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System for monitoring the process continuity of the intravenous infusion – development study

Streszczenie. *W artykule przedstawiono Autorską koncepcję systemu do monitorowania i detekcji niskiego poziomu płynu infuzyjnego. Wyniki przedstawione wcześniej w [1] zostały uzyskane dla systemu opartego na wadze z butelką z płynem. Ponieważ metoda ta jest wrażliwa m.in. na ruchy pacjenta, Autorzy postanowili zbadać również inne metody, np.: metodę optyczną. W układzie wykorzystano również. komunikację sieciową, która może posłużyć do budowy systemu rozproszonego na użytek procedur opieki szpitalnej podejmowane podczas leczenia. (**System monitorowania ciągłości procesu infuzji dożylnej – studium rozwojowe**)*

Abstract*. The paper presents Authors' development of the concept of a monitoring system for the low level infusion fluid detection. The results presented previously in [1], were achieved for a system based on the scale and weight of the fluid bottle. As this method suffers from i.e. subject's movements Authors decided to investigate also other methods with the optical one as first. Also network communication was introduced. It can be involved in the hospital care procedures undertaken during subjects' treatments.*

Słowa kluczowe: zabiegi medyczne, proces infuzji, system mikrokontrolerowy, system rozproszony, komunikacja przewodowa.
Keywords: medical treatment, infusion process, microcontroller system, distributed system, wired and wireless communication system,

Introduction

The steady growth of the world population inevitably leads to higher population density, especially in already dense urban areas. Large concentrations of people lead to increased risk of widespread pandemics. Airborne viral diseases thrive especially in large cities, where one has indirect contact with hundreds if not thousands of people daily. One of the most recent examples would be the COVID-19 pandemic, which has spread incredibly fast among urban populace. Such rapid-spreading diseases can pose a significant threat to healthcare systems nationwide by forcing hospitals over their designed capacity. Furthermore, when facing critical situations, one must quickly identify bottlenecks that cause significant operation slowdown. Additional beds can be installed, makeshift hospitals created, but the capacity of the healthcare system is strongly determined by the number of people working in medical facilities. While rapidly increasing the number of employees may be impossible, one of the solutions to the problem presented could be to increase work efficiency. Automation might be the answer that could resolve critical problems. To increase effectiveness, the number of unnecessary processes should be reduced to a minimum. One of such processes is a continuous need to check the bottles on IV stands (IntraVenous stands) and determine whether they need to be replaced yet. The proposed solution is a sensor network that could perform this task allowing personnel to perform more crucial tasks and only interact with IV stands to replace depleted bottles with infusion liquid.

Goals

To make the system viable for healthcare few prerequisites have been defined:

- Flexibility - the system has to be easy to mount and replace, it should fit as many IV stands as possible.
- Integrity - there can be no tampering with the physical structure of bottles, such as puncturing, squeezing, and scratching.
- Reliability - when it comes to the lives of real people there is no room for error,
- Easy handling - either minimal or no training should be required to use the system.
- High sturdiness and long service life- as mentioned before, high reliability and sufficient resistance to shocks and mechanical damages must be ensured.
- Good cost/quality ratio- it should be as high as possible (highest quality delivered for a favorable price). Some cost restrictions are still to be applied in order to make these solutions appealing for wider use.

The systems

Having above goals in mind, two systems have been created, allowing a comparison of solutions, which later led to determining which are more adequate to solve the problem posed. The systems have been determined by three scopes: measurement method, power supply and a method of data transmission.

Strain gauge based solution

The concept solution was already presented in [1]. It was based on a strain gauge bar with a measurement up to 2kg and a AVR ATmega 328 microcontroller based system [5,6].

Fig. 1. Electronic components of the scale and the developed concept of the infusion fluid level monitoring system presented in [1].

Currently being developed solution is based on a strain gauge bar [6] and a Node MCU v3 board with a built-in ESP8266 wi-fi module [7]. The bar is capable of measuring weights up to 1kg (covering the range of the mass for mostly used infusion bottles). With the addition of the HX711 module, an analog signal transmitted from the beam is amplified and converted into a digital signal which is then received by the microcontroller. Through such signal processing, high resolution has been achieved, allowing accurate tracking of the current IV weight. The overall size of the system including battery power source is 85 mm x 35 mm x 18 mm without the strain gauge. At the end of the strain gauge beam, a hooked holder is mounted to allow the load to be suspended (figure 2).

