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A multi-robot path planner for a disabled person assistance system: a framework

Gilbert Pradel Francois Saïdi[1]

Abstract –This work aims at modelling a system which allows a user and more particularly a disabled person, to give a mission to a team of robots and to determine the whole process leading to its execution. This paper proposes a participative model to set up this system. We separate the actor: active element subjected to the stimulus (the user and its request, for example), the objective form: object designed in the mind of the actor, the object: element satisfying and corresponding to the satisfaction of the stimulus. In agreement with this model, the system is based on a several levels diagram for a design directed towards a multi-agents system. In this paper, we mainly describe the four stages of the mechanism which lead to the trajectory determination of the robots group. These steps use a Voronoï's generalized graph and a wave front algorithm. The computation of the configuration space for a robot group and an adaptation of the group trajectory allow the group to be formed and reach the final position.

Keywords: multi-robot, cooperation, disabled person, path planner.

I. INTRODUCTION

Many applications such as space and underwater exploration, operations in dangerous environment, service robotics, military applications, etc. can call upon multi-robot systems. These systems, although far from achievement, can carry out difficult or even tasks impossible to achieve by a single robot. A team of robots provides a certain redundancy, contributes to the achievement of a task in a collaborative way and should be able to go beyond what could be done by a single robot. We will try to draw up a general state of the work in the restricted field of mobile robotics implementing one or more robots for the assistance to dependent people.

According to Parker [Parker2000] and Arai [Arai and al.2002], works can be classified in three categories:

- Reconfigurable robots systems also called "Cellular Robots Systems". A cellular robot is an auto-organized robot-like system composed of a large number of units called cells. This idea is inspired by the organization of a living system. Various fields were studied in this domain: swarm's intelligence [Bonabeau and Theraulaz2000],"cyclic swarms" [Beni and Hackwood1992], CEBOT system [Fukuda and Nakagawa1987].
- Trajectory planning in the multi-robot system field: control of the air traffic [Premvuti and Yuta1989], movement of groups of robots in formation [Arai and al.1989][Wang1989].
- Architectures for multi-robot co-operation: ACTRESS [Asama and al.1989][Sellem and Dalgalarrondo1999] resolves conflicts between robots and allocates tasks by creating staffs of robots.

[Balch and Parker2002][Schultz and Parker2002][Parker and al.2002] define 7 directions of study in multi-robot systems:

- biologically inspired systems,
- systems which study the communications,
- systems which are interested in architectures, tasks allocation and control,
- systems directed towards localization, mapping and exploration,
- systems for objects transport and handling,
- systems for displacements coordination,
- systems dealing with the design of reconfigurable robots.

Section II makes a non exhaustive synthesis of works in the multi-robot field. Section II-F presents projects in connection with the assistance for handicapped or disabled people.

In agreement with the studies on the assistance devices for handicapped people, the user must be able to take part in the control of the system, its management and in certain cases to take part in its design. Moreover, the user wishes to have permanently information on the evolution of the tasks or missions given to the system. These characteristics lead us to consider the system design as a participative system.

These participative aspects will involve:

- the Human-System interface (HSI),

[1] Laboratoire Systèmes Complexes, Université d'Evry Val d'Essonne CNRS FRE 2494
40, rue du Pelvoux, CE 1455 Courcouronnes, 91020 Evry cedex FRANCE
Email: gpradel@lsc.univ-evry.fr saidi@lsc.univ-evry.fr

- the request input seen as a set of remote services carried out either in individual or collective way by the robots.
- user intervention in the construction of the request solution,
- a way to act directly on the robots or on the mission scene in the event of modification, breakdown or execution failure,
- an always available information on the system state.

The system design will call upon several levels of abstraction [Arkin and al.1999], levels discussed in the following sections. We will be successively interested:

- by the general model of design in the section III-A,
- by the inference engine (section III-B) and with the choice of the robots,
- by the determination of the robot's group path (section III-D).

