# DEVELOPMENT OF PERSONAL AREA NETWORK (PAN) FOR MOBILE ROBOT USING BLUETOOTH TRANSCEIVER

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## DEDICATION

*Dedicated to my beloved family, miss Koid Shiau Yen for her support, members of ROBOCON UTM 2003/04 for their spiritual support.*

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# ABSTRACT

The work presents the concept of providing a Personal Area Network (PAN) for microcontroller based mobile robots using Bluetooth transceiver. With the concept of replacing cable, low cost, low power consumption and communication range between 10m to 100m, Bluetooth is suitable for communication between mobile robots since most mobile robots are powered by batteries and have high mobility. The network aimed to support real-time control of up to two mobile robots from a master mobile robot through communication using Bluetooth transceiver. If a fast network radio link is implemented, a whole new world of possibilities is opened in the research of robotics control and Artificial Intelligence (AI) research works, sending real time image and information. Robots could communicate through obstacles or even through walls. Bluetooth Ad Hoc topology provides a simple communication between devices in close by forming PAN. A system contained of both hardware and software is designed to enable the robots to form a PAN and communicating, sharing information. Three microcontroller based mobile robots are built for this research work. Bluetooth Protocol Stack and mobile robot control architecture is implemented on a single microcontroller chip. The PAN enabled a few mobile robots to communicate with each other to complete a given task. The wireless communication between mobile robots is reliable based from the result of experiments carried out. Thus this is a platform for multi mobile robots system and Ad Hoc networking system. Results from experiments show that microcontroller based mobile robots can easily form a Bluetooth PAN and communicate with each other.

# ABSTRAK

Kerja ini menunjukkan konsep untuk memberi satu Rangkaian Kawasan Peribadi (PAN) untuk robot bergerak berasaskan pengawal terbenam dengan menggunakan pemancar-penerima Bluetooth. Melalui konsep penggantian kabel antara perkakasan eletronik dengan kos dan penggunaan kuasa yang rendah serta jarak komunikasi dalam lingkungan 10 m ke 100 m, Bluetooth sesuai untuk media komunikasi antara robot bergerak kerana kebanyakan robot bergerak menggunakan bateri dan bermobiliti tinggi. Rangkaian PAN bertujuan menyokong kawalan segera dari robot ketua kepada dua robot bergerak yang lain menggunakan pemancar-penerima Bluetooth. Jika rangkaian radio yang pantas dapat direalisasikan, ianya merupakan era baru untuk penyelidikan dalam kawalan dan kecerdikan buatan robotik iaitu menghantar gambar dan maklumat dengan segera. Ini bermakna robot boleh berkomunikasi melepasi halangan atau dinding. Topologi *Ad Hoc* Bluetooth memberikan komunikasi yang mudah antara peralatan berdekatan untuk menghasilkan rangkaian kawasan peribadi. Satu sistem yang merangkumi perkakasan dan perisian telah direkabentuk dan dibangunkan untuk membolehkan robot menubuhkan rangkaian kawasan peribadi dan seterusnya berkomunikasi serta berkongsi maklumat. Tiga robot bergerak berasaskan pengawal terbenam telah dibina dari peringkat permulaan untuk kerja penyelidikan. *Bluetooth Protocol Stack* dan kawalan robot mudah alih dimuatkan dalam satu mikro pengawal tunggal. Rangkaian kawasan peribadi membolehkan beberapa robot bergerak berkomunikasi antara satu sama lain untuk menyempurnakan tugas-tugas yang diberikan. Ini merupakan satu platform untuk sistem robot bergerak pelbagai jenis dan sistem rangkaian *Ad Hoc*. Keputusan dari ujikaji menunjukkan bahawa robot bergerak berasaskan mikro pengawal mampu menghasilkan rangkaian kawasan peribadi dengan mudah dan boleh berkomunikasi antara satu sama lain.

