SBSD: Towards a Proactive Sensor-Based Schistosomiasis Detection

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Abstract. After the malaria, Schistosomiasis or Bilharzia is the second disease that calls for admission to hospital. In fact, the Schistosoma that transmits the illness lives in water points. The proposed Sensor-Based Schistosomiasis Detection (*SBSD*) architecture considers data collected by several sensors such as water temperature, water point pH, solar irradiation that are deployed in a natural environment, in order to develop more-sensitive disease-prediction and control-model. The main goal is to stop the transmission cycle of Bilharzia by forbidding the access of water point, for treatment, when the environmental factors are favourable.

Keywords: Schistosomiasis · Sensors networks · Internet of Things

Schistosomiasis or Bilharzia is a parasitic disease affecting more than 200 million people distributed over 76 world countries [1]. In sub-Saharan Africa, 165 million people are affected which represent roughly 82.5% of the people reported to be infected all over the world. The main reasons are due to the spread of hydraulic developments and the fact that daily life activities in rural areas are done around water points. Furthermore, the lack of safe drinking water and sanitary infrastructure increase human water contact. Consequently, water point can be contaminated by human faeces and urine.

The urinary and intestinal Schistosomiasis is a significant public health problem in Senegal with a prevalence rate varying between 0.3% and 1%. In Senegal, the treatment is based on Praziquantel that is not effective and may aggravate symptoms. The epidemic of intestinal schistosomiasis in Richard Toll region after the newly built dams of Diama and Manantali on the Senegal River and the related irrigation projects is now legendary in Africa [2]. Actually, the bilharzia life cycle is based on physical and chemical factors [3–6]. The physical factors include temperature, solar irradiance, water movement, water-level fluctuation and desiccation, depth of water; whereas the chemical factors, such as salinity, the ion balance, the hydrogen-ion concentration, are measured within the water point where the intermediate hosts that transmit the bilharzia are living.

Despite the efforts made by the World Health Organization and the Bilharzia local control programs, the number of patients infected remains constant

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in Africa. The diagnosis of Bilharzia, if the patients go to health centres, is performed by the microscopic examination of urine or faeces in order to demonstrate the presence of eggs. Quite often, without symptoms and morbidity, rural people that have Positive serology do not go to hospital for diagnostic, and then continue to infect water point. In the case of positive diagnostic, the treatment can be done by chemotherapy or prophylaxis. According to chemotherapy approach, the Praziquantel treatment is efficient in the situation of low outbreak and reinfection. Nevertheless, in the case of high morbidity and reinfection, as observed in Richard Toll in northern Senegal, the Praziquantel has very low cure rates [1]. Furthermore, the Praziquantel has no impact on immature schistosome and eggs [1]. Recent studies [7,8] showed that existing drugs such as Praziquantel and Arthemeter are not effective against acute Bilharzia.

Therefore, prophylaxis approaches should be more investigated. So far, existing solutions are based on: *i* the use of chemicals such as copper sulfate in order to destroy the snails that act are intermediate hosts. This solution can break the ecosystem of water points; *ii* The improvement of sanitation and the implication of women committee and social economical stakeholder in rural areas. These solutions are not very efficient due to the lack of information in real time of infected water points and the identification of people that require priority treatment. Therefore, we promote the use of Wireless Sensors Networks (WSN) that enable continuous and remote monitoring of water points [9]. During the last decade, WSN are widely used for surveillance and monitoring [10,11].

Our Sensor-Based Schistosomiasis Detection ($SBSD$) architecture aims to remotely monitor physical and chemical environment factors of water points in order to determine environmental changes. To the best of our knowledge, $SBSD$ is the first tool that is deployed, tested in a natural environment and is able to predict in real time the potential risk of bilharzia transmission.

The remainder of the paper is structured as follows. Section 1 discuss the bilharzia life cycle transmission and the background on design metrics. In Sect. 2, we introduce the $SBSD$ architecture and its methodology to use sensors networks with Internet or 3G network to monitor water point. Following that, we present in Sect. 3 our experimental results. Finally, Sect. 4 concludes this work.

1 Background on Design Metrics

The bilharzia life cycle is based on physical and chemical factors. Climate factors, including water temperature, water pH, solar irradiance, have a significant effect on freshwater snails population dynamics [4–6].

