Design and Development of a Unique Drop Sensing Unit for Infusion Pump

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In the present set-up, the precise assembly of drop sensor unit has three IR-LED/detector pairs placed at different planes across drip chamber to detect the falling drop. The prismatic effect, due to drops sticking to the walls in front of one pair of transmitter/detector, is compensated by other two pairs. This increases a reliability and dependability of the overall system. Most importantly, the unit can accommodate variable sizes of drip chambers available in the market. This paper gives details of the above unit and also discusses about the overall performance improvement that has occurred by the introduction of this device.

Introduction

Drop type Drug Infusion Pump & Controller is used to infuse the drug precisely, drop-by-drop into the patient, at a predetermined rate, by peristaltic type of pumping action on the intravenous (IV) set tube. The Drug Infusion pump has several advantages, like accuracy and precision in drug infusion and initiation of various alarms so as to attract the attention of operator in the case of malfunctioning. Since the required infusion rate is in mL/h, it can be converted into drop rate/min for a particular set as:

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\text{Drop rate (drop/min)} = \frac{\text{Volume to be infused (mL)}}{\text{Time for infusion (h)} \times \text{drop size (mL)} \times 60}
\]

The drop sensor unit is used for accurate detection of drops in such a instrument. The accuracy in drop detection plays an important role in such type of instruments. The IV set available in market consists of liquid container, drip chamber, PVC tube and injecting needle. The drip chamber is clamped inside the drop sensor unit. In the presently available imported instruments (like Diginfusa-Swiss make and Dragger-German make, etc.), the drop sensor unit has only one pair of IR-LED and detector2. After operating the Infusion pump for sometime, tiny droplets get stuck to the walls of the drip chamber due to condensation in the chamber. These tiny droplets act like tiny prisms and deflect the light rays from the source IR-LED away from the detector. Thus the light does not fall on the detector and it misses to register the drop count. Also, sometimes these condensed liquid droplets on the wall are wrongly sensed as drops falling down. Both the above conditions result in wrong counting of number of drops actually falling and infused into the patient’s body. This can generate false alarms. These problems were taken care of in our modified design.

Design Requirements

Following are the requirements which have been taken care of in our drop sensor unit:

1. The instrument should be able to handle drop rate from 1 drop/min to 99 drops/min, i.e. it should be compatible with the Infusion Pump requirements.
2. The instrument should provide reliable detection of the falling drop in the drop chamber. The reliable functioning of Drug Infusion Pumps depends on reliable drop detection and accurate drop count will provide accurate information about number of drops infused to the patient.
3. The device should be able to handle all types/sizes of IV sets available in the market for infusing drugs to neonates and adults.

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The device should give signal for activating alarm in the case of rise in the level of liquid above a particular level in the drip chamber due to any obstruction in patient’s vein or in PVC tube.

System Design

The arrangement of various LEDs and detectors around the drip chamber is shown in Figure 1 and 2. Isometric view of complete drop sensor unit is represented in Figure 3. Figure 4 represents the path followed by the drop, as it falls down. It also shows the path of light as it traverses from LED to the detector. Figure 5 represents how the pulses sensed by three detectors a, b, c are processed and resultant found.

Our drop sensor unit (Figure 3) is a multi-level, multi-directional, and self centering device. It is to be connected with the Drug Infusion Pump. A lever loaded with springs helps to open and close the space for inserting the drip chamber of IV set. The drip chamber after insertion in its place, gets clamped automatically by the release of the lever. The motion of the lever is transferred to LED/detector holder through two cams and a positioner. LED/detector holder slides in the slots of the positioner. Top cover helps to eliminate the effect of ambient light. As the drop falls, it obstructs the beam of light travelling from the transmitter (LED) towards the receiver (detector) on the opposite side. The LED/detector gives a change in voltage level as the drop falls. This change in voltage is sensed by the phototransistor(detector) and is converted to a pulse and is electronically processed further for controlling the peristaltic action and for actuating alarms in the case of malfunctioning. The LED/detector pairs are placed at different levels and different directions along the drip chamber (Figure 1 and 4). The design is such that the axes of all the three pairs are directed towards the axis of the falling drop in the drip chamber, as shown in Figure 2. The IR-LED/detector pairs are located at 50° angle to each other at different levels along and around the drip chamber.

The fourth LED, shown in Figure 1, is for level detection. In some makes of IV sets, drip chamber shows a level mark. Rise of liquid, above this mark, indicates that there is some obstruction in the path of drug delivery flowing into the patient’s vein. This is an alarming condition.

Waveforms corresponding to two consecutive drops falling in the drip chamber are shown in Figure 5. Pulses are generated at $t_1, t_2, t_3$ times corresponding to 1st drop and $T_1, T_2, T_3$ times corresponding to the next falling drop. These are detected, shaped by comparators and logic circuits, to give a single pulse of $< 600$ ms duration out of multiple pulses from multiple detectors (3 each in our case). This increases the reliability of the system when the condensation has taken place as every drop is sensed reliably. The main parts are injection moulded with glass filled Nylon to provide dimensional stability, durability, and the required strength.

Results and Discussion

In every drop type Drug Infusion Pump, a drop sensing unit is used for accurate and reliable detection of
Figure 3 — Isometric view of drop sensor assembly

Figure 4 — LED/Detector arrangement

Figure 5 — Pulse processing for three LED/Detector pairs
drops falling in the drip chamber. Signal from this unit helps in the feedback control, measurement of number of drops infused and controlling alarm conditions in the system. In the existing Infusion pumps, drop sensing unit consists of an IR-LED as transmitter and matched phototransistor as detector, fixed across the drip chamber for detection of falling drops. After operating for sometime, due to condensation on the drip chamber walls and formation of droplets, prismatic effect takes place and detector is not able to sense the falling drops, resulting in malfunctioning of the system. In our design the prismatic effect due to drops sticking to the walls in front of single transmitter-detector gets compensated by other two pairs. This results in a reliable and dependable overall system. The limited space in the drip chamber forbids us to put more sensors for further reliability. In addition the alarm indicating rise in the level of liquid above the mark in the drip chamber due to obstruction in patient’s vein or in PVC tube further helps doctors/attendants to take timely action. Various makes of IV sets, available in the market, whose drip chamber diam. varies between 14.5-19 mm, can be used. The design of the drip chamber clamping mechanism is such that even with variation of the chamber diameter the drop axis and beam axes always intersect. The performance of the system has been found to be better as compared to other similar types of system available commercially because of the better design of the drop sensing assembly with multiple sensors at different angles and planes which minimizes the false alarms and counts drop accurately. The technology of the system has been transferred to the four Indian industries.

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References