sensors. Using one large or three smaller mirrors, the IR beam is directed into the sensor.	Such drops sensors are accurate, but they are difficult to produce. Their production costs are high; in addition they need a lot of time to accurately calibrate the mirrors, because these sensors are working only through them. Evaluating cost and time of production of these sensors relatively to their accuracy, they are hardly worthwhile to produce.
Str. A61M5/14	Operates on electronic basis. Basically formed from three IR LEDs arranged at different heights, and sensors located before them at the same height.	These drops sensors are easy to produce. They are quite accurate, and the production cost is not high. However, these sensors are large and unwieldy.

5. CONCLUSIONS

Drops sensors are available in different designs, but all of their principle of operation is similar, and the goal is the same. It was found that:

- Almost all of the drops sensors are based on the use of optical IR pairs;
- Lenses and mirror systems are used to increase reliability;
- Most of the sensors have a convenient fastening on the drops chamber mechanism;
- Most of the sensors have a simple or more complex electronic part;
- Specialized or standard connectors are used to connect to peristaltic pump;
- Most sensor designs ensure that the Sun's rays are prevented from entering the sensor active area.

The study distinguished two main weaknesses of peristaltic drips:

- At high dripping speed, drops form a sort of continuously flowing faint trickle so the individual droplets cannot be identified with any drops sensor;
- At low dripping rates drop formation can take a long time. It is very difficult for drops detection, because it is difficult to determine whether the dripping rate is very low, or there is no drip at all. In general, this is the problem of not only drops sensors, but of the pump PI algorithms as well.

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