

Fuzzy Multi Agent Interaction

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Abstract— In this paper a fuzzy communication protocol among agents in a group is presented as an alternative solution to the classical ones used in architectures for the cooperation of agents. In order to achieve this goal, the integration of previous works carried out on fuzzy behaviors and on cooperative architectures at the Intelligent Agents Lab. (LAI) has been used. This cooperation/coordination protocol is necessary to successfully control a group of autonomous robots. The protocol will take into account the fuzzy controllers used in the design of the robots. Three different fuzzy protocols have been considered and tested, both in a simulator and in real robots. The results of the experiments carried out and the conclusions obtained are presented.

Keywords— Multi-Agent, Distributed, Cooperation, Fuzzy, Multi-Robot, Communication Protocol

I. INTRODUCTION

The problem of activities coordination in a group of agents has been extensively faced using different architectures. Within this context, our approach mainly considers the coordination problem from two complementary points of view: the communication and the behavior perspectives. Firstly, the coordination of agents may be achieved by explicit communication between individuals, usually performed through messages. Secondly, the global coordination of a group may be implicitly influenced by the effects of the agent behavior, which are manifested through its actions and the changes made in the world. These direct and indirect ways of coordination are very useful complementary mechanisms for obtaining a high level - intentional - cooperative agent, and can be integrated in a unique model.

In this paper, a fuzzy protocol for the coordination of robots in a group is presented as an alternative solution to the protocols used in more classical architectures [1], [2], [3]. This kind of coordination protocol would provide a more flexible and soft behavior, by means of fuzzy knowledge representation and reasoning. In fact, inaccuracies and uncertainties of sensor data or in robot action execution, as well as hardware errors like communication failures, are easily coped with a fuzzy approach. In particular, the adoption of the fuzzy philosophy can be exploited in order to leave vague or undetermined both the recipient of a message and its content. This will provide a smoother communication. Moreover, it can also be adopted in order to produce a softer fusion of the robot behaviors, not only at the low level of reactive tasks, such as motor control, but also at the high intentional level of

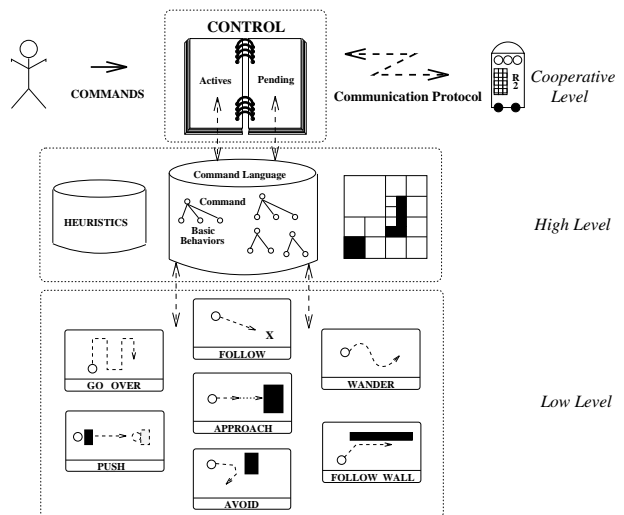


Fig. 1. Architecture of the Robots

cooperation.

The integration of previous works on practical experiments on fuzzy behaviors [4], [5] and on cooperative agent architectures [6] have been considered as the basis for achieving an architecture of cooperative robots. A first model of this architecture has been defined and can be summarized in Figure 1. The main idea consists of considering a two levels architecture for the control of autonomous robots: a reacting low level, which carries out all the basic and instinctive activities of a robot (e.g. moving, turning, avoiding, etc.); and a coordinating high level, which controls intelligent activities, such as the cooperative behavior.

This paper focuses on the analysis of the communication perspective according to fuzzy principles. An experiment is described in order to present the potential influence of a fuzzy communication on the behavior of a real mobile robot. The data obtained in the experiment, as well as the conclusions extracted from these data are also presented.

II. FUZZY PROTOCOL

Some previous works have shown that robots can take advantage of the fuzzy reasoning theory [7], [8]. In the same way, we have used reactive fuzzy controllers to cope

with the uncertainties of a particular situation in the control of autonomous robots [4]. These fuzzy *behaviors* have been designed to become part of the global architecture shown in Figure 1. The architecture has been thought to coordinate robots in cooperative tasks. This implies the need for communicating some information among the robots. This communication will be based on a fixed protocol, where classical protocols have usually been adopted to communicate traditional information. A new approach for the communication of fuzzy information among robots is here presented.

