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LOOSE COOPERATION OF MOBILE ROBOTS

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Abstract: This paper deals with a special case of cooperation of some mobile robots, where the participants communicate in a new way without any explicit communication channel. We propose fuzzy communication and intention guessing to reach a loose cooperation of intelligent mobile robots where the codebooks are built up by fuzzy signatures. In a special experimental environment this new communication approach is investigated for intelligent cooperation of autonomous mobile robots.

Key words: Intention guessing, Robot cooperation, Fuzzy communication, Fuzzy signatures

1 Introduction

In control of autonomous mobile robots are many complex, well structured problems, where a hierarchical structure within the data is present. This means, that one or several components of the structure are determined at a higher level by a sub-tree of other components. The concept of fuzzy signatures was introduced to help model these kinds of problems. Fuzzy signatures which structure data into vectors of fuzzy values, each of which can be a further vector, handle complex structured data. This will widen the application of fuzzy theory to many areas where objects are complex and sometimes interdependent features are to be classified and similarities / dissimilarities evaluated. Often, human experts can and must make decisions based on comparisons of cases with different numbers of data components, with even some components missing. Fuzzy signature is created with this objective in mind. This tree structure is a generalization of fuzzy sets and vector valued fuzzy sets in a way modeling the human approach to complex problems.

The cooperating robot systems belong to the most complicated control problems, where are high-scale information and many ambiguity in observations. The effective communication is one of the most important parts in such a system. Sometimes the explicit communication line is weak, failed or simple does not exist, i.e. in case of man – robot cooperation. We are investigating such cooperation problems where are not any explicit communication channel between the participants thus there are very weak common communication opportunities.

In this paper we propose a strategy of context understanding on Fuzzy Communication base and information extraction based on an original data structure named the fuzzy signature and on a priori knowledge data base, named the robot codebook. By context we understand the goal of robot activity which involves cooperation, the state of the environment where the cooperation takes place and the task involved in the goal realization.

Finally a possible cooperative robot application on a realistic example with missing data components will be shown. The base idea of this example has come from the partly unpublished research projects at LIFE [1].

The paper presents a loose cooperation system where a group of autonomous intelligent mobile robots is supposed to solve transportation problems according to the exact instruction given to the Robot Foreman (RF). The other robots have no direct communication links with RF and all others, but can solve the task by intention guessing from the actual movements and positions of other robots, even though they might not be unambiguous.

The loos cooperation means the participants are not in a deterministic hierarchy and can work alone, but if need build up a loos hierarchical cooperating structure.

2 Fuzzy signatures

The original definition of fuzzy sets was $A: X \to [0,1]$, and was soon extended to *L-fuzzy sets* by Goguen [2]

$A_L: X \to L$, L being an arbitrary algebraic lattice. A practical special case, *Vector Valued Fuzzy Sets* was introduced by Kóczy [3], where $A_{V,k}: X \to [0,1]^k$, and the range of membership values was the lattice of k-dimensional vectors with components in the unit interval. A further generalization of this concept is the introduction of fuzzy signature and signature sets, where each vector component is possibly another nested vector (right).

Fuzzy signature can be considered as special multidimensional fuzzy data. Some of the dimensions are interrelated in the sense that they form sub-group of variables, which jointly determine some feature on higher level [4, 5]. Let us consider an example. Fig. 1 shows a fuzzy signature structure.

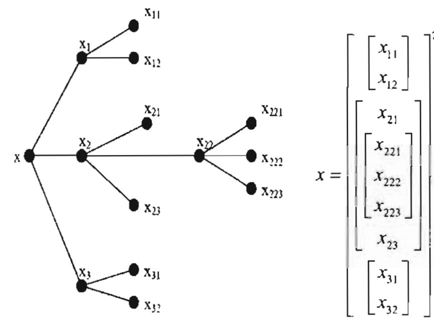


Fig. 1. A Fuzzy Signature Structure

Here $[x_{11}\ x_{12}]$ from a sub-group that corresponds to a higher level compound variable of x_1. $[x_{221}\ x_{222}\ x_{223}]$ will then combine together to form x_{22} and $[x_{21}\ [x_{221}\ x_{222}\ x_{223}]\ x_{23}]$ is equivalent on higher level with $[x_{21}\ x_{22}\ x_{23}] = x_2$. Finally, the fuzzy signature structure will become $x = [x_{221}\ x_{222}\ x_{223}]$ in the example.

The relationship between higher and lower level is govern by the set of fuzzy aggregations. The results of the parent signature at each level are computed from their branches with appropriate aggregation of their child signature.

Let a_1 be the aggregating associating x_{11} and x_{12} used to derive x_1, thus $x_1 = x_{11} a_1 x_{12}$.

By referring to Fig. 1, the aggregations for the whole signature structure would be a_1, a_2, a_{22} and a_3. The aggregations a_1, a_2, a_{22} and a_3 are not necessarily identical or different. The simplest case for a_{22} might be the min operation, the most well known t-norm.

