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Design and Construction of a Precise Intravenous Fluid Rate Calculator

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ABSTRACT

The rate setting method of current visually judged, gravity driven intravenous infusion sets are time consuming and human error is highly probable. In this research project, a device with a precise rate calculation, a display and an indication are developed without altering the gravity driven design. Aclass-3laser (with intensity reduced), produces a plane of light perpendicular to the path of the fluid drop. Considering that a falling drop interrupts the intensity falling on the detectors placed opposite to the laser, the time between two interruptions are processed by a microcontroller in milliseconds, rate is calculated and displayed with only the delay of a falling drop. This device is capable of detecting rates up to 20 ml min^{-1}. A wireless indication takes place for a change of rate from the set rate using a 315 MHz Radio-Frequency (RF) module that can range approximately up to 100 meters. Rechargeable batteries which are estimated to hold for three days per cycle, power the device and a battery-low indicator is included. The design was developed using easily available components, prone for hard use and considering low cost construction. The device was tested under laboratory conditionsfor normal infusion of saline(0.9% NaCl).

1.0 INTRODUCTION

Body fluids that approximately accounts for 60% of an average persons' body weightconsist of electrolytes and nutrients that support metabolic processes. Therefore, afluid overload or a deficit could result harmful effects inside a persons' body up to much critical levels. Infusion of fluids intravenously comes in to use in order to bring such animbalance back to normal or to maintain the balance until a patient recovers.
Christopher Wren (1632-1723) created the first ever intravenous infusion device in a working condition using a quill and pigs' bladder[1]. From there onwards, the field kept evolving with attempts of blood transfusions. It was the two world wars that accelerated the advancements towards modern instruments used for IV infusion.

In the present, a gravity driven infusion set simply made out of plastic is used. But this requires frequent inspection by medical personnel trained for the particular purpose. The rate at which fluid flows is determined by visual judgment of a nurse or a doctor by counting the drop rate against time which is not precise and time consuming. A change in rate is identified only when the nurse or the doctor rechecks. With improvements in technology, electronic accessories such as pumps and rate calculators that can be coupled with this infusion set have been introduced such as pumps and rate calculators. Precision level of some of these equipment depends on human error and therefore, are left questionable. Ones with higher accuracy are quite complicated, expensive and not primarily designed for hard use. Therefore, in most third world countries like Sri Lanka, such electronic accessories are very limited and are used only in case of emergencies. In hospital general wards, the gravity driven, visually judged system plays the major role. Goal of this work is to develop a device that determine and display the rate of fluid flow by detecting drops optically. According to the design, the drop is captured by identifying an interruption for a continuous laser beam set as a plane of light and interruption data are fed to a microcontroller to process the time between two drops into rate in millilitres per minute.In addition, once the expected rate is reached, the system can be acknowledged.Once the rate changes from the acknowledged rate, a signal is sent to a distant indicator which indicates the change.

2.0 METHODOLOGY AND IMPLEMENTATION

Development of the precise intravenous fluid rate calculator was done using two separate circuits,

- Main processor Unit – where detection information is fed to and rate is calculated.
- Indicator unit – where indication of a rate change is indicated.

The development was carried out in four main phases,

1. Optical detector of the fluid drop
2. Main processor unit
3. RF module and indicator unit
4. Power source and battery low indicator

Optical detection was done with a red laser (wavelength of 650 nm) and a phototransistor. The main unit has to be powered on and the roller clamp is adjusted so that drops start falling. The detection of drops by the phototransistor is captured by the microcontroller and it is set by program to count the milliseconds between two drops. Then the corresponding rate is calculated and displayed on a seven segment display. When the required rate is displayed, the clamp should be let go and wait several seconds making sure the rate is constant. Then, by pressing a push button the rate can be ‘set’ and a LED indicates this. Optionally, another LED is provided on the device to blink at each drop fall, still enabling manual rate calculation as well.

Every three seconds, the program checks for a rate change from the set value and if the rate changes and does not come back to the set rate within 3 seconds, the RF transmitter transmits an 8-bit address specified for the device. Then a buzzer sounds and a LED,corresponding to the device that is transmitting the address, lights up on the indicator unit. This indication takes place until the rate returns to the set value or the nurse approaches the device and presses the reset button. If reset command is given, the process of adjusting and setting the rate has to be done again.

