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Infusion Auxiliary Service System Based on ZigBee Wireless Network

YONGHONG ZHANG[1], XINFENG SHEN[2], QING YANG[3], CHENGSHAN QIAN[2,4], AND GUANGCHI LIU[5]

[1]School of Information and Control, Nanjing University of Information Science and Technology, Nanjing 210044, China
[2]School of Computer and Software, Nanjing University of Information Science and Technology, Nanjing 210044, China
[3]Department of Computer Science and Engineering, University of North Texas, Denton, TX 76210, USA
[4]Jiangsu Engineering Center of Network Monitoring, Nanjing University of Information Science and Technology, Nanjing 210044, China
[5]Stratifyd Inc., Charlotte, NC 28208, USA

Corresponding author: Qing Yang (qing.yang@unt.edu)

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ABSTRACT Conducting high-quality nursing practice for patients in infusion room at medical facilities is an essential medical issue nowadays. To this purpose, this paper proposes a framework for smart infusion auxiliary service system with ZigBee wireless network. The framework is mainly composed of three components: a master service platform; multiple independents control platforms; and a wheeled robot. When entering an infusion room, each patient will hold a radio frequency identification card and be assigned a seat accordingly. Each seat is equipped with an independent control platform. With the independent control platform, a patient is able to send various service requests to the master service platform, as well as control the instruments around him. Upon receiving the patients' requests, the master service platform will broadcast and display users' demands. Meanwhile, the independent control platform will update the task schedule. The wheeled robot is used to deliver goods requested by the patients and achieve accurate parking using bang bang control. All of the components are connected through the ZigBee wireless network, which is stable and reliable.

INDEX TERMS Infusion auxiliary service, ZigBee wireless network, RFID card, wheeled robot, bang bang control.

I. INTRODUCTION

Despite of the development of intelligent service systems, they have been rarely deployed in medical facilities, such as infusion room. The timely, comfortable and reliable medical service has became a heavy burden for medical systems. Therefore, applying the intelligent service system into medical services has attracted the attentions of many medical providers [1]. Envisioning of this increasingly growing needs, in this paper, we have designed an intelligent Infusion Auxiliary Service System as shown in Fig 1. This work will Advance the development of the intelligent service system of medical service.

Despite of the popularity in other domains, the challenges that the intelligent service system is facing in medical services is nontrivial. One of the biggest challenges lies in patients' user experience. Particularly, patients' user experience will be seriously impacted in the following scenarios.

- Due to the busyness of nursers, the patients' needs might not be well taken care of.

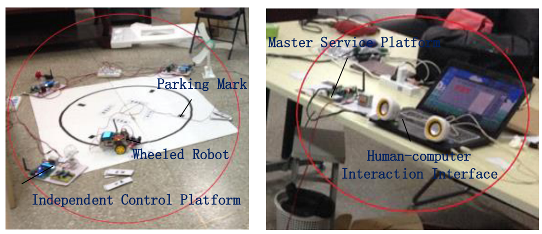

FIGURE 1. **The performance test of overall system.**

- Due to the crowd circumstance, patients may not get timely treatment;
- In order to provide patients with medical services, the nurses will be arranged in the infusion room. In most cases, the process of patients' infusion is very long. So, the service staff' work efficiency is very low;
- Oral service requests will increase the burden of the service staffs, which is not convenient. What's worse,

the communication between patients and staffs is prone to error.

For the above problems, many hospitals are in need of the intelligent service system to improve the efficiency and customer services of infusion services. With the comprehensive vertical domain research and the cpllection of a large amount data, we have proposed the entire framework and implement it into a real system. The innovation of the framework is that it brings intelligent control mechanism into medical services [2]–[4]. With the help of the three main components, medical stuff's working load will be significantly reduced. In addition, the system employs ZigBee technology to realize wireless module communication in the infusion room. As a state-of-the-art industrial WSN protocol, ZigBee is able to provide reliable and low energy cost communications. Once these wireless modules have been setup, they will form a small LAN automatically. In the experiment, we find that the data transmission in LAN is not be affected by the distance because of the multiple wireless nodes. The RFID cards assigned to each patient are used as a token to access the independent control platform on each seat. Once the independent control platform on a seat is activated by a RFID card, the card holder will get the permission to be seated. And then, they can use the independent control platform. The independent control platform of the system provides users with a variety of functions, such as fan control, light control and service calling, etc. In addition, a environment detector [5] is incorporated to indicate the surrounding temperature and humidity. In order to facilitate disabled patients, the system also employs one intelligent wheeled robot as un-maned courier. In order to achieve precision at a certain position, we use bang bang algorithm to control the motor of wheeled robot. All of the designs are integrated into the system to provide patients efficiency, reliable and comfortable services. This system proposed in this paper will become a pro-type and baseline for industrial products in the future.

