Bluetooth Network for Distributed Autonomous Robotic System

Se-Hee Whang* and Kwee-Bo Sim *

* School of Electrical and Electronics Engineering, ChungAng University, Seoul, Korea
(Tel : +82-2-820-5319; E-mail: kbsim@cau.ac.kr)

Abstract: Distributed Autonomous Robotic System (DARS) is defined as a system that independent autonomous robots in the restricted environments infer their status from pre-assigned conditions and operate their jobs through the cooperation with each other. In the DARS, a robot contains sensor part to percept the situation around themselves, communication part to exchange information, and actuator part to do a work. Especially, in order to cooperate with other robots, communicating with other robots is one of the essential elements. Because Bluetooth has many advantages such as low power consumption, small size module package, and various standard protocols, Bluetooth is rated as one of the efficient communicating technologies which can apply to small-sized robot system. In this paper, we will develop Bluetooth communicating system for autonomous robots such as DARS robots. For this purpose, The Bluetooth communication system must have several features. The first, this system should be separated from other robot parts and operate spontaneously and independently. In other words, this communication system should have the ability to organize and maintain and reorganize a network scheme. The next, this system had better support any kinds of standard interfaces in order to guarantee flexible applicability to other embedded system. We will discuss how to construct and what kind of procedure to develop the network system.

Keywords: DARS, robotics, Bluetooth network, self-organized network

1. INTRODUCTION

In the Distributed Autonomous Robotic System (DARS) [1, 2], each independent individual robot understands its situation through the surroundings, and then operates its jobs through cooperation with each others. For these cooperative works, the exchange of the information between the robots should be essential and communication module is an important element to construct a distributed autonomous robot.

Bluetooth [3, 4] is a kind of short-distance wireless communication methods. It is developed for portable device and has several kinds of more advantageous things than other wireless communication methods – low power consumption, cheap price, and small package size. Moreover Bluetooth provides various standard protocols. In these reasons, Bluetooth is regarded as the most suitable wireless technology for build up the small-sized robots.

In this paper, we will introduce Bluetooth network for distributed autonomous robotic system. First of all, the Bluetooth network has the ability of independent operations. We will design the system to organize a network scheme and to maintain the network scheme in the small sized communication module. In addition to these features, the network module should serve a kind of standard interface which commonly used by the most people. If the Bluetooth network is developed in this way, development convenience will be increased because of independent operation of each part in the robots and this Bluetooth network will be applicable to other embedded systems easily.

Except the previous hardware features, many considerable view points are remained – about network scheme, constructing sequence, and routing problem. We should deliberate on how to organize the network system, what kind of network form to be constructed, and what sequence to be used.

The features of Bluetooth are briefly demonstrated in the chapter 2. The constitutions of network module are described in the chapter 3. The problems related to network formation are investigated in the chapter 4. The conclusions and future works about the Bluetooth network system are denoted in the final chapter.

2. BLUETOOTH

Bluetooth was developed as low power consumption and low price solution to connect mobile phone with peripheral device by Ericsson in 1994. After it was proved the potential of wireless communication solution, Bluetooth SIG was organized and it was occupied one of the wireless communication technology.

2.1 Features

Bluetooth is designed for portable devices using the power of a battery, so it satisfies the conditions – low cost, low power, and compact size. With these reason, Bluetooth is recognized as suitable wireless communication technology for applying to robotics. Besides, this technology commonly supports various standard protocols. Basically most of Bluetooth modules serve HCI level interface and higher protocol stacks are implemented by software. Sometimes, the rest serve RFCOMM level interface – higher protocol than HCI – in the Bluetooth module. The following figures show compositions of Bluetooth Stack in the typical system using Bluetooth.

