Development of a low-cost and open-source autonomous surface vehicle for waste stabilization pond monitoring

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Abstract
The underperformance of existing wastewater treatment systems represents a constant threat to the environment and public health. The generalized lack of water quantity and quality monitoring data in developing countries makes decision-makers unaware of the current performance of wastewater treatment systems. In ongoing research, a prototype of a low-cost and open-source Autonomous Surface Vehicle (ASV) for monitoring the treatment performance of WSP was developed. The ASV is capable of navigating autonomously along a predefined trajectory based on geographic coordinates, and, meanwhile, performing measurements at different locations within the pond. The challenging circumstances inherent to wastewater management in developing countries were taken into account during the design and construction. The open-source nature allows to integrate any type of sensor according to user needs. The ASV can be applied as a low-cost and flexible tool for a variety of WSP monitoring applications.

KeyWords: autonomous surface vehicles, monitoring, open-source, waste stabilization ponds

DESARROLLO DE UN VEHICULO SUPERFICIAL AUTONOMO DE BAJO COSTO Y OPEN-SOURCE PARA EL MONITOREO DE LAGUNAS DE ESTABILIZACION

Resumen
El bajo rendimiento de los sistemas de tratamiento de aguas residuales existentes representa una amenaza constante para el medio ambiente y la salud pública. La falta generalizada de datos de monitoreo de cantidad y calidad de agua en los países en desarrollo hace que las personas encargadas de tomar las decisiones no estén en conocimiento del desempeño actual de los sistemas de tratamiento de aguas residuales. En la investigación en curso, se ha desarrollado un prototipo de Vehículo Superficial Autónomo (VSA) de bajo costo y open-source, para el monitoreo del rendimiento del tratamiento de lagunas de estabilización. El VSA es capaz de navegar de forma autónoma a lo largo de una trayectoria predefinida en base a coordenadas geográficas, y, a la vez, realizar mediciones en diferentes puntos dentro de la laguna. Las desafiantes circunstancias inherentes a la gestión de las aguas residuales en los países en desarrollo fueron tomadas en cuenta durante el proceso de diseño y construcción. La naturaleza de open-source permite integrar cualquier tipo de sensor conforme a las necesidades del usuario. El VSA puede ser aplicado como una herramienta flexible de bajo costo para una variedad de aplicaciones en el monitoreo de lagunas de estabilización.

Palabras clave: lagunas de estabilización, monitoreo, open-source, vehículo superficial autónomo

Introduction
The waste stabilization pond (WSP) is a wastewater treatment technology that relies solely on ecological processes (Nelson and Murray, 2008). There are three types of WSP in common use, i.e., anaerobic, facultative and maturation ponds, and these are arranged in series (Peña and Mara, 2004). WSP is widely used in developing countries due to its very high efficiency in pathogen removal and low cost of construction and maintenance (Kivaisi, 2001). Experiences in Brazil show that although treatment technologies with proven efficiency in developing countries are selected,

there is still no guarantee of a satisfying performance of wastewater treatment plants in practice (Von Sperling and Oliveira, 2009). The observed poor performance of treatment facilities cannot be attributed to the treatment processes per se but rather to design, operational and maintenance problems (Oliveira and Von Sperling, 2008). The same observation was made for sanitation infrastructure in Paraguay (Cuppens *et al.*, 2013). Although technically well-designed, the sanitation infrastructure in reality was degraded and not working as planned. This represents a constant threat to the environment and public health. The lack of water quantity and quality monitoring data makes decision-makers unaware of the current performance of wastewater treatment systems.

For WSP, possible causes of decreased treatment performance are organic overloading and the occurrence of hydraulic short-circuiting and dead zones. In order to efficiently diagnose these phenomena, the traditional approach to WSP monitoring, consisting out of the analysis of grab samples taken at the in- and outlet, does provide too limited information. In order to obtain a thorough understanding of the internal processes and their impact on the overall treatment performance, measurement of relevant variables at different locations within the WSP should be carried out.

