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Brooklyn Atlantis: A Robotic Platform for Environmental Monitoring with Community Participation

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Abstract - In this paper, we summarize recent findings on the "Brooklyn Atlantis" project supported by the National Science Foundation at New York University Polytechnic School of Engineering. Brooklyn Atlantis is a citizen science project, which has the twofold aim of aiding in the environmental monitoring of a heavily polluted water body in New York City and allowing for hypothesis-driven studies on social networking and human-machine interactions. Here, we specifically focus on the design and development of the environmental monitoring platform with citizen scientists' participation. The platform consists of a robotic vehicle capable of uploading water quality and image data to a remote server while maneuvering about a polluted body of water. Volunteers aid in environmental monitoring by performing image analysis tasks through a web-based interface. An administrator has the ability to vary the interface provided to the user and access various performance metrics. As a proof-of-concept validation of Brooklyn Atlantis, we report on field testing and community involvement since the project launch.

Keywords: Citizen science, environmental monitoring, mechatronics, robotics.

1. Introduction

Environmental monitoring is critical for environmental impact assessment, cleanup of contaminated sites, and health advisories. Quantification of environmental data, such as monitoring climate and water quality in rainforests (Corke *et al.*, 2010), modeling of pollution (Lu *et al.*, 2011), and ocean sampling (Leonard *et al.*, 2010) can be accomplished with relatively limited manpower, once the necessary sensory infrastructure is in place. On the other hand, if classification of data is of interest, significant manpower may be required. This issue has been addressed in several projects through the use of *citizen science*. Citizen science projects involve members of the general public, or citizen scientists, to partake in research projects coordinated by experts (Hand, 2010; Bonney and LaBranche, 2004). These projects often benefit both the scientists leading the project, by providing them with useful data (Sauer *et al.*, 2003; Niven *et al.*, 2004; Dickinson *et al.*, 2010),

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and the citizen scientists, by educating them through involvement in authentic scientific research (Cooper *et al.*, 2007; Bonney *et al.*, 2009).

Citizen science projects typically vary in the degree of involvement of the participant (Nov *et al.*, 2011). For instance, in SETI Live (http://www.setilive.org), volunteers' personal computers collectively analyze large quantities of data gathered from outer space when not in use, requiring little commitment. A step beyond distributed computing, the Quake-Catcher network (http://qcn.stanford.edu) equips volunteers' computers with specialized sensors, forming a distributed sensor network that provides scientists with pertinent data on recent earthquakes (Cochran *et al.*, 2009). Some projects offer participants a more active role; for example, in NoiseTube (http://noisetube.net) volunteers use their smart phones to capture acoustic data for mapping noise pollution (Maisonneuve *et al.*, 2009).

In this paper, we summarize recent findings on the "Brooklyn Atlantis" project supported by the National Science Foundation. Specifically, we summarize the design and development of the mechatronic platform used for the project and presented in (Laut *et al.*, 2013), as well as the public involvement in the activity described in (Laut *et al.*, 2014). Brooklyn Atlantis (http://www.brooklynatlantis.poly.edu) is a citizen science project consisting of a mechatronics-based system and an online peer-production platform. Citizen scientists can participate in Brooklyn Atlantis both remotely, by classifying environmental data through images on the project website, and on-site, through special events organized in collaboration with other community groups. The data and images available on the project website are captured and uploaded remotely by an aquatic surface vehicle operating in the Gowanus Canal in Brooklyn, NY, while on-site participation offers participants the opportunity to control the aquatic surface vehicle. A project administrator has the ability to vary the web-based interface provided to each user, and the participants gain points and privileges on the basis of their task performance. Not only does Brooklyn Atlantis aid in the environmental monitoring of a heavily polluted water body in New York City, but also it allows for hypothesis-driven studies on social networking and human-machine interactions through the use of these novel features.

The Gowanus Canal, an Environmental Protection Agency (EPA) Superfund site, has become extensively polluted due to years of neglect and discharges of raw sewage, industrial waste, sewer outflows, and storm water runoff. Despite this, the canal is still home to many birds, fish, and small mammals (EPA, 2011). Brooklyn Atlantis requires a robotic device capable of gathering both image and water quality data at various locations within the canal, while being robust enough to be deployed for an extended duration. Recently, platforms with similar capabilities have been developed. The ASMV (Wood *et al.*, 2007) is a solar-powered vehicle designed to assess ocean pollution and through an anchor, can keep its position without the use of motors. Also solar powered, the OASIS platform (Low *et al.*, 2009) autonomously measures water quality and temperature while acquiring images. Communication and data transfer with scientists is achieved through satellite links. The Brooklyn Atlantis platform must also be small enough to navigate an environment that may be polluted with debris, while also being low-cost.

