Using Situated Communication in Distributed Autonomous Mobile Robotics

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Abstract

When using communication in multi-robot systems it's often not desirable to choose an abstract form of communication that separates the messages from the physical environment in which they have meaning. If the messages are separated from the environment localization information has to be encoded into the messages in order for the receiver to be able to situate the content of the messages. Here we point out that if we instead use a situated form of communication that exploits the physical properties of the signal transferring the message localization information is not needed. We demonstrate this idea by showing how an extremely simple control system that uses short range communication can keep four LEGO Mindstorms robots together in a group. It's also discussed how this idea can be extended to make it possible to simplify path planning in multi-robot systems.

1 Introduction

In this work we distinguish between situated communication and abstract communication. Abstract communication is communication where the physical signal that transports the message is considered not to have any meaning. In abstract communication only the content of the message has meaning. This type of communication is encountered for instance when robots communicate using wireless Ethernet.

On the other hand situated communication is communication where both the physical properties of the signal that transfers the message and the content of the message contribute to its meaning. An example of situated communication is a human saying:"move toward me". From the physical properties of the sound we can locate the sound source and the content of the message tells us what to do. Notice that the content of the message alone does not give meaning to the message nor does the physical properties of the signal. It is only when they are combined that the meaning is obvious.

In the robot community abstract communication, through the use of long range wireless communication, is becoming more and more used as wireless communication is becoming cheaper and its efficiency increases[20]. The combination of abstract communication and multi-robot systems has produced several successful results [17][7][18][4]. These solutions use a model such as a 2d map, a graph of landmarks or a self organizing map to represent the environment. The robot uses this model and its own location in the model to merge information received from other team members into its model and in this way benefit from the experiences of other robots.

These systems rely on the model and the localization estimate to be correct. Therefore the robustness of these systems depends on the robustness of the localization mechanisms. Localization has been the focus of much research see for instance [6][13], but often the algorithms are not robust. Often a blocked corridor, a landmark that has moved or lifting a robot and turning it 180° is enough to make these localization systems fail. Some of the more advanced systems can handle these disturbances, but at least it takes some time for the system to recover. This implies that communication systems based on localization are not robust either.

We believe that this problem is similar to the problem of good old-fashioned artificial intelligence (GOFAI). The GOFAI control systems relied heavily on a world model in which actions were planned. The key problem was that it was difficult to keep the world model up to date especially in dynamic complicated environments due to limited sensing and a not straightforward mapping from the robots sensors to the world model. Due to these problems GOFAI control systems were often slow and fault intolerant. We encounter these problems again when we try to find a common abstract representation of the environment that makes it possible for robots to communicate about it using abstract communication.

Behaviour based robotics [2][1] has taught us the importance of exploiting the real world and the robots interaction with it. We have seen that instead of relying on a model in which actions are planned, actions should be taken based on sensor input directly[3] resulting in fast and fault tolerant robots. These insights have been used in multi-robotics to produce very elegant solutions to for instance the garbage collection task[8][9].

When using abstract communication we once again have forgotten one of the lessons of behaviour based robotics: The importance of exploiting the environment. This is the motivation for the work presented here. We avoid using abstract communication, but as an alternative, try to explore the properties of a situated communication system in which each of the communicating devices has limited range and the communication range is furthermore constrained by the physical environment.

First, in section 2, we give a brief description of related work. After that, In section 3, the physical properties of our communication hardware is investigated. Later, these properties are exploited to make an extremely simple solution to the problem of keeping a team of robots close together. Finally, in section 4, we discuss how to use situated communication to solve hard problems like path planing in distributed autonomous mobile robot systems.

2 Related Work

As will be described soon we use short range communication as an example of situated communication. There has already been some work on short range communication. In computer science the work on amorphous computing is particularly interesting[5]. The research question in this field is:

> How does one engineer prespecified, coherent behavior from the cooperation of immense numbers of unreliable parts that are interconnected in unknown, irregular, and time-varying ways.