According to the bilharziasis life cycle transmission, the solar irradiance plays an important role when the eggs are released, by an infected person, on contact with water points. Indeed, the diurnal light intensity has a great impact on the maturation of eggs [3]. Furthermore, a more recent work [5] shows the correlation between the light intensity and the breeding of snails. Moreover, the breeding includes the following milestones: oviposition, larvae, and youth. The light intensity has a stimulating action on the reproduction between adult snails and the growth of larvae and young forms. The mean solar irradiation in Senegal is roughly equals to 242 µmol/m^2/s[1] which represents a solar irradiance of 5, 8 kWh/m^2/day. Therefore, this value illustrates a high degree of light intensity.

On the other hand, chemical factors including salinity, ion balance, hydrogen-ion concentration have a deep effect upon breeding conditions of snails. A water pH range from 6.5 to 8.5 is mandatory for an optimal conditions of development of most aquatic organisms [6]. For instance, the optimum water pH, according to favourable breeding conditions, for Bulinus snails (respectively Biomphalaria) lies between 6.0 to 6.5 (respectively 7.0 to 8.2) [3].

Finally, the water temperature has an important role in solubility of gases such as oxygen necessary for the balance of aquatic life. The metabolic activity of aquatic organisms is also accelerated according to the fluctuations of temperature. If the temperature of the water is warm enough during a long period, the freshwater snails that transmit schistosomiasis are able to growth up in suitable condition. The optimal temperature that enables favourable breedings is measured between 25 °C to 28 °C [3,4]. Afterwards, when the temperature ranges from 28 °C to 30 °C, the conditions are unfavourable. In such away, the breeding ceases [3]. Nevertheless, a temperature upper than 42 °C, during two hours, causes snail's death [4].

As summary, a correlation is noted between schistosome vectors, water pH, water temperature and solar irradiance. Thereupon, by measuring these parameters with WSN, we can whenever determine: *(i)* if the condition are favourable for the maturation of eggs; *(ii)* whether the intermediate hosts freshwater snails can still alive, growth up optimally; *(iii)* even if a successful breeding of snails is possible. We aim to predict whether physical and chemical factors are favourable to the bilharzia transmission life cycle by deploying an efficient wireless sensors network.

2 Sensor-Based Schistosomiasis Detection (SBSD) Description

Figure 1 depicts our general architecture which enables to measure different physical and chemical environment factors. This architecture is formed by three main layers called application layer, network layer, and perception layer.

The application layer contains two sub layers. The first one is dedicated to users that request different kind of information and the second one represents the service management layer which contains several servers that manage the whole architecture. Afterwards, the goal of the network layer is to route the collected information from the data acquisition modules which are located at the perception layer towards the service management sub layer where information are gathered.

It should be noted that in this work only the sensors module located in the collecting layer is considered (Fig. 1). Therefore, water temperature, water pH,