II. MOBILE COLLECTIVE ROBOTICS

A. *Biologically inspired systems*

Most of multi-robot systems of biological inspiration follow upon works [Brooks1986]. The "behaviour-based" paradigm (behavioural robotics) that he introduced has a biological source. [Drogoul and Ferber1993] were interested in modelling insects or animals societies (ants, bees, birds, fish...) and reproduced successfully their behaviours by observing simple local rules. [Goldberg and Mataric1999] show the possibility for multi-robot systems to carry out the collective behaviours. The Animatlab approach conceives simulated or real artificial systems named "animats" whose behaviours exhibit some animal characteristics [Ani2002].
These studies gathered in a rather general class called systems using a swarm type co-operation in opposition to another class gathering the systems in which communications are intentional, have a common point which is not to be subjected to severe temporal constraints.
Experiments using the dog Aibo from Sony on the locomotion mechanism show that the walking command system obtained were more powerful than the one programmed by the engineers, and made the dog walk faster.
Other experiments implementing a co evolution between species were carried out by [Floreano and al.1998][Funes and al.1998]. Limits of the approach are underlined in [Meyer and Guillot2001] who quotes the attempt to evolving the nervous system of Robokoneko (an artificial cat).

B. *Systems dealing with the communications*

Communications between the various entities of a multi-robot system are a crucial point. Explicit communication is a relational operation between an entity and one or more others. In implicit communication ("through the world") an entity broadcasts a message which will be received by all others entities.
The problems involved in the user-system communication part are tackled in [Jones and Rock2002] and applied to the use of robots team in the space construction industry. The user dialogues with a community of agents through a series of implicit and explicit questions. The operator plays a significant role in the stock management and the scheduling of the robots tasks. Authors underline the difficulties to:

- establish the structure and the range of the dialogue,
- create an infrastructure which allows for the system/robots to conduct a dialogue with the user,
- determine the methods which can take into account the subjacent social aspect in this kind of dialogue,
- develop an interface which allows the user to dialogue with the system.

In [Fong and al.2001], authors recommend adapting the autonomy and the human-system interaction to the situation and to the user. According to these authors, part of the decision making process, which is most of the time not structured, must remain in the human's domain, in particular because the robots remain very limited for the high level perceptive functions. Their approach tends to treat the robot not like a tool but like a partner.

C. *Systems directed towards architectures design, tasks allocation and control*

Problems tackled in these systems are: tasks allocation, tasks planning, communication system design, homogeneity or heterogeneity of the robots, delegation of authority, global coherence and local actions... In [Iocchi and al.2001], multi-robots systems are initially shown like a particular case of multi-agents systems with specific constraints due to the immersion of the agents in a real environment.
[Rybski and al.2002] presents a software architecture intended for the control of a team of miniature robots. The used algorithm tries to dynamically allocate the resources to the robots according to their needs and to the evolution of the tasks they are carrying out. Tasks allocation is also discussed in [Mataric and al.2002] [Gerkey and Mataric2003] who present a strategy for tasks allocation by using a form of negotiation to optimize the use of the robot's resources.
The multi-robot architecture ALLIANCE [Parker1998] takes into account the faults tolerance aspect and the breakdowns for the tasks allocation. This system applies the problems studied in distributed artificial intelligence to collective mobile robotics:

- the formulation, the description, the decomposition and the problems allocation among a group of intelligent agents,
- the communication and the interaction between these agents,
- the coherence in the actions of the agents,
- the detection and the resolution of the conflicts.

D. Systems dedicated to localization, cartography, exploration, transport and handling of objects

[Burgard and al.2000] consider the problem of the collaborative exploration of an unknown environment by a team of robots. The main challenge is to coordinate the robots actions in order not to explore the environment while following the same way. The LOST system (LOcalisation-Space Trails for robot teams) [Vaughan and al.2002] uses trails of landmarks to navigate between various points of interest, in the same way pheromones trails are used by the ants. [Yamashita and al.2003] propose a method for movement planning of a robots team for the collective transport of an object in a 3D environment. This task raises various problems such as obstacles avoidance and the stability of the transported object.

E. Systems for displacements coordination

In the field of displacements coordination of the various robots inside a formation, the main directions of study are the trajectories planning, the generation and the keeping of the formation as well as the traffic control such as they are defined in [Yu and al.1995]. The system MAPS [Tews and Wyeth2002] is interested in multi-agents planning by generating an abstract representation of the robot environment seen from each robots point of view and is used for soccer player robots.
[Das and al.2002] describe a framework for the co-operative control of a robots group. Simple controllers and estimators are used to build complex systems applied to the co-operative handling and object transportation by a semi-rigid formation.
[Tan and Xi2004] presents a distributed algorithm for the co-operation and the redeployment of a network of sensors embarked on mobile robots. This model allows a formal analysis of faults tolerant space-time fusion of information from the sensors, allowing the deployment of the robots in the environment. The system reconfigures itself to cover the most possible space.
[Spears and al.2004] introduces an interesting concept entitled "physicomimetics" which proposes a decentralized control method for several mobile physical agents. The agents are subjected to virtual forces and react to them. The robots are seen as particles subjected to gravitational and repulsive attractions. This article shows how one can organize the robots on a lattice without expensive calculations. It also shows how this technique can be used for the obstacles avoidance by modification of the formation.

