PERFECT: PErformant and Robust read-to-fly FlEet ConfiguraTion: from Robot to Mission Plan*

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Abstract
With the increasing autonomy of aerial, ground and underwater robots, fleets of robots are now being used for many types of missions, such as exploration, rescue, disaster relief or civil and military security. Some of these applications require fleets of heterogeneous robots, i.e., with different capabilities, different means of mobility and different equipment, which may or may not be coordinated autonomously to carry out the missions for which the fleet is dedicated. The problem of multi-level configuration of a fleet of heterogeneous robots and the scientific issues raised by such a problem are explored in this short article.

Keywords
Configuration, Multi-agent Systems, Operational Research, Performance, Robustness

1. Introduction

We present here a prospective application of configuration to a heterogeneous robot fleet (or swarm). This very problem has been the subject of a joint project between ONERA Toulouse France and ISAE SUPAERO France.

The structure of the article is as follows. The context of our study topic is presented in Section 2. Then, because multi-level configuration is a complex and quiet new field, some open research questions are presented in Section 3.

2. Background and Research Statement

With the increasing autonomy of aerial, ground and underwater robots, fleets of robots are now being used for many types of missions. Examples include package delivery, flying taxis, field exploration, rescue and disaster relief. More and more applications require fleets of heterogeneous robots, e.g., with different capabilities such as *detect*, *communicate*, *observe*, *move*, etc. For example, an exploration mission may require the collaboration of ground robots with at least the ability to *move* and *communicate*, and aerial robots with at least the ability to *observe* and *communicate*. The success of a multi-robot mission depends, among other things, on the configuration of the fleet carrying out the mission [1].

This article examines the problem of multi-level configuration of robot fleets. By multi-level configuration, we mean the simultaneous configuration of each robot (first layer) and the robot fleet itself (second layer) in order to perform the dedicated missions in a high-performance and robust manner (third layer). That multi-level configuration problem requires an analysis of the relationships between these three levels of configuration, both upstream in fleet composition and downstream in fleet operation.

By *configuration*, we mean:

1. for each *robot*: the selection of its equipment and capabilities,
2. for the robot *fleet*: its composition, i.e., the number and type of each robot, and its layout. By layout, we mean the architecture of the swarm: cloud, diamond, rung refused, etc.
3. and for the *missions*: the set of missions that the robot fleet can perform by its reconfiguration.

This multi-level configuration problem raises numerous research issues, such as (1) the representation/modelling of the configuration knowledge (compact modelling language), (2) the elicitation of constraints (what is allowed or forbidden) and criteria (what is preferred) that apply both to the fleet configuration and to each robot in it, and (3) the development of algorithms to generate optimal or at least good quality solutions.

It is generally expected that a robot fleet performs well and is robust during the mission execution. For example,

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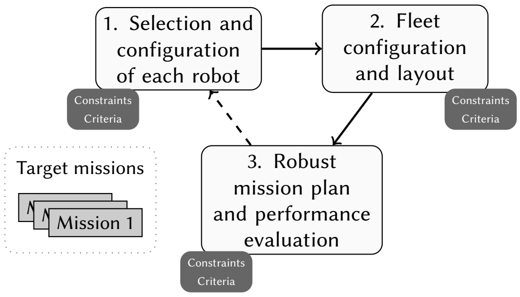

Figure 1: Multi-level configuration problem steps

for a parcel delivery mission, the performance of the fleet can be defined by the time required to complete all deliveries, and its robustness can be defined by the ability of the fleet to complete the mission despite the failure of one or more robots, with the least loss of performance. Assessing the performance and/or robustness of a fleet for a given configuration generally involves generating one or more mission plans for the fleet and then analysing the metrics associated with these plans. The generation of such plans is a combinatorial problem by itself.

Here a mission plan consists in the allocation of the different mission tasks to the robots and their scheduling, meeting the constraints (time, resource availability, etc.) and optimising the performance and/or robustness criteria (mission duration, minimisation of resources used, contingency management, etc.). For example, determining the minimum time required to deliver parcels using a given number of robots whose capacities are fixed *a priori* is a hard problem (NP-complete problem of vehicle rounds [2])). Similarly, planning problems with the presence of uncertainty constitute a vast subject of research ([3, 4]).