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| | | |
|---|---|---|
| $\alpha$ | - | Angle made by BlueBot |
| $\beta$ | - | Angle made by wheel |
| r | - | Radius of wheel |
| R | - | Radius of BlueBot |
| $S_1$ | - | Displacement of BlueBot's perimeter |
| $S_2$ | - | Displacement of wheel perimeter |
| $n$ | - | Encoder value to make an angle or displacement on BlueBot |
| N | - | Total encoder value to complete a turn on wheel |
| ACL | - | Asynchronous Connection Less |
| AI | - | Artificial Intelligent |
| AP | - | Access Point |
| ACL | - | Asynchronous Connection Less |
| API | - | Application Programming Interfaces |
| ATM | - | Asynchronous Transfer Mode |
| CAC | - | Channel Access and Control |
| CAN | - | Controller Area Network |
| CMOS | - | Complementary Metal Oxide Semiconductor |
| COM | - | Component Object Model |
| CRC | - | Cyclic Redundancy Check |
| CSMA/CA | - | Carrier Sense Multiple Access/Collision Avoidance |
| CTS | - | Clear To Send |
| DECT | - | Digital Enhanced Cordless Telecommunications |
| DSP | - | Digital Signal Processing |
| ECG | - | Electrocardiograph |
| ETSI | - | European Telecommunications Standards Institute |
| FHSS | - | Frequency Hopping Spread Spectrum |

| | | |
|---|---|---|
| FSK | - | Frequency Shift Keying |
| GMSK | - | Gaussian Minimum Shift Keying |
| HCI | - | Host Controller Interface |
| HRFWG | - | Home Radio Frequency Working Group |
| I/O | - | Input/Output |
| $I^2C$ | - | Inter-Integrated Circuit |
| IEEE | - | Institute of Electrical and Electronics Engineer |
| IP | - | Internet Protocol |
| ISM | - | Industrial Scientific and Medical |
| ISO | - | International Standards Organization |
| ISR | - | Interrupt Service Routine |
| L2CAP | - | Logical Link Control and Adaptation Protocol |
| LAN | - | Local Area Network |
| LCD | - | Liquid Crystal Display |
| LED | - | Light Emitting Diode |
| LMP | - | Link Manager Protocol |
| LSB | - | Least Significant Bit |
| MAC | - | Medium Access Control |
| MSB | - | Most Significant Bit |
| MTU | - | Maximum Transmission Unit |
| OBEX | - | Object Exchange Protocol |
| OCF | - | Opcode Command Field |
| OFDM | - | Orthogonal Frequency Division Multiplexing |
| OGF | - | Opcode Group Field |
| OS | - | Operating System |
| OSI | - | Open System Interconnection |
| PAN | - | Personal Area Network |
| PC | - | Personal Computer |
| PDA | - | Personal Digital Assistant |
| PSTN | - | Public Switch Telephony Network |
| PWM | - | Pulse Width Modulation |
| QoS | - | Quality of Services |
| RAM | - | Random Access Memory |
| RF | - | Radio Frequency |

| | | |
|---|---|---|
| RISC | - | Reduced Instruction Set Computer |
| RTS | - | Ready To Send |
| SCM | - | Stack Connection Manager |
| SCO | - | Synchronous Connection Oriented |
| SDP | - | Service Discovery Protocol |
| SIG | - | Special Interest Group |
| SLA | - | Sealed Lead Acid |
| SNR | - | Signal to Noise Ratio |
| SPI | - | Serial Peripheral Interface |
| SWAP | - | Shared Wireless Access Protocol |
| TCP | - | Transport Control Protocol |
| TTL | - | Transistor-transistor Logic |
| TDD | - | Time Division Duplex |
| TDM | - | Time Division Multiples Method |
| USART | - | Universal Synchronous Asynchronous Receive Transmit |
| USB | - | Universal Serial Bus |
| UTMS | - | Universal Mobile Telecommunication System |
| WEP | - | Wired Equivalent Protection |
| YAKS | - | Yet Another Khepera Simulator |