In this work, the tentative protocol will not be a closed interchange of *crisp* concepts identically defined in all the robots. Where the term *crisp* means that the value of a variable, or any other information to be exchanged among the robots, is defined in its exact numeric terms. This means that in order to design our protocol we will have to face some semantic problems.

Let us illustrate these concepts by means of a simple example. Let us suppose that a robot, which is sensing the real environment through its sensors, gets some knowledge about an object width. This concept (*width*) will be defined in the controller using a *fuzzy variable* referred to as *width*. The value of the variable is obtained by the corresponding fuzzification process and it is expressed by the activation levels of the *linguistic labels* defined over the variable range. For instance, the variable *width* can be defined by the set of labels {VERY HIGH, HIGH, SMALL and VERY SMALL}. The knowledge about the object width can be expressed in fuzzy terms as: VERY HIGH (0.8), HIGH (0.5), SMALL (0.1) and VERY SMALL (0), where 0.8, 0.5, 0.1 and 0 represent the degree of membership of the sensors measures to each linguistic variable respectively.

When the labels are defined, the domain of the variable has to be considered. For example, when defining the variable *width* the domain is fixed to 0 - 1000. In most of the cases, the domain is fixed by the physical requirements. For instance, the domain of a variable concerning the distance to an object measured by a sensor, will be fixed by the sensor range. If the sensor range is 0 - 1023 (as in the Khepera robot), this range will be the one of the variable.

Now, if our robot wants to share its knowledge about the object, we have considered three possible communication methods in order to exchange the information with other robots (see Figure 2):

1. The communication of fuzzy variables.
2. The communication of the fuzzy labels.
3. The communication of protocol concepts.

The first method is based on the communication of fuzzy variables stored as a set of linguistic labels values. These labels will have been defined by a set of functions defined over the domain of the variables. That is, the activation value of each label is calculated using its function (named *membership* function). Usually, the values are assigned by simple functions such as the linear ones.

Then, if we send the whole variable, the labels of all robots will use the same domain and the same member-

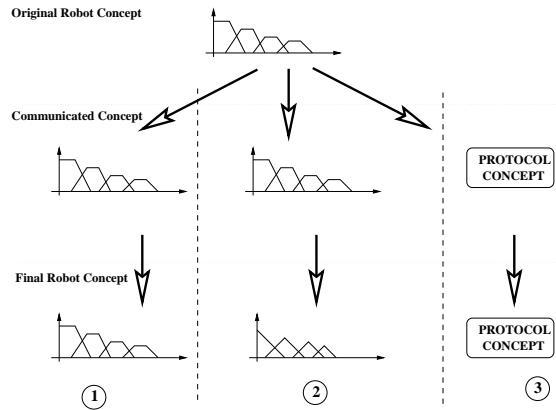


Fig. 2. Three communication protocols

ship functions. In this case, the receiver gets the same fuzzy information that the sender robot has got. In the example, this means that we have sent the definition of the labels { VERY HIGH, HIGH, SMALL and VERY SMALL }, through its membership functions, and the activation values: VERY HIGH (0.8), HIGH (0.5), SMALL (0.1), VERY SMALL (0).

The second method uses labels defined over different domain ranges of the variables. This means that each robot will use the same labels to define the fuzzy variable *width*, that is { VERY HIGH, HIGH, SMALL and VERY SMALL }, but the domain now would be different. For example, the receiver can use the domain 0 - 2000 instead of the previous 0 - 1000. The receiver robot uses the labels defined over a different domain, using its own membership functions (labels). This makes the robots have got the same fuzzy information. They have got the same subjective *impression*. For instance, the concept *wide* for a small robot (let's say 6 cm. in diameter) can be defined as VERY HIGH for an object in the range 6-12 cm. When this information is transmitted to a greater robot, let's say a 30 cm. diameter one, where VERY HIGH is defined in the range 30-60 cm, the information actually exchanged is different, but the idea (VERY HIGH) about width is the same.

In order to solve this problem it is possible to tune the knowledge inside each robot. In the previous example, if the big robot knows that the other one is smaller, then the information received from it can be translated from VERY HIGH to SMALL inside the receiver. In this case, what is transmitted is the idea (VERY HIGH), but what the receiver has obtained is the real information. This solution leads us to a third method where independent and shared concepts, in the form of linguistic labels for the fuzzy variables, are used.

