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Synchronized Communication in a Set of Autonomous Mobile Robots Using Bluetooth Technology

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Abstract

This paper presents the implementation of a communication system Bluetooth for synchronous communication between autonomous robots moving between predefined appointments points. Every robot executes individual tasks such as navigation and obstacle avoidance. Also, it executes global tasks such as synchronization for a pair of robots appointments in predetermined points and a synchronous communication establishment. A full-duplex communication algorithm between two Lego Mindstorms robots, in a configuration Master - Slave, was developed and implemented using the Java language and Lejos technology. To establish a synchronous communication between master robot and slave robot into a bounded time, we modeled the system using P-temporal Petri nets can represent parallel systems under time constraints to calculate the waiting time maximum of each robot on his appointment point.

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Keywords: Bluetooth technology ; synchronized full-duplex communication ; Master - Slave Configuration ; Lego Mindstorms ; Follow line ; appointments points ; autonomous mobile robots ; Java (LeJos) ; P-temporal Petri nets.

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1. Introduction

Mobile robotics knows an increasing development; one of the current goals is to design multi-robots systems which can cooperate and communicate between them wirelessly and to make tasks without human intervention [4], [7].

Recently, wireless communication technology allows the development of several communicating mobile robotic platforms, leading to the development of a multitude of applications in the field of cooperation and communication between groups of mobile robots. Among these technologies we find the Wi-Fi [3], Infra-Red (IrDA) [4] [10], ZigBee [5] and Bluetooth [6] [8] [3]. Indeed, Cooperation means that the robots should communicate to exchange information and coordinate their actions in order to achieve a joint overall mission.

Bluetooth technology is a standard communication for bidirectional exchange of data between several devices using UHF radio waves at a rate of 1 Mbps. It allows several robots to connect wirelessly between them with a range of 10 meters, contrary to the IrDA [9] which is a protocol that uses the infrared light waves to transmit information, this protocol as RS232 allows only connection of oncely device with a range of 1 meter only. There are several advantages of using Bluetooth wireless technology. The most important is the fact that the data transfer rate is much higher than that of Wi-Fi. [3]. By using Bluetooth, the rate of data transfer can reach kbps 800, while the Wi-Fi is sensitive to data loss that leads to lower speeds. At the end of exchanging data using Bluetooth technology, the devices must be paired. Communication is done after starting the search procedure of homologous and exchange code, which makes this technology in a higher level of security than other wireless communication protocols.

In order to implement a wireless communication system based on Bluetooth, each robot must have the necessary tools of perception in its dynamic environment to move between two points of appointments, and establish a point to point connection to exchange necessary information [6].

This paper presents one of the main problems of the cooperation in a multi-robots system which is the wireless communication in full-duplex using Bluetooth technology. Each robot has its own Bluetooth communication module. The establishment of a synchronous communication in full duplex mode between two robots placed in a configuration master - slave imposes the slave robot to communicate at first time its information with the master robot and the master robot to get hold of the slave when the latter is not available. Moreover, we propose a communication algorithm in a set of autonomous mobile robots, using Bluetooth technology between master and slave. The communication is established if robots are present on respective appointments points. Two scenarios appear, the first scenario is the arrival of the slave robot in a first time on the appointment point, and the second scenario corresponds to the arrival of the master robot firstly on the appointments point. The used robots are robots types' lego Mindstorms NXT 2.0.

2. Related researches

Choo et al. [8] present the implementation of the technology Bluetooth in the autonomous mobile robots. The robot has capability to move in an autonomous way using complex and powerful algorithms. These algorithms are stored on a computer which acts as a master server. All data mobile robot sensors are sent to master and after processed. Commands that depend on new measurements transmitted from the master to the autonomous mobile robot in a full-duplex communication mode.

Gulati et al. approach [3] the problems met by rescue teams of people snuff in the rubble of collapsed buildings in case of natural disasters. They show how a robot controlled by Bluetooth or Wi-Fi connection can effectively help to save the number of people in the rescue teams. The document also underlines the advantage to use the Bluetooth technology that of other technology. The proposed robot can be also used for the navigation in places as the coal mines and the nuclear power plants where the human search is rather risked and dangerous.