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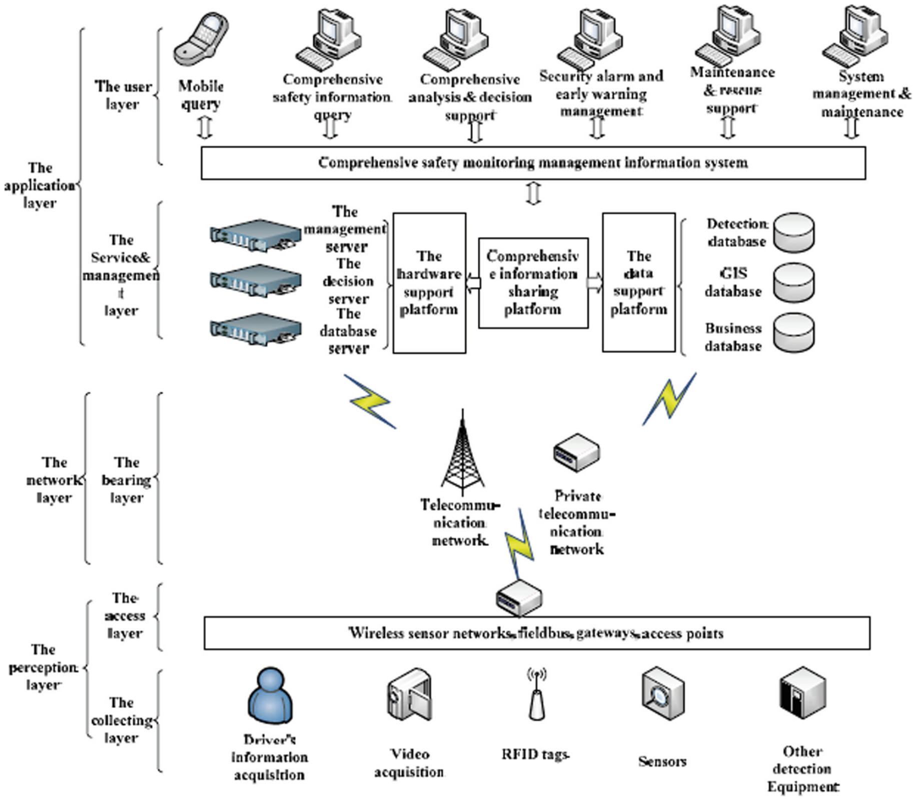
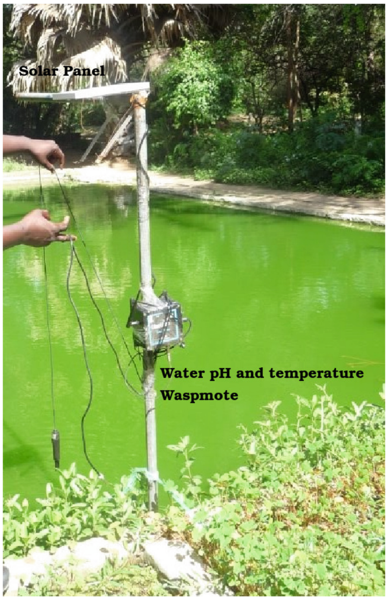


Fig. 1. SBSD architecture.

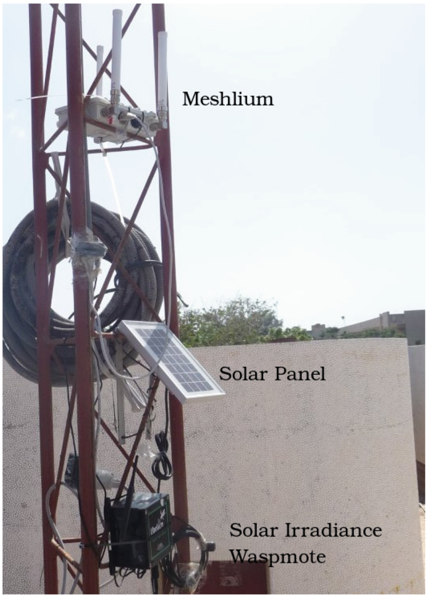
and solar irradiation sensors are used during the first evaluation phase of the *SBSD*. The data acquisition (*"DAQ"*) architecture is formed by a DAQ module that can embed different type of sensors. Wireless sensors networks are usually energy-constrained networks. Therefore, we consider DAQ modules which use solar panel as power supply.

In our context, the *Waspmote* [12] is chosen as DAQ module. A *Waspmote* is just an enhanced *Libelium* [12] mote which is used for wireless sensors networks. Thence, the deployed sensors are *Waspmote* type and connected directly to the DAQ module (Fig. 2(a)).

Two *Waspmote* devices have been used during the test. The first one embeds the pH and temperature sensors, whereas the second one hosts the solar irradiance sensor. Figure 2(a) shows the water pH and water temperature which are connected to the Waspmote. The embedded battery in the Waspmote is charged by an external solar panel. This kit measures the water pH and the water temperature, and then sends the collected data to a gateway. Figure 2(b) illustrates the solar irradiance sensors with its external solar panel.



(a) Water ph and temperature measurement kit



(b) Meshlium gateway and solar irradiance measurement kit

Fig. 2. Data acquisition in SBSD architecture.