II. RELATED WORK

In this section, we will introduce the related work of this paper. In Section. II-A, we will introduce the background of ZigBee wireless network technology. In Section. II-B, we will introduce the background of radio frequency identification technology. In the end, we will summary the purpose for designing the system in this paper.

A. ZigBee WIRELESS NETWORK TECHNOLOGY

ZigBee wireless network technology is essentially a wireless LAN protocol [6]–[9]. As an industrial solution, ZigBee is able to provide secure, reliable and low power wireless network communication. It also has streaming indicators of distance and energy consumption in transmission. In addition, as the evolution of Zigbee protocol [10]–[13], the latest version of Zigbee can reduce the cost for deploying the entire system module and daily operation. The main advantages are as follows:

- *The enhanced transmission distance*. A significant strength of Zigbee is its transmission process. Specially, the fancy design of Zigbee network protocol contributes to a low energy cost in transmission. With the same energy cost, it's transmission distance is longer than benchmark protocol. ZigBee's transmission module is similar to the mobile network base station. Users even in long distance regions can also use Zigbee for communication. In fact, Zigbee's transmission module supports unlimited transmission range extension. Therefore, its communication distance ranges from 75m to kilometers.
- *Efficient processing*. For the system proposed in this paper, the communication needs to handle different information resources to ensure the efficiency of subsequent transmission. As a low-cost wireless communication solution, Zigbee is able to process data efficiently. For example, in ZigBee communication protocol, a transmission is accomplished such that the energy cost, workload is optimized.
- *Communication security*. Security is a major risk in WSN communication. The technology reform of Internet of Things should focus on solving data security issues [14]. we have added the MD5 algorithm to the communication of the nodes [15]–[17]. The computational complexity of the algorithm is low and the data can be effectively prevented from tampering. under the reliable transmission performance of ZigBee, the lightweight algorithm can ensure the security of the data.

B. RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

Radio Frequency Identification (RFID) is a wireless communication technique [18]–[20] that can identify specific targets, read and write relevant data by radio signals. It does not need mechanical or optical contact between the system and a specific target. A RFID system is composed of two parts: reader and tags The reader sends radio signal sends to the tags, which are attached on the target items. Each tag is burned with unique identity information, which can be identified by a reader. By processing and analyzing the signals sent back from the tags, the reader is able to identity and track the item automatically by recognizing the identity information carried on it. Note that some of the tags do not require any battery. This kind of tags are powered by the signals sent from the reader. One the other hand, some of the tags are installed with batteries, which can power themselves to send radio waves. Unlike bar codes, RFID tags do not need to be within the sight of the reader. What's more, the communication range of RFID tags is longer than bar codes.

Envisioning of bringing intelligence into medical service system, we designed the infusion auxiliary service system [21], [22], which will make a contribution to the intelligent medical service in the future. In the infusion room, with the intelligent service, the patients themselves do not have to move frequently. Most importantly, the patients can enjoy comfortable and reliable intelligent service, which mitigate the workload of medical staffs. Particularly, they can response to the patients' request at the master service platform, which improves the efficiency of the staff and provides a comfortable and timely service for patients.