F. Field of assistance supply for dependent people

If the field of assistance supply to dependent people using mobile robotics, one realizes that in many applications, this help is considered by a better ergonomics of the robot and a thorough instrumentation of the robot (the robot can be, for example, the armchair of the handicapped). Without being exhaustive, one can mention the works of the French multidisciplinary national group for the assistance to handicapped people (IFRATH) in which various problems on the man-machine co-operation and the co-operation between robots were studied.
In ARPH project [Colle and al.2002] from the LSC Complex System Laboratory in Evry France), the mobile robot equipped with an arm manipulator is intended to bring an assistance to the handicapped person. This system must help the handicapped person to carry out by his own some functions of the everyday life: to seize, collect, carry and move. To achieve a task, the person cooperates with the assistance system, each one bringing her own competences and capacities. This collaboration has as main benefit the limitation of the system complexity and therefore its cost. The system does not make "instead of" but implies the person at various degree in the realization of the required service.
Other projects are carried out in this direction as well in France as in Europe. The laboratory of Automatics and the Automated Systems (LASC) in Nancy France develops a prototype of armchair called VAHM mainly intended to help of the handicapped people for whom it is difficult, or even impossible to control a conventional armchair [Bourhis and al.2001]. On a conventional electric armchair were added the necessary sensors for the navigation and the obstacles avoidance process.
Projects proposing the implementation of a team of robots for people's assistance are to our knowledge very few.
The interest of this approach stays in its multi-domain aspect. Among them, one will point out:
- the interaction between the user and the system,
- the study of the groups creation,
- the use of automation such as it can be made by a human.

Other works, without having for goal the assistance of handicapped people, are interested in the aspects bound to:
- the way in which a user can do a request to the system,
- a development environment of low-level behaviours in a multi-robot system,
- a system assigning tasks among a set of autonomous robots,
- the interaction between a user and a multi-robot system.

[Arkin and al.1999] are interested in a military oriented application in which the user, in that case the soldier, specifies a mission in a high-level language. This mission is then compiled through series of languages to output a program executable by a particular robot.
The RAVE [Dixon and al.1999] project is interested in a real and virtual environment for an autonomous multi-robot system. This environment simplifies the development of the low-level collective behaviours. ROBODIS [Surmann and Theissinger1999] provides an example of decentralized system using internet network to connect various software and hardware elements.
The MokSAF system [Payne and al.2000] proposes a multi-agents architecture which introduces three categories of agents. The "providers" agents have a certain know-how and competences. The "service requesters" agents have a set of preferences on the demands that they can address to the "providers" agents. The latter "pass an announcement" to propose their services.
We propose in the following section a design framework for a multi-robot path planner.

III. PARTICIPATIVE MULTI-ROBOTS ASSISTANCE SYSTEM

The main objective of this work is to model a system allowing a user and more particularly a disabled person, to give a mission to a team of robots and to determine the whole process leading to its execution.
The modelling takes into account the various levels presented in the section III-A. This work, in order to be realizable, has some limits and constraints:

- Experiments take place on a group of 5 compact, low cost, heterogeneous robots embarking only the minimum processing power and a fixed part managing the heavy computation and the information storage.
- The environment in which move and operate the mobile robots is an indoor structured environment. Moreover the system has a model of the environment, i.e. a map of the places including all the obstacles and objects the robot will interact with.
- The user is part of the system; he may, to various degrees, intervene on it, accept or reject its decisions.

The user has at his disposal:

- the knowledge of the apartment, robots and an external view of their possibilities,
- a report on the state of the system,
- a number of displacement and domestic missions:
  - go to, go towards, return, stop, take, put,
  - gather,
  - bring closer, move away,
  - move an object by pushing it or by pulling it,
  - move an object by collecting it.

