Environment modeling for cooperative aerial/ground robotic systems

Teresa Vidal, Cyrille Berger, Joan Sola, and Simon Lacroix

LAAS/CNRS
University of Toulouse
7, Ave du Colonel Roche
31077 Toulouse Cedex 4, France
Firstname.Name@laas.fr

Extended abstract

Environment representations are of essential importance in multi-robot systems, as they are required to establish cooperation or coordination schemes. Be it for exploration, surveillance or intervention missions, environment models are indeed necessary to plan and coordinate paths, but also to determine the utility of vantage points, to asses whether robots will be able to communicate or not, and to localize the robots in a common frame.

In a priori poorly known or unknown environments, the ability to build and share environment models among the robots is therefore a pre-requisite to the development of cooperation schemes. With respect to the single robot case, this ability brings forth the following additional issues:

- The mapping algorihtms must be distributed among the robots. They must not rely on a complete and permanent communication infrastructure between the robots, as this a too strong constraint to ensure.
- The maps built by the various robots must be compatible, in the sense that they can be fused and shared among the robots.

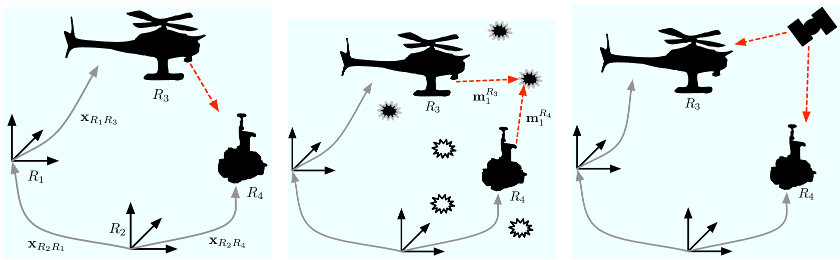
Finaly, similarly to the single robot case, and essential requirement has to be satisfied: the built maps must be *spatially consistent*.

The work presented here focusses on this latter point in the context of cooperating aerial and ground robots. The contribution is twofold: on the one hand, we propose an approach that stems on hierarchical SLAM [ENT05] to manage the various maps among the robots [VCBL09], and on the second hand we propose to build landmarks map on the basis of line segments [SVCD09], so as to be able to match and merge maps built from the very different vantage points of the aerial and ground robots.

Managing multiple maps among multiple robots

A hierarchical SLAM approach in the multi-robot case seems a priori straightforward: each robot manages a set of submaps and a global graph of poses. But the interests of multi-robot mapping arise of course when the robots exchange position or mapping information, which allows to enhance the individual maps spatial consistency and to build up a *multi-robot pose graph*. The following events provide such information (Figure 1):

- *rendez-vous* between robots, *i.e.* relative robot to robot pose observations,
- *map-matching* of independent submaps between two robots (or of landmarks belonging to independent submaps).
- *absolute position observation*, as provided by *e.g.* a GPS fix or an algorithm that matches landmarks with an initial georeferenced map.



(a) *Rendez-vous* (b) Map matching (c) GPS fix

Fig. 1. Loop closure events for multiple maps and multiple robots.

These events create a link between the robot's global level. Whereas in a single robot case a loop closure only occurs when the robot revisits a previously mapped place, in a multi-robot case these events trigger loop closures: any cycle that appears in the overall graph defined by the concatenation of each robot graph (the *multi-robot graph*) is a loop closure. The compounding of all relative transformations defines a cycle, and a batch optimization over the transformations can be performed. Note that to obtain a cycle in the graph defined by the concatenation of two robots' global levels, at least two events between these robots are required.

Besides a low algorithmic complexity, the main advantage to exploit a hierarchical map structure in multi-robot mapping is the low communication bandwidth required among the robots: only the individual global graphs need to be exchanged to update the multi-robot graph.

Building higher level landmark maps with vision

Among the three possibilities to close loops in the overall graph of maps, *map matching* is the most difficult to achieve when maps have been built by heterogeneous robots, *i.e.* with differents kinds of sensors or vantage points. Point feature landmarks ususally exploited in visual mapping are for instance very different when detected from aerial and ground imagery, and are therefore difficult to match. To be able to match maps, one need to represent in maps characteristics of the environment that are invariable with respect to view point changes.

Line segments have this property, as they carry a lot of information on the *geometric structure* of the environment, which, as opposed to visual feature points, does not depend on the camera's characteristics or viewpoint.

Building maps with visually detected line segments raise two issues:

- The detection, tracking and matching of lines segments in images remain an issue, as these processes are very sensible to image noise.
- The estimation of the geometric characteristics in a SLAM context is challenging, especially from monocular imagery, where two parameters can not be observed from a single viewpoint.

The paper proposes solutions to these issues, and illustrates maps based on visually detected line segments can be matched between aerial and ground robots.

References

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[SVCD09] J. Solà, T. Vidal-Calleja, and M. Devy. Undelayed initialization of line segments in monocular slam. In *International Conference on Intelligent Robots and Systems, St Louis, MO (USA)*, Oct. 2009.

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