Their work is highly relevant, but still their results are from simulation and the communication devices are not actuated. The focus of Winfields work is to develop ad hoc wireless networking for application in distributed mobile robotics[19]. In his work the assumption is also that the robots are equipped with short-ranged wireless communication, but the communication system is analysed with abstract communication in mind and the communication range is therefore seen as a problem instead of an advantage.

In the work by Ficici et al.[14] the use of local communication is exploited in embodied evolutionary robotics. When a robot gets close to a light source it is considered successful and is given energy that it can use to transmit its genes to other robots. This is not enough though since the robot has to be within close proximity to another robot in order to transfer its genes. This way local communication is used to ensure that robots that get around are more likely to pass their genes to other robots.

Interestingly enough a new industry standard for short range wireless communication, Bluetooth[16], has recently been introduced. The vision of this product is to wireless connect not across the world, but within a room. This technology is short-ranged and a good candidate for future use in robotics.

3 Results

3.1 Experimental Setup

The experiments were run in the main corridor of our office building. The corridor is 35 meters long and 4 meters wide. The height of the corridor is 4 meters in one half and 8 in the other half. In the experiments we used robots built using LEGO Mindstorms[15]. The robots communicate with each other using the infrared receiver/transmitter on the RCX control unit.

3.2 Properties of the Communication Hardware

We tested one aspect of the communication properties of the RCX by placing a transmitter pointing upwards sending 25 messages per 30 seconds. A receiving RCX was then placed for every half a meter from the sender, also pointing upwards. These receiving RCXs counted the number of messages they received. The results can be seen in figure 1. The three graphs reflect the fact that the height to the ceiling varies in the building and it can be seen that the ranges of the communication changes with the height to the ceiling, but overall the communication range is reliable within 1.5-2.5 meters of the sender depending on this height. It is important to note that numerous other factors affect the quality of communication, but this experiment just shows that the communication is indeed short-ranged. This implies that we are dealing with situated communication because if the control system receives a message it knows that another robot is nearby without examining the content of the message.

3.3 Keeping Together

Four robots are used in the following experiments. The task is to make the robots stay together in a group. The robots have bump sensors on the front and the sides. These sensors are used in a simple reactive obstacle avoidance behaviour. If one of the bump sensors is activated the robot is moved back a bit and by random turned approximately 90 ° left or right on the spot.

A communication process takes care of the communication between the robots. The part of the process that does the sending is very simple - it just sends a message every 0.5 seconds.

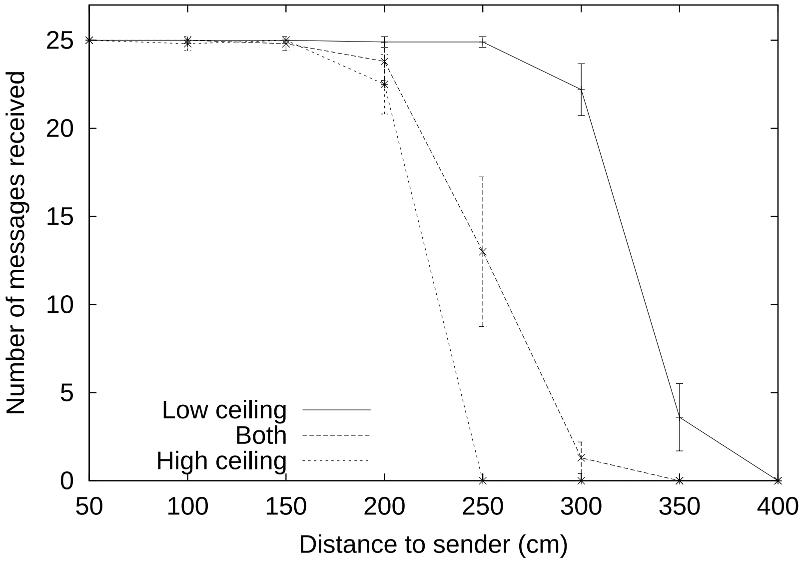

Figure 1: Communication ranges in different parts of the environment (average and standard deviation of 10 experiments).

