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ScienceDirect
IFAC-PapersOnLine 48-2 (2015) 100–106

An Approach for Planning a Safe Mission Begin and End for Teams of Marine Robots

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Abstract: This paper describes an approach for Mission Planning for heterogeneous marine robot teams, with a special emphasis on the ability of the robots to start and end a mission in a quick, but safe manner (safe in terms of collision avoidance). This work was inspired by practical experiences during sea trials, in which the process between the termination of a mission (due to success or failure) and the starting of the next mission after manually sorting the vehicles into an initial formation consumed a lot of valuable time. In general, a mission planning concept is of great importance for robotic teams performing complex missions at high levels of autonomy. The planning concept must be flexible enough to allow for an adaptation of a preplanned mission file to the circumstances just before the mission starts, like vehicle states or whether conditions. In this paper, we will present our concept of robust mission planning for a specific class of missions for marine robots, and how it is embedded into an open source Geographical Information System (GIS). Also, we will present the concept for safe mission begin and end to meet the described requirements and how the concept was realized within our planning software.

Keywords: Marine robotics, Cooperative Robots, Mission Planning, Geographical Information System.

1. INTRODUCTIONIn the current research on marine robotics, the importance of cooperative and coordinated behaviour between single autonomous vehicles is constantly increasing.

The research project MORPH (FP7-ICT-288704), which gave the framework for the work presented in this paper, strives for the development of a novel concept in which several spatially separated single autonomous robot-modules (nodes) are working in close vicinity to create a supra-vehicle with logical links between the single nodes. The nodes can adapt their relative formation to the present requirements in each state of the mission, which leads to the change of the supra vehicle's outer shape (the so called 'Morphing').

This methodology was inspired by the aimed mission scenario in the project which was formulated by marine biologists: They are interested in creating high resolution Digital Terrain Maps of vertical cliff walls. This task cannot be performed autonomously with state-of-the-art technologies. The mission requires the employment of several sensors at different distances from the wall (sonar systems, cameras), the possibility of terrain following in unstructured areas and the ability of the team to approach the wall and adjust the formation, once the wall is detected. Fig. 1 provides an overview. More details can be found in Kalwa *et al.*, 2009.

There are several challenges that need to be addressed, like navigation, control, or communication. Another important issue is the offline planning of the mission. Single vehicle

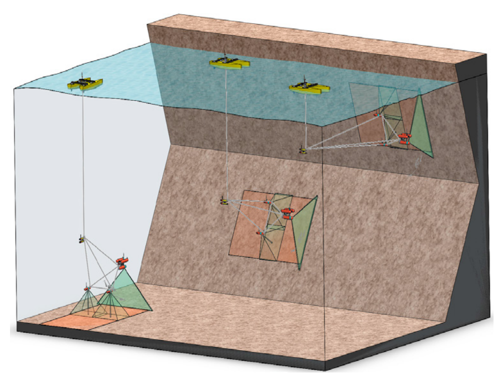

Fig. 1. The MORPH mission scenario

mission plans usually only consist of some geometrical manoeuvres like lines or arcs and are not changed during the mission. If vehicle teams ought to be used, it is important to relieve the operator from planning single paths for each vehicle individually. The operator should only plan the general path for the whole team, while the planning software should provide adequate plans for each individual vehicle. Such a concept was demonstrated in Glotzbach *et al.*, 2007.

Usually, existing planning concepts are based on an a priori known path to be executed by the vehicles. New challenges, like in the described mission scenario of MORPH, require a concept that allows the vehicles to react online both to each other and to the terrain of the mission area. It is reasonable to use existing geographical data of the mission area to execute a preliminary planning of a path to guide the vehicles close to

10.1016/j.ifacol.2015.06.017

the area of interest, like the cliff wall. Then, the vehicles must organize their movement according to online measurements of their sensors, like forward looking sonar or multibeam echosounder. A new planning concept must allow for the classical geometrical planning principle, but also consider the new requirements.

