INTRAVENOUS INFUSION MONITORING SYSTEM BASED ON WSN

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Abstract

In various treatment plans, the progress and velocity of intravenous infusion must be strictly controlled. Undeniable, present artificial monitoring methods not only increase the burden of patients, relatives and medical staff, but are vulnerable to lead oversight as well. This paper presents the design and implementation of a novel wireless sensor network for intravenous infusion monitoring based on slot-coupled infrared emitting diode as sensors, chip ATMEGE128L as MCU and chip CC2420 as ZigBee-based RF communication. The system has following characteristics: non-touch droplet monitor, easy to reuse, multiple protections on system accuracy and reliability, easy to integrate with existing hospital management system due to flexible design of the host computer software, low cost, and easy to launch large-scale applications.

1 Introduction

Intravenous infusion is an important clinical treatment [8]. Reviewing various treatment plans, the progress and velocity of intravenous infusion must be strictly controlled; otherwise, it will result in serious medical accidents. Undeniable, present artificial monitoring methods not only increase the burden of patients, relatives and medical staff, but are vulnerable to lead fatigue and oversight as well. Here is an example, in 2009, an 18-month child died of reflux during intravenous infusion in the hospital of Liangchen area, Wuxi city, Jiangsu province, PRC. Fortunately, some specialized medical instruments can be part of solution to these problems [10][11]; for example, infusion pump is able to control the velocity of infusion strictly, and cut down infusion tube at the end in case of reflux. However, those similar instruments have some common disadvantages: large-scale applications are limited by high cost; requiring special cleaning before being reused makes these instruments cumbersome, as opposed to disposable infusion tube; no network communication functions eliminate these products to integrate with hospital management system present.

Wireless sensor network (WSN) technology [2][3], which is based on novel sensor and RF communication technology provides a low-cost, easy to deploy and flexible method for reality perception and data acquisition as well as transmission. This paper describes the design and implementation of a novel WSN for intravenous infusion monitoring based on slot-coupled infrared emitting diode as sensors, ATMEGE128L as MCU and CC2420, ZigBee-based [1] RF chip produced by the Chipcon Company. The system has following characteristics: non-touch droplet monitoring, easy to reuse, multiple protections on system accuracy and reliability, easy to integrate with existing hospital management system due to flexible design of host computer software, low cost, and easy to launch large-scale applications. Large quantities of experiments guarantee the accuracy and reliability as well as high precision of the system which conforms to realistic applications [4].

This paper is organized as following parts: introduction of intravenous infusion monitoring principle, the whole architecture of the system, the choice of sensor components, the design of monitoring circuit, the design of MCU with RF communication circuit, the software of sensor, the software of host computer; finally we focus on the precision and reliability of the system by experimental results and analysis.

2 The principle of the monitoring system

This paper shows we perceive the progress and velocity of droplet through droplet monitoring. Hydromechanics theory shows that the weight of the droplet is only related to the surface tension under approximately static 'Nkosi steady state' conditions [6] when the velocity is slow enough; and there are many factors influence the surface tension such as liquid concentration, species, and the sectional dimension, shape, temperature as well as humidity of the droplet. Under practical conditions, given fixed type of infusion tube, and little change in temperature and humidity, the main factor affecting droplet weight is liquid species and droplet velocity [9]. We could gain an empirical value formula through analysing the experimental statistics of the droplet amounts contained in per millilitre under different medicine species and droplet velocity conditions. Based on this formula, the system design a tuning algorithm [5] managed to improve the precision of automatic monitoring. In experimental analysis section of this paper, we will analyse the influence on monitoring precision caused by liquid species and droplet velocity in details.

MCU module based on ATMEGE128L, and RF communication module based on CC2420 chip.

3 Architecture of the monitoring system

System deployment is shown in Fig 1.