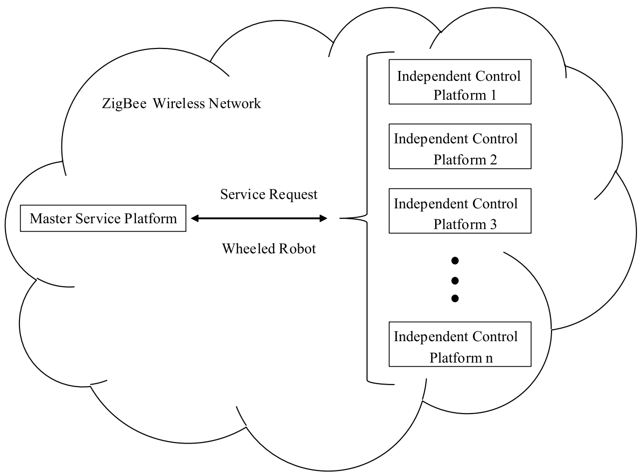

FIGURE 2. **The block diagram of overall system.**

III. OVERALL SOLUTION

After setting up a small LAN using ZigBee technology, the goal of this system is to design the aforementioned three components of the system, as shown in Fig. 2. Note that the master service platform is responsible for communicating with PC and the intelligent wheeled robot. Considering the functional requirements and design costs of the three components, we use different MCUs in each module of the system. In the independent control platform, we select the chips of 51 series [23], [24]. The reason is that their pin numbers meet the design requirements and the second functions of pins also bring convenience to the design. To enable the communication between the master service platform and PC, we select the chip of STM32 series [25]. In the design of intelligent wheeled robot, we select the chip of Tiva of TI company, for the high demand of frequency. Specifically, the frequency of the Tiva chip is 80M. Therefore, it can quickly respond to the input signal of sensors. We select CC2530 chip [26] of TI company as the wireless communication module. Using ZigBee-based protocol stack, multiple CC2530 chips can automatically set up a wireless LAN. Because of the aforementioned advantages of ZigBee technology, the wireless LAN has a low energy cost and the high transmission rate.

The framework of the entire system is stated as follows. First of all, a user is automatically assigned a seat by his RFID card. Then, the user send various service requests via the independent control platform on his seat. The master service platform responds to these service requests and prompt the users' information on the graphical user interface (GUI) of PC-side terminal. To remind the medical staffs with both vision and voice, we have added both voice prompt and interface pop-up prompt in the GUI. The GUI can display the service request from each user and send responds back to the independent control platform by clicking the visual button. After receiving the response, the independent control platform will show the progress of the sent request. This information will also be regarded as request confirmation for the patients.

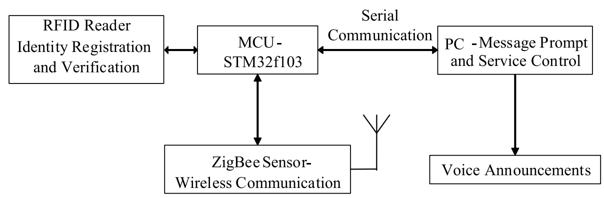

FIGURE 3. **The block diagram of master service platform.**

A. SOLUTION OF MASTER SERVICE PLATFORM

As shown in Fig. 3, the master service platform is composed of a MCU, a RFID reader, a ZigBee communication module, a voice announcer and a PC. The PC communicates with MCU via serial port. Considering portability of software, we use the QT development environment to design the control and prompt interface modules. When the RFID reader has received the card information, the master service platform will assign one seat to the user accordingly. It will release the access permission of the independent control platform to the patient. Once the patient get the permission, he can manipulate the independent control platform. Meanwhile, the service interface at the master service platform will update the seat status information. After receiving a patient's service requests, the service staff can respond it on the service interface, according to the information displayed on the interface. Note that among all the request service, needle withdrawal request is the most important one which requires medical staffs respond immediately. To handle this request, we added both pop-up and voice reminder on the GUI of master service platform. With the voice reminder, the master service platform will broadcast the needle withdrawal request via announcer,such that the medical staff can quickly respond to it.