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# CHAPTER 1

# INTRODUCTION

Since the past decades, robotics has been a fast growing field of research. Humanoid with Artificial Intelligence (AI) that will dominate the human race in the future has been created in the imagination of human beings. From the movie "MATRIX" and "TERMINATOR" which based on robots, the world in future has been depicted to be conquered by machines and robots. Additional, robot competition such as "Robot Soccer"- International, "ABU Robocon"- Asia Pasific, "RoboSumo"- Japan, "Robofest"- Malaysia, are being held all around the world which clearly shows the interest in robotics area. While all these events may appear to be fun and games, the goal are still serious, to advance the state of robotics. For example, Robot Soccer has contributed a lot of research and development in the area of multi-robot system, communication, image processing and simulation.

There are a lot of different objectives in robotics researches. For an instance, Robot Soccer aims to produce a team of robots that can play soccer with world cup team in real football field by year 2050. Honda ASIMO aims to produce a fully autonomous humanoid robot that can assist humans in day life work. Others aimed to develop robots for industrial usage. Although the development of robotics is still new, the applications of robots are very wide. These included the usage of robot in gaining access to dangerous environments such as cleanup of hazardous waste sites, inspection of nuclear power stations, and deep sea and planetary exploration. Robots can also assist humans in the automation of routine tasks, such as vacuum cleaning, task delivery, tour guides and so on.

Although robots have shown their compatibility and effectiveness in industrial applications and daily activities, a multi-robot system operating in our everyday environment would be a rare sight. With the motivation to build such a system, this work investigates the issues involved in the design of communication for microcontroller based autonomous mobile robot using Bluetooth transceiver. There are a few ways of connecting a group of mobile robots together wirelessly. The easiest ways to achieve multi microcontroller based mobile robot communication is by using RF module, which is cheap and easy to be used. However, it offer low security and low bit rate communication. Another method is to provide Bluetooth or other wireless technology for a group of computer based mobile robots where these wireless technologies require high processing speed and large program memory for Operating System (OS) and communication protocol. To build a group of fully functional mobile robots from scratch is a challenging work. Furthermore, to embed protocol stack for Bluetooth communication and robot control program on single chip microcontroller is the other main challenge to be overcome.

The research presented here focuses on two main problems. They are:

1. The ability of microcontroller based mobile robot to interface with Bluetooth transceiver and form its PAN automatically without the help of computer based system.
2. The ability of a microcontroller based mobile robot to maintain the Bluetooth communication while completing its own control commands.

Discussion on the suitability of Bluetooth technology for mobile robot is included by comparing the power consumption, size and communication range among a few other wireless technologies.

## 1.1 Introduction to Mobile Robots and Multi-robot System

Mobile Robots has been defined as a class of robots that have the capability to transport themselves in three dimensional spaces (Tan, 2002). Mobile robot may be in the factories carrying raw materials, or final products for long distances, or in the farms, where mobile robots can be used in planting and placing the seeds in soil, irrigation, or in the reaping. The mobile robots may be also used in houses as cleaning machines, surveillance, security and cooperative task. Though these tasks are not so important like a life saving machines, they are useful to save the time, reduce the cost, or to achieve better results (Abd Alsalam Sheikh, 2000).

Most of robot applications involve independent work such as navigation, vacuum cleaner, industry automation and competition. But, if two heads are better than one, then four arms are probably more useful than two. Actually, networked robots can accomplish more than they could achieve individually by sharing sensor readings and computing power, by coordinating their actions (Akash *et al*., 2003). Nature presents us with numerous examples of highly efficient, adaptive, and fault-tolerant distributed multi-agent systems in which individuals (insects, animals, human, cultures, nations) because they can successfully cope with incomplete and noisy information (state and knowledge), nondeterministic environments, delayed feedback in response to actions, collaborators, opponents, and competition for recourses (Maja,1998). For example, ant has little capability, but when many of them are working together, they can do incredible tasks (Mohd Ridzuan, 2003). Similarly, if several robots can work together, the task can be completed more efficiently. Multi-agent systems are desirable for many reasons. Many cheap robots working together could replace a single expensive robot, making multi-agent more cost effective. In fact, Robot Soccer has proven the capabilities of a number of cooperative robots in competition with an opponent team in dynamically changing environment and showed an interesting development. Although multi-robot system seems to have the interest of researchers nowadays, developing the system is a challenging work. Single robot development may encounter many similar challenges, i.e:

- Robot sensors provide noisy and incomplete information.
- Effectors slip.
- Communication is typically low band-width.
- Resources (time, battery power) are limited.

Multi-robot system has to face greater challenges compared to single robot system. Furthermore the performance in such a system depends significantly on issues that arise from the interactions between robots. These interactions complicate the development of this system since they are not obvious in the hardware or software design but only emerge in an operating group. It is difficult or even impossible to model the group behaviors and design centralized controllers in a top-down manner for robot teams in unknown or dynamic environment. For instance, cooperation and interference between robots are not considerations for a single robot system since the system do not involve cooperation between robots. However, cooperation and interference between robots are crucial in multi-robot system.

There have been a lot of interests in cooperative robotics in the last few years, triggered mainly by the technological advances in control techniques for single vehicles and the explosion in computation and communication capabilities. The research in the field of control and coordination for multi-robots is currently progressing in areas like automated highway systems, formation flight control, unmanned underwater vehicles, satellite clustering, exploration, surveillance, search and rescue, mapping of unknown or partially known environments, distributed manipulation and transportation of large objects (Calin, 2003). Although there are a lot of researches going on in cooperative autonomous mobile robotics, it is still new that no topic area within this domain can be considered mature. Some areas have been explored more extensively, however, and the community is beginning to understand how to develop and control certain aspects of multi-robot team (Tamio *et al*., 2002).

As proposed in the work by Tamio *et al*. (2002), the area of research for multi-robot system could be organized into seven principles. The seven principle areas of multi-robot system which have been identified are:

1. Biological Inspirations
2. Communication
3. Architecture, task allocation, and control
4. Localization, mapping, and exploration
5. Object transport and manipulation

6. Motion coordination
7. Reconfigurable robot

As stated above, one of the main topics is the communication among robots. Multi-robot system required communication between each other to share sensors reading, decision making and action distribution. Wireless robots can interact as a cooperative team or as a competitive team (for example, legged soccer player robots) with varying degrees of control. Communication between robots may take place directly via explicit communication facility such as radio link or indirect (pseudo communication method) through one robot sensing a change in other robots or it environment. Explicit communication is defined as a specific act designed solely to convey information to other robots on the team.

## 1.2 Challenges in Developing Communication for Multi-robot System

During the last few decades, major research efforts were focused on improving the performance of many mobile robots by using advanced sensors, actuators, and intelligent control algorithm. But very few people have ventured into the field of communication between robots. Communication plays an important role to provide the path for robots to share information, computing power and planning among robots in the system. The review work by Tucker and Ronald (1995), described that there is work reported that task achieving behavior can still be successful even in the absence of communication between robots. On the contrary, there is also report on 50% of improvement in robots performance for target acquisition using infra-red signal for communication. Others have studied the evolution of communication between robots and shown that robots with communication were 84% fitter than those which communication was suppressed. Several researchers have studied the effect of communication on the performance of multi-robot system in a variety of tasks, and have concluded that communication provides certain benefit for particular types of task.

Practically, it is very difficult to develop a perfect communication scheme for multi-robot system. Works have been carried out to provide fault tolerance in multi-robot communication, such as setting up and maintaining distributed communication networks, and ensuring reliability in multi-robot communications. Experimental results on how the communication bottleneck affects the overall performance of the system have been reported by Paul *et al*. (2002). Thus, effective communication between robots helps to improve the performance of multi-robot system.