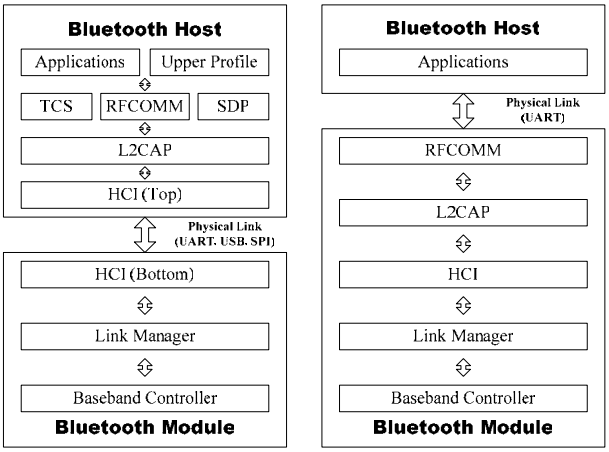

Fig. 1 Bluetooth Stack and Typical Bluetooth System

2.2 Network Support

Fundamentally, Bluetooth is developed to support master and slave structure. One master should have up to 7 slaves. Master and slave role can be operated in a module. There are two kind of network concept in Bluetooth. The first, a piconet is made up of only one master and several slaves. The next, a scatternet, which consists of piconets, is larger than the piconet.

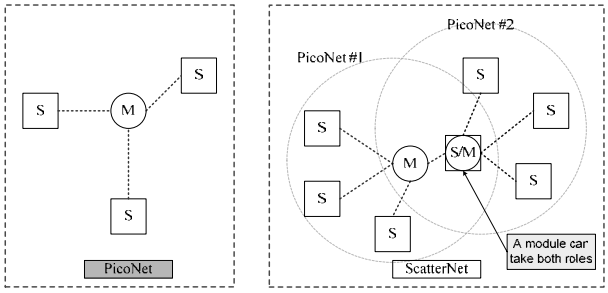

Fig. 2 Bluetooth network structure (Piconet / Scatternet)

3. NETWORK MODULE

Bluetooth communication system consists of Bluetooth network modules – define as a hardware module in this paper – and each module operates independently of the embedded system connected to it. In a word, Bluetooth network module takes charge of constructing wireless networks. Since only Bluetooth module can't construct and maintain networks, Additional circuital elements are required. Moreover when this network system is applied for other system, standard interfaces are necessary for serving more convenience to developers.

3.1 Hardware

Bluetooth network module is composed basically of a Bluetooth module and a network controller to organize a network system with the Bluetooth modules. We use the Bluetooth module which contains CSR Bluetooth chipset [5] – It support UART interface – and use ATmega128 [6] – Atmel's 8bit RISC microcontroller – as a network controller. The reason why we choose the CSR Bluetooth chipset is simple. This chipset supports UART interface and is the most commonly used. An ATmega128 contains about 128KB memory and supports 2 UART interfaces and is widely used in the world. The network controller communicates only HCI commands with the Bluetooth module. Interfacing with network controller and Bluetooth module, logic voltage difference problem may occur. However, it is easily solved by a level shifter device. If external UART use the same voltage of Bluetooth module, exchanging ATmega128 for ATmega128L can solve the interfacing voltage problem.

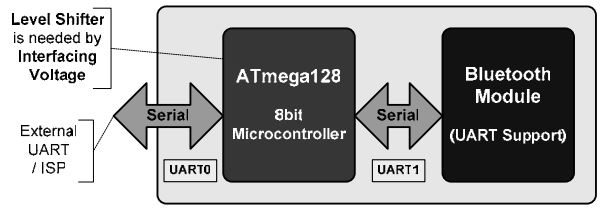

Fig. 3 Bluetooth Network Module Diagram

3.2 Adaptation to robots

In our lab, we are developing DARS agent robots. In this DARS robot, Bluetooth network module takes a role of communication part and uses UART as an interface with other parts.