2. Hardware Details

The robotic vehicle has been designed to operate for extended periods of time while capturing and transmitting environmental data, see Figure 1. The vehicle is comprised of three sub-components: the central supporting platform, the submerged section, and the solar panel unit. The vertically developed column shape of the vehicle allows it to maneuver through narrow spaces and avoid debris within the canal. Two lateral canister floats have been employed for buoyancy, solar panels have been used for recharging the batteries, and an arrangement of two Seabotix thrusters capable of delivering 6.4 lbf of thrust each has been utilized to provide high maneuverability of the robot.

The central support contains the vehicle's electronics, anchor winch, above-water level camera, and data transfer devices. It has been constructed of 1 inch polyvinyl chloride (PVC) pressure schedule 40 pipe and

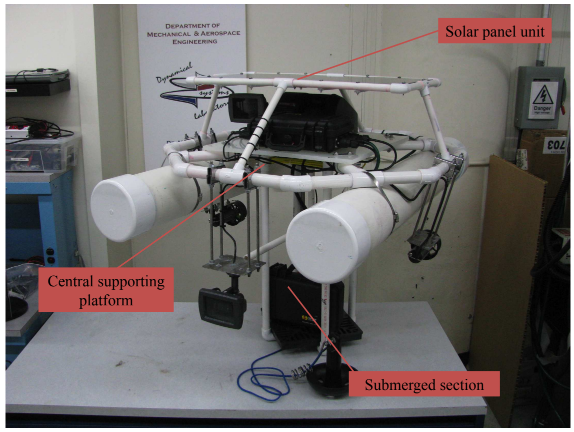

Fig. 1. The Brooklyn Atlantis robotic vehicle displayed with nomenclature.

fittings and has side to side dimension of 37.5 inches, while a $20 \times 20 \times 0.5$ inch plastic panel is fastened on top as a platform. A Trac Fisherman winch motor situated on the plastic panel of the central support controls the position of the anchor, located in the submerged section. The canister floats, connected to the central support using stainless-steel hose clamps, have been assembled from 4 foot long PVC pipes, 6 inches in diameter, sealed off by 5.25 inch end caps.

(a) Thruster (b) Sensor array (c) Above-water camera (d) Below-water camera

Fig. 2. Detailed views of various parts of the robotic vehicle.

The solar panel unit provides a peak of 10 Watts to the batteries through two Sunforce solar panels. The amorphous solar cells each measured $13.1 \times 14 \times 0.75$ with a weight of 4.6 lbs, and are completely waterproof. The solar panel unit is constructed of 0.5 inch PVC pipe joined with 90° elbow fittings to provide a perimeter and support for the solar panels, and has been connected to the central support structure through 0.5 inch PVC support pipes, which also provide and encasement for the wires connecting the solar panels to the charging system.

The submerged section contains both the battery pack and anchor, increasing vehicle stability by shifting the center of mass downward. It is constructed from four vertical 23.5 inch long, 0.75 inch diameter pipes running down the spokes of the central support, terminated with 90° elbow fittings. The water quality sensors are affixed to the two rear vertical pipes and anchor line pipe, which also offer protection from collision with canal debris.

Three sensor modules (WQ201, WQ401, and WQ-Cond-2 by Global Water) are utilized to assess the water quality of the canal, where WQ201 measures pH, WQ401, measures dissolved oxygen, and WQ-Cond-2 measures both conductivity and water temperature, see Figure 2(b). Each of these sensors provides a metric from which the water quality can be assessed. The pH sensor quantifies the acidity or alkalinity of the water, a factor that most wildlife are sensitive to (Schofield, 1976). The dissolved oxygen sensor offers relevant information on the sustainability of a body of water through the oxygen content (Kramer, 1987), an important metric for fish habitats. The concentration of dissolved salt ions (Tsai, 1973) is assessed by the conductivity sensor, and the level of thermal pollution (Davidson and Bradshaw, 1967) is indicated by the temperature sensor. Above- and below-water cameras are incorporated for capturing videos and still images of the canal, see Figures 2(c) and 2(d). Sensor and image data is shared with the web-based interface through a mobile broadband internet connection.