A. *General model*

The participative model of this system is given in figure 1. We consider, in this diagram:

- the actor: active element submitted to the stimulus (the user and his request, for example),
- the objective form: object conceived (in the actor's mind, if this one is human, it can be described as a program if the actor is a compiler),
- the object: final state, element satisfying and corresponding to the stimulus (it can be a process whose execution will carry out the stimulus).

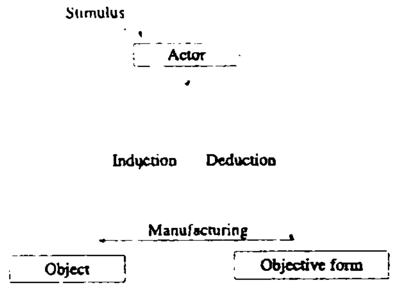

Fig. 1. Modelling of the step

The deduction transition is called upon a a priori knowledge represented as rules. The manufacturing transition transforms the objective form in its material form: the object. This model can be used at any level from the request level to the execution level.
The system design calls upon several levels of abstraction. The service required by the user will have to be analyzed to decide which resources are necessary and a complete script of the scenario must be built. Then the script will be submitted to the user and accepted or not (induction transition: participative model). These levels are found in [Arkin and al.1999].
Our approach is presented on the figure 2. The first objective form required is the expression of the request. The language which seems both the simplest and the most convivial to represent the proposal for a mission to the user is a form close to the natural language: "the robot Robot_Name do Action_Name". The object deducted is the choice of the robots likely to act on the concerned objects and on their respective missions. Among the constraints to be taken into account are the current situation, the availability, the type of robots (e.g. a robot equipped with an arm or a carrier robot).

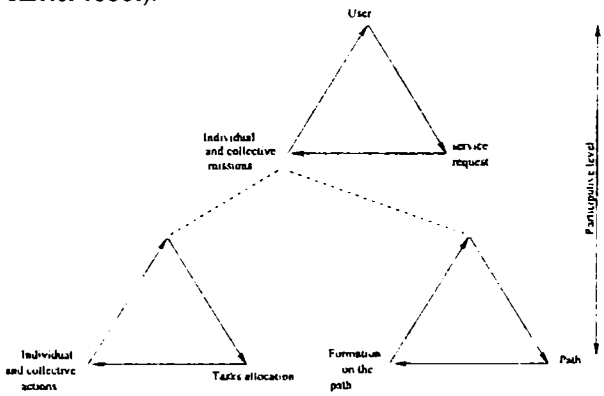

Fig. 2. Modeling of the approach

The second level will set up the routes in the environment and will infer from them the formations that the team of robots will adopt. Manufacturing associated to this level should determine the key points (by using for example generalized Voronoï graph). The collective behaviours defined in [Goldberg and Mataric1999] are directly associated to the various parts of the road to follow.

This second level deals also with tasks allocations. The manufactured object must represent the collective and individual tasks which are assigned to the robots at the beginning of the mission, without prejudging if this distribution will be or not modified during the execution. We implemented this model in simulation within the existing multi-robots demonstrator ARMAGRA in the LSC. We present in the following sections this implementation in the case of the path planning.

B. *The inference engine*

The first objective form is obtained by using an inference engine with a set of rules. Our work is based on [Fong and al.2001] [Abella and Gorin1999] for the input of the mission by the user and the human-machine interaction study. The representation of knowledge takes the declarative shape of Jones in [Jones and Rock2002] and uses CLIPS [Aldridge and al.2002] inference engine.

The formulation of the requests in an imperative form Subject-Verb-Complement was implemented for a set of simple missions. The input of the requests is done by the mean of a graphical interface (figure 3) as suggested in [Jones and Rock2002]. The main elements that the rules must check are:

- the availability of the robots,
- the proximity of the robots to the place where the action
- must take place,
- the competences of the robots, in particular in term of sensors/actuators,
- the semantic consistency (e.g. one cannot transport certain type of objects).

The user can be more or less precise in the formulation of the mission, nevertheless some information are mandatory.