The other part first counts the number of messages it receives in a second n. This number is then used to calculate a very simple estimate of the time derivative $\dot{n}$ using:

$$\dot{n}_t = n_t - n_{t-1} \tag{1}$$

This estimate is too noisy to be used directly so an estimate $\widehat{n}$ is calculated:

$$\widehat{n}_t = (1-\alpha)\,\widehat{n}_{t-1} + \alpha\,\dot{n}_t \tag{2}$$

In the experiments α is chosen to be 0.1.

The robot is also equipped with a behaviour that reacts to changes of $\widehat{n}$. This behaviour checks the sign of $\widehat{n}$. If the sign is positive it means that the robot receives more messages which means that it is moving toward an area with more communication and therefore the behaviour does nothing. If on the other hand the value of $\widehat{n}$ is non-positive the behaviour takes control of the robot and turns it approximately 180°. After that the behaviour is disabled for five second to give the robot a chance to move to a new area.

3.3.1 Without Communication

In this experiment the purpose is to show that without communication the robots will wander away from each other. It is possible that this is not the case because the interaction between the environment and the simple obstacle avoidance behaviour of the robots could be able to keep the robots together. Therefore, to test this, the behaviour that makes the robots react to change of sign of $\widehat{n}$ is disabled. Initially the four robots are placed in the middle of the corridor making the four corners of a square with side length 0.5 meters. The robots are facing away from the center of the square. The four robots are started at the same time and the experiment lasts for five minutes. During the experiment each robot logs n the number of messages received per second every second. The solid line in figure 2 shows how the average number of messages received by the four robots changes over time. The average

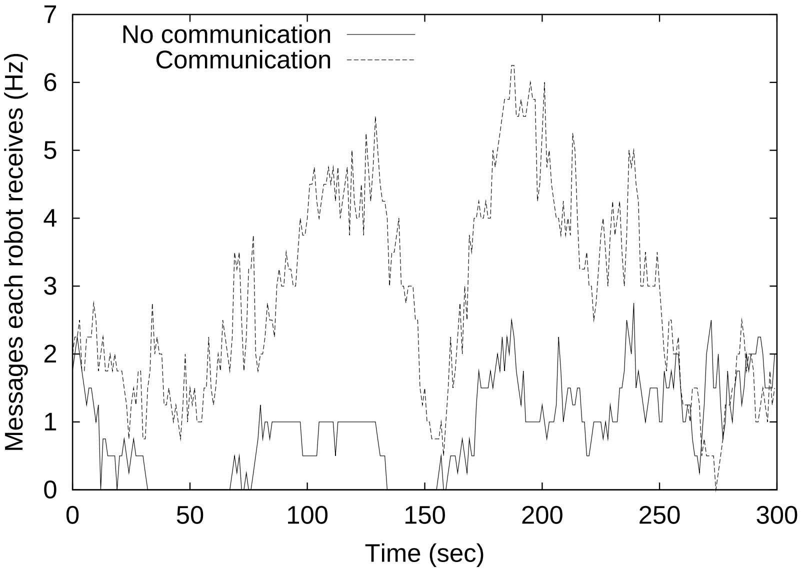

Figure 2: The number of messages received per second (average of four robots).

number of messages received is 0.92 and the 95% confidence interval is [84.7;99.1]. It can be seen from the figure that the average number of messages received stays constantly low throughout the entire experiment. The reason to why there always is a little communication is that the robots are trapped in the environment so just at random they pass each other or move in the same direction, which was what happened toward the end of the experiment. The solid line in figure 3 shows the frequency of the number of messages received per second. The robots received zero messages most of the time, but frequently also two were received. Remembering that messages are sent every 0.5 second it is interesting to note also that one, three and five messages are received in some time intervals. This indicates that even though one of the messages made it the other was lost. This is not surprising since in our analysis of ranges we found that at certain distances there is only a certain probability that a message will make it. Also a small fraction is lost because the robot has moved in the mean time, imprecise timing in the control system or due to interference with other communicating robots.