A conventional method for the collection of monitoring data in WSP is manual measurement from a small manned boat. However, for the individual pond size typically encountered for WSP in Paraguay (between 0.8 and 3 ha), this method seems less practical and time-consuming. In addition, this method carries the inherent risks of potential exposure to pathogens and disturbing the water column stratification (McLaughlin *et al.*, 2014). Recently, unmanned boats have been deployed for water monitoring purposes. Initially, these *autonomous* surface vehicles (ASV) were large and costly. Recent developments, however, demonstrate the feasibility of small-scale and low-cost ASVs for monitoring in operating environments like lakes, rivers, canals and floods (Valada *et al.*, 2014).

In ongoing research, a prototype of a low-cost ASV for WSP monitoring was developed. The ASV is capable of navigating autonomously along a predefined trajectory based on geographic coordinates, and, meanwhile, performing measurements at multiple locations within the WSP. Currently, a more robust version of the ASV is being constructed, which will be applied for the collection of monitoring data at real-scale WSPs in Paraguay. In this extended abstract, the design methodology and technical details of the ASV prototype are presented, followed by a discussion of the first results. Finally, specific applications of the ASV for WSP monitoring are presented.

Materials and methods

Design approach

Taking into account the challenging circumstances inherent to wastewater management in developing countries (Cuppens *et al*., 2013), the following guidelines for the design and construction of the ASV were defined:

- Use of low-cost and commonly available construction materials. In addition to maintaining the costs as low as possible, it guarantees access to replacement parts in case the ASV gets damaged.
- Use of open-source hardware/software for the autonomous navigation capability. The benefits are 1) low cost of the electronics, 2) access to vast amount of online information and 3) peer-support by the open-source community.
- Use of open-source hardware for datalogging. The ability to connect any sensor to the ASV provides flexibility to the user. A single open-source datalogger makes it unnecessary to buy a customized datalogger for each individual sensor.
- The ASV must fit comfortably within a standard car and must be easy to transport.

Components of the ASV prototype

The design concept of a catamaran was selected for the ASV platform (See **Figure 1**) because multihull vessels demonstrate better navigation behavior and higher stability in comparison with monohulls (Luhulima *et al.*, 2014). The propulsion mechanism based on wind thrust was placed on top of the ASV in order to reduce the disturbance of the water column. The pontoons consist of 2 PVC pipes **(1)** connected by plywood **(2)**. On top of the upfront plywood, plastic waterproof containers **- (3)**, **(4)** and **(5) -** containing the electronic devices were attached. The main components of the propulsion system are a steering servo **(6)** and a brushless DC motor with propeller **(7)**. A pair of steel rods **(8)** links the servo to the motor mount, which is composed by a small diameter PVC pipe standing vertically **(9)** over a furniture caster **(10).** As such, the servo controls the rotation of the motor mount and attached DC motor with propeller. A safety cage **(11)** made from the top of a bucket and a steel grid was incorporated for protecting the operator against the propeller.

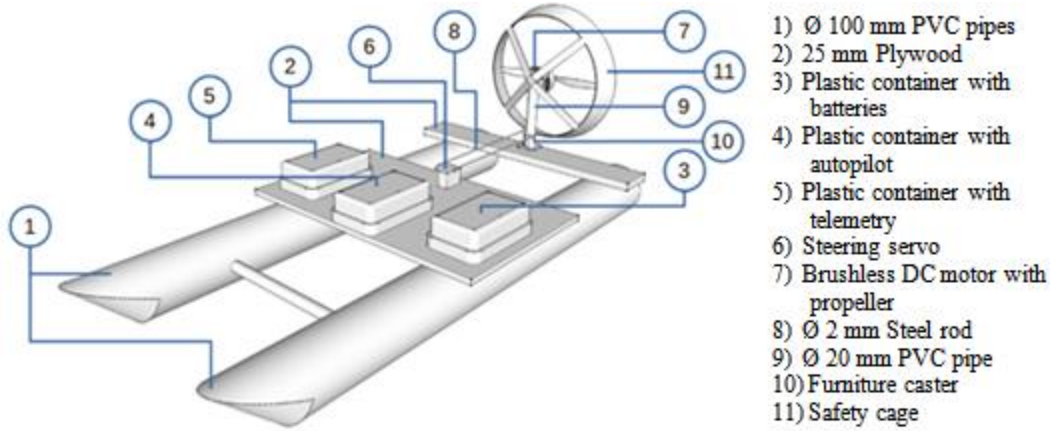

Figure 1. Main components of the ASV prototype

A schematic representation of the autopilot and the connections to peripheral electronic devices is presented in **Figure 2**. The open-source autopilot Pixhawk (3DR, 2016) was selected for achieving the autonomous displacement capability along a trajectory of predefined geographical coordinates called waypoints. The autopilot continuously receives information about the actual position of the ASV from a GPS sensor. Based on the comparison of the actual position and the next waypoint, adjustments are made to the steering in order to navigate the ASV towards the next waypoint. Sensors as compass, gyros and accelerometers, assist in achieving this objective. Via radio telemetry, the position of the ASV can be monitored in real time within the open-source ground control software Mission planner (Oborne, 2016) installed on a notebook. Adjustments to the planned trajectory can be made at all time.