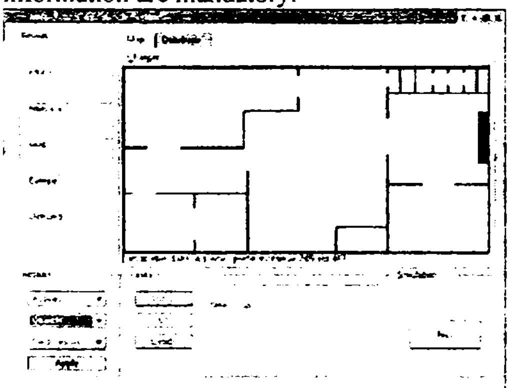

Fig. 3 User's interface

Table I shows the link between the selected action and the type of argument required: any missing mandatory argument produces an error, which leads to a message signalling the missing argument and asking the user to be more precise. Some actions such as PUT (table II) are more particular and need a group of specific rules: the user can specify either the robot that transports or the carried object. Another rule set allows the system to determine the number and the features of the robots for the achievement of the task.

Table 1

Action	Goto	Gather	Take	Search
Optional Arguments	Robots_list	Robots_list area	Robot	Robots_list area
Mandatory Arguments	area		transportable object	object

Table 2

Put	Optional Argument	Mandatory Argument
case 1	robot	carried object
case 2	carried object	robot

C. *The robots choice*

Each robot has a usage score, calculated according to its functionalities. When the user does not specify the robots having to take part in a task, the system chooses the lowest scored robot capable of achieving the task. Two modes can be activated in CLIPS.

- **the parallel mode:**

The system optimizes the parallel execution of the robots' tasks. If the user doesn't specify any robot for the first task of a mission, the system will choose for him a robot with the minimum of functionalities in agreement with the task it must carry on. For each following task, the system tries to choose a different robot while satisfying the constraints of "minimum expertises". This process goes on until there are no robots left. Then, in the following tasks, the system chooses the robots that have not been selected for a long time. This is done to help the decoupling of the tasks in order to increase parallelism during the execution.

- **the sequential mode:**

In this mode, the system tries to help the user to construct a mission step by step. In contrast to the parallel mode, the system always tries to assign the tasks to the same robot. This is done in order to allow the user to build an elaborated mission. At the current state of the project, the system cannot change the robots assigned to the previous tasks. This feature can be useful when the user inserts at stage N an action which cannot be achieved by the robot selected automatically for the N-1 previous tasks. In the future, the influence of a task on the choice of the robot involved in the preceding tasks will be considered. Lastly, it is planned that the system can switch from one mode to another during the edition of a mission in order to benefit from the two modes according to the context. Figure 4 shows an example of rules used for a simple mission.

In the following section, we present the path planner for group navigation.

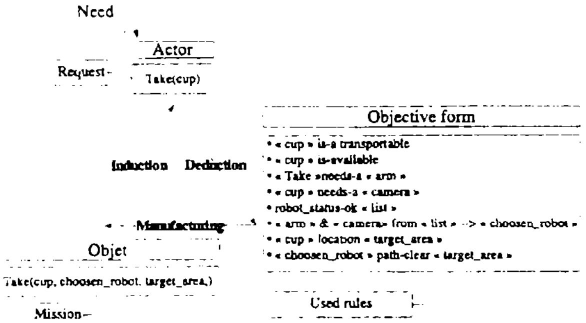

Fig 4 Exemple of operation

D. The robot group's path computation

In this section are described the results obtained on the robot group's path computation. The tests are carried out in a realistic indoor type environment (figure 5). The 2D configurations space of a single cylindrical robot is first computed.

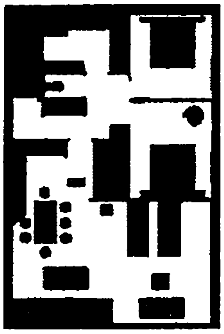

Fig 5 Realistic indoor type environment for the robot

Fig 6 Generalized Voronoi's Graph of the environment

The generalized Voronoï graph (GVG) in the configurations space (figure 6) is transformed into a network, in which nodes represents the junction points of the GVG (figures 7 and 8). This network is common to all the robots and shows all the possible trajectories for a single robot without taking into account the formation which the robots group will have to take.

Fig 7 The GVG overlaying the wave front map

Fig. 8. The path network

For each robot a trajectory is calculated from the robot current position to the GVG. A path on the network to reach the target is computed. The navigation on the network is done using the wave front map which tells what direction the robot must take to reach the target (figure 8). The merging of the various robots individual path, allow us to find the meetings points as well as the trajectories parts along which the robots travel in group. On each segment defined previously, the system selects which formation the robots group will adopt. This choice is done according to several criteria:

- the number of robots
- the user's choice
- the decision system's choice

The following stage consists in generating the 3D configurations space for a group of robot in formation for each segment of the trajectory obtained previously (robot formations has some axes of symmetry which reduces the problem complexity).