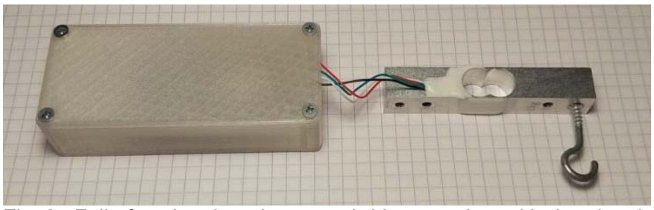

Fig. 2. Fully functional strain gauge bridge together with the signal conditioning and microcontroller in the chassis.

Laser based solution

This solution is based on a phenomenon of a photoresistor changing its resistance while being shined on. A rigidly mounted laser, which is directed at the photoresistor emits its beam. Liquid located inside the bottle refracts the light beam so that it does not land on the photoresistor. Only when the liquid level goes beyond certain point, the beam finally hits photoresistor what is registered as a voltage change.

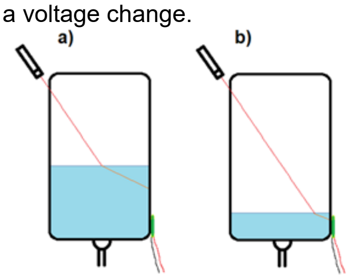

Fig. 3. Liquid levels: a) liquid level is too high and light does not reach the sensor; b) level is low enough for light to refract onto the sensor.

Fig. 4. a) Laser based sensor connection circuit

While using the light dispersion would be preferable method for the measurement of the liquid level it proved to be not possible. While theoretically photoresistor would produce different signals as the level of liquid decreases if mounted in parallel to the bottle in practice laser proved itself to be too strong. While usage of weaker light source could lead to a better result, it would also mean that the ambient light is a much bigger concern. Changing levels of both natural and artificial light would make the measurement disturbed.

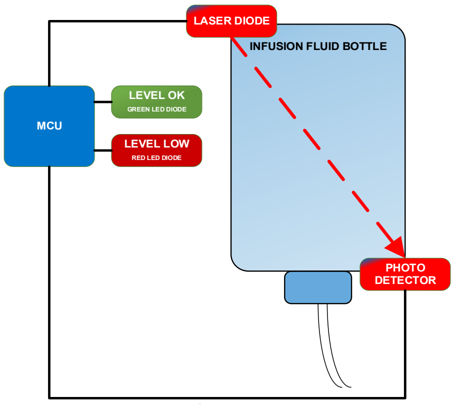

Fig. 1. b) Laser based system functional diagram.

Furthermore, this method of measurement is very susceptible to physical disruptions. Bottles containing the infusion liquid are not perfectly uniform and in various places plastic that they are made of has different thickness and there are many imperfections. It leads to a situation where even a small difference in placement of the laser and photoresistor can cause a vast difference in the output signal. So, for example a person touching the IV could lead to a disruption.

While it could be compensated by making a more robust housing for the measuring system it would also lead to a large interference to each liquid container which is undesirable.

This solution gives us only a possibility of determining if the liquid level has dropped below a certain point. After powering up, a 5-second calibration takes place, in which the system determines initial voltage. Should the liquid level fall, allowing laser light to hit the photoresistor, voltage level changes considerably when compared to initial one. Device is powered and communicates via an ethernet cable.

Data transmission

Startup procedure of the device control software consists of automatic calibration of the scale and connecting to a predefined wi-fi network. Network communication is based on UDP – User Diagram Protocol in both proposed solutions It is a connectionless protocol, therefore there is virtually no overhead for establishing a connection and tracking sessions. Moreover, there is no flow control, retransmission mechanisms, or any other task that would need to be handled by a network module/microcontroller.

This protocol enables a reduction in the energy consumption and time needed to send data to the host computer boosting the overall per watt efficiency. However, these advantages come at a cost. The protocol does not guarantee that a sent datagram will ever reach its destination or even be delivered in the correct sending order. Furthermore, in the standard implementation, invalid messages are not reported to the system but are silently dropped.