Barnhard et al. [6] proposed the conception of a multi-robot system using Bluetooth communication to solve the tasks made by bees. Bee's task is a simple navigation research problem that requires a robot guide to lead another blind robot to a specific target in the environment.

Junli Wan [5] Propose a multi-robot communication system based on ZigBee technology. He adopted a ZigBee star structure between different robots, with a coordinator robot that supports network management. Robots cooperate between them by communicating their information with the coordinating robot.

A special study of Bluetooth communication between two homogeneous mobile robots is presented by Ismail et al. [1] in witch the two robots baptized "*Mecha*" and "*Mechi*" are autonomous and uniform mobile robots.

Movements made by the robot Mecha are sent, in small distance, to the Mechi robot via Bluetooth which moves to have the same behavior as the Mecha robot. A measure, based on distance, was made for comparison between the two robots behaviors.

3. Architecture of mobile robotics platform

To communicate the robots exchange messages. The robot that emits information has the status of "master" and the one that has the status "slave". In [1], an example of robot considered as master executes actions and orders robots considered as slaves to reproduce them.
The application consists in two Lego NXT autonomous mobile robots equipped with Bluetooth modules. Each robot moves on a closed black circuit on a white background with an appointment point in a green color and the presence of possible dynamic obstacles which can slow down the travel of one of the two robots as shown in Fig 1. The appointment point is modeled by a zone of an equal size in the range of robots Bluetooth. When both robots are outside the appointment area they desactivate their Bluetooth modules to save energy. Once a robot reaches its appointments area, it activates the Bluetooth module and starts a search for its homologous.

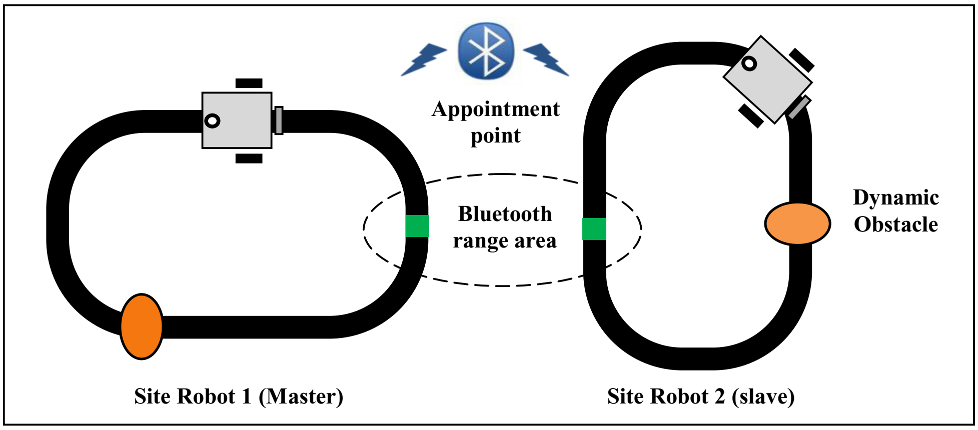

Fig. 1. Architecture of Mobile robotics platform

3.1. Robots hardware

The used robots used in our application are Lego NXT [12], identical autonomous robots with differential configuration as shown in Fig 2. They contain two wheels commanded independently, a free wheel placed behind the robot to assure its stability. This platform is very easy to control, since it is sufficient to specify the speeds of the two wheels, and further allows the robot to turn around itself, each robot is equipped with:

- A brain containing a microprocessor 32bits ARM7d'Atmel Atmel [13].
- Two servo-motors allowing the propulsion of the robot.
- A color sensor allowing the robot to follow black line and to detect the green color of its appointment point.
- An ultrasonic sensor allowing the robot to detect possible dynamic obstacles on its way, and to stop until liberation of these obstacles.
- A Bluetooth module allowing a communication between several NXT.