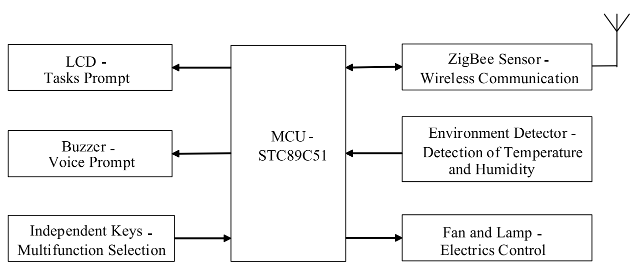

FIGURE 4. **The block diagram of independent control platform.**

B. SOLUTION OF INDEPENDENT CONTROL PLATFORM

As shown in Fig. 4, The independent control platform is composed of LCD, Buzzer, Independent keys, MCU, ZigBee communication module, environment detector and household appliances. The user can select the service by pressing the corresponding button. The service content can be viewed on the LCD screen. In order to circulate the air and adjust brightness, each independent control platform is equipped with a fan and a light. Users can turn on the fan according to personal physical condition in the hot season. Hospitals will set up some ice blocks or air conditioners to cool them down, but we can provide additional and enjoyable services to the patients by adding these facilities. The light is used for reading and watching, when the surrounding is not bright enough. When the log data of using these functions can be collected and fed back to the medical staffs. For those who cannot be affected by the wind, the service staff can promptly give the user a reminder according to the management information on the interface. Each independent control platform is equipped with an environment detector. So, the user can use the function keys to select whether or not to view the surrounding temperature and humidity values. When the infusion is completed, the user can request a call service to call relatives to leave the infusion room together. The relatives can receive acousto-optic hints and observe the source of the call on the LCD screen. This is more convenient than the use of mobile phone communication, because you can call a key. Such a design saves the tedious dialing and saves the communication cost. In addition, each independent control platform has the other functions: needles withdrawal request, disposable items purchasing requests, water taking request.

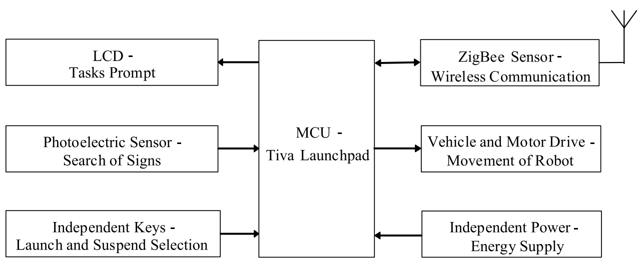

FIGURE 5. The block diagram of wheeled service robot.

C. SOLUTION OF WHEELED SERVICE ROBOT

As shown in Fig. 5, the wheeled robot is composed of LCD, Photoelectric sensor, independent keys, MCU, ZigBee communication module, motor drive and independent power. The main usage of the wheeled robot includes sending medical records, goods purchasing, stuff delivering, etc. The two sides of the vehicle body are equipped with many photoelectric sensors. The photoelectric sensors are used for navigation. Particularly, the left extra one is used to identify special marks, such that the robot can realize self-localization via identifying marks. When the robot receives a task from the master service platform or independent control platform, it will be locked for accepting any other commands until the current task is completed. In addition, the robot is able to change permissions. It can be switched only to respond to the master service platform, the independent control platform or both. When a task is received, the display on the vehicle body will show the task being executed.

The wheeled robot uses the bang bang control to brake when it stops at the mark. As shown in Algorithm. 1, when the wheeled robot has passed through the long straight or short bend, if it encounters the stop marks, it will be forced to descend rapidly with the maximum braking value, according to these two different situations. Such a state will last several times. And then, we set a super-parameter K. Such a super parameter needs to ensure the motors loss is small, and also need to ensure the deviation distance. We use the method of linear attenuation to anti-brake and test it, then we obtains the Table. 1. In our experiments, we found that when the value of the super parameter is 25, for different speeds, it is the best under comprehensive consideration.

Algorithm 1 The Process of Bang Bang Control

When the car has passed through the long straight
if (*Actual Speed* $\geq$ *Target Speed* $*$ 2/3) **then**
  Output the full negative PWM
end if
When the car has passed through the short bend
if (*Actual Speed* $\geq$ *Target Speed* $*$ 3/5) **then**
  Output the full negative PWM
end if
Brake several times with maximum PWM
if (*Actual Speed* $\leq$ *Target Speed* $*$ 1/5) **then**
  Output $(0 - \textit{Actual Speed}) * K$
end if
if (*Actual Speed is in a very small value range*) **then**
  Output 0
end if

TABLE 1. Braking effect at diffirent speeds.

Target Speed(m/s)	Braking Efforts(K)	Deviation Degree(mm)	Heating Degree
0.6	1	±2	low
0.6	25	0	low
0.6	50	0	medium
1.2	1	12±5	low
1.2	25	5±3	low
1.2	50	0	high
2.4	1	30±5	medium
2.4	25	20±5	medium
2.4	50	5±3	high

IV. HARDWARE DESIGN

Considering the complexity of wiring and system aesthetics, we use a toolkit naming Altium Designer to design PCB diagrams [27]. In the design of PCB board, we separate the discrete modules within one circuit board. When wiring,