3 Fuzzy communication

There are orthogonally contradicting interpretations of the idea of Fuzzy Communication. In [6] a scenario is described where the lack of precise and sufficient information in a business environment leads to employees creating their own fictive scenarios where they fill the information vacuum with conjecture and wrong assumptions, which eventually leads to catastrophic results. Another kind of scenario is taken from the Laboratory for International Fuzzy Engineering Research (Yokohama) that operated between 1989 and 1995 as the spiritual center of applied fuzzy research in Japan [1]. This latter gives a positive example for using fuzzy elements for compressed and effective communication between humans.

Fuzzy communication contains vague or imprecise components and it might lack abundant information. If two robots are communicating by a fuzzy channel, it is necessary that both ends possess an identical part within the codebook. The codebook might partly consist of common knowledge but it usually requires a context dependent part that is learned by communicating. Possibly it is continuously adapting to the input information. If such a codebook is not available or it contains too imprecise information, the information to be transmitted might be too much distorted and might lead to misunderstanding, misinterpretation and serious damage. If however the quality of the available codebook is satisfactory, the communication will be efficient i.e. the original contents of the message can be reconstructed. At the same time it is cost effective, as fuzzy communication is compressed as compared to traditional communication.

4 Cooperating robot group

We built up a simulation system for investigation of many aspects of robot – robot and man – robot cooperation problem. Our simulated experimental environment is an arena where n square boxes wait for arrangement in a given structure (Fig.2). We have m similar autonomous mobile robots which are supposed to build the actual configuration according to the exact instruction given to only the human operator who telemanipulates one robot namely the "foreman or telemanipulated robot" (R0). The other robots have no direct or explicit communication links with R0 and each others, but they are able to observe the behavior of R0 and all others. Each robot possesses the same codebook containing all possible box configurations.

The individual boxes can be shifted or rotated, but always two robots are needed for actually moving a box, as they are heavy. If two robots are pushing the box in parallel the box will be shifted according the joint forces of the robots. If the two robots are pushing in opposite directions positioned at the diagonally opposite ends, the box will turn around the center of gravity. If two robots are pushing in parallel, and one is pushing in the opposite direction, the box will not move or rotate, just like when only a single robot pushes.

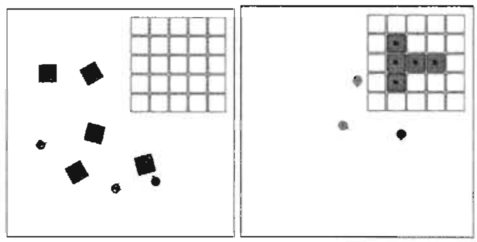


Fig.2. Starting and finishing state of an arrangement task

Under these conditions the task can be solved, if all robots are provided with suitable algorithms that enable intention guessing from the actual movements and positions, even though they might be unambiguous.

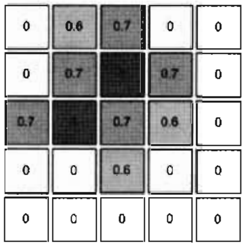
In the actual scenario are five boxes and a telemanipulated robot (R0) and two autonomous assistant robots (R1) and (R2) in the arena and only "T-shape" configuration is enabled in any direction.

5 The settling-map

The settling-map is a lattice with fuzzy data in each node where each position depicts a fuzzy box-settling plausibility value in [0, 1]. These nodes are as long and wide as a box so each of them is a possible position of a box. The measure of the settling-map is equal to the area of the working arena.

Each robot has the own settling-map which works as a trigger for action and behavior selection. This settling-map is formed dynamically based on the a priori knowledge and actual observation of the state of the workplace. The detailed information of working of the settling-map algorithm is too complex to write down in this paper.

The Fig.3 shows a common settling-map in our robot controller.



$PV = 0 \rightarrow$ "A box in this position is not to be suffered"

$\vdots$

$PV = 0.5 \rightarrow$ "A box in this position is not my bussines"

$\vdots$

$PV = 1 \rightarrow$ "A box in this position is a prime necessity"

Fig.3. The settling-map

6 Conclusion

Fuzzy communication contains vague or imprecise components and it might lack of abundant information. If two entities (man or/and machine) are communicating by a fuzzy channel, it is necessary that both ends possess the same codebook. The codebook might partly consist of common knowledge but it usually requires a context dependent part that is either learned by the communicating entity or defined by expert knowledge. Possibly it is continuously adapting to the input information.

If the quality of the available codebook is satisfactory, the communication will be efficient i.e., the original contents of the message can be reconstructed. At the same time it is cost effective, as fuzzy communication is compressed as compared to traditional "abundant communication". This advantage can be deployed in many areas of engineering, especially where the use of the communication channel is expensive in some sense, or where there is no proper communication channel available at all.

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