The intravenous infusion monitoring sensor is deployed at each 'Murphy's tube' in disposable infusion tube which is responsible for signal perception, waveform adjusting, data transmission and light alarm with sound. Sink node is connected to PC deployed in the nursing station through transfer line between RS232 and USB which is responsible for collecting signals on the infusion progress and velocity from each monitoring sensor, then transmit these signals to host computer through COM port. Monitor software on host computer is in charge of data processing, interface display and alarm as well as integrated interface with other system.

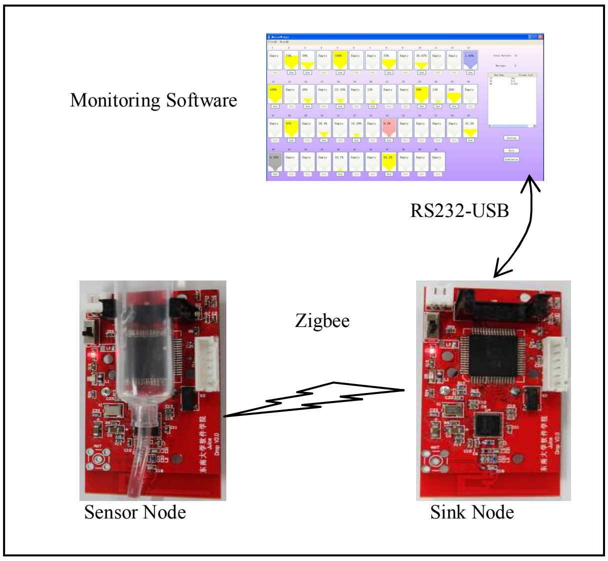

Fig 1 System deployment topology

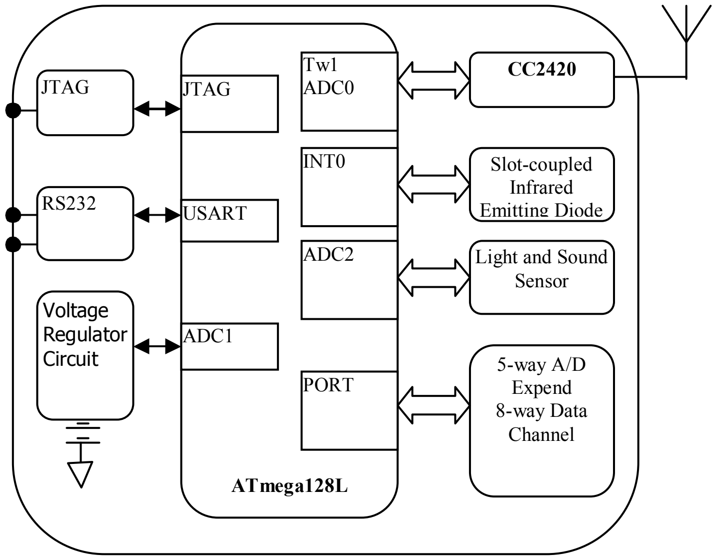

Fig 2 Structure of sensor node

4 Design of monitoring sensor

4.1 The selection of sensor components

By investigation, available components in market which can monitor droplet or liquid level monitoring can be divided into: ultrasonic sensors, laser sensors, separate infrared emitting diodes, coupled infrared emitting diodes. The system finally adopts coupled infrared emitting diode after taking precision, anti-interference, cost, power consumption, distance, size and deployment into account.

Table 1 Comparison of droplet monitoring sensors

Type	Precision	Anti-interference	Cost	Power	Distance	Size	Cost
Ultra-sound sensor	High	Strong	High	High	Middle	Large	Inconvenient
Laser sensor	High	Strong	High	High	Far	Middle	Inconvenient
Separate infrared emitting diode	Middle	Weak	Low	Low	Middle	Small	Inconvenient
Coupled infrared emitting diode	Middle	Middle	Low	Low	Near	Small	Convenient

The structure of intravenous infusion monitoring sensor is shown in Fig 2. The structure of sink nodes is similar to those of monitoring sensor. The difference between them is the latter has no sensor component and waveform adjusting circuit. The sensor is mainly consisted of three components: droplet signal monitoring module based on slot-coupled infrared emitting diode and its waveform adjusting circuit,

Coupled infrared emitting diode with 1.5cm diameter slot adopted by the system has prominent advantages on low cost, low power consumption and small size; moreover, 1.5*5cm 'Murphy's tube' in disposable infusion tube can be exactly embedded into 1.5cm diameter slot on coupled infrared emitting diode; hence deployment is easy.