A Gumstix Overo FireSTORM embedded computer is employed to perform computational and control tasks, see Figure 3. To facilitate the data acquisition from the water quality sensors and create a means to communicate with other devices on the robotic vehicle, the onboard computer is paired with a Robovero expansion board, including magnetometers, accelerometers, and gyroscopes in 3 axes. Each water quality sensor outputs a current signal, which is then processed for the Robovero to read a corresponding Voltage signal. The onboard computer is programmed such that a single sensor value is composed of an average of ten samples to reduce the effect of sensor noise. To reduce power costs when data is not being collected, the sensors have the ability to be powered down. Improving power efficiency is of crucial importance, as extended duration missions are of interest. Connected to the onboard computer via a serial connection, two Pololu 24v23 motor controllers are employed to regulate the power delivered to each thruster. WiFi and Bluetooth modules allow for local communication with the robotic vehicle and a USB dongle for a 3G mobile broadband connection.

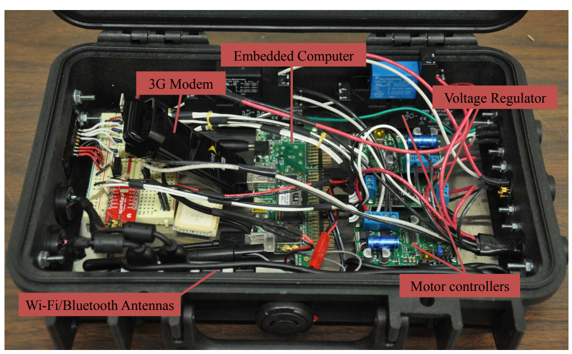

Fig. 3. Detailed view of the electronics case with the cover opened, displaying the embedded computer and overlaid labels for each component.

3. Software Details

A web-based interface based on the BOSSA open-source framework (http://boinc.berkeley.edu/trac/wiki/BossaIntro) was developed to facilitate citizen scientist participation and performance assessment. While citizen scientists perform tasks, such as the classification of images and forming social groups as networks of friends, the administrator is given access to a variety of statistics pertaining to performance and interactions of users.

Within Brooklyn Atlantis, citizen scientists are tasked primarily with image classification through a web-based interface, shown in Figure 4. Classification of animal species, flora, and debris are examples of objects

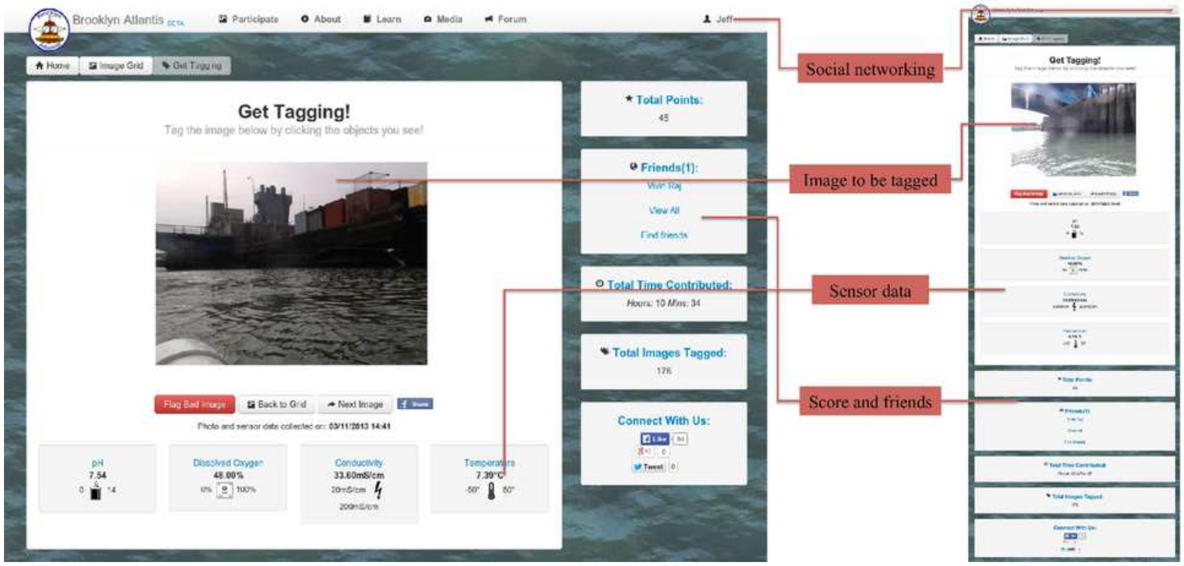

Fig. 4. Instances of the current user interface on a device with a wide aspect ratio (left) and a narrow aspect ratio (right) with overlaid labels. The website's modular design allows for dynamic rearranging of components to provide an intuitive interface over a wide range of devices.