3.3.2 With Communication

Now the experiment is rerun but this time with the behaviour that makes the robots react to change of sign of $\widehat{n}$ enabled. The dashed line in figure 2 shows how the average number of messages received per second changes over time. The average is 2.90 and the 95% confidence interval is [2.79;3.01]. It can be observed that the number of received messages varies a lot over time. The reason is that the approximation of $\widehat{n}$ changes too slowly. In the phases where the robots are moving closer and closer together $\widehat{n}$ become positive and large. When the robots again are moving away from each other either because they passed each other or they avoided each other. The number of messages received starts to fall, but it takes quite some time before this is reflected in $\widehat{n}$ so it becomes non-positive and triggers the turn around action. The dashed line in figure 3 shows the frequency of the number of messages received per second. Again we can see that a lot of messages are lost because often an odd number of messages is received. Furthermore we can see that the ratio between the frequency of the odd numbered observations and the frequency of the even numbered increases as the number of

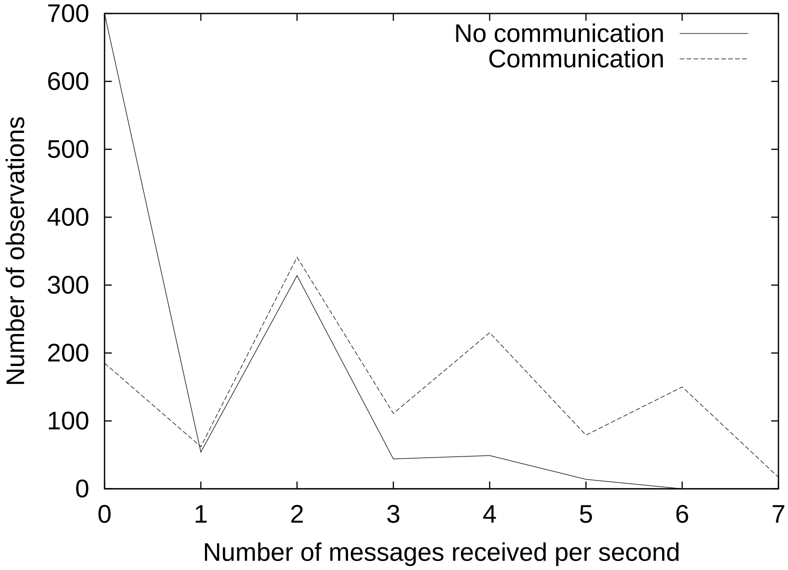

Figure 3: The frequency as a function of the number of messages received per second (sum of four robots).

messages per second increases. This can only be explained as an increase in communication interference with the other robots.

3.3.3 Comparison

Since the robots are constrained by the environment we can not say that the robots failed to stay together in the experiment without communication and succeeded in the experiment with communication. We can only conclude that when using communication the robots stayed together to a higher degree. The two-sided students t-test shows that at the 95% confidence level the probability that the difference between the means of the number of messages received per second in the two experiments is zero is less than 0.001. Meaning that when using communication the robots received significantly more messages. Since we know that the number of messages received is a monotone decreasing function of the distance to the sender this implies that the robots stayed significantly closer to each other. The problem with this result is that it doesn't say anything about the individual robot since it is based only on the mean. Therefore it will not show up in the analysis if one robot got away from the group. Therefore a further analysis is needed. From figure 2 it can be seen that several times during the experiment with communication the robots on average received five or more messages per second. This implies that all the robot must have been within communication range in those time intervals. Therefore we can conclude that all the robots stayed in the group for the entire length of that experiment.

4 Discussion

The task of making the robot team stay together has been chosen to investigate one way of exploiting situated communication. Another way to solve this problem is to use the Boids algorithm[12]. This algorithm presents a simple way to make groups of simulated animals produce a flocking behaviour just by adjusting the speed and heading to match neighbors and also try to maintain a certain distance to them. This produces very nice looking results in simulation because all the values needed for control are directly accessible in the model. The problem is that it doesn't transfer to real environments and robots easily. Again the problem is the model. It is difficult to map the robots sensors onto speed of, heading of and distance to neighbors. Also the question of how to distinguish other robots from the environment becomes an important, yet a difficult question. Alternatively, these values could be obtained by using abstract communication and a localization system, but as discussed earlier these systems are not robust and also the precision might become a problem. Therefore the Boids algorithm, even though it at first looks simple, is not directly applicable to real robots.

