Realization of A Bluetooth Network-Based Multi-Module System

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ABSTRACT

Multi-module systems are composed by many modules. By combining and controlling these modules in different ways, they are able to achieve different functionalities to suit various applications. This capability (so-called reconfigurability) needs not only appropriate module structures, but also a well connected communication network. The object of this research work is to build a multi-module system with focuses on wireless communication network implementation. In this paper, we explore some wireless data transmission methods used in personal computing and communications devices. After comparing these popular wireless technologies, Bluetooth is chosen for its low-cost and low power-consumption characteristics. Based on the project requirements and Bluetooth specifications, a PAN (Personal Area Network) consisting of several Bluetooth-enabled nodes are established for controlling the multi-module system. To verify the communication system and demonstrate the reconfigurability of the system, a worm-like robot is developed, and the corresponding hardware and CPG (Central pattern generators) algorithm are introduced also. The qualitative experiments show that the controlling and sensor data could be transferred in the Bluetooth communication network, and the system is able to achieve the predefined functionalities.

Keywords: Multi-Module System, Bluetooth, Ad-hoc Network, Piconet, Scatternet.

1. INTRODUCTION

Multi-module systems are made from a number of independent modules that can be used to form various configurations to suit different applications. This characteristics has attracted many research interests in recent years, and many systems have been developed [1]-[6]. Due to there rich configurations, multi-module systems have many advantages compared with conventional systems, such as robustness, versatility and low cost. However, as a distributed system, the modules are needed to be coordinated all the time to achieve the global effects not possible by any single module. Therefore, communication sub-systems are the essential parts for constituting multi-module systems.

Cabled networks are widely used in many areas. They are easy to be implemented and suitable for real time data communication. But the shortcoming of cabled networks is their limitation to the mobility of the two communication devices. The replacement of cabled network by a wireless network will introduce many advantages to the multi-module system. With the wireless communication, the module can connect to other modules or to a PC. Thus, we can control the system wirelessly via a computer or even construct a multi-agent system. Hence, the system can be much more flexible and configurable. By far, there are a lot of different wireless technologies available. In Section 2, an overview of wireless technologies is given, and their characteristics are discussed as well. Based on this analysis, Bluetooth is chosen and Bluetooth network is developed for the realization of the multi-module system.

The object of this work is to build a Bluetooth network based multi-module system. We developed a worm-like multi-module mechatronic system including several modules. Each module consists of two moving parts, a servomotor, a magnetic solenoid valve and a control unit with Bluetooth enabled. The modules act as slaves in the Bluetooth network, and a PC with a Bluetooth standard adapter acts as a master for coordinating modules' activities. Then, through the connected network, the slaves are able to send the master node their sensor data, get coordination commands and execute tasks designated by the users.

The next sections are organized as follows: An overview of wireless technologies is introduced in Section II, the Bluetooth network is described in Section III, the development of the multi-module system is given in Section IV, hardware and software implementation are shown in Section V, and concluding remarks are given in the last section.

2. OVERVIEW OF WIRELESS TECHNOLOGIES

RF transmitter & receiver is the most common wireless technology in use. However, it is half-duplex. Furthermore, the communication is easily interfered by noise.

IR data transmission, which is also employed in short-range communication among computer peripherals, such as mobile phone and PDA, provides a secure and simple way to transfer data by utilizes low frequency light waves. But due to the fact that infrared transceivers must operate on a line-of-sight basis, it must be placed at a 30-degree angle and no farther than 1 meter apart [7].

One of the PAN (personal area network) networks -- Bluetooth is a wireless protocol that is used to communicate from one device to another in a small area - usually from 10 meters to 100 meters with speeds up to 3Mbps [8]. Bluetooth was mainly developed for low power consumption, low price and small chip size by Ericsson and other companies. It is less susceptible to interference as it operates in the 2.4GHz ISM band with a frequency hopping mechanism enabled.

Nowadays, WLAN (wireless local area network) becomes more and more popular. It is specified by IEEE 802.11 standards, which uses the Ethernet protocol and CSMA/CA (carrier sense multiple access with collision avoidance) mechanism for path sharing [9]. Although WLAN has larger distance range and higher data transmission rate compared with the mentioned above wireless technologies, it is relatively expensive, complex and power consuming.

