# Optimization of Multi-Attribute Tasks for Underwater Motion of Robotic Sensor Agents

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Target detection, identification, and tracking are tasks of great importance in counterterrorism preparations. The development of a new generation of mobile autonomous wireless robotic sensor agents provides new advanced opportunities for target monitoring and tracking. We are particularly interested in the investigation of the underwater motion of the mobile robotic sensor agents. However, the trajectory of the underwater motion of a robotic sensor agent from the initial point to the destination significantly differs from the ground motion trajectory. Firstly, an underwater vehicle is affected by the current flow and its motion strongly depends on the structure of the river (cross-section shape, bottom type, etc) or ocean. Secondly, the battery power is limited and it almost impossible to recharge the batteries while the agent is underwater. Also, the time for robotic sensor agents to reach the target may be crucial. Consequently, finding the fastest path to the destination given a water stream is important. Thus, how should cluster of underwater robotic sensors move to optimize multi-attribute tasks?

We propose an optimal control underwater motion algorithm with respect to both the time needed to reach the destination and the usage of battery power. As we mentioned above, the underwater motion of mobile sensors depends greatly on the remaining battery life of the sensor, which, in turn, is a decreasing function of $v^2$ – the squared speed of the sensor. From another point of view, the motion of sensors should meet the optimal time criterion – the target should be captured as soon as possible at time *T*. Consequently, for a non-moving target we arrive at the problem of minimization of the functional of the form $F(v,T) = \alpha v^2 + \beta T^2$ with positive coefficients *α* and *β*, which reflect the influence of *v* and *t* and make the expression dimensionless. The minimum of this functional meets both criteria: fast time to target and low battery usage. However, on the base of the analysis of data (acoustic, visual, location, or others), every target has its own threat. Therefore, it is assigned the threat probability *p*: When such a probability is close to one then the target is considered to be a terrorist ready to attack. If $p \approx 0$, then it is unlikely that the target is a terrorist. Of course, in the case $p \approx 1$, the time optimality must prevail over battery preservation. In contrast, if $p \approx 0$, then we do not care too much about time optimality. These reasonings yield the following modification of the above functional to be minimized: $F(v,T) = \alpha(1-p)v^2 + \beta p T^2$. This expression is obtained under the assumption that the sensors have constant speed. However, the better results require the consideration of time-dependent velocities, and we arrive at the following functional to be minimized.

$$F(v,T) = \alpha(1-p)\int_0^T v^2(t)\,dt + \beta p T^2$$

This optimal control problem is endowed by the dynamic system, which expresses the coordinates of the agents in terms of speed *v*, the time-dependent direction of motion, and the velocity field of the water. The condition that the sensors must arrive at the destination is also applied. As control parameters, we use the directional cosines at the initial time. In the case α=0 (purely optimal time problem) we use the Pontryagin maximum principle with the construction of the corresponding Hamiltonian and the search for its maximum. However, the general battery-time optimal problem is more complicated, and it is solved by means of the construction of a specific control equation based on the adjoint equations approach. We consider both two and three dimensional cases. We demonstrate the corresponding solutions both for the case of one moving sensor and for the cooperative motion of sensors. For example, we show that the cluster of mobile robotic sensor agents moving along obtained "optimal" trajectories reach the target 20-30% faster compared with the time that agents need to move along the straight line connecting the initial placement with the destination. We implement our approach for the several ocean and river flow models and demonstrate the effectiveness of the proposed underwater motion control algorithm with the optimal usage of the battery life and time to reach the target.

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