2.1 Optical detection of the fluid drop

All intravenous fluids are electrolytes, nutrients, blood components and medications dissolved in water[2]. Therefore, to detect a drop of intravenous fluid, it is appropriate to consider a beam or a ray of electromagnetic radiation travelling through water. Such a beam or a ray may undergo reflections, refractions and most importantly, absorption of its energy.Moving up the spectrum, beginning from visible region, the colour red displays a median absorption and rays from visible region is less likely to affect the properties of a fluid. Therefore, a red (650 nm) laser was chosen as the optical emitter especially due to the ability of obtaining an evenly distributed line/plane of light by placing a series of lenses shaped as below (Fig. 1) in front of the laser emitter.

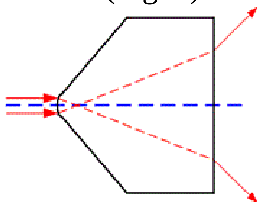


Fig.1: Laser line generator lens[3]

Optical detector used is the widely available L14G2 phototransistor. One such phototransistor was used such that its reception angle (half reception angle = 10^0)[4]covers a plane across the drip chamber.Then the laser was mounted and aligned right opposite to the phototransistor on the same plane across the drip chamber such that the planes of detection and emission are on each other (Fig. 2).

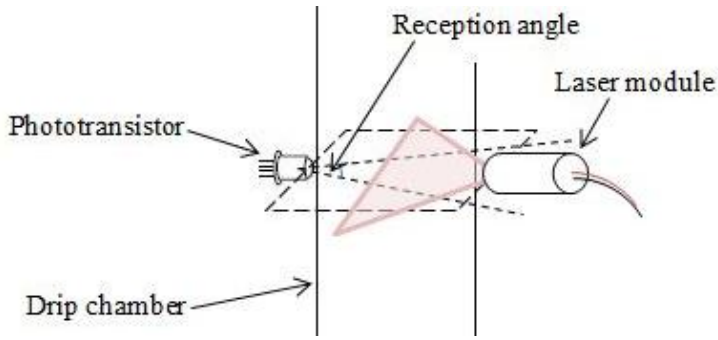


Fig.2: Laser and phototransistor aligned

2.2Main processor unit

The main unit schematic was designed using ‘Cadence Orcad Capture Cis’ software and the PCB layout with ‘Orcad Layout Plus’. The schematic was designed with open ports to connect external inputs and outputs. This unit mainly consist a 5 V voltage regulator, a PIC16f877a microcontroller, a 4 MHz oscillator and a battery low indicator. Externally, a pair of seven segment modules, a RF transmitter, a phototransistor and a laser module was connected to the unit.The final algorithm (Fig. 3)was developed in steps:

1. The phototransistor output was connected to RC2/CCP1 of the microcontroller. The drop detection was confirmed by letting a LED blink at each capture.
2. Then the captures/ drops were counted and displayed on the seven segments.
3. By setting a timer, the number of milliseconds between two drops was calculated and thus, the rate. Then rate was displayed on the seven segments.

4. Finally, other options of selecting a rate and RF indication of a change were implemented. RF transmitter was connected to RC6/Tx and other LEDs and push buttons were connected to general I/O ports of the microcontroller.