4.2 Design of monitoring circuit

The principle of sensor components is shown in Fig 3. When there is a droplet going through slot-coupled infrared emitting diode, the receiver of the component will generate a signal. The signal will be amplified after comparison by LM393, and then the waveform will be adjusted to the same duty cycle making use of monostable function designed in NE555CN chip. After that, the signal will be sent to the fourth interrupt pin in ATMEGE128 MCU. Meanwhile, there is a led connected to signal output interface, facilitating the observation of infrared emitting diode working correctly.

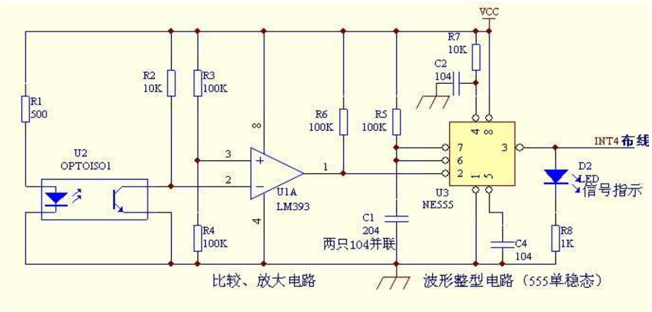

Fig 3 Schematic of sensor component

4.3 Design of MCU with RF communication circuit

MCU with RF communication circuit of intravenous infusion monitoring sensor is the same as those of sink node. MCU is mainly consisted of ATMEGA128L chip produced by ATMEL Company. Designed in RISC architecture, this chip performs highly qualified in low power consumption. It works under the voltage of 2.7-5.5V, easy to be supported by various batteries or external power supply. The chip also offers six kinds of sleep modes to reduce power consumption, improving the lifecycle of the sensor.

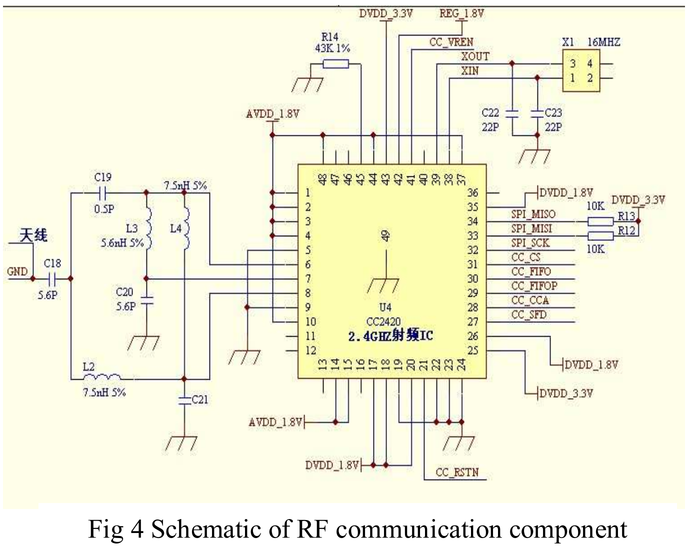

Fig 4 Schematic of RF communication component

RF communication module is mainly consisted of CC2420 produced by the Chipcon Company. Chip CC2420 is produced with 0.18um CMOS technology based on the technology of SmartRF 03 developed by Chipcon Company. It performs steadily even in very low power consumption. Meanwhile, CC2420 conforms to the IEEE802.15.4 standards and exceeds it in selectivity and sensitivity to guarantee the effectiveness and reliability of short-range communication. Effective bandwidth of 250kbps provided by CC2420 ensures network scalability. RF communication can be easily realized via CC2420 accompanied by few external components. In the design of our nodes, external circuit of CC2420 is shown in Fig 4.