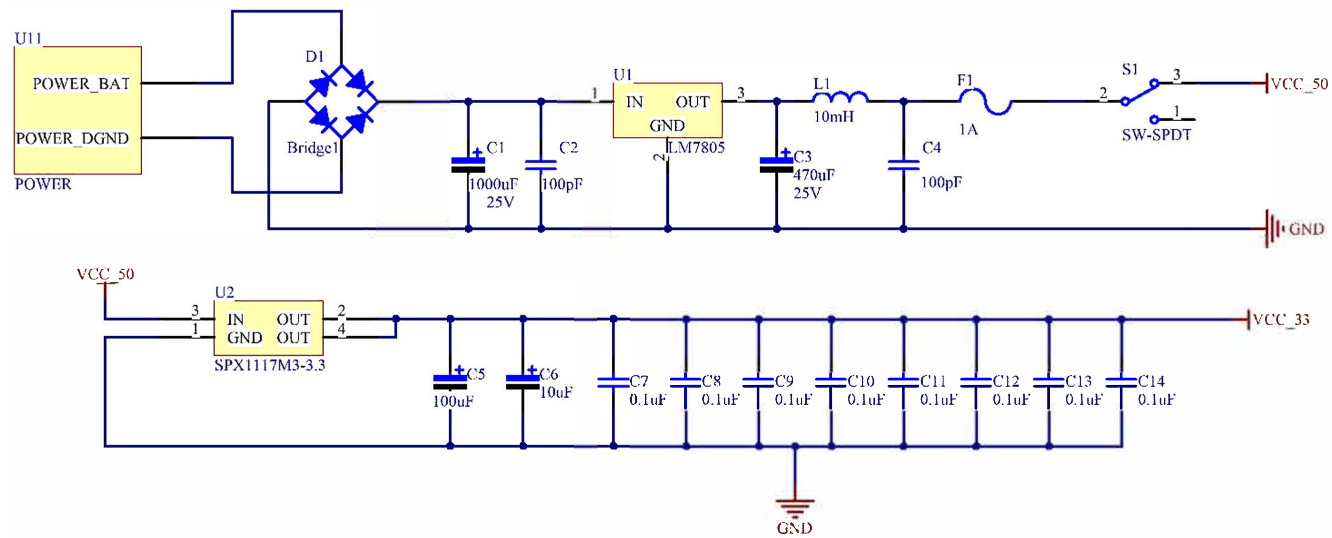

FIGURE 6. Power supply circuit.

we set different line width to ensure the normal operation of each module. In addition, to avoid line interference, the location of each module and the distance between lines are arranged flexibly. With this design, the PCB board can resist the interference of current noise and can withstand the impact of large current.

A. POWER SUPPLY MODULE

As shown in Fig. 6, firstly, we use the transformer to convert the household 220v AC into 12v AC. Secondly, we use the bridge rectifier circuit to convert the 12v AC to 12v DC. Finally, we use the integrated chip LM7805 to convert the 12v DC to 5v DC. Then, we use the the integrated chip AMS1117-3.3 to generate a stable 3.3v DC from 5v DC.

In this design, we use such a specific circuit to power the master service platform and independent control platform. Note that most of the modules on master service platform use 3.3v DC, while most of the modules on the independent control platform use 5v DC. Particularly, the ZigBee communication module of the independent control platform is powered by 3.3v DC. To enable it communicate with the MCU which is powered by 5v DC, we also added the serial level conversion module. In the end, we use batteries to power the wheeled robot.

B. RFID MODULE

As shown in Fig. 7,the required voltage of RFID module is 3.3v. The module can be directly connected to any MCU via the SPI interface which ensures the stable and reliable operation of the module. The data communication rate of the interface SPI on the RFID module can reach up to 10 Mbps. The MFRC522 chip is integrated into the RFID module [28]. It uses advanced modulation and demodulation techniques to integrate passive non-contact communication methods and protocols under 13.56MHz. In addition, it supports

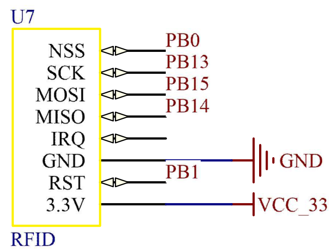

FIGURE 7. RFID module circuit.

14443A-compatible transponder signals and fast CRYPTO1 encryption algorithms.

In this design, the RFID reader communicates with the master service platform via the SPI interface. The users holds the RFID card for non-contact communication at a short distance. The master service platform will flash a led light a few seconds if the RFID reader connected to it has successfully read the data of the card. Once the master service platform has read the information, it begins to verify the information. If the verification succeeds, the master service platform will assign a usage permission of the independent service platform to the user. Otherwise, the master service platform will wait for the next read operation.

