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Facilitating Planning by using Self-organization

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***Abstract*—Current approaches to increase autonomy of multi-robot applications are often tailored to particular applications. This specialization is necessary due to specific requirements to the robots' capabilities in dedicated applications or environments. We present an approach to overcome this specialization by separating capabilities from robots and enabling their self-organized reconfiguration at run-time. This reduces the need of re-planning by absorbing uncertainties and at the same time enables to easily use the same robots in different scenarios.**

***Index Terms*—MAS; SAR; Planning; Self-optimization;**

1. Motivation

Mobile multi-robot systems gain increasing attention in research and industry. While applications in the domain of *Search and Rescue (SAR)* have profited from these developments for years (e.g., human-robot-interaction in *alpine SAR* scenarios [1], or *wilderness SAR* [2]), the potential of multi-robot applications now is recognized in many other domains. These include environmental research with unmanned underwater [3], [4] or surface vehicles [5], distributed surveillance of critical infrastructure [6], [7], [8], or dealing with major catastrophes (e.g., chemical accidents) [9], among others. We identified common steps relevant in all of these applications and call them *tasks* of *ScORe missions* [10]. Given, e.g., a chemical accident, the situation has *1)* to be assessed by *searching (S)* for the relevant harmful substance with as much robots equipped with a universal gas sensor as possible. Within a subsequent task, the dissemination of the identified substance has *2)* to be *continuously observed (cO)* by robots equipped with specialized sensors as well as robots capable of estimating local weather conditions. As can be seen, the distribution of capabilities on robots is highly specific to environmental conditions and might change over time. Observations may trigger *3)* appropriate *reactions (Re)*, e.g., the evacuation of inhabited areas, done by robots equipped with appropriate actuators (e.g., sirens) that has to be done in parallel to the *cO* task. In all tasks, robots have to be able to fly. Existing approaches for coordinating and controlling multiple robots in ScORe applications can roughly be divided into two groups. On the one hand, there are the so-called *swarm robotics* approaches [3], [5], [11], where great numbers of homogeneous robots are used to collectively achieve a common goal through emergent, fault-tolerant behavior. Such algorithms are very useful to robustly solve special tasks (i.e., single tasks of ScORe missions), like finding the highest parameter concentration with particle-swarm optimization techniques [12], finding consensus over multiple options [13], [14], clustering [5], or collectively transporting objects [15], [16], among others. But as theses approaches often lack a sophisticated decision logic, their ability to deal with complex tasks is limited [17], as a swarm has no clue what comes next after achieving its current goal. Thus, in the context of ScORe missions, swarm robotic approaches are not capable of autonomously switching from one phase to another, nor to a different ScORe mission. On the other hand, approaches that focus on combining the special abilities of few, heterogeneous robots for reaching a goal are often explicitly designed for a certain application or environment (e.g., searching or retrieving an object in an indoor environment [18], supporting human guided SAR missions in alpine [1] or wilderness [2] environments). While the proposed solutions deliver promising results for their dedicated applications, they lack the flexibility to easily adapt to slightly different scenarios (different ScORe missions), as they are highly specialized towards the use case they have been designed for, with regards to software [18], [19] as well as hardware [15], [20]. This at least is the case when the adapted scenario requires different capabilities from participating robots, e.g., switching from *chemical accident handling* to *environmental monitoring*. Another deficiency current approaches for ScORe missions suffer from is their way of handling uncertainties. These typically occur during execution within a real world environment [21]. Solutions like online re-planning [22] are time-intensive and comprehensive as they require details for multiple agents (e.g., multi-agent planning [23] or [24]).

2. Objectives

We envision an ensemble of cooperative robots consisting of several modular hardware parts, re-combinable at run-time. These will contain actuators like quadrocopters and mobile ground units as well as different sensors. Hardware modules are assumed to be self-aware and easily exchangeable, which will be achieved by an accompanying dissertation. For terms of simplification, we assume to have a reliable WiFi network for communication purposes, e.g., achieved through techniques developed in other projects like [25], [26]. The main objective of this dissertation is to *develop a reference system architecture and distributed algorithms for ScORe applications*. The goal is to enable the dynamical re-configuration of robots' capabilities within