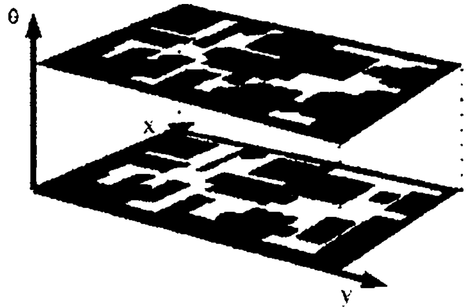

Fig. 9. The configurations space for a group of robots in formation

Each trajectory segment is then differenciated in order to calculate the speed vector direction at any point of the path. This per ti n ... d ll w t p iti n th t p th in the configuration space of the associated formation. However each trajectory segment is only valid for a single robot and probably includes some clashes with obstacles when used for a robots group. Each trajectory segment must be adjusted to allow a group navigation:

- step 1 : checking the connexity of the two ends of the trajectory segment,
- step 2 : tuning the trajectory in order to avoid obstacles.

A wave front algorithm checks the existence of a path between the two ends of the trajectory. The wave front algorithm was modified in order not to increment the distance during the diffusion along the dimension (θ dimension stand for the rotation of the formation)

When the connexity of the two ends is established in the configurations space of the formation (this only means that a clear path between the two end of the trajectory exists), it is still necessary to check the absence of collisions between the trajectory curve and the C-obstacles (C-osbstacles: configurations in which the formation collides an obstacle). For each collision zone, the trajectory is locally tuned in order to satisfy to the constraints. Tuning consists in a deformation of the original trajectory by selecting a clear path between the point preceding the clash with the obstacle and the point following that same clash. This method ensures the least deformation between the original trajectory and the new one. This deformation according to the three dimensions of the C-space corresponds to translations and rotations of the formation in the Euclidean space. At the end of these stages we obtain a succession of segments of individual and collective trajectories (figure 10).

However several points remain to be studied:

- the creation of the initial formation,

- the merging between a robot and an already existing formation,
- the optimization of the possible gathering zone. If, for example, two assemblage points corresponding to two robots are very close, it is more advantageous to merge them and to create directly the final formation rather than to create an initial formation before incorporating a new robot, leading to an expensive modification of the formation of the group.

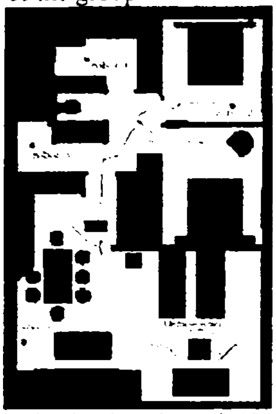

Fig. 10. Final result showing the individual and collective trajectories and the gathering points

IV. CONCLUSION AND PROSPECTS

In this work, we present a framework for a multi-robots path planner for group navigation. This framework allows a person and more particularly a disabled person to give a mission to a robot group, and to determine the whole process leading to its execution.

According to some hypotheses among which:

- the indoor structured environment is knows,
- the small number of robots,
- the cost which influences the system's architecture,
- the user may interfere with the system decision's,

The user can request some displacement missions the system is able to accomplish. We mainly insist on the system's participative aspect in order to be accepted by the user in spite of his limitations, this participative aspect implies:

- a human-system interface taking care of the communication in a friendly, click and drag, icon based, high-level language,
- the expression of the request is proposed as a set of remote services carried out by a reduced number of robots,
- the possibility of intervening in the construction of the solution to the request,
- a way to act directly on the robots and on the mission scene in the event of modification, breakdown or execution failure,
- an information on the system state is always available.

The system modelling is based on a several levels diagram for a design directed towards a multi-agents system. In this paper, we mainly describe the mechanism which leads to the trajectory determination of the robots group. This determination is done in four stages:

- computation of the generalized Voronoï graph in the configurations space of a single robot,
- selection on this graph of the path for each robot,
- determination of regrouping points, choice and validation of the formation,
- deformation of the formation's trajectory in order to avoid the obstacles.

At the end of this process, the trajectory is presented to the user. If the latter is validated, it will then be carried out. The following stage of our work is the execution of this trajectory by the real robots [Pradel and Comfaits2002]. In parallel, the tasks allocation concerning the actions that the robots must carry out at the end of their displacement must be done based on the work described in the section II-C.

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