In practice, the performance and robustness of a fleet for its mission is often approximated at the time of configuration. It is only after the fleet is configured that a powerful, robust plan for the mission is generated, allowing performance and robustness to be assessed in detail. However, this sequential aspect can lead to sub-optimal solutions. As illustrated in Fig. 1, the performance and robustness analysis can lead to a modification of some robot configuration, which implies going through a whole new configuration cycle. In the general case, there can be numerous iterations before reaching satisfactory results for each configuration level. For example, an undersized or poorly configured fleet can have a significant impact on mission performance or even cause a mission to fail. On the other hand, some missions may require specific fleet configurations and/or specific robot configurations to meet performance objectives. For instance, a rescue mission may require specific communication capabilities for certain robots acting as routers. Note that some research deals simultaneously with the configuration of a fleet and its optimal planning ([5, 6, 7, 8]). However, the associated configuration problem is weakly combinatorial in the sense that it is possible to enumerate all configurations at the time of mission planning.

In this work, we aim to address the performance and robustness constraints and criteria right from the fleet configuration phase, in cases where the configuration is complex. More specifically, given one or more mission types for the fleet with target performance and robustness and associated robot capabilities, a set of possible equipment with their compatibility constraints and the relationships between equipment and robot capabilities, we aim to define the number of robots that make up the fleet and the configuration of each robot so as to achieve the desired performance and robustness targets. The problem then consists in exploring the space of configurations, guided by the performance and robustness evaluation.

This problem can be approached in several ways. First, there is the question of how to express knowledge, constraints and preferences, both from the point of view of fleet configuration and from the point of view of performance and robustness in the context of the [9] mission. Approaches such as constraint programming and multi-agent modelling [10] can be used. Appropriate solution strategies must then be developed. One possible approach would be to take inspiration from bi-level optimisation ([11, 12, 13]) and define one level dedicated to configuration and another to performance or robustness evaluation. The challenge is then to allow the levels to interact and guide each other towards optimal solutions. Several algorithmic approaches can be used: constraint programming, local search, metaheuristics and possible coupling with learning-based strategies. The approaches developed in the project will be validated by experiments on multi-robot problems that are representative of the applications dealt with at ONERA.

3. Research Questions

In order to address the multi-level configuration problem described above, three main scientific questions arise:

- **RQ1: What is the formal modelling of this multi-robot fleet configuration problem?** More specifically, the knowledge base in input to the problem must contain all the knowledge needed to solve the problem. In particular, all the following elements should be formalized:
  - the description of the platforms and the fleet,
  - the constraints and objectives associated with this equipment and the fleet,

  - the capabilities required to solve the mission and the links between equipment and capabilities,
  - definitions of performance and robustness for the mission(s).

  It should be noted that it is also possible to consider the organisational aspects of the fleet in the configuration. For instance, a robot fleet for a field exploration mission could be organized following a centralized or decentralized scheme. In the first case, it means that one robot plays a central role and must therefore have the corresponding capacities such as the ability to communicate with all other robots. In the second case, robots must have their own planning decision module and should therefore be equipped accordingly.
- **QS2: What types of approaches and algorithms are effective in solving the multi-robot fleet configuration problem?** This question can be broken down into a number of sub-problems:
  1. How can configuration and multi-agent system approaches be combined to define the configuration of the multi-robot fleet?
  2. How can robustness and performance indicators be used to guide the configuration of multi-robot fleets?
  3. How can the multi-robot fleet and mission plans be defined simultaneously to quickly converge to a good solution?
  4. How can we integrate the notion of uncertainty into the different levels of decision making and assess its impact on the quality of the proposed solutions?

  These algorithmic strategies may vary depending on whether we are considering a single-criteria or multi-criteria problem, and whether we are searching for optimal or non-optimal solutions. In the case of searching for non-optimal but good quality solutions, there is also the question of the distance to optimality and the calculation of good bounds for evaluating this distance.
- **QS3: How will the proposals be evaluated and validated on realistic case studies?** This will involve not only the implementation of the defined algorithms, but also their evaluation on concrete data sets. Depending on the type of mission under consideration, there will be issues of re-use and adaptation of data sets, or their generation, as well as simulation requirements.

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