In the third method, a concept which results from the interpretation of the linguistic variable that a robot wants to transmit, is used. This means that a global concept is defined as a communication protocol concept. In the example, the fuzzy variable values would be translated into activation values of a new set of labels, {ENORMOUS,

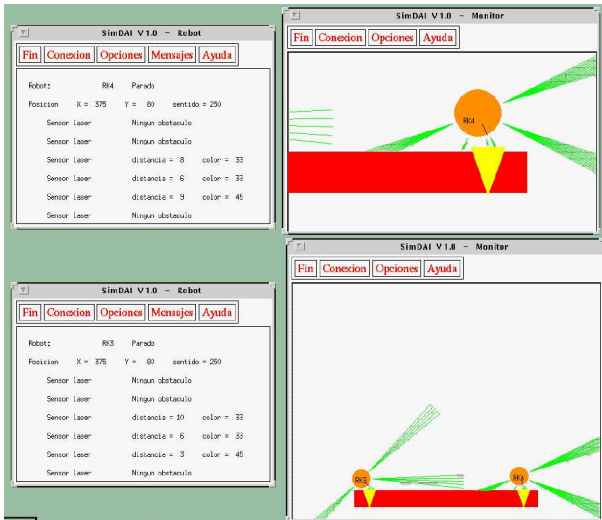


Fig. 3. The Simulated environment

GREAT, NORMAL, SMALL, TINY}. Thus, it is only necessary exchange one of these labels to transmit the information.

From this point of view, this is a simple communication protocol. Due to the fact that concepts are not defined in the same way in each robot, the same concept is differently interpreted from each robot point of view. This case is similar to human communications: one person has a perfect image of a situation that he/she lived, but when he/she communicates this information, he/she uses a rule-base to translate his/her experience into words, which implies a reduction of the global information stored in the brain. Then, these words are transmitted to the other person, who translates them into thoughts using his/her own rule base.

In the example, the system can consider that all the information in the fuzzy variable can be summarized by the concept GREAT, which is the transmitted information. Thus, all the robots have the same concepts defined as a protocol. The other robot may adopt this limited information doing a different interpretation according to the sender robot characteristics.

III. EXPERIMENTS

In order to prove the different alternatives of communication, some experiments have been carried out using both a simulator and real robots. The simulator used, SimDAI [11], allows the simulation of a group of independent robots, which run on different computers and carry out simple tasks in a user-defined world shared by the robots. The simulator also provides a mechanism to let the robots communicate each other.

The real robots used in the experiments have been two Khepera mini-robots [9]. This 5.5 cm. of diameter mini-robot has got two independent motors and 8 infrared sensors. The sensors can measure both the dis-

tance from objects or the ambient light. The robots can work autonomously or connected to a computer through the serial port.

A simulated world (Figure 3), which resembles the real one (Figure 4), has been defined in order to design the experiments before implementing them in the real world. The same controllers have been used in both cases, except the differences in the treatment of the sensors. The Khepera's distance and ambient sensors have been simulated in SimDAI as laser and sonar sensors respectively, see [11]. This difference is due to the distinct ranges of the sensors in the simulator and in the real robot.

In the next section only the real experiment is described, considering the simulation results less significant.

A. Description of the experiments

The experiments carried out aim to show the influence of the fuzzy communication in a coordinated behavior. The global goal of the experiment was to push an object, in a cooperative way, by two robots. This task can be divided into two main tasks, prepare to push and to push. In order to prove the communication alternatives the first task has been considered to be the relevant one. This task has been divided into three different phases:

1. The first robot finds the object.
2. It aligns to the object and sends a description of its alignment to the second robot.
3. The second robot tries to align exactly as the first one and close to it.

The first phase can be carried out by a simple fuzzy controller, as one of the previously developed [4], or by other kinds of controllers. A version of a reactive controller from V. Braitenberg [10], has been adapted in order to recognize the correct alignment position.

Once the robot has found the object, it aligns to it in a particular way. This phase needs a more precise controller than the previous one because the alignment will determine if the cooperative task will be well accomplished or not. Using a real robot such as the Khepera, the definition of the alignment has to be done in terms of the sensor measurements and has to be taken into account in the controller.