The Pixhawk allows the connection of various types of external sensors (e.g., analog, digital and serial). Hence, the user can connect the sensor most suitable for the planned monitoring activity. The monitoring data and associated GPS coordinates are logged into a micro SD card. This information can be visualized in real time by the ground control software.

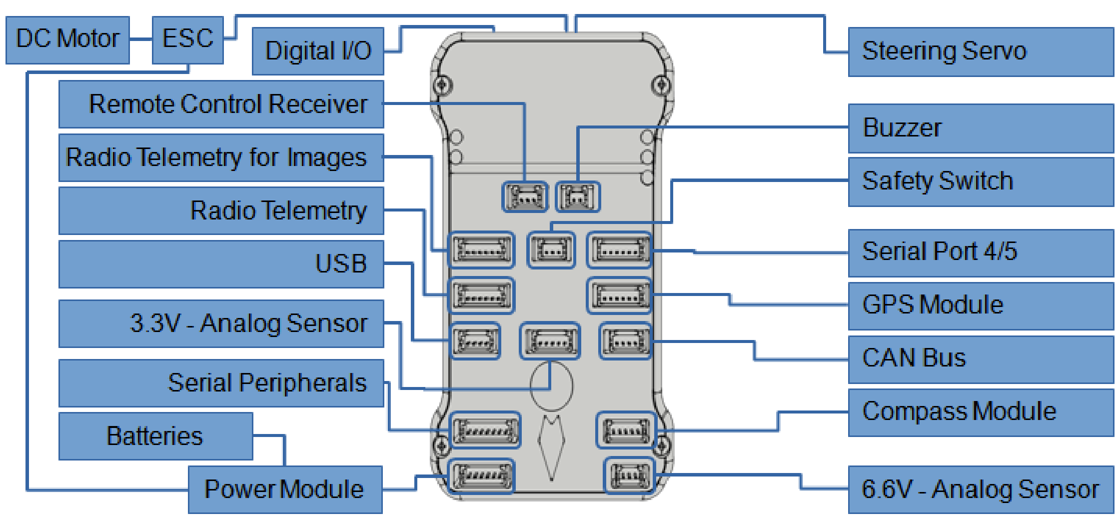

Figure 2. Schematic representation of the autopilot and connections to peripheral devices

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Results and discussion

The prototype of the ASV, as presented in **Figure 3**, meets the requirements for its intended working environment:

- Compact: The outer dimensions of 1000 mm (length), 500 mm (width) and 450 mm (height) allow the ASV to be transported in a standard vehicle. The total weight of 4.5 kg facilitates handling by 1 person.
- Low-cost: The total cost of the ASV is approximately US$ 900; US$ 875 for electronics and US$ 25 for the materials. The most costly components are the Pixhawk (US$ 249), the telemetry set (US$ 129) and the GPS uBlox (US$ 119).
- Easy to build: The ASV was built by a last-year engineering student without an electronic engineering background. The required time -including testing- was approximately 4 months. With access to the material list and construction plans, the required construction time by a third person will significantly reduce.
- Flexible integration of external sensors: Due to the open-source nature of the ASV platform, the user can integrate any type of sensor according to the monitoring needs.