As discussed in section 1.1, multi-robot system requires information sharing among each other and communication provides the path for it. Furthermore, implementation of multi-robot platform amplifies the difficulty and challenges to develop communication for multi-robot system. The criteria for the communication system which need to be considered include not only the physical hardware for communication, but also protocol to handle connection (connection oriented or connection less), protocol to handle data, and protocol to handle the network. Considerations such as power consumption, bandwidth, networking possibility and communication range must also be taken. The size of the transceiver (physical or hardware) must be small to be easily fitted on robot. Power consumption of transceiver must be low because most autonomous mobile robot is powered by batteries. When dealing with microcontroller based mobile robots, the interfacing and communication protocol must be as simple as possible. Because most microcontrollers support communication such as Inter-Integrated Circuit ($I^2C$), Universal Synchronous Asynchronous Receive Transmit (USART) and Serial Peripheral Interface (SPI), microcontrollers seldom support communication through Universal Serial Bus (USB). In terms of communication protocol, microcontrollers come in 4 – 40 MHz clock and have limited memory for program and data storage. Thus the communication protocol must be as simple as possible to reduce communication error between host and transceiver. Furthermore, with small protocol stack, there will be more memory space left for robot control architecture. All these factors increased the challenges in developing the communication for multi-robot system.

## 1.3 Objectives and Problem Background

As mentioned in section 1.1 and section 1.2, communication in multi-robot system do improve overall performance of the system. For multiple mobile robots, wired communication such as cable, serial com port and parallel port will not be suitable. These cables will disturb the mobility, sensor reading and increase the complexity of the setting of the system. Furthermore, the base station has to provide as many ports as the number of robots if a group of robots were involved. Thus wired communication is obviously not suitable for multi-robot system.

There are various types of wireless technologies available in the market which could provide the wireless communication. These technologies include HomeRF, IEEE 802.11b Wireless LAN - WiFi, IrDA, HyperLAN and Bluetooth. Review on these technologies will be discussed in Chapter 2. Bluetooth wireless technology has been chosen to provide the communication among robots. Bluetooth is a low cost, low power, short range (10-100 m) and small size wireless technology. With security and networking possibilities provided by Bluetooth technology, many investigations have been carried out to implement Bluetooth transceiver on mobile robots for research and development in multi-robot system and Ad Hoc networking study. Integration of Bluetooth is not limited on mobile robots as many cell phone and video camera manufacturers have also enhanced their product with the Bluetooth technology. Among the works that have been done in communication for multi-robot system, Bluetooth communication protocol was handled by a computer or computer based controller (Henrik *et al.*, 2001). In other words, the protocol and networking maintenance was handled by a host computer. In this work, the ability of a microcontroller based mobile robot to manage the protocol and provides Bluetooth wireless communication has been investigated. Compared to computer based system, microcontroller system provides cheaper, easier installation and smaller size of system. Therefore, most multi-robot systems are microcontroller based. Furthermore, more and more products in market and development tools are equipped with microcontroller. Microcontroller vendors such as ATMEL, Microchip, Toshiba, Motorola, Texas Instrument and Intel are pushing hard to develop and enhance current microcontroller with higher processing speed, more memory space, and special features on a single chip computer. Developments have been greatly carried out to enhance microcontroller based system with Operating System (Handy Board, RoBIOS), vision process capability and AI control architecture (Thomas, 2003). The microcontroller based system has been developed to compete with computer based system in a specific area. The work presented herein is to embed the Bluetooth technology on microcontroller based multi-robot system without any help of computer based system to provide basic PAN. The robots can communicate with each other in the PAN.

The objectives of this work are:

- To develop a controller (single chip microcontroller) that is capable of interfacing with Bluetooth transceiver and control mobile robot.
- To design and build three autonomous mobile robots which can establish PAN automatically via Bluetooth transceiver for wireless communication (hardware and software).
- To setup a point to multipoint Bluetooth network with a purely microcontroller-based system.