In this way, we have made the definition of the alignment in terms of fuzzy variables related to the sensors of the Khepera robot. Thus, we have supposed that a robot, using a standard controller, has been aligned when its proximity sensors and its ambient light sensors returns a particular fuzzy values. Then, the robot informs the other one about *how* much it is aligned. At this point, the three different communication alternatives already mentioned are considered.

Besides the three fuzzy alternatives, the most traditional communication method has also been considered. It consists of exchanging the crisp concepts. In this case, the sender communicates the exact measurements of its sensors to the other robot. This solution will be the ideal one if the two robots were physically identical, including its sensors sensibility, and also if there were no errors in

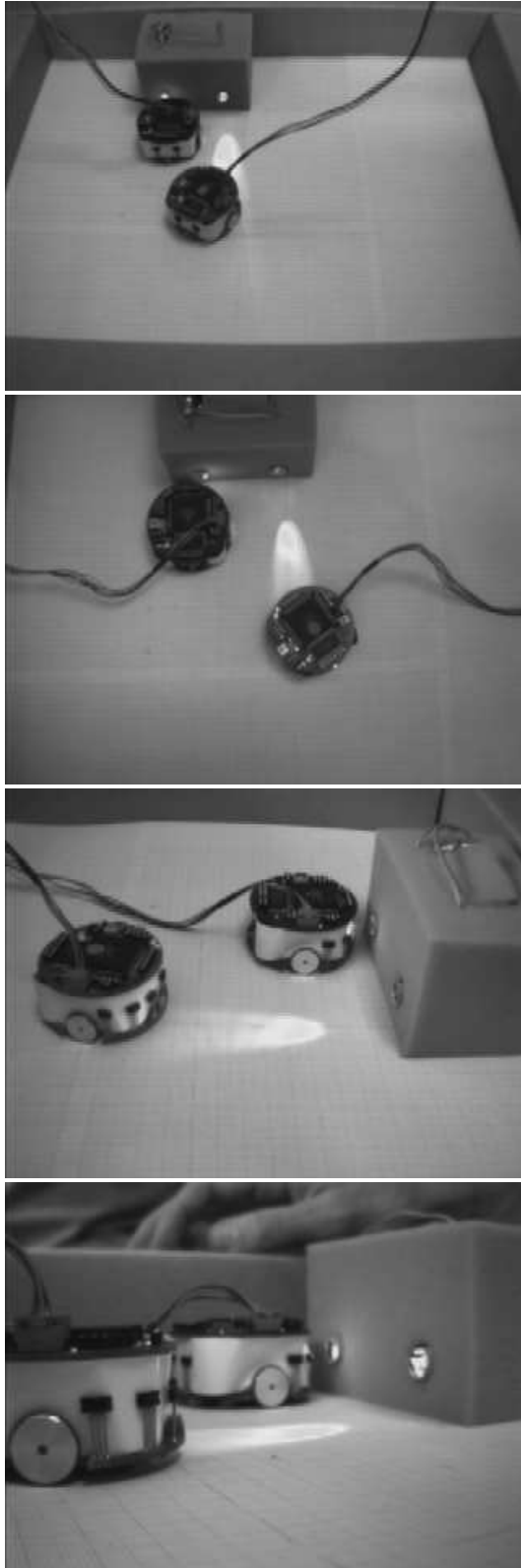


Fig. 4. The experimental environment

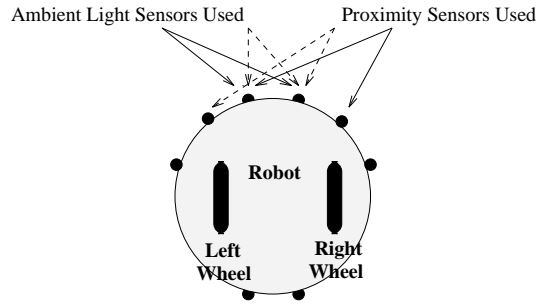


Fig. 5. Sensors distribution used in the experiment

the measurements.

In order to show the performance of the different solutions we have made some trials of the experiment in the real environment shown in Figure 4. This experiment was previously designed in the simulator SimDAI [11] and then implemented in the real world. In the simulated one, the task was to align in front of a predefined position of an object. The position was indicated in the simulated one using a different color, as shown in Figure 3.