We learnt another important lesson at the various sea trials in the course of the MORPH project, the last one in Horta, island Faial, Azores in September 2014, where we operated the full MORPH supra vehicle with five marine robots at the same time over flat terrain. As those implementation works require a lot of testing and debugging, a great number of missions were started, stopped and restarted during the testing time. There were a total number of five autonomous agents in the water, of which four had to dive and were consequently pulling an umbilical with a buoy on a string behind them for safety reasons. This complicated especially the start and end of a mission tremendously. Before mission start, the vehicles had to be driven to reasonable starting positions manually by the individual operators. After mission termination, the vehicles needed to be moved to safe positions away from each other, while the next mission was planned. This procedure led to waiting periods of up to 45 minutes between two missions, which was considered a waste of the valuable daylight time by the project members. Therefore, a process had to be developed in order to speed up these processes by designing an automated behaviour prior and after a mission.

This paper is structured as follows: In Section 2, we will comment on the general planning concept and software developed in the scope of the MORPH project. In Section 3 we will discuss the mentioned method to accelerate mission start and end and the implementation into the planning software. Some simulative validation of the concept is shown in Section 4.

2. MISSION PLANNING FOR MARINE ROBOT TEAMS

Single vehicle planning concepts are often closely related to the individual vehicles and the intended missions. For teams of heterogeneous vehicles, new concepts must be developed to tackle the cooperative behaviour which is not covered by the existing planning procedures for the single robots. As it was stated for single vehicles, also the team-oriented concepts need to be closely adapted to the aimed mission scenarios. In this Section we will provide a short overview on solutions from literature before describing the MORPH planning concept and its realisation.

2.1 State of the Art

As an example for the orientation of planning concepts towards the aspired mission scenarios, the work of Prats *et al.*, 2011 can be stated where a sensor based planning for a single AUV with a mechanical manipulator is presented.

The concrete mission control language for single vehicle missions can be realized in various ways. Widely used are imperative descriptions, for example the AUV Scripting Language (ASL) for Gavia AUVs or the scripting language for Autosub AUVs, as described by Kao *et al.,* 1992. Another possibility is the usage of a higher mission control language and an automatic compilation to a Petri Net, like in COLA2, a control architecture for AUVs (Palomeras *et al.,* 2012).

Both concepts can be extended to be used in missions with multiple vehicles. The imperative scripting language for teams was used in the GREX project (Glotzbach *et al.*, 2007). An approach for using a Petri Net for team missions is described by (Palomeras *et al.,* 2008). Again, the concepts are usually related to the concrete scenario, like e.g. for a mission with cooperation marine robots and flying agents, see Sujit *et al.,* 2009.

2.2 The MORPH Mission Planning Concept

The first step for the development of the mission programming and mission control systems was to exam at least one representative mission scenario and extract performance requirements. The expected major outcome of this activity was the clear definition of a number of so-called MORPH primitives (MPs), which can be viewed as basic building blocks for the construction of the MORPH mission control architecture. In this context, the execution of a MORPH mission requires the serial and/or parallel execution of different behaviours in response to events that may be either internal (e.g. energy status notification or detection of a fault) or external (e.g., arrival at a desired site or detection of proximity to a vertical cliff). Thus, the unfolding of the missions will be time and event-driven, and not simply time-driven as it is customary in standard AUV mission scenarios up to date. Underlying the definition of the MORPH primitives is the tenet that the execution of a primitive should be decentralized. Thus, each of the vehicles involved must know the list of primitives to be executed, and for each primitive that it can effectively contribute to, it must be able to execute a number of actions that include:

1. summoning the resources required to accept data from its neighbours and acquire extra data from the environment,
2. processing the data and run selected navigation and control algorithms, and
3. broadcasting relevant data to selected neighbours.

The challenging tasks that are addressed in the MORPH mission planning require team behaviour elements with more complex structures than in earlier approaches. On the other hand, it is still necessary to realize an interface between the complex MORPH mission description and the single vehicles with their existing control software. As first results, it was decided that MORPH primitives (MPs):

1. may be consistent of several sub-proceedings that describe a certain team behaviour, called MORPH methods (MMs),
2. must be translatable into a meta mission plan for every single node, which then consists of so called Single Vehicle Primitives (SVPs).