the ensemble in a self-organized fashion by exchangeable, self aware hardware modules. Thereby robust execution of ScORe missions will be enabled, absorbing uncertainties typically occurring in this context (e.g., loss of components, changing ScORe task requirements). This will facilitate the planning process for ScORe missions, where actions of single robots no longer have to be planned in detail, but only actions of the whole ensemble. Planned task only have to guarantee the general feasibility of each planned ScORe task, independent of the concrete assignment of tasks to robots as well as of the concrete assignment of capabilities to robots. Assignments on both levels will be calculated and executed by the ensemble itself in a distributed and self-organized fashion, respecting all low-level constraints concerning the availability of capabilities in certain hardware configurations for each robot. This approach will enable the system to adapt to frequently changing situations that typically occur in ScORe applications (i.e., changing tasks or even changing missions) and separate this problem from the planning problem. By establishing this system architecture, we will overcome the specialization issue of current approaches (cf. Sect. 1). For being able to instruct the ensemble with ScORe missions, a task and capability formalism has to be found. This formalism has to support task decomposition and planning in an abstract manner, regarding only the ensemble as a whole as well as generally available abilities of the ensemble in one of its possible configurations (multi-robot coalitions, single-robot capabilities), respecting user defined time or quality constraints. Ensemble abilities are meant to be self-organization mechanism that can be used to solve ScORe tasks (e.g., **S**earch can be performed with an adapted particle swarm algorithm [12]). Robot abilities result from certain capability configurations and are meant to indicate if a robot is able to participate in such an ensemble mechanism. This approach should ease handling uncertainties in real-world environments that typically increase the complexity of planning.

3. Methodology

To reach the goals described in Sect. 2, we will adopt and extend a broad field of existing technologies and methodologies in an iterative development process. For appropriately realizing the ScORe reference system architecture and for managing the dynamic availability of capabilities at runtime, we plan to build on the multi-agent framework Jadex [27], which offers possibilities for cross-device distribution of algorithms and communication between them. Robots as well as their capabilities and functionalities will be represented by agents within this framework. The architecture of the system will be structured into layers to enable planning of a ScORe mission on ensemble level, and avoid detailed, agent-level planning. Therefore, we plan to adopt existing approaches for multi-robot task definition like [22], [28], [29], [30], enriched with an abstract robot- and ensemble-ability description formalism on the topmost **task layer**. On a second **ensemble algorithm layer**, we plan to integrate self-organization algorithm adaptations, that fit the ScORe phases context, e.g., particle swarm optimization [12] or coverage planning [31] for search, or guided collective movement (boiding/flocking) [32], [33], [34] for navigation, able to solve tasks from the task layer. The required robot behavior for participating in these ensemble layer algorithms is located on a third **agent layer** whose execution may be possible or not, depending on the robots' current capabilities. Capabilities result from the combination of attached hardware modules, their availability is calculated in a fourth **capability layer**. To decide which agents fit best to the requirements of an ScORe task on ensemble layer, we will adopt appropriate distributed task allocation approaches, e.g., market-based task allocation [35]. To resolve situations, where task requirements cannot be met with the current robot/ensemble configuration, we will use distributed constraint optimization technologies [36] to collectively decide which configuration is capable of solving the current task. For our real-world evaluations we will use the RoboticsAPI [37] for concrete hardware control as well as simulation. We see great potential in combining planning with self-organization in the proposed way. Because single agent actions no longer have to be planned explicitly and failure-states can be resolved by re-configuring the system, the need for re-planning is heavily reduced. We will evaluate this thesis by comparing our approach against state of the art multi-agent task planners like [29], [30] to determine the level of complexity each approach is suitable for.

#	Workpackage	Start	End
1	architecture design and implementation	Running	Q4 2019
2	ScORe definition language evaluations	Q1 2018	Q4 2019
3	simple ScORe mission handling	Running	Q1 2018
4	ScORe including reconfigurations	Q2 2018	Q4 2018
5	resource handling MR-MT	Q1 2019	Q4 2019
6	real-world experiment	Q1 2020	Q3 2020

TABLE 1. WORKING PLAN FOR THE NEXT THREE YEARS.

4. Research Plan

We already gained experience in handling ScORe missions [38], [39], robust and distributed multi-agent task allocation [40], developed and evaluated a first version of our proposed architecture [10], [39], and investigated current challenges and perspectives of self-organizing systems [41]. Our architecture will be iteratively improved throughout the dissertation project. Its performance against other solutions will be frequently evaluated in its particular state of extension, starting with *1)* simple ScORe missions without the need of capability re-configurations, continuing with *2)* ScORe missions that need adaptation of the system's configuration normally requiring re-planning, and finaly *3)* extending the capability concept to enable MR-MT [42] handling for ScORe missions. In addition to that, we will evaluate appropriate formalisms for ScORe task definition in each state of the iterative process, which will be done by extending current techniques suitable for our proposed approach. All of our results will be evaluated iteratively in simulation as well as in a real-world scenario, that constitutes a simplified version of the ScORe scenario introduced in Sect. 1 including multiple robots as well as reconfigurable hardware modules. Tab. 1 shows a chronological schedule of packages portioning the proposed workload.

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