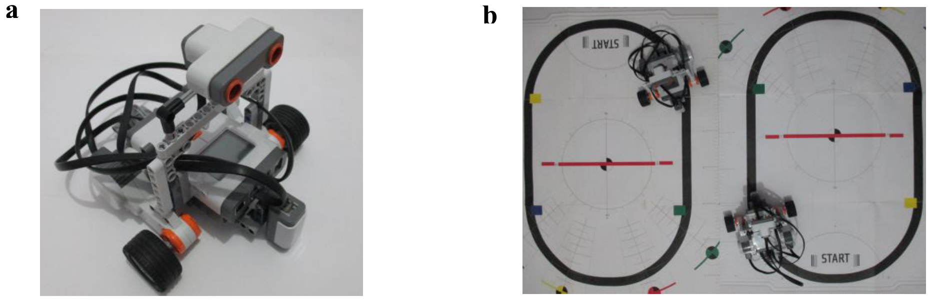

Fig. 2. (a) NXT mobile robot; (b) Sites of robots.

4. Modeling with Petri Net

The Petri net models the local course of every individual robot as shown in Fig 3.

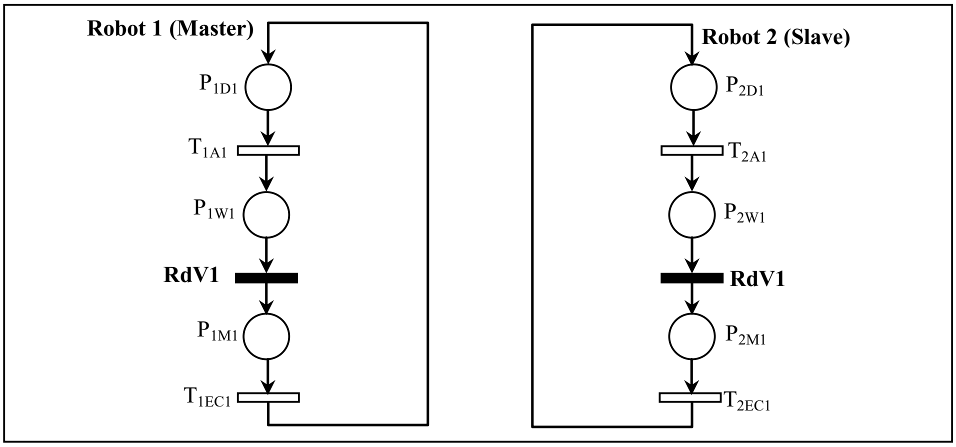

Fig. 3. The local behaviors of each robot

With :

$\mathbf{P_{iDj}}$: Is a finite non empty set of places presenting the displacements of robots $\mathbf{R_i}$ to appointment point $\mathbf{RdV_j}$.
$\mathbf{T_{iAj}}$: Is a finite non empty set of transitions presenting the arrival of the robot $\mathbf{R_i}$ on its appointment point $\mathbf{RdV_j}$.
$\mathbf{P_{iWi}}$: Is a finite non empty set of places presenting the waits of robots $\mathbf{R_i}$ in appointments $\mathbf{RdV_j}$.
$\mathbf{RdV_j}$: Appointment point $\mathbf{RdV_j}$.
$\mathbf{P_{iMi}}$: Message exchange of Ri robot in its appointment point $\mathbf{RdV_j}$.
$\mathbf{T_{iECi}}$: End of communication of $\mathbf{R_i}$ robot in its appointment point $\mathbf{RdV_j}$.

After synchronization of appointment point, we obtain the Petri net as shown in Fig 4.