Under the author's point of view, for our work, Bluetooth is the best communication solution. It has a small size and simple architecture. It provides higher data rate than RF and IR transceivers, drains less power than the WLAN. Moreover, it is robust to interference for its FHSS (frequency hopping spread spectrum).

3. BLUETOOTH NETWORK

The Bluetooth is designed for and optimized for low cost, low power and compact applications. Therefore, it is very suitable to apply to the multi-module system running on batteries. In order to utilize Bluetooth to transfer data between modules and the users, the Bluetooth enabled module must comply with the Bluetooth specifications. These specifications define not only a radio system, but also a protocol stack to find other Bluetooth devices, discover their services, and how to use these services [10]. Figure 1 shows the Bluetooth protocol stack.

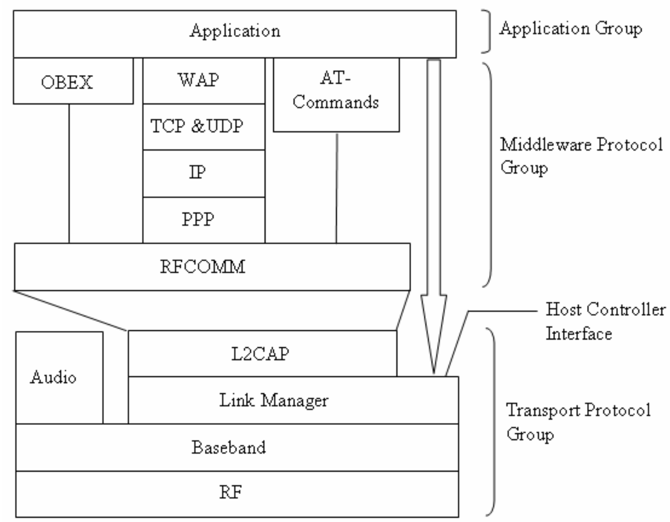


Figure 1. Bluetooth protocol stack.

To coordinate all the modules at the same time, the modules should be connected as a communication network. According to the Bluetooth specifications, every Bluetooth device has a unique Bluetooth device address and a 28-bit Bluetooth clock. The baseband part of the Bluetooth system could get the frequency hop sequence from the master's clock and device address via a special algorithm. The link between two Bluetooth devices is established by one device addressing the other device's unique address. When many slaves are connected to one master, the communication network is formed, which is called Piconet. The number of Slaves in a Piconet is limited to seven. Also it is possible for a master in one Piconet to be a slave in other Piconets. Thus, larger networks referred to as Scatternet can be achieved. Figure 2 shows the network architecture.

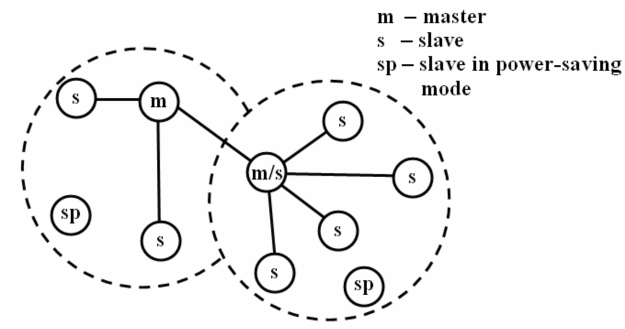


Figure 2. Scatternet topology formed by two piconets.

4. DEVELOPMENT OF THE MULTI-MODULE SYSTEM

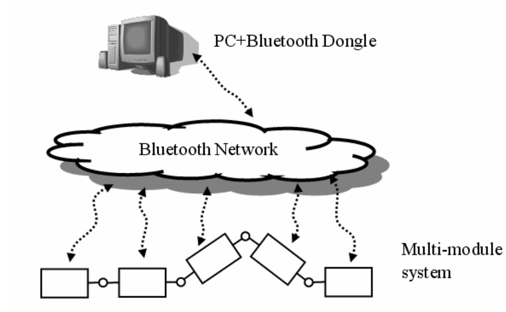
System architecture design

Figure 3 shows the architecture for a Bluetooth network-based multi-module system. It is a worm-like modular reconfigurable robot developed for testify the Bluetooth-networked controlling method and the reconfigurable concept. As shown in the figure, the system is mainly composed of a control point using a PC with a USB Bluetooth standard adapter and several modules with Bluetooth communication capabilities.