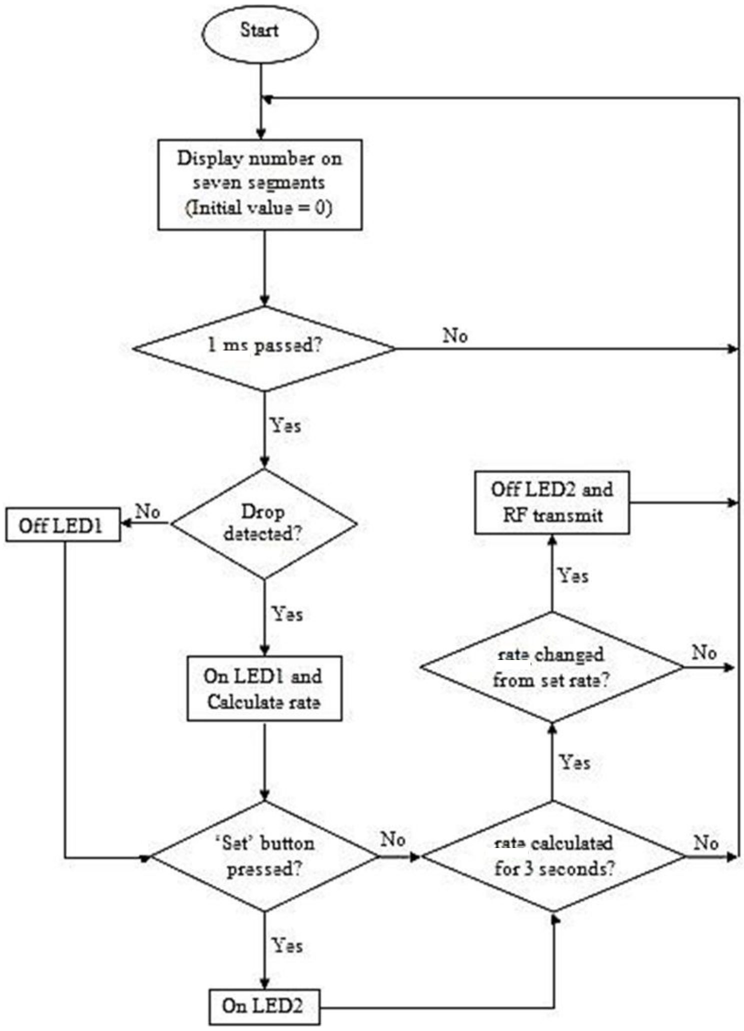


Fig.3: Flow chart for main unit

2.3RF module and indicator unit

In a general ward, there can be a number of IV infusions taking place at the same time. It requires a device per stand and if a rate change happens in one device, it might arouse a problem in identifying the particular device. Therefore, in order to identify the devices separately, an 8-bit key which acts as an address is assigned per device.

This 8-bit key is transmitted from the RF transmitter on the main unit and it is received by the RF receiver in the indicator unit. The transmitter, initiates transmitting with a header value (0xaa), followed by the 8-bit key. On the receiver side, in order to avoid interfering of signals, the receiver keeps checking for an 8-bit header value (0xaa) and if it is received, the next 8-bits are considered as the key. Only then the receiver starts searching for the header again. Due to this process there are no conflictions between two signals sent from two devices[5].

The design of the indicator unit consists a number of LEDs with each assigned to each device. Therefore, when a key is received the corresponding LED lights up with a buzzer sound, so that the nurse can locate the corresponding device easily and readjust the rate back to the required. A PIC16f877a microcontroller is used as the processor in this unit since the number of devices (LED indicators) coupled to a single unit can be allowed to vary from one to the number of I/O ports available (32 ports except RC7/Rx which connects to the RF receiver).

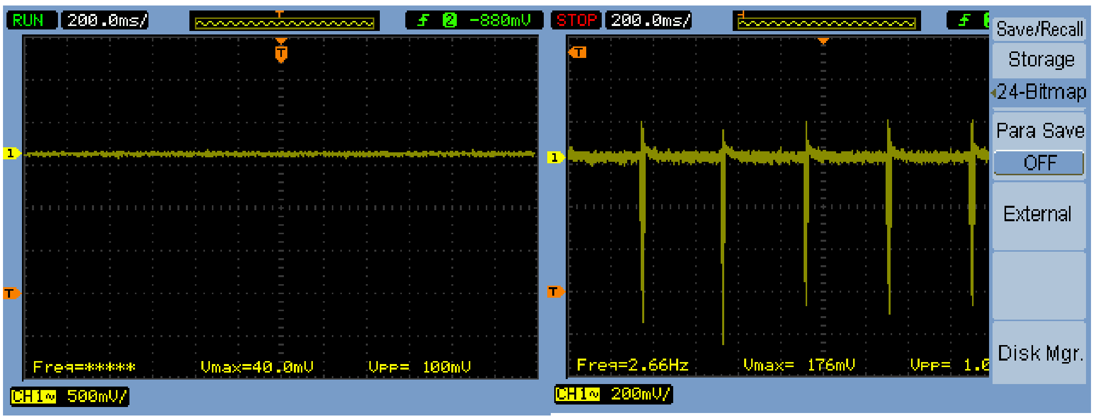
2.4Power source and battery low indicator

