Reliable SLAM in ambiguous environments

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We present a reliable method of Simultaneous Localization And Mapping (SLAM), robust to ambiguities in homogeneous environments.

Loops

SLAM is a concept that links the problem of estimating the state of a mobile robot to the mapping of an unknown environment in which the robot evolves. A SLAM algorithm exploits similarities in the environment in order to compute *loop closures* corresponding to places visited several times by the robot.

An example of loop is given in Figure 1, with a mobile robot that came back at time t_2 to a previous position reached at t_1. In this work, for a given trajectory, a loop is defined temporally, see [1], as a 2d vector $\mathbf{t} = (t_1, t_2)^\intercal$ such that $\mathbf{f}(\mathbf{t}) = \mathbf{0}$ with

$$\mathbf{f}(\mathbf{t}) = \int_{t_1}^{t_2} \mathbf{v}(\tau) d\tau,$$

a function describing robot's move from t_1 to t_2, based on its absolute velocities $\mathbf{v}(t) \in \mathbb{R}^2$.

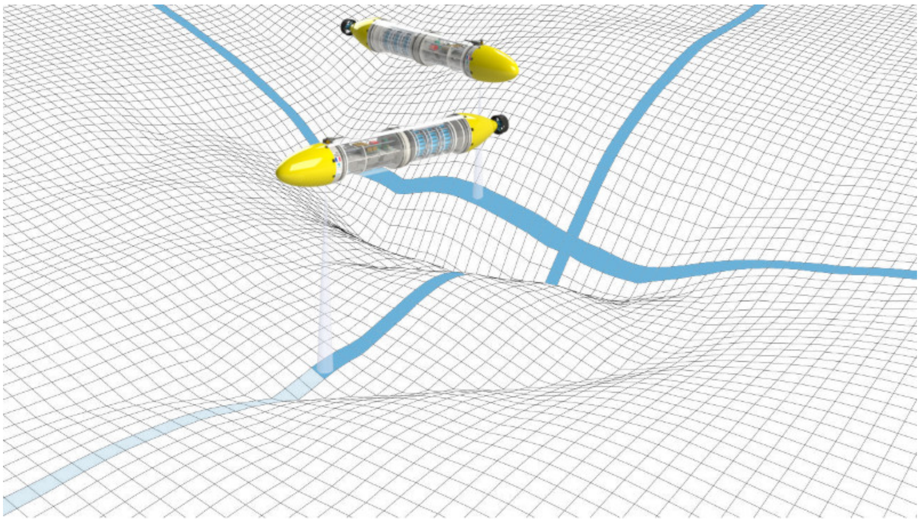

Figure 1: An underwater robot exploring its environment, before and after performing a loop. The robot trajectory is projected in blue on the sea-floor.

In a reliable context, any feasible trajectory has to be considered, based on the uncertainties coming from the measurements of $\mathbf{v}(t)$. Tubes are used for this purpose. The set-membership method we propose stands on tubes $[\mathbf{x}](\cdot)$, that are intervals of trajectories $\mathbf{x}^-(\cdot)$ and $\mathbf{x}^+(\cdot)$ such that $\mathbf{x}^-(t) \leqslant \mathbf{x}^+(t)\ \forall t$. Most of the classical mathematics operations we know on intervals can be extended to tubes. In this work, integral computations of tubes will allow to approximate all feasible loops $\mathbf{t}$: so-called *loop sets* denoted by $\mathbb{T}$. From tubes, we can compute reliable inclusion functions $[\mathbf{f}]$ of $\mathbf{f}$. Then:

$$\mathbb{T} = \{\mathbf{t} \mid \mathbf{0} \in [\mathbf{f}](\mathbf{t})\}\,.$$

$\mathbb{T}$ corresponds to a feasible loop set with respect to proprioceptive measurements. For each loop, observations from the environment based on scene recognitions will allow to improve the estimate of the trajectory for the localization purpose.

Environment ambiguities

When the environment is wide and homogeneous, as is the case for the seabed, loop closures are difficult to guarantee due to ambiguities in the observations: scene recognitions become challenging and not always reliable. Figure 2 is an example of observation associated with a loop closure, in the case of underwater SLAM using a multibeam echosounder.

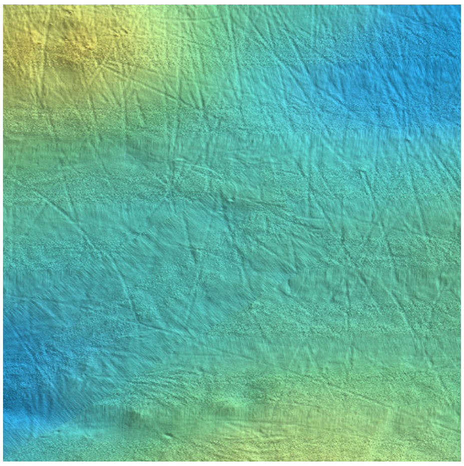

Figure 2: Example of seafloor perception obtained with a multibeam echosounder.

For a reliable SLAM method, we have to verify that a loop has been done in $\mathbb{T}$: $\forall \mathbf{f} \in [\mathbf{f}], \exists \mathbf{t} \in \mathbb{T}$ such that $\mathbf{f}(\mathbf{t}) = \mathbf{0}$, which is equivalent to verifying a zero of an unknown function $\mathbf{f} \in [\mathbf{f}]$ on $\mathbb{T}$. For this zero verification, we employ the notion of *topological degree* that originates in the field of differential topology. An algorithm exists [2] to verify a zero of an uncertain function $\mathbf{f} : \mathbb{R}^2 \to \mathbb{R}^2$ known to belong to an inclusion function $[\mathbf{f}] : \mathbb{IR}^2 \to \mathbb{IR}^2$.

This allows to prove that a robot has completed a loop, whatever the uncertainties in its evolution [3]. The main asset is to avoid bad convergences in SLAM algorithms. We can now consider difficult homogeneous environments even with challenging scene recognitions.

Localization

When coupled with exteroceptive measurements, loop closures allow to propagate information from known states to states with large uncertainties. A contractor framework can deal with these inter-temporal measurements [4]. The following constraints apply around a loop closure:

$$\dot{\mathbf{x}} = \mathbf{v}$$
$$\mathbf{x}(t_1) + \mathbf{d} = \mathbf{x}(t_2)$$

with $\mathbf{x} \in \mathbb{R}^2$ the position of the robot and $\mathbf{d} \in \mathbb{R}^2$ the translation between the two positions at t_1 and t_2. $\mathbf{d} = \mathbf{0}$ corresponds to a strict loop closure at $(t_1, t_2)^\intercal$. In practice, due to uncertainties, these $(t_1, t_2)^\intercal$ are not known. We select randomly one t-pair in the loop set $\mathbb{T}$ and we then compute the correction $\mathbf{d}$ based on exteroceptive data. The propagation is then run using a contractor network.

As long as we are able to prove that a loop has been made in $\mathbb{T}$ (with zero verification), then we can safely rely on scene recognitions for providing a bounded correction $[\mathbf{d}]$. The SLAM can run iteratively without risking a wrong convergence. This method will be illustrated on real data from an Autonomous Underwater Vehicle performing a navigation at sea.

References

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