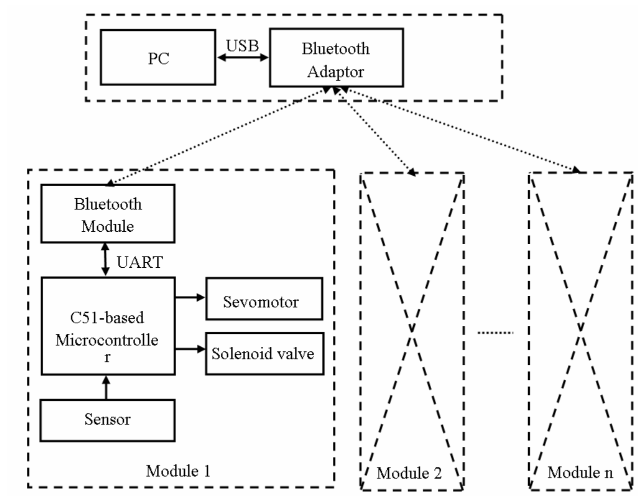
The control point has two-layered structure. In the bottom layer, the Bluetooth adaptor including the Radio, Baseband, Link Controller and Link Manager Protocol is responsible for low level operations such as inquiry, paging procedures, security authentication, communication channel establishment and etc. In the top layer, the PC with powerful processor and memory runs the other part of the Bluetooth protocol stack, calculates each module's movement, sends control commands and maintains the GUI for user interaction.

The composing module has mechanical parts, actuators, a microcontroller and a Bluetooth device embedded the complete protocol stack and applications. The mechanical parts and actuators are the basic elements to achieve the reconfigurability. The microcontroller samples the sensors and sends the data to the control point. It also converts the commands from the control point to PPM (Pulse-Position Modulation) signal to control the servo motor, to relay signal to switch on/off the solenoid valve.

By connecting all the modules and the control point together via the Bluetooth network, different configuration for different module could be achieved, and consequently to obtain many system configurations.



(a)



(b)

Figure 3. Architecture of the Bluetooth network-based multi-module system. (a) An overview of the system. (b) System architecture.

Performance evaluation of the multi-module system

This multi-module system mentioned above has good performance compared with conventional integrated system. The following is the great characteristics of it:

Versatile: Versatility is useful where the system is required to perform a range of tasks in the environment. In these situations, the modules of multi-module systems can be configured in different ways to enable different shapes or functions, which is more suitable to perform a specific task.

Adaptive: Conventional systems can only change their software to adapt to different task and environment, while, multi-module system can adapt both their configurations and software to perform various tasks in different environments.

Robust: The modules in a modular system are independent function units. If one module fails, it will not affect other modules, and it is also possible to get recover from the failure by replacing the failed module instead of replacing the whole system.

Easy to design and maintenance: Modularity helps the designer to break down a complex system into many simpler modules. This characteristic could be very helpful in design, analysis and maintenance.

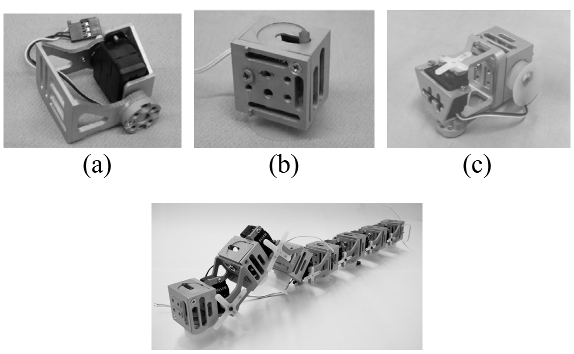
5. HARDWARE AND SOFTWARE IMPLEMENTATION

This section illustrates the implementation of the Bluetooth networked multi-module robot. An overview of the hardware and software realization is presented.