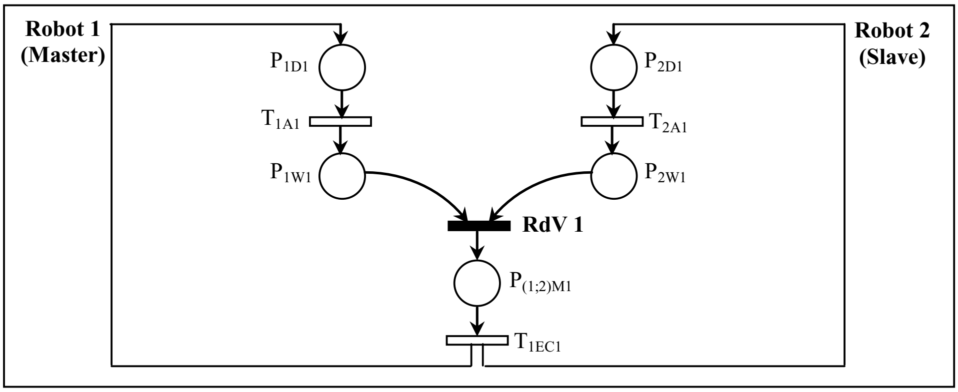

Fig. 4. The Petri net modeling the appointment point of the two robots

The condition of crossing of the transition RdV1 is that both robots should be present to establish a Bluetooth connection.

5. Synchronized communication protocol between master and slave robots

Given the synchronization of appointment between both robots, two scenarios of Bluetooth communication can appear between the **master** and the **slave**:

Scenario 1: ***The slave robot comes first on the appointment point.***
In Bluetooth communication, the waiting time on the appointment point of the robot configured as slave is unlimited. Once the robot configured as master reaches the appointments point, it immediately starts the search of its homologous. The connection is established and the exchange of messages is then realized.

Scenario 2: ***The master robot comes first on the appointment point.***
Once the robot configured as master, arrives on the appointments point, it starts the search for its homologous configured as a slave and as it did not find it, the communication fails and there will be no exchange of messages, the waiting time of master robot at the appointments point is void.
To find a solution to this situation we have used the P-temporal Petri nets [14] [15]. That is associated with each a $\mathbf{P_{iWj}}$ place an adequate $[a_i, b_j]$ time interval:

- In the case where the slave robot is on site, and by setting the lower bound a_i at zero, one allows the master robot instantaneously to establish Bluetooth communication.
- In the case where the slave robot isn't present on site, and by estimating and setting the value of upper bound b_i, one forces the master in waiting situation.

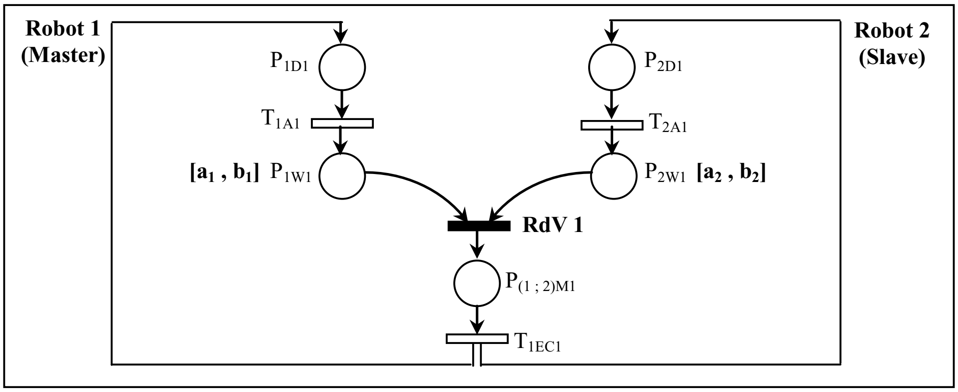

Fig. 5.P-temporal Peti Net modeling the waiting time

Similarly, to prevent the slave robot for not waiting indefinitely the arrival of the master robot at appointment point, this situation has been modeled by an $[a_2, b_2]$ time interval.
If one of the two robots waits his homologous on the appointment point and the time b_i is exceeded, so the communication fails and reordering is then started.

Communication protocols between the master robot and slave robot are represented by the flowcharts shown in Fig 6.a and Fig 6.b.