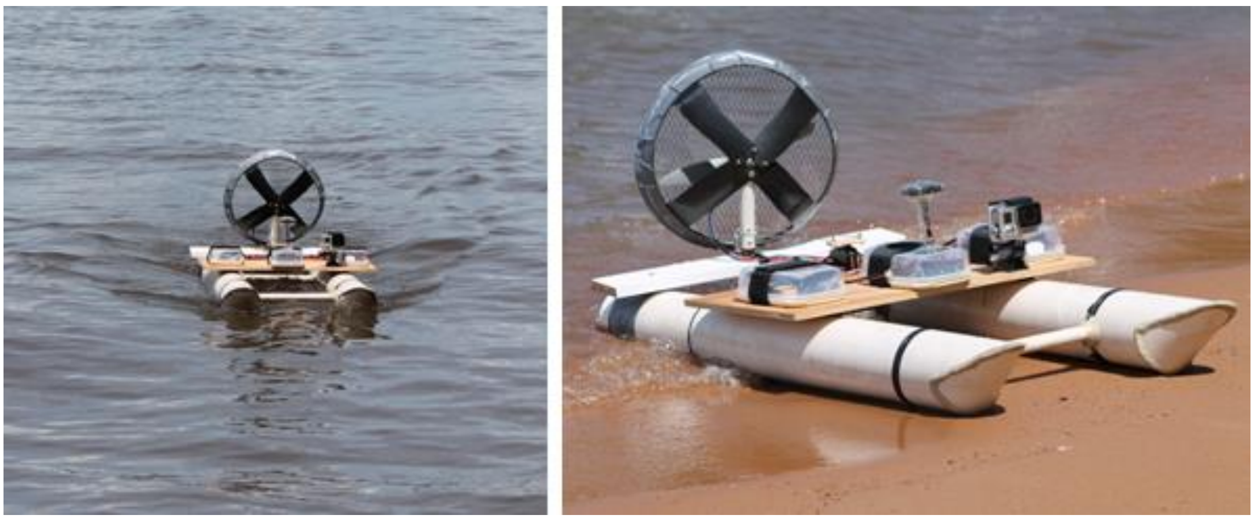

Figure 3. Testing of the ASV prototype

The results of the first trials (See **Figure 4**) demonstrate that the ASV prototype was able to follow the predefined trajectory with a very low turning radius at the waypoints. The ASV can navigate for approximately 20 minutes with an average speed of 2.6 km/h, which means a trajectory of at least 860 m.

Although the autonomous displacement capability was considered satisfactory, several limitations were identified:

- The low-height of the prototype represents a potential risk during higher waves. A second version of the ASV is being built in order to increase the height and robustness.
- The prototype only provides space for 1 battery, limiting the endurance. In the second version of the ASV space is foreseen for a total of 4 batteries. Other sources of energy (like solar energy) will be investigated for achieving longer operational duration.
- A lightweight and low-cost winch needs to be incorporated into the ASV in order to enable the letting out and pulling in sensors. As such, measurements at different depths can be realized.

Figure 4. Screen view of the *Mission Planner* (Oborne, 2016). The home point represent the start and stop location of the mission. The green numbered symbols indicate the sequence of user-defined waypoints. The yellow and purple line represent respectively the predefined and real ASV trajectory.

Applications for WSP monitoring

Given its open-source nature, the ASV serves as a flexible tool for a variety of measurement. Some specific applications for WSP monitoring are:

- Measurement of water temperature at different locations and depths to monitor thermal stratification.
- Measurement of pond depth throughout the pond to monitor sludge accumulation.
- Measurement of DO concentration at different locations and depths to detect aerobic/anaerobic conditions.

In ongoing research, the ASV will be applied to measure tracer concentration at locations within WSPs. The mapping of the tracer distribution within the pond itself is a valuable source of information for improved understanding of the internal flow patterns (Broughton and Shilton, 2012).

Conclusion

Quantitative monitoring data are critical for detecting and understanding the causes of underperformance of existing wastewater treatment systems in developing countries. In addition, monitoring data are of great value for daily operation and for the elaboration of a long-term management strategy (Cuppens *et al.*, 2013). In the case of WSP, it is recommended to realize measurements at multiple locations and depths within the ponds, in addition to the traditional monitoring of the influent and effluent. A promising technology therefore is a compact ASV capable of navigating autonomously along a predefined trajectory based on geographic coordinates, and, meanwhile, realizing measurements by means of integrated sensors. In ongoing research, a prototype of a low-cost and open-source ASV was developed specifically for WSP monitoring. During the design and construction process, the challenging circumstances inherent to wastewater management in developing countries were taken into account. The open-source nature allows the integration of any type of sensor according to user needs. Hence, the ASV can be applied as a low-cost tool for a variety of WSP monitoring applications.

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