With respect to the real case, an artificial object with two lights has been built (see Figure 4). These lights are the points where the robots have to be aligned to. When one of the robots gets aligned, it sends its perceived environment to the other robot using one of the communication methods previously mentioned. In the real experiment, the environment is perceived using the proximity sensors and the ambient light sensors. In order to simplify the controller, only the sensors shown in Figure 5 are used. Depending on the side of the object where the robot is going to align, the proximity sensors used are the ones indicated by the dashed arrows (align to the left light) or the ones indicated by the continuous arrows (align to the right).

Being the Khepera sensors very sensitive to the external environment, some preliminary experiments were made to choose a significant configuration, adjusting the starting points for the robots or the ambient light in the lab. A final configuration which makes the robots find the light easily has been chosen, because the goal was to test the communication protocol and not the controllers used.

In the final experimental environment, we have measured the distance from the object to know how the communicated values have been used by the controller. In some situations, the time needed by the second robot to align can give us a valuable information. For instance, if the first robot sends the crisp (numerical) values measured by its sensors, the second robot is unable to align in a reasonable time. This is due to the fact that in the real world there is a very low probability that the sensors of the second robot measures exactly the same as the corresponding sensors of the first robot. Therefore, a maximum running time has been introduced, and a time out considered. This problem was the origin of this work.

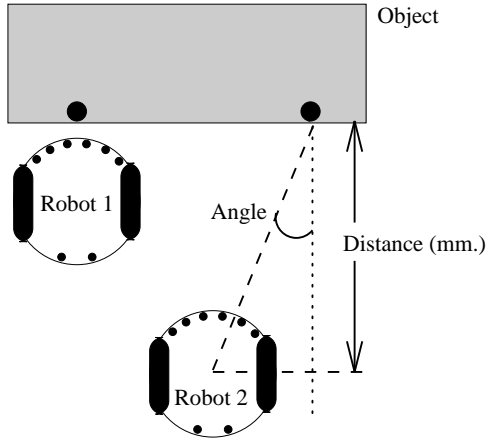


Fig. 6. Experimental environment

However, in most cases the time variable only measures the quality of the controller. For example, the time employed in the alignment, when the fuzzy communication is used, depends on external conditions and only measures the quality of the controller used in presence of these events.

B. Results

In the analyzed situation, the first robot is stopped in front of the left light at a distance of 7 mm. The other robot must stop at the same distance and with a similar orientation. Before acquiring the experimental data, we have tried several configurations of the environment, changing the start point and initial orientation of the robot and the light source, modifying its luminosity, etc. In the chosen environment the robot is placed at 190 mm from the light and with an angle of 16° , as it is shown in Figure 6. The initial orientation is perpendicular to the object.

The second robot starts from this situation using a controller that avoids obstacles and goes to the light. The first robot sends a description of the real situation of its sensors to the second robot which stops the execution when the perceived situations are the same. The evaluation of the distance from the second robot to the object, measures the accuracy used in the communication to obtain a successfully "same" situation.

Fifty trials have been repeated for each type of communication (type 1,2,3 of fuzzy concepts and type 4 of crisp concept using a timeout of five minutes). The number of trials was calculated as a function of the variance of the results. When the variance is below a certain level we could consider that, in the experiments, the external conditions have no effect and we can measure the accuracy of the communication protocol type considered.

A graphical description of distances obtained for each communication type, except for the fourth type, are shown in the graphics of Figure 7. In the fourth type, where the numerical values of the sensors of the first ro-

bot are sent, repeatedly exceeded the timeout. In this case, the robot was never able to align to the object.

A summary of the results obtained using the other three types can be seen in the following table, where the average distance and the variance in the measures are presented.

Results	Communication Protocol			
	Type1	Type2	Type3	Type4
Distance (mm)	7.5625	8.0937	7.1562	—
Variance (mm)	2.8617	3.6042	2.9745	—

Evaluating the average distance, it can be observed that there is not a great difference among the results of each type 7.56, 8.09, 7.15, for type 1,2,3 respectively. These results show that the fuzzy information communicated represents the environment with sufficient detail to know a good stopping position. The deviation of the second type is due to the different definition of the membership functions. For example, the label HIGH in the first robot is defined between 0 and 300, while in the second robot is between 0 and 400. This modification makes that the concept <very near> in the first robot is interpreted as <near> in the second one, making it stop at a greater distance from the object.