The work presented embedded wireless communication on mobile robot, this involve two research area which are robotics and telecommunication; therefore the scopes of the research area are defined. The scopes of this work include:

- The robots built are equipped with encoder feedback and infrared proximity sensor.
- Furthermore, the network only support three nodes where these are the minimum nodes required to setup a point to multipoint network.
- Embedding Bluetooth lowest protocol layer - HCI layer on single chip microcontroller where HCI is sufficient for mobile robot wireless communication.
- The group of three mobile robot could established the PAN automatically and communicate to achieve group's objective.
- Research and study on PAN using Bluetooth technology for mobile robot.

## 1.4 Proposed Approach

At least 2 nodes are required to prove that communication exists. Therefore, to show the communication between mobile robots, at least 2 mobile robots should be used. While 2 nodes are enough to show a point to point connection, 3 nodes are essential to show a point to multipoint link. Three mobile robots are built to investigate the capability of microcontroller based mobile robot to be the master of Bluetooth network which is responsible to manage the network, including forwarding data from one slave to another slave since there is no direct communication between slave nodes. In the proposed system, the master node is provided with extra tasks to be performed. Bluetooth network is a star topology network, where there will be no direct communications between slaves. There must be a master that is responsible for all data traffic in the network. From the hardware point of view, a controller that provides platform to implement robot control algorithm and Bluetooth protocol stack must be prepared. PIC18F458, a model of microcontroller from Microchip Inc. has been chosen to provide the platform mentioned. This microcontroller has 32 KB of program memory which is more than enough to implement both the robot control and Bluetooth stack on a single chip. The software implementation was done step by step, from the basic communication and control to higher layer of protocol stack and algorithm. Assembly language of PIC18F was used to develop the software. Although all robots are different in terms of size, wheels, motor gear ratio, weight and even Bluetooth transceiver, this work tried to make sure they can communicate which each other and cooperate to carry out collaborative tasks. Experiments were carried out to prove that microcontroller based mobile robots are able to form its own Bluetooth PAN and communicate with each other to achieve group's objective.

## 1.5 Outline of the Thesis

The preceding sections briefly summarized the introduction and objectives of the research work. This section presents the outlines of the thesis. The remainder of the thesis is organized into six main chapters. Chapter 2 discusses literature review on wireless technology and some related works. Various kinds of wireless technology are discussed and investigated from the point of microcontroller based mobile robot. Contributions from other works are also presented here. The details of Bluetooth technology and Personal Area Network (PAN) are discussed in Chapter 3. Bluetooth Protocol and Bluetooth Development kits are also discussed in detail in this chapter. The design and implementation of Bluetooth Enabled Mobile Robot – BlueBot will be discussed in Chapter 4. This will included the design concept behind building BlueBot and PIC microcontroller board. Chapter 5 is about the software architecture of BlueBot. This chapter discuss the details of the software on PIC18F458 chip which included the Bluetooth protocol stack – Host Controller Interface (HCI), communication protocol between robots, bootloader and robot control architecture. Chapter 6 covers the experimental results and discussion. Finally, the conclusion is presented in Chapter 7. This comprises the contributions of the work presented and recommendations for future development.

Designing and providing a real platform for multi-robot system is a very challenging work. The process must consider hardware and software design. Communication between robots must be as robust as possible to provide easy setup and reliable data sharing. Bluetooth provides a low cost, low power, short range and networking communication. This technology is suitable for mobile robot which is powered by batteries and small in size. The work presented is to implement the whole system in microcontroller based mobile robot, executing robot control architecture while maintaining the communication protocol and network management. Three mobile robots were built and fully equipped with infrared proximity sensor, motors, wheels, batteries and a microcontroller board. Software architecture also been developed and implemented on the BlueBot to show that microcontroller based mobile robots can form its own PAN and perform cooperative tasks. A few experiments have been carried out to show the suitability of Bluetooth technology in communication for multi-robot system.