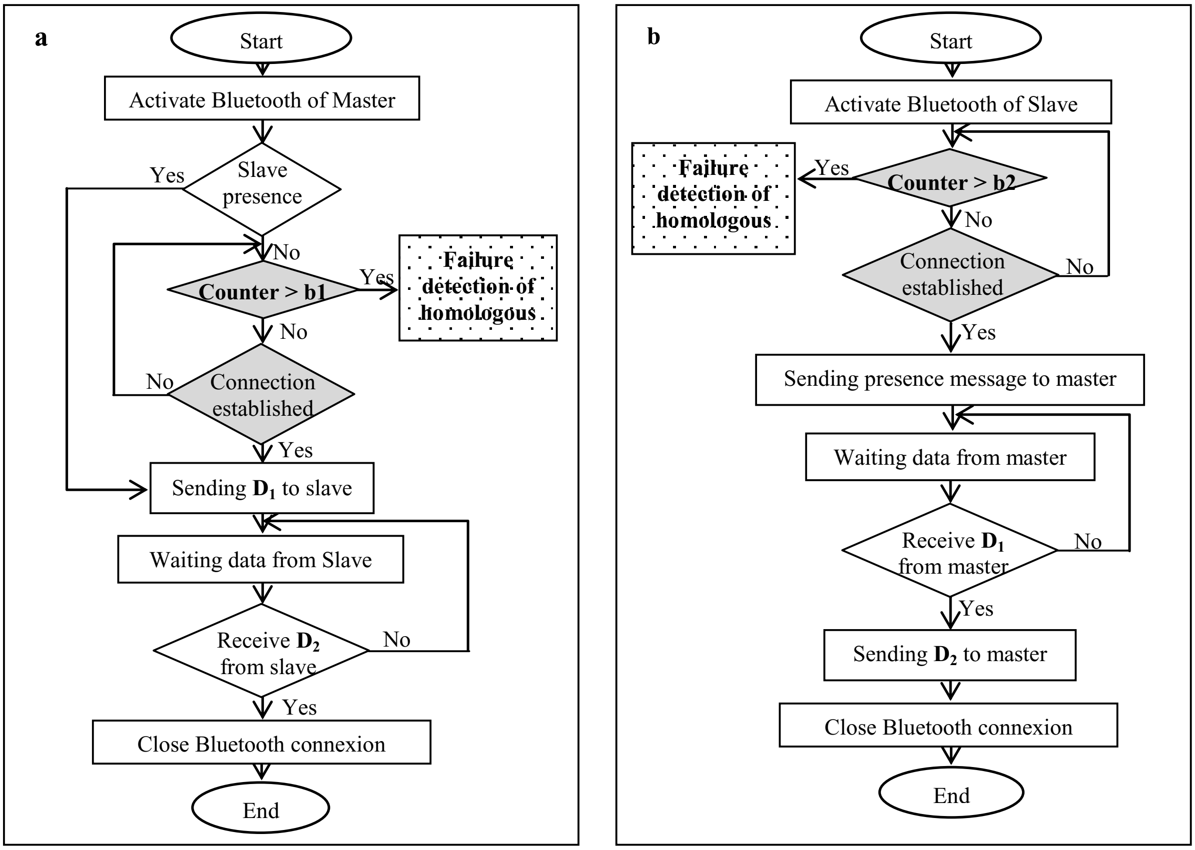

Fig.6. (a) Communication Master to Slave; (b) Communication Slave to Master.