Afterwards, the data collected by our two *Waspmotes* are sent to the *Meshlium* device which is fixed on the top of the pylon (Fig. 2(b)). It represents a gateway router for *Waspmotes* sensor networks. It is worth noticing that the *Meshlium* is a Power over Ethernet network device. It receives in its local *MySQL* database the data sent by *Waspmotes's* via the ZigBee-Pro protocol. Additionally, the *Meshlium* re-transmits, in a fixed interval time, these data towards an external database or a Cloud platforms by using either its Ethernet or 3G interface. Indeed, according to our SB^{2}D architecture, we used the Internet network and an external *MySQL* database.

3 SBSD Evaluation

3.1 Experimental Settings

The botanical garden of University Cheikh Anta Diop is used as real environment experimental test bed before the deployment in the Richard Toll area. The water point (Fig. 2(a)), where the *Waspmote_1* is deployed, is located within the botanical garden. The *Waspmote_2* as well the *Meshlium* gateway are placed on top of the roof of the Computer Science Building. The *Waspmote_1* (respectively *Waspmote_2*) sends the pH and water temperature (respectively the solar irradiance). The distance as the crow flies between the targeted water point and the Computer Science building is approximately 200 m.

The *Waspmote* device embeds several hardware components such as an *ATmega1281* microcrontroller running at 14 MHz, a *Xbee-ZB-Pro* transmitter using the *ZigBee-Pro* protocol [13] within the 2.4 GHz frequency. The ZigBee-Pro is an enhanced version of *ZigBee* technology which is based on the IEEE 802.15.4 standards [10]. ZigBee-Pro has the ability to provide low-power wireless connectivity as well to manage large networks having up to thousands nodes.

The dataset we consider is obtained during a period of 2 weeks in early July 2016. The frame sent by *Waspmote* has a length of 128 octets and contains several information including "ID"'s *Waspmote*, frame type, frame number, type of sensor, measured value, battery voltage, timestamp, etc. The sampling interval is fixed to 1 min (respectively 2 min) for *Waspmote_1* (respectively *Waspmote_2*). Moreover, the sampling rate is a tuning parameter. The frames sent by *Waspmote* are received by the *Meshlium* by the intermediate of its XBee ZigBee radio interface.

Thereafter, a Sensor Parser software parses the frames and store the data in the *Meshlium*'s database. Finally, in each interval of 1 min the received data are synchronized with an external *MySQL* database by using a fixed couple of internet IP address and port number. The stored information can be accessed from a Web user interface. In order to reduce experimental cost, *Meshlium*'s Ethernet interface is used during the data transfer. Notwithstanding, its 3G radio interface has been successfully tested.

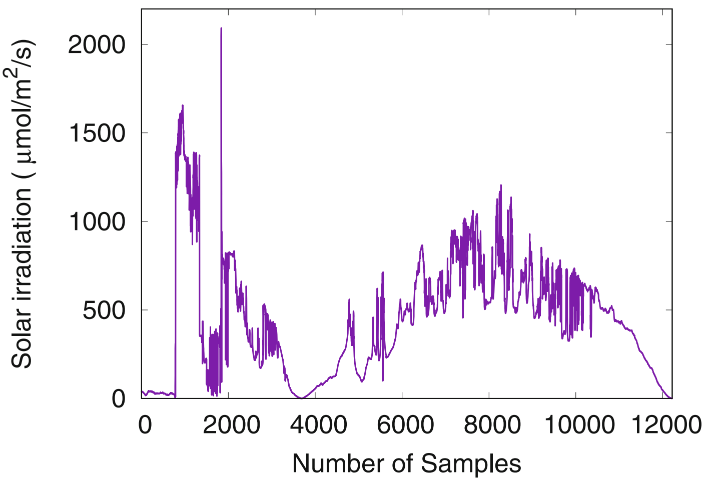


Fig. 3. Solar irradiance.