5 Intravenous infusion monitoring software

5.1 Software on monitor node

The software of sensor is run on the MCU of intravenous infusion monitoring nodes and sink nodes which is responsible for node control, interrupt handling triggered by liquid signal, wireless communication, serial communication, alarm on exception, fault recovery, etc. On the condition that the MCU program has been developed by us totally, there exist many disadvantages, ranging from heavy workload to depending on specific hardware and to poor portability, just to name a few; thus, the software is developed on TinyOS which is a kind of component-based operating system developed in UC Berkley. In TinyOS, task switching, interrupt handling, serial communication and ZigBee protocol stack are provided as components, so developers just need to focus on business logic. Moreover, TinyOS has many advantages such as tiny object code, high efficiency, Shielding hardware differences, etc. Thus, it is very suitable for wireless sensor network which is restricted in calculation, memory and energy.

In order to simplify the complexity of software of sensor, lower power consumption and save bandwidth, the software of sensor is only responsible for the most fundamental function required for precise and reliable infusion monitoring. Once the interrupt is triggered by droplet signal, the software changes the droplet counter and droplet interval timer. The droplet velocity is calculated with the interval of the latest N droplets (general value of N is 5). If droplet velocity exceeds initial scope of velocity, the software will immediately send out an emergency alarm datagram as well as light alarm with sound. Droplet count and droplet velocity are sent to host computer software periodically in the form of synchronous datagram. The frequency of datagram sent is changed according to infusion progress. The frequency is low at the beginning, but every droplet will trigger a synchronous datagram at the end stage of infusion. Working in this way not only ensures precision but saves bandwidth and power consumption as well. In order to avoid faults caused by downtime due to the host computer, wireless signal interference and lower hardware failure, the software among intravenous infusion monitoring sensors, sink node and host computer software adopts the method of transmitting heartbeat diagram among them to ensure normal working condition of all parts. If any part cannot receive other's heartbeat diagram in expected time, it will alarm in light with sound.

5.2 Monitor software on PC

Host computer software is run on PC deployed in the nursing station which is responsible for human-machine interface, automatic detection of the infusion progress and velocity, visual alarm functions; it also provides interface to other information management systems. The software records all the droplet sizes at different droplet velocity and different medicine species as tuning parameters to estimate the progress of intravenous infusion. There is some information such as patient's identity, medicine species, total volume, velocity scope which should be initialized when a new patient comes; the information can also be obtained from existing hospital information system through RFID. Host computer software provides visualization of infusion monitoring interface according to infusion progress, velocity and exception from monitoring. The interface is shown in Fig 5.

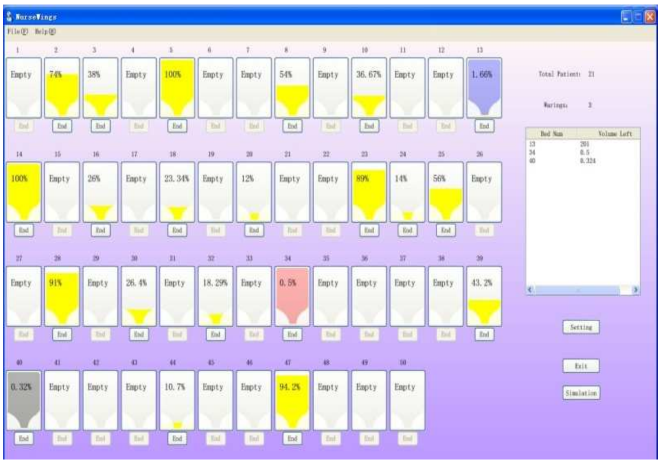

Fig 5 Graphic interface of infusion monitoring system

Fig 6 Picture of intravenous infusion monitoring sensor

6 Experiment results and analysis

6.1 The result of hardware and software development

Intravenous infusion monitoring sensor we produce is shown in Fig 6.