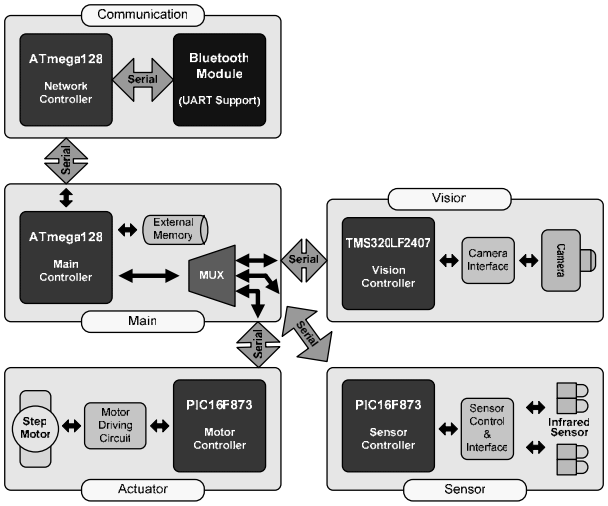

Fig. 4 Bluetooth Network Module Diagram

3.3 Development & Test

Bluetooth module which we use supports several kinds of interfaces such as UART, USB, and SPI. In order to test Bluetooth network system in the same environments that robot operates, we had better directly program to the robot. However, if only the operation of Bluetooth module is inspected, the result would be similar to that of direct programming. So we recommend the following procedures.

[1] The operation procedures of every Bluetooth module should be designed in order of time sequence.
[2] After that, to test the designed procedures is executed. In this stage, we recommend test with serial dongles, because HCI level command is standard and HCI level test program is offered [7].
[3] If thus much is correctly performed, network controller may be programmed. After the programming, test of each Bluetooth network module and entire Bluetooth network system should be examined. Passing the test, the Bluetooth network system would be operated well.

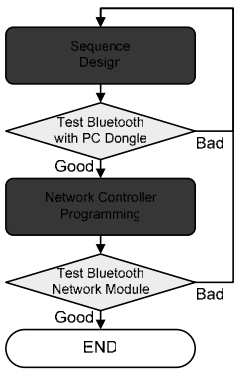

Fig. 5 Bluetooth Development and Test

4. BLUETOOTH NETWORK

4.1 Researches in Scatternet

There are three major parts about researches in scatternet – scatternet structure formation algorithm, routing algorithm, and scheduling in the bridge node. Routing and Role scheduling is dependent on the network structure, so these three parts of scatternet researches are organically associated with each others.

There are three kinds of representative formation algorithm by the shape of the scatternet structure – tree, star, and ring. Representative tree structure researches are MIT-TSF [8], MIT-BSFA [9, 10], and Bluetrees [11]. This structure has high extensibility but also has potentiality of bottleneck at the root of the tree. In the star structure, BlueStar [12] is the representative algorithm. Star structure is connected to a number of piconets through the bridge node. In the ring structure two kinds of algorithms exist by whether the basic unit is node or piconet. Nevertheless, the connected form of basic units is a ring.

4.2 Formation of Bluetooth Network

In this paper, we use the tree structure of the network formation, because tree formation is easy and light to adapt for small embedded system. Besides, in order to implement self-organized Bluetooth networks, self-organizing algorithm is essential and usually has four procedures – discovery, organization, maintenance, and re-organization [13, 14].

[1] Discovery phase

: All of Bluetooth modules are initialized and receive unique module name from network controller. After initializing, each module sends inquiry command to detect neighbor modules and stores information about neighbor modules.

[2] Organization phase

: Using stored information about neighbor modules, Bluetooth network structure would be constructed. At this time, efficiency of the structure is affected by which is the root of the tree. To estimate the efficiency thorough the tree root candidate, we define simple fitness function. The Bluetooth module, which has the largest Fitness function value, becomes the root of the tree.

1. initialize variables : $sum = 0$, $f_{candidate} = 0$
2. number of neighbors around candidate module :
   $sum += n_{neighbor}$, $f_{candidate} += sum$
3. candidate is replaced with neighbors during the origin candidate's neighbors and operates the followings.
   3.1. initialize variables : $sum = 0$
   3.2. fitness function adds multiplied sum by coefficient of neighbor order :
   $$f_{candidate} += (\frac{1}{2})^{order} sum$$
4. Unless the neighbor module does not exist, repeat the 3 procedure

[3] Maintenance phase

: Each module updates the information about neighbor module through periodic inquiry command.

[4] Re-organization phase

: Through the updated information, recalculate the simple fitness function value of every Bluetooth module. If necessary, change the structure of the tree.

4.3 Routing of Bluetooth Network

Bluetooth transmit rate is up to 1MBPS in Bluetooth core specification 1.1. Hence, transmission of the massive packet - such as image data - could lead any problems. Also, because of the structural problems, the larger numbers of modules exist, the heavier transmission load is concentrated at the root of the tree. As these reasons, we should use the pre-processed and light-weight packet data.