The algorithm presented here does not produce as good looking results, but it is simpler since it only reacts on information directly available through the robot sensors in this case the infra-red receiver/transmitter. Therefore it is also possible to make the algorithm work on extremely simple robots like our LEGO Mindstorms robots. We can say that the properties of the communication hardware does the calculation for us. All the parameters that we otherwise would have squeezed out of an advanced vision or localization algorithm we get for free by exploiting the limitations of the communication signal.

5 Towards More Interesting Systems

The task of keeping the robot group together is chosen because it is especially simple and highlights the benefits that can be gained by using situated communication. What will happen when we try to solve more complex problems like traditional problems such as path planning in multi-robotics and so forth? This is the focus of our future research. To continue we need to find out what should be communicated. Here we can get some inspiration from Amorphous computing[5]. Where a basic capability of the communication devices is to propagate a hop count. The idea is again very simple. Imagine that a robot detects an object of interest to the robot group using its feature detector and sends out “1”. All robots that receives this send out “2” . All robots that can hear “2” but not “1” send out “3” and so on (remember that the robots use short range communication). This generates a very coarse potential field where robots can follow the gradient and use their navigation behaviours to get to the location of “1”. Also note that if we choose a signal to communicate that doesn't cross physical structures like walls we get rid of the local minimum problem that is common in most path planning algorithms. Also in this formulation the robot gets an estimate of the distance to the target if it relies on the fact that the communication range is limited. If the number it receives, n, is sufficiently high it knows that the distance to the source is roughly n times the average communication range, because the variations for high enough n cancels out.

Again, by exploiting the physical nature of the communication medium we get rid of the model and avoid some error prone and expensive calculations. Which is important since Parker in her recent review on path planning in multi-robot systems writes[11]:

> One of the most limiting characteristics of much of the existing path planning work is the computational complexity of the approaches.

Also by having the path plan not in the robot but in the environment we can achieve a high degree of robustness. More robots can be started as needed and immediately participate. As long as connectivity in the communication network is maintained robots can fail without affecting the system.

What about maps then? The first questions is what do you need maps for? If it is used internally for navigation, then the above mentioned approach could be extended with a color for each landmark of interest and the robot could then at all times have an estimate of the distance to the landmarks and an approximate direction calculated from the gradient. Nagpal[10] has made an initial attempt on making a global coordinate system in an amorphous computing system. A 2d metric map should really only be considered as an interface between a human operator and the robot team which, of course, also is important. How such a metric map can be build on top of this system is an interesting topic for future research.

In the current formulation the communication devices have to form a communication network because if a subset of the robots wanders out of range they would be isolated from the rest of the robot team. This could also be considered a feature instead of a problem because sometimes you might want to divide a robot team to solve tasks in different parts of the environment. But robots that are to cooperate to solve a task have to form a network most of the time.

Finally, it should be mentioned that this is a new approach so there are a lot of problems that should be the focus of further investigations. What is for instance the connection between communication range, number of robots, environment size and the resolution of the gradient. It seems likely that the system will break down if the area that is covered by the communication devices is small compared to the size of the environment. Can this problem be solved by introducing memory? How will this then affect the ability to handle a dynamic environment?

6 Conclusion

We have pointed out that when only relying on abstract communication usable information directly available in the physical signal that transfers the messages is lost. We have seen that by using situated communication which implies keeping the information in the physical signal the solution to the problem of keeping robots in a group is very simple. This is traditionally not the case for robots in real environments. It has been discussed how situated communication can be exploited to do efficient path planning with low computational cost under the assumption that the robots form a communication network. We have argued that there is a huge potential in exploiting the properties of situated communication systems to produce simple and robust control systems for robot teams.

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