6. Global tasks realized by the master and slave

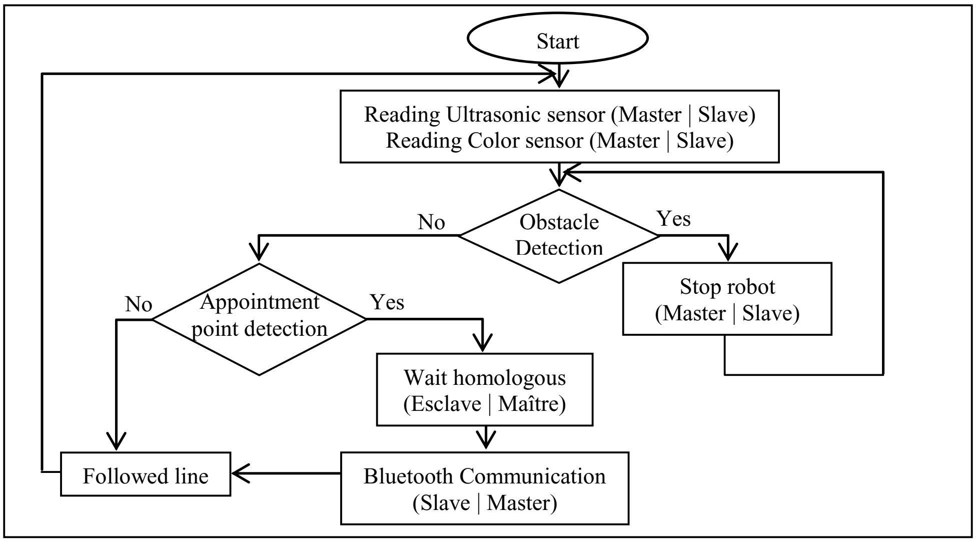

Fig.7. Tasks made by every robot.

The flowchart of Fig 7 shows the different tasks performed by the two robots to cooperate between them to achieve a common task. Initially, each robot reads its ultrasonic sensor; if there is an obstacle in its path, it stops waiting for the liberation of this one, reading its color sensor, if the green color was detected, it stops and waits for its homologous, when both robots are present on respective appointments points, they start Bluetooth communication to exchange information collected on their sites. At the end of the exchange of information, each robot starts the procedure of following the line using the color sensor.

7. Discussion of results

We have chosen a simple example to verify the effectiveness of our algorithm. The global task of the group is to calculate the hypotenuse of a right triangle **ABC** using the Pythagorean Theorem as shown in Fig 8. Each robot has in its memory the length of both sides the right angle of the triangle noted **Dj** and must retrieve the other length of its homologous on the appointments point (see table 1).

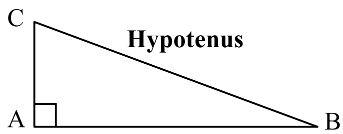

Fig.8. Hypotenuse of a right triangle ABC.

On arrival, at the appointments point, a connection between the 2 robots is established to perform Bluetooth communication through the exchange of data. As soon as the exchange is done, each robot computes the hypotenuse of the triangle, at the end of the calculation; each robot returns to its homologous the result for verification. If the result of the comparison is positive both robots continue their site visit.

Table 1.

	Data Dj	Computing of hypotenuse
Robot 1	$D_1 = AB$	$H_1 = BC = \sqrt{D_1^2 + D_2^2}$
Robot 2	$D_2 = AC$	$H_2 = BC = \sqrt{D_2^2 + D_1^2}$

The results of the application show that the two robots are capable for synchronizing to a point of appointment and exchange information. The appointments point is an area bounded by the range of the Bluetooth module using, in our case, the range is 10 meters.

Once a robot reaches its appointments, he start a search for its homologous; if it is present the data exchange is carried out immediately, otherwise, the first arrived robot at the rendezvous point waits for its homologous.

8. Conclusion

In this work, the wireless Bluetooth communication between master and slave robot has been successfully carried out. Bluetooth communication is between Master and Slave, one of the problems is when Master robot reaches the appointment point before the arrival of the slave robot. Indeed, to establish a data exchange between master and slave via Bluetooth, the slave must be waiting for the master, if there is failure of the implementation of the embedded program on the master robot. To solve this problem, we have forced the master to reestablish a connection with the slave as long as this is not available, i.e., to impose the master to wait for the slave. This is done by using the P-temporal Petri nets, which represent a system running in parallel with synchronization under time constraints. This model allowed us to calculate the maximum waiting time of each robot on its appointment point. If one of the robots waits his homologous on appointments point and the time b_i is exceeded then the communication fails and reordering is restarted.

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