C. ZigBee COMMUNICATION MODULE

As shown in Fig. 8, the voltage that the ZigBee communication module uses is 3.3v. The CC2530 chip is integrated into the ZigBee communication module. It is a powerful RF transceiver module containing industry-standard enhanced 8051 CPU, in-system programmable flash memory and 8-KB RAM, etc. A CC2530 can be divided into four parts, including CPU and memory-related modules, peripherals, clock and power management related modules, radio-related modules.

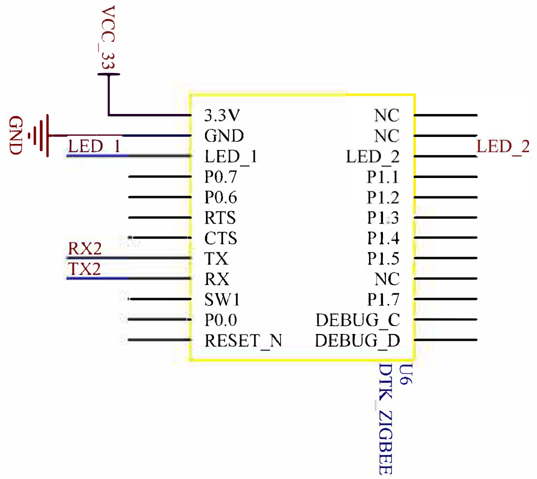

FIGURE 8. ZigBee communication module circuit.

The CC2530 is installed with an IEEE 802.15.4 compatible wireless transceiver. The RF core provides an interface between the MCU and the wireless device. The wireless device also includes a packet filtering and address identification module. UART 0 and UART 1 provide double buffering for RX and TX and hardware flow control. Each has its own high-precision baud rate generator.

There are two types of modules in the ZigBee part: coordinate and route. The ZigBee data transmission uses the point to point transmission mode. Each ZigBee module is assigned a short address, which can be addressed to any route or coordinate in the network. Since short address of the coordinate is fixed, the short address of the route can be set. The coordinate is installed on the master service platform and the routers are installed on the wheeled robot and independent control platforms. With the agreed frame, each individual part can communicate with each other.

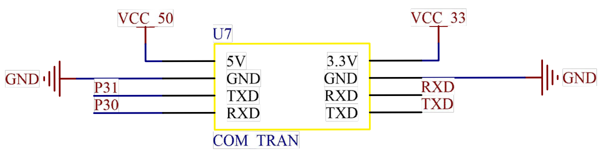

FIGURE 9. Serial level conversion module circuit.

D. SERIAL LEVEL CONVERSION MODULE

In the independent control platform, the MCU cannot directly communicate with the ZigBee module. The reason is that they are powered by different voltage, which are 5v and 3.3v, respectively. To address this issue, a serial level conversion module is used between the ZigBee module and the MCU. As shown in Fig. 9, the serial level conversion module can achieve the direct conversion from 5v to 3.3v. Its highest stable communication baud rate can reach up to 28800 bps. The communication between the MCU and the ZigBee module is to transmit data by serial port.

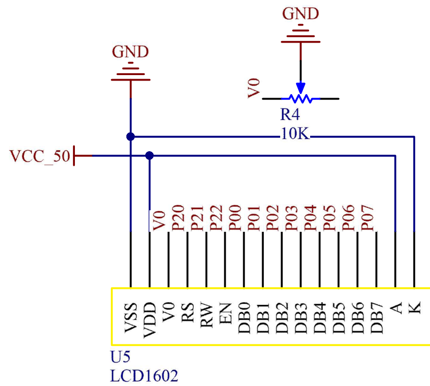

FIGURE 10. LCD module circuit.

E. LCD MODULE

As shown in Fig. 10, the voltage that the LCD module (M1602) uses is 5v. The display component of the independent control platform uses M1602 module. The module has two lines, 16 characters for each line to display. Since M1602 module is a slow display device, it has to be idle before executing each instruction. For M1602, a low level indicates idle. Otherwise, the instruction will be invalid. In the initialization of the M1602 module, its display mode has to be set. To display the character, the module will need the address of the displaying character. When the M1602 module displays characters, the cursor is automatically shifted to the right, without any manual intervention.

In this design, the display will show the service options and the progress of the current task. In addition, patients can see the address of the current calling request and view the temperature and humidity conditions by pressing the button.

