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Mobile Robots for Qualitative and Quantitative Management of Water Resources: Opportunities and Challenges

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Abstract This paper aims at presenting a reflection on possible contributions of robots to answer human's needs in matter of qualitative and quantitative management of water resources. We describe challenges and advocate the use of mobile robots. We list requirements for a robot-based water resource management. These requirements are the foundation of a framework we have introduced to build solutions addressing the targeted problem.

Keywords: Water Resources, Mobile Robots, Large-Scale Systems.

1. INTRODUCTION

1.1 Context and Motivation

The water resource is known for its scarcity and for its precious value. It is impacted by various sources of pollution, often linked to human activity. In addition, extreme climatic events such as floods worsen these situations by discharging contaminated water into the natural environment, or by causing damages to human's economic activity and property.

In this context, it becomes crucial to preserve water resource by improving and designing management strategies both from a qualitative and a quantitative point of view. To contribute to these objectives, water resource management requires a better knowledge of the dynamics of water systems. Besides, it needs a better and quicker estimation of their quantitative and qualitative states. Mitigation solutions based on management strategies, are also necessary, particularly in crisis situations. Previous objectives require new solutions that address the 3 facets of water resources management:

Surveillance Detect abnormal situations (*e.g.* pollution, extreme water level), and diagnose what is going wrong (*e.g.* pollution source, faulty mode of a pump or other hydraulic device).

Supervision Observe the evolution of some phenomena, and possibly deduce a prognostic of the evolution, *e.g.* how pollution will diffuse.

Remediation Control Strategy to address a undesirable situation, *e.g.* clean up an oil spill, collect floating garbage, open gates of an expansion area, run auxiliary pumps.

1.2 Challenges

Achieving surveillance, supervision and remediation of water resources, first requires sensors to collect data. Collected data will then help taking appropriate actions such as activating some actuators (*e.g.* pumps) and give feedback on the impact of these actions. However, collecting data and controlling actuators is tedious and slow if done by human operators. To be

effective, a solution should provide regular and precise measurements (high resolution). Hence, automation is compelling but it is also challenging because of the scale of hydrographical networks or water bodies and their limited accessibility. A trivial solution would be to set up a dense network of sensors or actuators but this is not realistic. Realistic solutions are a trade-off between the economical costs, the ecological impact and the system's performance such as the resolution of measurements.

1.3 Robot-based Management of Water Resources

In this paper, we advocate that mobile robots allow for a flexible, economically and ecologically viable solution for managing water resources. Indeed, a fleet of robots can operate as a sensor network. But contrary to a fixed network, robots are mobile and can organize themselves to maximize performance given the conditions (*e.g.* topology, weather). Indeed, each robot can be equipped with different sensors and actuators to collect data and perform some tasks at desired positions. They can also collectively build maps with data of interest, by moving around until covering a whole area. The resolution of these maps can be adjusted by simply adjusting the distance between robots. For example, robots might move in a row while searching for the source of a pollution. Then, when they find it, they can collectively limit the diffusion of the toxic substance by organizing themselves in circle around it.

Mobile robots provide support for designing cheaper, more flexible and ecologically respectful water management systems. However, they should be part of a larger framework that target all kind of problems related to water resources management, including, but not limited to localizing pollution sources (?) and collecting waste and pollutants (?).

2. REQUIREMENTS FOR A ROBOT-BASED SYSTEM FOR MANAGING WATER RESOURCES

2.1 Mission

Designing a system to manage water resources requires to define *what* is its *mission* and *how* to achieve it. According to

Section 1.1, a mission is related to one or more facets namely: Surveillance, Supervision or Remediation.

The target of a mission (*what* part) is the physical phenomenon that is observed or act upon. Examples are: water level, PH, floating waste, phytoplankton, and conductivity.

The *mission strategy* (*how* part) can be to keep the physical phenomenon close to an objective value, or patrolling over an extended period of time. The following section 2.2 discusses how a mission strategy decomposes into *tactics* addressing different aspects of the solution.

2.2 Tactics to Implement a Mission Strategy

To implement a mission strategy, the first step is to choose the appropriate *kind of hydraulic devices and robots*. This means choosing a hardware, with sensors and actuators that best fit the mission. Although in theory, one can choose hydraulic devices for a given mission, in practice, this is often not an option, mainly because these are big and expensive infrastructural projects, requiring political decisions. This is why, choosing hardware boils down to picking the appropriate robots.

For instance, consider surveillance or supervision missions of inland waterways. In this example, surface aquatic robots are more appropriate to accurately measure the amount of deposited sediments, or to collect floating waste. Other kinds of hardware are more suitable for other missions, such as underwater robots for measuring water pressure or PH, at different depths. A review on aquatic unmanned vehicles is proposed in (?), and in (?) for marine applications.