The power source of such a device mainly requires durability. Therefore, two 3.7 V, 2800 mAh, Li-ion, rechargeable batteries were used.Since this apparatus is mostly required to be switched on for a long number of hours, it is important to indicate battery status. Therefore, circuitry for an indication of battery was added. The circuit depends on current, and a LED is set to light up gradually with decreasing current.

3.0 RESULTS AND DISCUSSION

3.1 Optical detection

The device starts counting the time with the power up. Therefore, the rate displayed for the first drop after adjusting the roller clamp should be neglected. This single drop is the device's error with regard to fluid volume and is equal to the volume of a drop, 0.05 ml.
Interruptions by drop falls resulted clear fluctuations on the signal produced by laser falling on the phototransistor without interference. The similar intervals between interruptions can be observed using the drop interference output. Using frequency of the same output, the rates can be calculated and confirmed with the displayed rate output.



(a) **(b)**

Fig.4: Output signals from the phototransistor observed using an oscilloscope: (a) phototransistor output for laser, (b) Drop interference from phototransistor

The position of the phototransistor was optimized by considering the reception angle and the dimensions of the drip chamber.
Mean diameter ≈ 16.50 ± 0.01 mm
Mean height ≈ 38.37 ± 0.01 mm

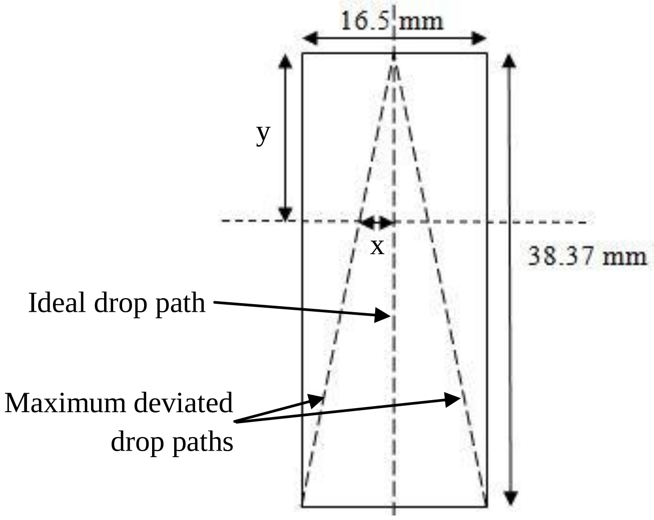


Fig.5: Drip chamber dimensions

The drip chamber may not always be perfectly vertical but the drops always fall vertically downwards due to gravity. Therefore, path of a falling drop with respect to the drip chamber may vary from the ideal path. It was considered that the maximum deviation of the path of the drop varies as shown above in Fig. 5.The radius of the detectable drop path range, x was determined according the trigonometry of the cross-section as shown below in Fig. 6.