V. SOFTWARE DESIGN

We design the software in a modulation and hierarchical manner. In addition, to help understand the architecture of the software, we also exhibit the flow chart of each module, as shown in Fig. 11, 12 and Fig. 13, respectively.

A. MASTER SERVICE PLATFORM PROGRAM

As shown in Fig. 11, when the program starts, the serial devices and the RFID device are initialized. In a main loop, the RFID reader firstly read the card number. If it successfully reads the car number, all led lights will be turned on and the system continues this process for a short time. Then, the system automatically assigns one seat and the permission to the user. If the process of reading the card number is not successful, all led lights will be turned off. Note that in practical, the main loop will be executed quickly. When the process of reading the card number is successful, the user will note the led lights on the master service platform flashes once. This means that the system has received the user's application. When the task of reading the car number is completed, the system will detect whether or not the flag of updating the PC interface is received. If the system has received the flag, it will send the electrical usage status information and

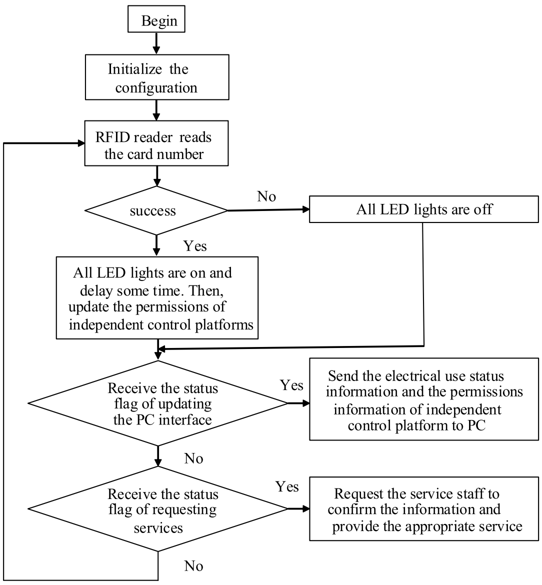

FIGURE 11. Master service platform program flow chart.

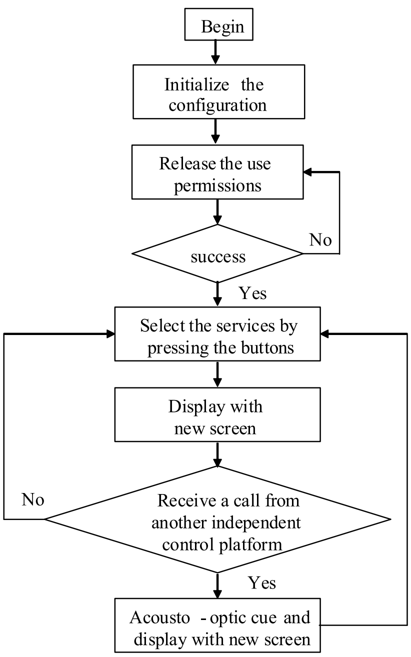

FIGURE 12. Independent control platform program flow chart.

the permissions information of independent control platform to the PC. Afterwards, the system detects whether or not the flag of requesting services is received. If the system has received the flag, it will request the medical staff to confirm the information and provide the appropriate service. Once the current task is completed, then the system will continue to read the card number. Such a process is carried out in a loop.

B. INDEPENDENT CONTROL PLATFORM PROGRAM

As shown in Fig. 12, when the programs starts, the serial device and the LCD1602 module are initialized. In a main loop, the independent control system detects whether or not the user's usage permission is released. If the permission is not released, the system continues to wait for the release command. If the permission has been released, the user can enjoy the service permission of the independent control system. Firstly, the system detects the user's key operation. If the key operation is carried out, the system will respond to the corresponding service including needle withdraw calling, electrical control, temperature and humidity display, relatives calling, water taking service and disposable supplies taking service. Secondly, the system detects whether or not a call from another platform is received. If such a request command is received, the system will issue sound and light prompts and update the LCD1602 display. If not, the system will continue to detect the user's key input. Finally, if the user swipe the RFID card to leave the infusion room, the system will recover the user's usage permission. This process is carried out in a loop.

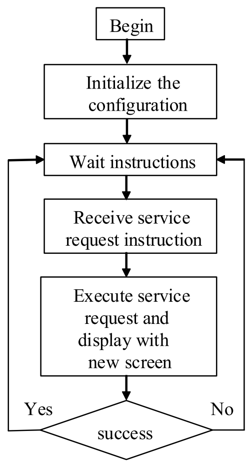

FIGURE 13. Wheeled robot program flow chart.