that users are tasked with classifying. Each Brooklyn Atlantis citizen scientist is assigned to a user group for which a separate interface was created. The interface may display individual user performance, the option to create a personal profile, and display the amount of time contributed.

4. Field Testing

The platform has been deployed bi-weekly in the Gowanus canal since October 2012 (Yee, 2012). With the robotic vehicle in the canal, the remote server receives sensor data approximately once per minute through the mobile broadband connection. As soon as the server receives data from the vehicle, such information is immediately shared on the web-based interface for classification by citizen scientists.

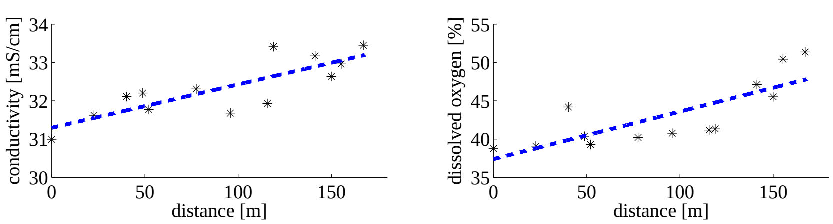

Fig. 5. Conductivity and dissolved oxygen values plotted against distance from the north-most sample. black stars indicate discrete data samples. blue dashed line represents a linear fit.

The robotic vehicle was thoroughly tested by traversing a length of the canal. The vehicle stopped at 13 locations for at least one minute throughout the canal for data collection, uploading sensor and image data to the remote server. While temperature and pH were found to be approximately constant in space with average values of 7.58°C and 7.26, respectively, the dissolved oxygen and conductivity have displayed an increase as the robotic vehicle traveled south, see Figure 5. This data may be explained by the fact that the Gowanus Canal, fed in the south by the water of the Upper New York Bay, has no source of water on the North end.

While the web-based interface offers citizen scientists the opportunity to contribute to the project remotely, users have also been invited to directly collect data themselves. During *Gowanus Voyage* (Laut *et al.*, 2014), members of the community were able to control the robotic vehicle and smaller sensor equipped remote controlled boats developed in collaboration with a group of local artists.

(a) Participants controlling the robot. (b) Robot and boat in the canal.

Fig. 6. Citizen scientists directly collecting environmental data during a public event.

The five hour long event attracted about 150 visitors, who were each able to control the robot or a boat for up to 10 minutes while viewing real-time plots of the data that they collect. Through surveys administered using iPads, it was determined that the majority of participants both enjoyed the activity and felt that they were contributing to environmental monitoring by participating while also learning about the pollution and recovery of the canal.

5. Conclusions

A summary of recent work on the citizen science project “Brooklyn Atlantis” presented in (Laut *et al.*, 2013, 2014) has been provided. Central to the project is a mechatronic device that collects water quality and image data in a polluted canal. Citizen scientists participate in the environmental monitoring of the canal through a web-based interface, where they view and classify the images captured by the robotic vehicle. A novel combination of performance metrics and user-interface controls allows for performing hypothesis driven research.

The robotic vehicle is designed to require minimal maintenance and supervision once deployed. A dual thruster arrangement with an independent anchor is used for both maneuverability and low-power station keeping. The environmental data is acquired through water quality sensors and cameras. The on-board computer, equipped with a 3G mobile broadband connection, exchanges the data with a remote server, which hosts the web-based interface. Citizen scientists primarily contribute to the project through the web-based interface, while a special event has allowed participants to go beyond classifying data by controlling the robotic vehicle.

Autonomous monitoring of the canal is planned for future work to allow for a continuous stream of data for classification by citizen scientists. A platoon of robotic vehicles will also be designed for a more comprehensive coverage of the canal while enabling further research on the interactions of networks of humans and robots.

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