Hardware

The hardware platform used is a multi-module robot equipped with actuators, controllers, sensors and a PC.

Mechanical design: The robotic module is shown in figure 4. It includes a joint mechanism and a suction mechanism. The joint mechanism has two moving parts driven by a servo motor. And the suction mechanism with a suction cup and a magnetic solenoid valve enabled the robot to stick to the glass-wall. A worm-like robot with six modules is shown in figure 4 (d).


(a) (b) (c)

(d)

Figure 4. Robot module and worm-like robot. (a) joint mechanism. (b) suction mechanism. (c) the robotic module. (d) a worm-like robot with 6 modules.

Electrical design: The electrical part of each module is build around a Silicon Laboratories C8051F320 microcontroller, a high-speed pipelined 8051-compatible controller with 2K bytes internal RAM and 16K bytes Flash. C8051F320 offers 3 sets of programmable I/O ports, up to 17 channel single-ended/differential 10-bit ADC, an I2C bus, an enhanced UART and a SPI interfaces.

The Bluetooth communication units used in each robotic module are GC-04 from Guochuntech, which connects to the microcontroller via the UART interface, and the master unit for PC is a USB Bluetooth dongle based on BCM2045. Both the slave and master Bluetooth units include integrated antennas.

Every module has two actuators. One is a magnetic solenoid valve used to control the suction process to make the modules stick to the working surface. The other is a RC servo for changing the posture relationship between the module's two moving parts. The RC servo is comprised of a DC motor mechanically linked to a potentiometer. It receives the Pulse-position modulation (PPM) signals from the microcontroller every 20ms, and move based on the pulse width. The width of the PPM signal from the microcontroller contains the position information of the servo's rotor position, based on which, the motor could rotate until the rotor reaches the expected position. Figure 5 indicates a servo pulse of 1.5ms width that is to set the servo to the neutral position.

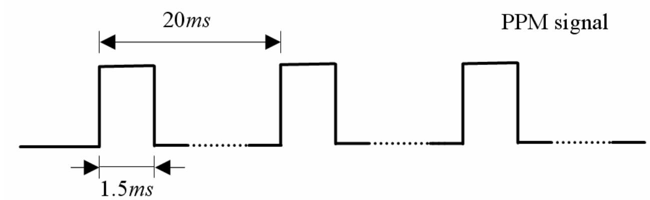


Figure 5. PPM signal format.

The experimental control system of each module is shown in figure 6. Since it is mainly for experimental purpose, Bluetooth and Micro Controller Unit (MCU) evaluation kits are utilized to control the robotic modules. At this stage of design, no special care was taken to reduce the board size and eliminate the communication interferences. In a future board release, layout and electromagnetic interferences will be the major concern, and a board comparable to the mechanical part is expected to be developed.

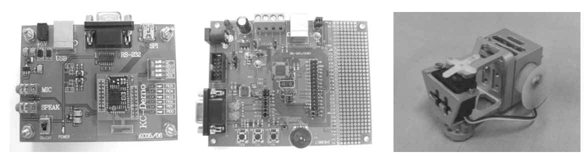

(a) (b) (c)

Figure 6. The experimental control system of each module.
(a) Bluetooth evaluation kit with UART interface.
(b) C8051F320 MCU evaluation kit. (c) System module.

Software

The software structure developed for the multi-module robot can be divided into 3 parts as in figure 7: user GUI program, communication program and control algorithm.

User GUI program: The user GUI program allows the user to operate the robot. It receives the user's input events, translates them into robot operation commands and then delivers control messages to the Bluetooth communication program running in the PC. For the incoming data from the communication program, it derives the robot status from the sensor feedback and displays to the users.