For this solution, fortunately, neither the packet order nor the guarantee of transmission is crucial. The system is designed in such a way that the messages are being sent often enough so that any packet drops shall not affect the overall monitoring performance. In case of no data transmission from a particular node, the end-user is informed about the problem so that verification of the issue can be performed.

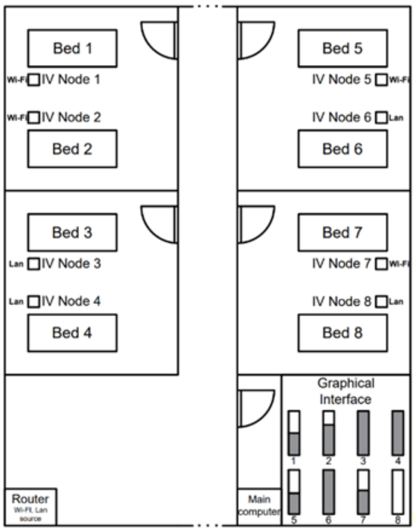

Fig. 5. Visualization of a block equipped with a drip monitoring system.

A star network topology is used in the presented implementation. The main computer, registered with an available UDP port is used for collecting and processing the data from individual nodes.

Nodes can be connected to the hospital's intranet via wi-fi or ethernet connection. Devices are distinguished by a unique IP address assigned to them by the host device e.g. router (fig. 5).

Graphical User Interface

User interface (fig. 6) consists of a window displaying individual IV's levels presented with vertical bars. For weight based solutions (IV 1), an exact visualization showing the IV level percentage is provided. With such acquired data, an approximated emptying time is calculated and shown, allowing for maximum usefulness and easing the workload on the medical staff.

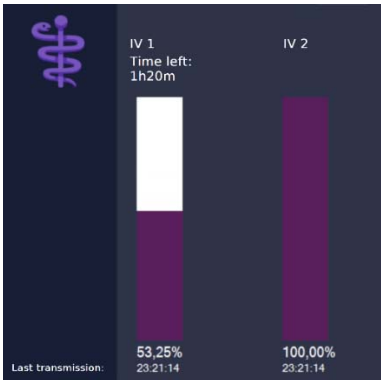

Fig. 6. Initial form of a user interface application.

In the case of laser based method (IV 2), only two levels can be displayed. Full level (above the defined threshold resulting from the design of the measuring system) or empty level (below the threshold). Such a solution may not be optimal, but with the right design and mount, the device is capable of improving staff performance by providing early information about individual IVs.

The number of bars is adjusted dynamically based on the number of nodes connected to the system.

Comparison of the developed solutions.

Both solutions have their strong and weak points. One of the biggest strengths of a strain gauge based system is its mobility and ease of installation. Both have been achieved by a combination of wireless power source and data transmission. The gauge itself allows continuous level monitoring, as opposed to the optical solution with a quantified number of control points.

The biggest weakness of the laser method is the unavoidable necessity of tampering with the liquid container. Whether it is a bottle or a bag, one may need special normalized handles that would allow to streamline the measuring process by introducing constants such as establishing that the bottom level is 20% of the IV's volume.

Further improvements

Future work on the project could address some of the problems encountered while working on it.

Strain gauge based system:

- Further reduction of size is achievable. By just detaching pins from the Node MCU v3 board, height could be reduced by approximately 9mm. Yet still, the most significant change when it comes to size could be achieved by replacing modules used with versions specifically fit for the task (either more viable ones already existing on the market or created from scratch).
- Should the solution be applied to actual medical facilities, it need to be a battery charge monitoring system. This adds further complexity to the entire solution, but as stated before, no gambling is permitted when human life is at stake. Replacement of batteries should be as quick and as simple as possible.

Laser based system:

- It is possible to provide more data by adding additional photoresistors on different levels. The version equipped with only one photoresistor can only inform the user about liquid level being higher or lower than the element itself. Should the system be equipped with 4 photoresistors, accordingly are to be set (i.e. at 20, 40, 60 and 80% of the bottle height). This way, data received would be more consistent and simple versions of countdown until empty could be implemented. It is worth noting that adding more components would make the solution more expensive and complicated, balance between these two options is to be found and validated.
- The optical method can be susceptible to various interferences, one of which is the light coming from the environment. To solve this problem, a special casing for the bottle could be created, preventing any outside light from affecting measurements. This solution is still non-ideal since it makes bottle replacement process more tedious. For this reason, among other things, the optical method is rather to be discarded for liquid level measurements.