The *number of robots* is also a parameter that defines a tactic to address a mission. A solution can rely on a single robot, or a fleet of two or more robots. For example, multiple robotic fish are used in (?), to collaboratively profile the characteristics of a diffusion process including source location, discharged substance amount, and its evolution over time. Surface multi-robots have been designed in (?) to measure the density of the plankton in water. Yet another example is a fleet of autonomous floating robots tracking the fate and the trajectory of oil spill (?), or collaborate to recover oil with the help of oil skimmers (?).

Robots involved in a water resource management mission can be either tele-operated by a remote human operator or autonomous. That is they can performed assigned tasks, without human intervention. Hence, the level of *robots autonomy* is also a question to consider when implementing a mission strategy.

To achieve a mission, robots need to go to different locations to collect data, or perform some action (*e.g.* gather waste). This is why mission managers need to choose a navigation algorithm that plans 2D or 3D paths that fit the mission. This algorithm should ensure obstacle avoidance in case of robots that are fully or partially autonomous. In (??), the designed robotic fish can follow a given track and change its direction to avoid collision with obstacles.

Another point concerns communications at two levels. On the one hand, autonomous robots operating in a fleet, need to communicate to coordinate their operations. On the other hand, robots might need to send collected data to a base station. These data will inform a decision system (automated or with humans in the loop). Communication can also be directed from the base station to robots. The base station will then issue orders and assign tasks to robots (*e.g.* where to go next).

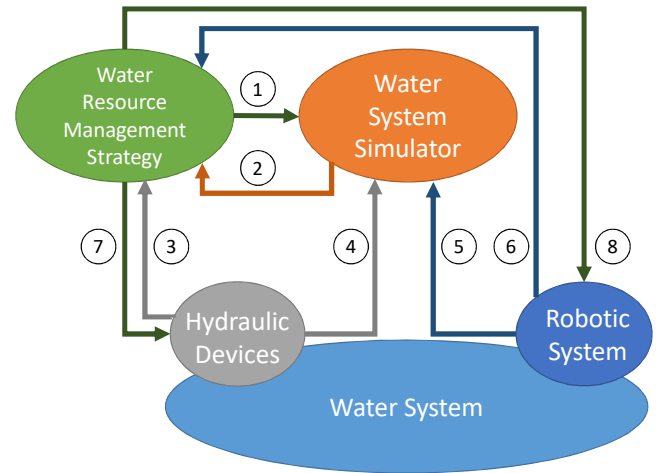


Figure 1. Framework for water resource management.

3. FRAMEWORK FOR WATER RESOURCE MANAGEMENT

We propose a framework for the robot-based management of water resources (*cf.* Figure 1). The water resource management strategy block (in green) defines strategies for surveillance, supervision and remediation to mitigate the impact of undesirable situations. Strategies require data provided by both hydraulic devices (arrow ③ in Figure 1) and robots (arrow ⑥). A simulator of the water system can be used to optimize the strategy ①. This simulator allows reproducing accurately the dynamics of the water system and predict its behaviour ②. Data collected in real-time by hydraulic devices ④ and robots ⑤ can feed the simulator for better results. The strategy will inform the robotic system about data to collect, where and how to perform measurements. Eventually, the strategy will issue commands to hydraulic devices ⑦ and robots ⑧ to mitigate undesirable situations.

A review of the literature, shows some work related to this proposed framework. Bayat *et al.* (?) did a survey gathering multi-robot solutions and algorithms for monitoring water pollution. This is a very interesting source for tactics to implement the robotic part of a system based on our framework. However, this paper does not deal with remediation solutions. It is also restricted to water pollution and does not study other phenomena such as floods or drought.

Another source of solutions to implement the robotic part of our framework is the application agnostic survey proposed by (?). It deals with task decomposition, coalition formation, task allocation, perception, and multi-agent planning and control.

Fernandez *et al.* (?) presents an overview of the work carried out by his group of robotic about cooperation between mobile robots and sensor networks, for different environmental applications. They propose an integrated platform for integrating mobile robots and sensors with a pre-existing infrastructure coping with heterogeneous and static devices, offering adaptive and optimal management strategies. Here again, it is a very interesting proposal for the deployment, operation and maintenance of large-scale sensor networks. However, this paper does not deal with remediation solutions, and does not consider directly management of water resources.

4. CONCLUSION

Designing better management systems for water resources is crucial nowadays. In this context, this paper presents some requirements for both qualitative and quantitative management of water resources. We advocate that using mobile robots can improve management strategies on these two levels. This article also introduces a framework to build solutions targeting various applications in this area. We pave the way for our effort to explore new solutions to water resource management.

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