In order to guarantee the availability in hospital, we have done plenty of experiments on precision and reliability.

First, we analyse the influence caused by different medicine species. We have fixed the related parameters like velocity and the type of infusion tube; and we test droplet amounts of different medicine species per millilitre repeatedly at room temperature. We find that droplet amounts per millilitre are mainly influenced by liquid viscosity. The results are shown in Table 2.

Table 2 Influence caused by different medicine species

Medicine Species	Droplet Amount Per Millilitre
5% Glucose	20
10% Glucose	19.5
Physiological Saline	20
Dextran-40	19

Table 2 shows that droplet amount of different medicine species per millilitre is different; so the system takes medicine species into consideration of system tuning algorithm.

We analyse the influence caused by droplet velocity then. The results are shown in table 3.

Table 3 Influence caused by droplet velocity

Droplet Velocity (drops/min)	5% Glucose (drops/ml)	10% Glucose (drops/ml)	Physiological Saline (drops/ml)	Dextran-40 (drops/ml)
10	21	20.5	21	20
40	20	19.5	20	19
70	19	18.5	19	18
100	18	17.5	18	17

Table 3 shows the relationship between droplet velocity and droplet size that, in common, high speed leads to bigger droplets so that droplet amounts are less per millilitre, consistent with Poiseuille equation [7] $Q=(p1-p2)/R$, Q stands for flow load, p1-p2 stands for pressure difference between the ends of the infusion tube, R stands for flow resistance. The system, automatic detection module of upper computer software, sets tuning parameters to ensure precision according to real-time droplet velocity.

Finally, we test the precision of the whole system. At room temperature with 10% glucose as an example, we compare the progress from monitoring system with the progress from the reality according to twenty sets of experimental raw data at different droplet velocity. Maximum error is controlled in 0.5% of the total volume, conforming to general realistic requirements [9]. The experimental statistics of 10% glucose is shown in Fig 7 where the vertical axis stands for drop volume remained (in millilitres) while horizontal axis stands for infusion span (in seconds).

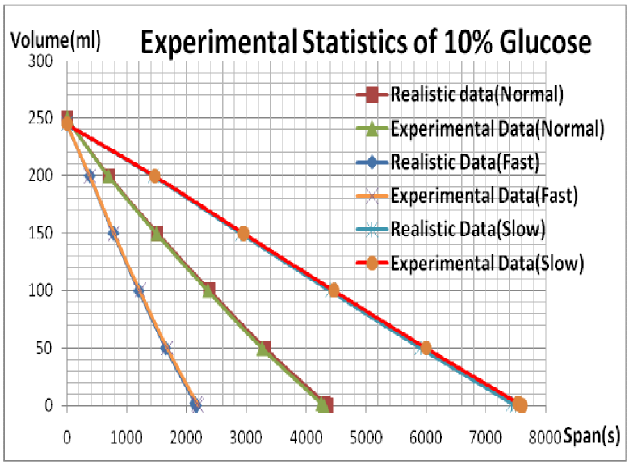

Fig 7 Experimental Statistics of 10% Glucose

7. Conclusion

This paper illustrates a kind of intravenous infusion monitoring network based on slot-coupled infrared emitting diode and ZigBee protocol. Large quantities of experimental statistics show that the monitoring system is able to realize the monitoring function on progress and velocity of intravenous infusion, precise and reliable. Moreover, the system has prominent advantages on low cost, low power consumption, small size, good scalability, convenient deployment, flexible use. Thus, the intravenous infusion monitoring network has high values in large-scale applications.

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