While the amount of information transmitted in the first and second type is the same, i.e. a linguistic variable, the information is reduced to one concept in the third type. This transmitted concept is obtained by applying a rule base system to the activation levels of the labels, using rules such as:

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IF (sensor1 activation = HIGH) > 0.7 AND
   (sensor2 activation = HIGH) < 0.2
THEN (send NEAR)
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In the third method, the two robots use the same linguistic variables to represent the numerical values of the sensors and the same rule base to interpretate them. When the second robot obtains the same concept ("impression") as the first one which sent the "impression" to the second the robot stops the execution. Although in the case of using the protocol concept the information is less accurate than in the other cases, it is more fault-tolerant to external conditions. The obtained distance is the smallest because we apply restrictive rules to calculate the concept.

IV. CONCLUSIONS AND FURTHER WORK

In this paper we have presented three methods of communication between agents in order to cooperatively carry out a global task. The communication has been based on the exchange of fuzzy messages instead of classical crisp messages. In general, the three fuzzy methods allow a softer, more reliable and flexible communication among the robots, letting the robot increases the semantics of the messages and obtaining better alignments than the ones obtained using the crisp communication.

Among the three methods it has emerged that the preferable method, in normal conditions, would be the

third one, because it provides an acceptable performance with the least use of communication resources. This method has also emerged to be the most fault-tolerant in presence of external events.

In the experiments, we have measured only the distance, and not the similarity between the orientation of the first robot and second one. The orientation could be described as a function of the sensor values. The first method performs in a more robust way than the third one because it employs the fuzzy logic to describe the situation and not a crisp rule. The choice depends on the intended use of the robot. A number of similar experiments are going to be carried out in order to prove the effectiveness of fuzzy communication in more complex tasks.

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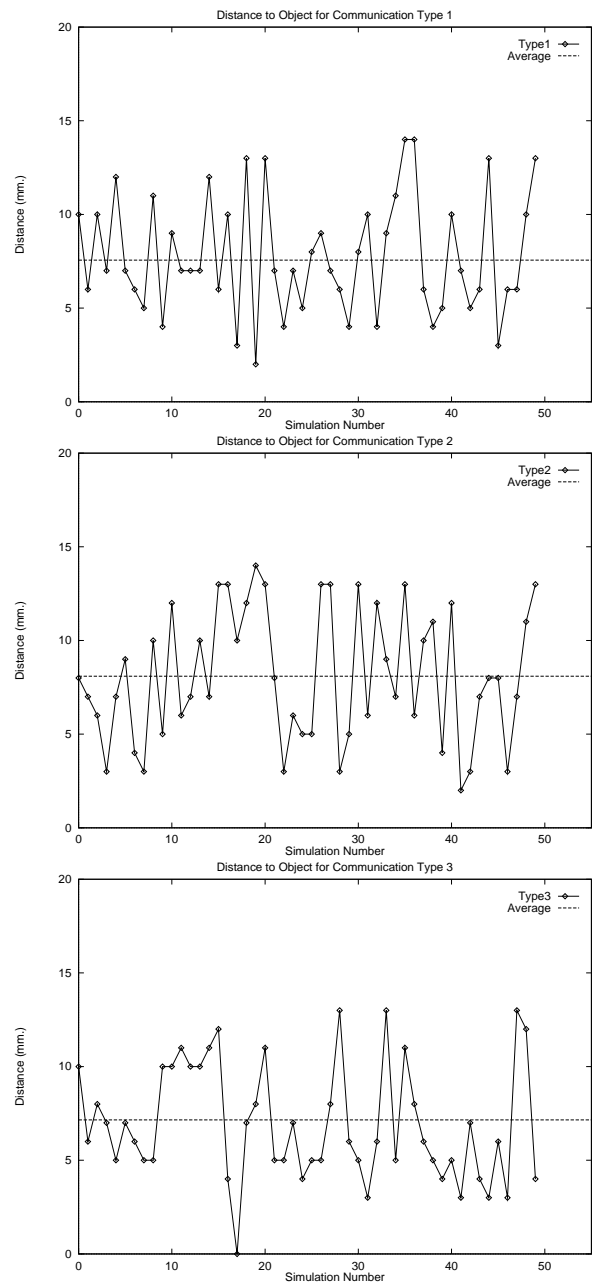


Fig. 7. Graphical results of the experiments