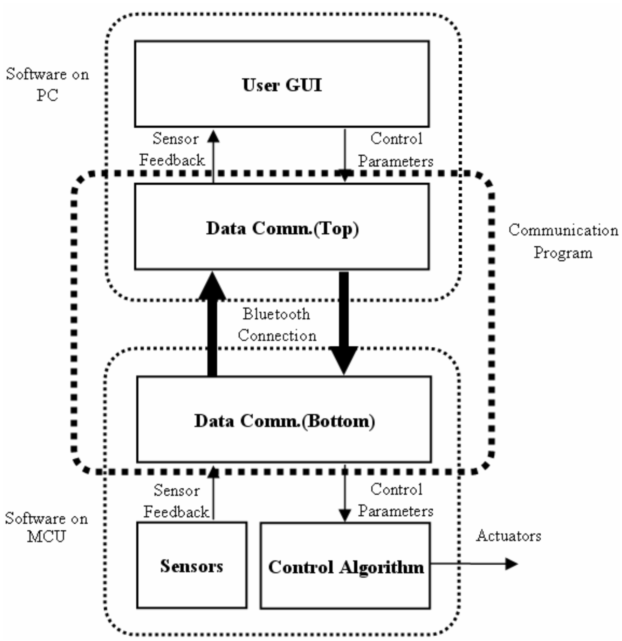


Figure 7. 3 layered software architecture.

Communication program: The communication program is application independent, and interface with the user GUI program and control algorithm by means of data buffer and synchronization signals. Figure 8 displays the communication architecture. As shown in figure 8, the communication program has two parts. The communication between PC with USB Bluetooth dongle is realized by Windows hardware driver. The communication program between microcontrollers with GC-04 Bluetooth modules is used a HCI (Host Controller Interface) program. The HCI packets sent between microcontrollers and Bluetooth devices contain both data and commands.

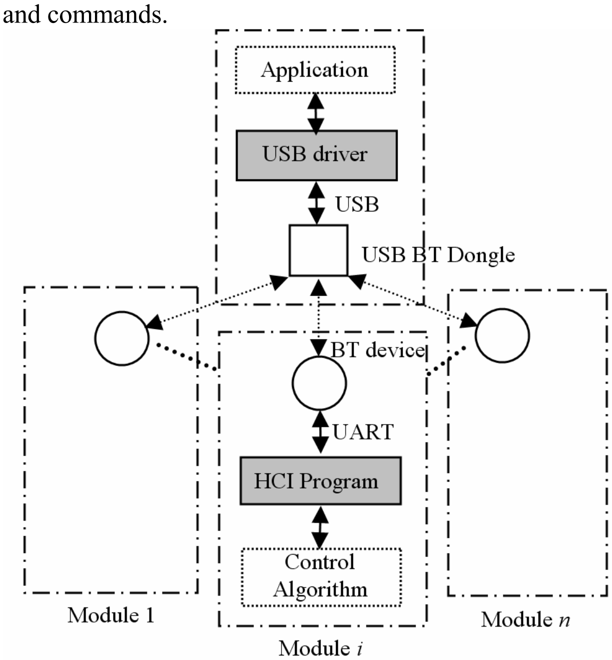


Figure 8. Communication architecture.

Control algorithm: The control algorithm is based on CPG (Central pattern generator). CPG is a biological neural network that generates rhythmic operations for animals, such as walking and swimming. For this robot, we employed a simplified sinusoidal CPG algorithm, the model of which is described as follows:

$$x_i = A_i \sin(2\pi f_i + \varphi_i) \qquad (0 \le \varphi_i < 2\pi, i = 1,2,\cdots n)$$

Where x_i is the position of the module *i*, A_i is the amplitude of the wave, f_i is the frequency and φ_i is the phase. Obviously, only 3*n* parameters are needed to control the locomotion of the robot with *n* modules. Therefore, for the communication architecture shown in figure 8, the PC just needs to send regulating parameters to the modules, and the modules will execute the corresponding behavior to achieve the designated global effects.

6. CONCLUSION

Multi-module system has many advantages over conventional systems, e.g. flexibility, configurability and robustness. However, as a distributed system, each module in the system is needed to be communicated and controlled all the time. In this paper, we developed a multi-module system with Bluetooth network enabled to enhance the performances of these systems. By far, an experimental communication and control system has already established to evaluate the system architecture and develop high-level application software. In the near future, a more complete system including communication network, hardware and software will be developed.

7. ACKNOWLEDGMENT

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