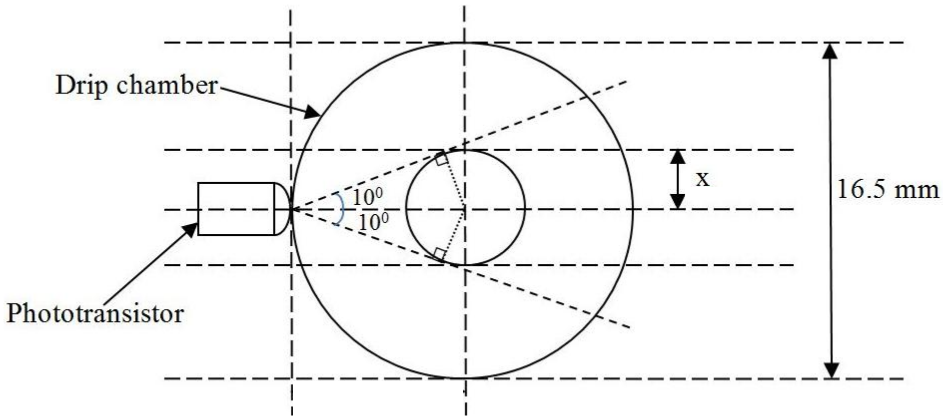
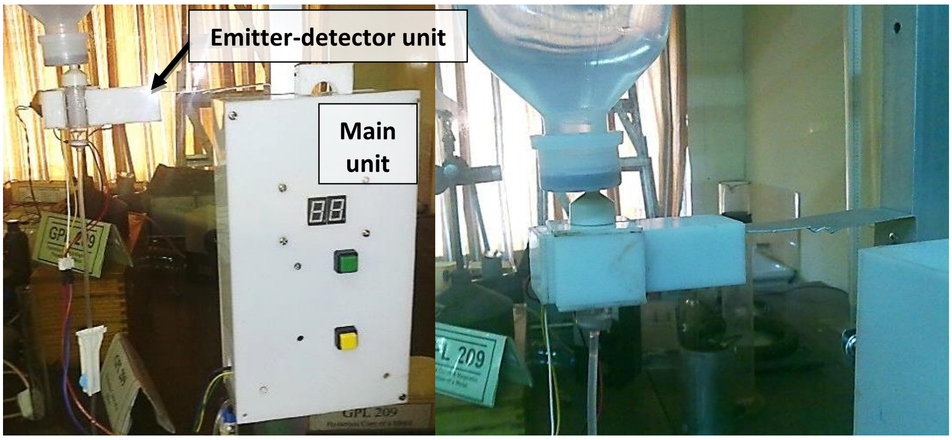


Fig.6: Cross sectional view of the drip chamber with the phototransistor

According to the value of x (x ≈1.433 mm), the optimum positioning for phototransistor varies up to y (Figure 5), and y was calculated to be 6.665 mm. Therefore, the phototransistor has to be positioned near the top to cover all possible drop paths (Fig. 6). But as the drop forming orifice is at the top, the phototransistor cannot be positioned at the very top since it may detect the drop while forming. It is essential to detect the falling drop. This problem can be overcome by using a phototransistor with a higher reception angle but they are relatively expensive.

The optical emitter and detector are constructed in a separate unit and placed around the drip chamber. It is important to use a black matt surface inside such that no light from the laser escapes outside and to avoid exceeding the maximum permissible exposure (MPE)[6]. Therefore, the unitshould not be openedwithout switching off the device.



(a) **(b)**

Fig.7: (a)Main unit and the emitter-detector unit, (b) Enclosed emitter-detector Unit

3.2 Other development considerations

The indication of a rate change is not done in the main processor unit that is fixed to the stand to avoid patients' unnecessary concern or distraction. It is done in a distant unit since such an indication on the device itself could confuse the patient.

During the development it was observed that several unexpected situations could arise. Specially, a mist formed on the inner walls of the drip chamber. This situation did not affect the laser beam. Then, as the IV fluid bottle was finishing, the drip chamber tend to take an angle from its expected vertical position. This was affecting the drop rate and therefore, the optical emitter detector system around it was mounted to the saline stand. Another effect was seen as the bottle was finishing, the drop rate seems to decrease and volume of the drop was apparently getting smaller.

4.0 CONCLUSION

In this research, a precise intra venous fluid rate calculator was designed and constructed with an optical method of detecting the drop falling through the drip chamber. The main task was to optically detect the drop. Apart from that several other tasks were done in order to complete the design and the construction; rate calculation, RF module and indicator unit, power source and battery low indicator.

Thesystem was designed for 20 drops per ml infusion set and constructed.The device performed as expected for tests under laboratory conditions for normal saline (0.9% NaCl). Using this as a prototype, the device can be developed commercially to be used with any infusion set, for any IV fluid. The use can be extended to anywhere that requires a drop rate calculation in the range of 1 ml min^{-1} to 20 ml min^{-1}. The main design consideration was for much appropriate use in a general ward of a hospital.

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