Practical enhancement

Device developed in [1], were verified by medical personnel. Results constitute a kind of an analysis of strong and weak properties of the device. This encouraged Authors to improve it and enrich its overall functionality. That is why Authors investigated different measurement methods and implemented features of remote, centralised devices monitoring. It pushed the solution into regions specific for the distributed systems for ma border of SCADA and IoT applications.

Additionally there are some enhancements applied to the construction of the device. As the IV stand height is regulated and can be as high as 2 meters it is not easy to develop single box unit containing both scale and user interface. Thus Authors decided to split the device into scale circuit and the user interface (UI) module. Thanks to that it is possible for personnel to have the UI module at the height of while the infusion fluid bottle is actually hung much higher. This is illustrated in the figure 7.

Fig. 7. Model of the splitted monitoring system IV Stand model on the left. Enlarged are: tensometric beam unit in the right upper corner and control unit in the right lower conrner.

In comparison to a previous version presented in the paper, the device has been expanded by features that allow on-site informing about crucial parameters. Adding such interface allows the staff to check on individual stands without a need to visit a nursing room in which a master device (i.e., a PC) is located.

Added features include:

- LED level indicator

Comprising of 6 LED diodes in distinct colours widely used as a mean of level / severity indication (red, yellow, and green), the subsystem allows for a quick estimation of IV fluid level. The higher the level the more diodes are lit, starting from red ones. Should the level fall below a set alarm threshold, the only lit (red) diode starts flashing, thus drawing attention to the emptying stand.

- Sound signaling

Using a buzzer, the device has been equipped with a way to audibly warn about the fluid level getting dangerously low. Unlike the flashing LED, alarm parameters depend on estimated time of emptying. The closer it gets, the more frequently an alarm sounds, ending with a constant signal while the time is close to running out. Due to operating environment's nature, the alarm can be switched on and off by a dedicated button. Such operation is audibly indicated, in a different way when muting and unmuting, which reduces a chance of the function being in an undesired state.

- Graphic display

Integrating such display has allowed to inform the person checking about exact status of the device and associated process. As for now the parameters displayed are:

- o Net mass of the fluid (without the container),
- o Level, displayed in percentage scale,
- o Estimated time of fluid level reaching zero level.

Unlike previous subsystems, this one provides exact data necessary for efficient and precise work coordination. Additional data could be added to the display, should the need arise. The display is also a mean of communication for the staff while configuring the device. Additional buttons have been introduced to enable parametrisation, such as setting the mass of an empty container (needed for precise calculations) and taring the scale.

Application of the elements described above forced Authors to exchange the microcontroller used in the device. The main reason for substituting ESP8266 for a Raspberry Pico W was the need for more GPIO pins than provided by the formerly used microcontroller. ESP could not provide enough GPIOs to implement all the planned subsystems. Additionally, the Pico W has a wider supply voltage range and is smaller in size, which makes it more suitable for compact, battery powered applications.

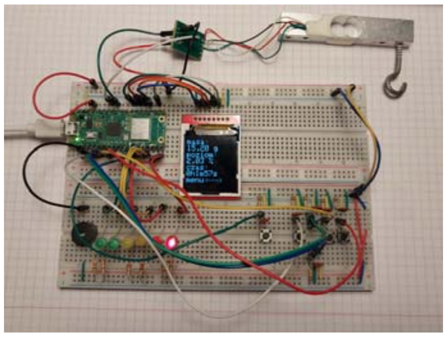

Fig. 8. Testing of the improved system microcontroller circuit

Conclusions

The scale design as posted before [1] is a response to the idea presented by physicians and is due to the problems encountered during daily activities in medical procedures. At present two measurement methods together with involvement of communication and information distribution have been applied. Though it still is expected to be equipped with more complex/automatic techniques i.e. bottle type (weight) recognition, alarm activation event i.e. dependent of a infusion speed and deactivation including manual way, it is a great, pushed forward step in developing useful in physicians' applications and procedures, system. Especially data communication feature added crucial functions to the desired overall functionality. This opens wide set of possibilities into the distributed applications of the proposed device in the field of hospital wards procedures and their automation.

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