Quaternion based control for robotic observation of marine diversity

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In the current context of increasing pressures on marine ecosystems, one of the main challenge of ecology is to be able to conduct accurate and reliable assessment of biodiversity. Until now, studies are mainly performed by divers, which induces high cost and heavy logistic on terrain missions and are limited to few meters depth. An underwater robot could be a solution to most limitations of human-operated observation (divers) in underwater environment, but requires to be specialized according to expert protocols and objectives.

This paper presents the design of the control architecture of an underwater hybrid vehicle, where control is distributed among expert (marine biologists) and autonomous system. The analysis of expert protocols drives the control design, resulting in a composition of 'functioning modes', according to the chosen observation strategy and the appropriate control distribution (operator/robot) and actuators allocation (redundant thrusters). We present here the design of the different control laws dedicated to each functioning mode (observation strategy). The performance of the solution is evaluated on the simulator of the ROV Ulysse.

I. Biologist's protocols

First, we studied the divers existing protocols of our biologist partners. Together, we have defined 3 main observation protocols, required by most marine biodiversity assessments: Transect, Localized Observation and Species Tracking.

- Transect [1], [2] is used to study the fish community in a given area. The study area is defined along a virtual line of 50m long. The counting (definition of species, number and size) is done on a strip of 5m wide at a constant depth.
- Localized Observation is the observation of a static feature (e.g. coral heads). It allows to investigate this region of interest with different angles of view.
- Species Tracking allows to follow a given species to dynamically study its behavior (Nutrition, Reproduction, Leak, ..)

Then, we transpose these observation strategies into functioning modes (Fig. 1), requiring specific configurations of the control architecture.

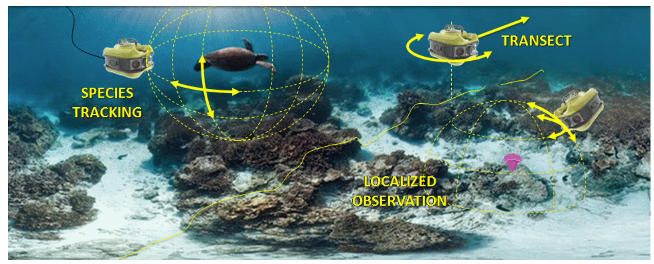

Fig. 1. Observation protocols

To execute a robotic transect, the robot has to be able to autonomously follow the reference, and to acquire pertinent information (typically video streams) on the environment to allow the specialist to proceed to the counting and identification of species. From a robotics point of view, we define this situation as distributed control (also called co-control) where parts of the robotic system is autonomously regulated (path-following the transects reference), while the mission progression and the direction of observation is left to the operator control.

The transposition of the localized observation within the robotic system is co-control, where the user has to be able to change or modify the direction and distance of observation, while the system autonomously centers (or path-follows) the interesting feature in the sensors field of view (e.g. video or acoustic camera), and insures its own safety (avoiding collision with environment).

From the robotic aspect, the species tracking mode can be considered as a mix between the two previous protocols, but generalised to trajectory-tracking. the operator can choose the tracking parameters (distance, angle of view), while the robot autonomously tracks the object of interest (see video [6]).

II. Control

To control the robot within the different functioning modes, we have chosen to use a generic and unique quaternion-based control law structure ([3], [4]), parameterized by the active functionning mode. In order to cope with the 3 targeted protocols, we decompose the problem definition in a set of

4 different frames on which different control strategies will apply, see Fig. 2 :

- Robot body frame $\{B_B\}$, which is located at the meta-center of the robot. Note that the robot actuation system results in forces and torques defined in this frame, [5] and control result is expressed in terms of 'actuation demand' w.r.t. $\{B_B\}$. Thrusters allocation is not in the scope of this paper, where we consider here the solution of [5].
- Sensor frame $\{B_C\}$, which is located on the sensor used in the functioning mode (mainly the front camera). Note that the extracted feature can be the result of a filtering process involving different sensors, and models. $\{B_C\}$ can be advantageously defined in a generic sensorial space, but not specifically attached to a unique sensor.
- Desired sensor frame $\{B_C\}_{desired}$, which represents the desired 3D location of the sensor involved in the current functioning mode.
- Target frame $\{B_S\}$, which represents the current target of control of the current functioning mode. It is virtual in the transect mode (the point of advancement on the imaginary transect line) or extracted from the environment in the localized observation (e.g. coral riff) or the species tracking (species to follow). Note that the two first objectives result in a path-following control problem, while the third is a trajectory-tracking issue.

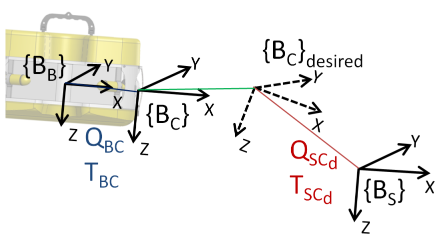

Fig. 2. Frame chain

All transformations between these frames are expressed by a quaternion rotation and a vector translation.

The transformation Q_{BC}, T_{BC} between the robot body frame $\{B_B\}$ and the sensor frame $\{B_C\}$ represents the sensor's situation in the body frame.

The transformation Q_{SC_d}, T_{SC_d} is defined according to the active functioning mode. Details of this transformation are described in the full paper.

The convergence of the sensor frame $\{B_C\}$ to the desired frame $\{B_C\}_{desired}$ is ensured by a quaternion-based control law for rotation. Design and proof of convergence are detailed in the full version of the paper.

Finally, the operator controls the attitude and position of $\{B_C\}$, while the system autonomously maintain $Q_{SC} = Q_{SC_d}$ and $T_{SC} = T_{SC_d}$. Note that the operator have access to the parameters of Q_{SC_d}. Hence, the operator can close the loop on different degrees of freedom of the task space of the current functioning mode. The next step will be to study the effect of mode switching on our solution. The commutation question will be tackled in a future paper.

Orders sent by the user are applied to the Target frame $\{B_S\}$ depending on the functioning mode.

III. Simulation

We have implemented this solution on the Real-Time simulator of the ROV Ulysse. For example, we simulate a transect with a change of observation direction, seeing left side (T = 20s to T = 28s) then right side (T = 36s to T = 42s). We observe the robot position error (Fig. 3) which increases on every transition (beginning and end of the transect or orientation change) and then becomes nullified thanks to control.

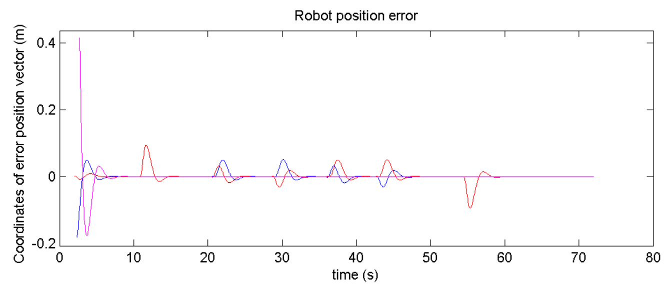

Fig. 3. Robot position error

IV. Conclusion

Our works are the basis of a collaboration between biologists and roboticians. The goal is to design a robotic system useful for the assessment of marine biodiversity. We designed a quaternion based control adapted to our needs in terms of functionning modes, and defined according to marine diversity assessment protocols.

The following of these works will include a mission to Mayotte with the Ulysse ROV to test the 3 functioning modes in real environmental constraints (april 2017). Then, the next step is to study and manage the switching between these functioning modes and their effect on the system (e.g. at the control level, including the software architecture).

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