C. INTELLIGENT WHEELED ROBOT PROGRAM

As shown in Fig. 13, when the program starts, the serial devices, Photoelectric sensor, led lights module and the LCD12864 module are initialized. The robot is equipped with photoelectric sensors for navigation and self-localization. In a main loop, the wheeled robot will be idle until it gets instructions from the service platform and the control platforms. If the robot has received the service instruction, it will execute the service task containing the instruction. In addition, in the process of executing the instruction, the robot will update the process of the current task on the LCD screen. In the process of executing the task, the other user's request will not be answered. When the task is over, the robot will return to the starting location and wait for the next instruction. This process is carried out in a loop.

D. COMPARISON OF OUR SYSTEM AND OTHER EXISTING SYSTEMS

Our first contribution is the main structure of the system framework. Our second contribution is to apply the bang bang control algorithm to the healthcare service industry. Our final contribution is the selection of low power chips and the recommendation of key sensors. At present, the application of the Internet of things in the medical service industry is uneven. The demand and price have become the main concerns of medical services. Firstly, compared with the traditional manual service requests, the design of the system reduces the labor service cost and improves the time efficiency. Secondly, compared to the system mentioned in [3], we have clearly defined the specific deployment of the network and the selection of the hardware. It is applied to the comprehensive health assessment assistance service, and our system can complement it to make the services involved more comprehensive. Finally, compared with the use of fcm and fuzzy QFD method to solve the complex connection of the system mentioned in [4], our connection is simple, but the operation is very stable, which benefits from the unified specification of the transmitted data frame format and the customization of the function requirements.

VI. CONCLUSION

This paper proposes a method of designing an intelligent infusion service system based on ZigBee wireless network. With the add-on design of ZigBee modules based on CC2530 chip, the system achieves information sharing between various independent platforms [29]. To meet the design requirements as well as reduce the costs, the system uses STM32f103 for the master service platform, STC89C51 for the independent control platform and Tiva Launchpad for the wheeled robot. On the one hand, the medical staff can view the patients' needs in real time and give the appropriate feedback. On the other hand, the patients who swipe the RFID into the infusion room can be automatically assigned a seat and the service permissions of the independent control platform. A large amount of the real scenario tests has proved the efficiency and reliability of the system. This intelligent infusion service system can be applied in the infusion room to reduce the labor cost.

In the future work, we will place cameras in the infusion room to track the location of the wheeled robot. With the cameras, the robot can choose best path to provide high quality services to patients quickly. In addition, we will employ wireless communication between the master service platform and PC instead.

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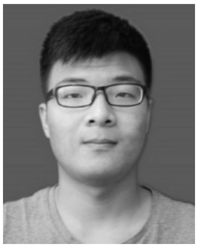
YONGHONG ZHANG received the Ph.D. degree from Shanghai Jiao Tong University in 2005. He is currently a Full Professor with the School of Information and Control, Nanjing University of Information Science and Technology. He has authored over 30 journal papers and has written two book chapters. His current research interests include optical instrument, environment remote sensing, and electronic systems.



XINFENG SHEN received the B.E. degree in 2016 and is currently pursuing the M.E. degree with the Nanjing University of Information Science and Technology, Nanjing, China. His research interests include deep learning, robot control technology, and machine learning.

QING YANG received the B.S. degree in computer science from Nankai University, China, in 2003, the M.S. degree in computer science from the Harbin Institute of Technology, China, in 2005, and the Ph.D. degree in computer science from Auburn University in 2011. He is currently an Assistant Professor with the Department of Computer Science and Engineering, University of North Texas. His research interests include Internet of Things, vehicular networks, and security and privacy.

CHENGSHAN QIAN received the M.S. degree in measuring and testing technologies and instruments from the Shandong University of Science and Technology, China, in 2003, and the Ph.D. degree in control theory and control engineering from the Nanjing University of Aeronautics and Astronautics, China, in 2009. He is currently a Professor with the School of Computer and Software, Nanjing University of Information Science and Technology, Nanjing, China. His current research interests include Internet of Things, intelligent control, and nonlinear system control.

GUANGCHI LIU received the Ph.D. degree in computer science from Montana State University, USA. He is currently a Research Scientist with the Research and Development Department, Stratifyd, Inc., Charlotte, NC, USA. His research interests include Internet of things, trust assessment, social network, and wireless sensor network.