Except these problems, data packet usually hops a number of steps. Accordingly, we must design the tunneling packet structure and related algorithm.

5. CONCLUSION AND FUTURE WORKS

In this paper, we develop the Bluetooth network system for distributed autonomous robotic system. In this system, we use Bluetooth modules, because of its advantages – low power consumption, cheap price, small size, and various standard protocols. To guarantee the applicability and flexibility of the hardware module, we design Bluetooth network module with a microcontroller and additional circuits. Also To build simple and light weight structure, we select tree-shaped network scheme and define a simple construction algorithm. Nevertheless, this Bluetooth module has several problems. After understanding about this module's features, we could use the Bluetooth network system.

This Bluetooth System has numerous rooms for performance improvements in the circuit, network formation algorithm, and routings. We should try to increase the performance in various ways – hardware improvement and other network structure formation algorithm.

For hardware improvements, there are several possibilities. We can replace the Bluetooth module with another module which has more high speed transmission rate. Also circuital modification is needed for convenience of usage. If the higher profile stack and application program interface (API) are contained in the network controller, it is certain that easier and more flexible than that of the old system.

In the network scheme, we should compare a tree formation algorithm with the other network formation algorithm. We should examine what kind of algorithm is really suitable for the Bluetooth network system.

ACKNOWLEDGMENTS

This research was supported by the Braintech 21 from Ministry of Commerce, Industry, and Energy.

REFERENCES

[1] H. Asama, T. Fukuda, T. Arai, and I. Endo, *Distributed Autonomous Robotic Systems*, Springer Verlag, 1994.
[2] H. Asama, T. Fukuda, T. Arai, and I. Endo, *Distributed Autonomous Robotic Systems 2*. Springer Verlag, 1996.
[3] Specification of the Bluetooth System Ver 1.1, Bluetooth SIG., [Online] Available: http://www.bluetooth.com, 2001.
[4] Specification of the Bluetooth System Ver 1.2, Bluetooth SIG., [Online] Available: http://www.bluetooth.com, 2003.
[5] BlueCore2-External Datasheet, CSR., [Online] Available: http://www.csr.com/products/bc2ext_over.htm
[6] 8-bit AVR Microcontroller with 128K Bytes In-System Programmable Flash : ATmega128 / ATmega128L, Atmel., [Online] Available: http://www.atmel.com/products/AVR/

[7] BlueTool for HCI User Manual, Bluetooth Lab., [Online] Available: http://www.bluetoothlab.com

[8] G. Tan, A. Miu, J. Guttag and H. Balakrishnan, "Forming Scatternets from Bluetooth Personal Area Networks," In *MIT Technical Report MIT_LCS-TR-826*, 2001

[9] C. Lay and K.Y. Siu, "A Bluetooth Scatternet Formation Algorithm," *Proc. of the Conf. on Global Telecommunications*, Vol. 5, pp. 2864-2869, 2001.

[10] C. Law, A.K. Mehta and K.Y. Siu, "Performance of a New Bluetooth Scatternet Formation Protocol," *Proc. Of ACM Symp. on Mobile Ad Hoc Networking and Computing*, pp. 182-192, 2001.

[11] G. Zaruba and S. Basagni, "Bluetrees-Scatternet Formation to Enable Bluetooth-Based Ad Hoc Networks," *Proc. of the IEEE International Conf. on Communications*, Vol. 1, pp. 273-277, 2001.

[12] C. Petrioli, S. Basagni and I. Chlamtac, "Confiquring BlueStars: Multihop Scatternet Formation for Bluetooth Networks," *Proc. of the IEEE Trans. on Computers*, Vol. 52, Issue 6, pp. 779-790, 2003.

[13] C. Chevallay, R.E. Van Dyck, T. A. Hall, "Self-organization Protocols for Wireless Sensor Networks," *Conf. on Information Sciences and Systems*, 2002.

[14] G. J. Pottie. "Wireless Sensor Networks," in *IEEE Information Theory Workshop*, June, 1998, pp. 139-140.