3.2 Results

According to Figs. 3 and 4 the x-axis depict the obtained number of samples as function of timestamp during the measurements campaign; whereas the $y-$axis represent the measured values either for the solar irradiance (Fig. 3), or the

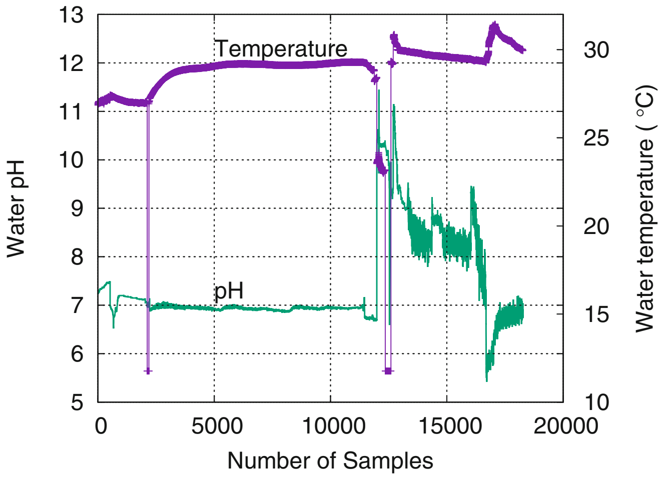


Fig. 4. Water pH and water point temperature.

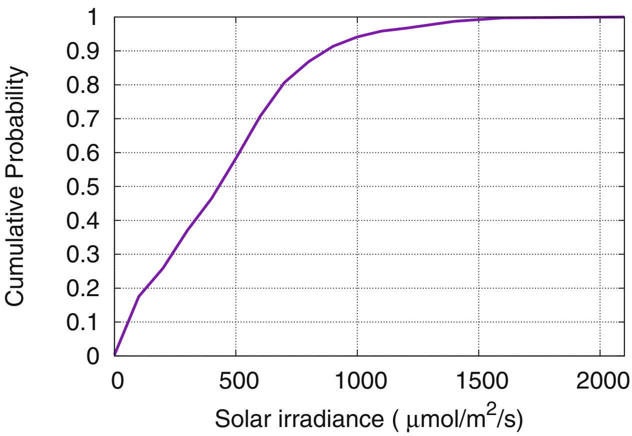
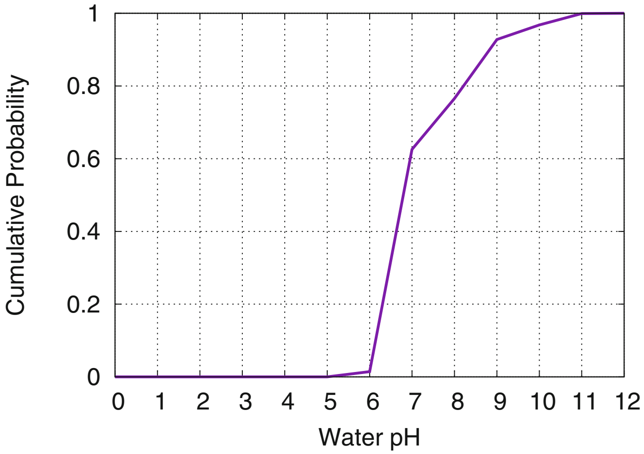


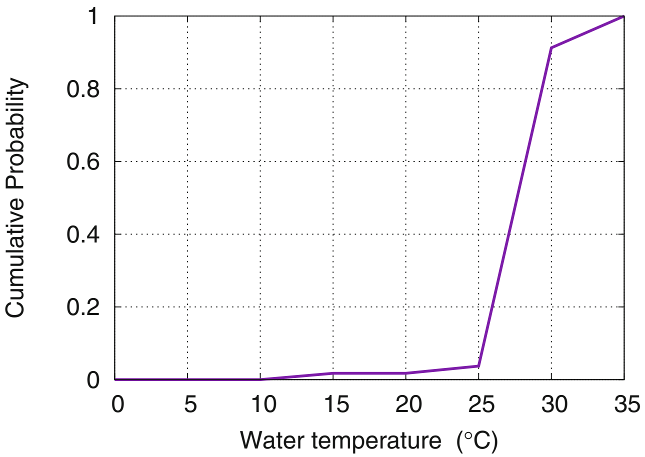
Fig. 5. CDF of solar irradiance.

water pH or water temperature (Fig. 4). Figure 3 illustrates the solar irradiance as function of number of samples. For instance, a value of 0 means that there is no measured light intensity. Figure 4 illustrates the water temperature and the water pH as function of number of samples.

Figure 5 provides the CDF (Cumulative Distribution Function) of the solar irradiance. According to More than 40% of measurements have a irradiation upper than 500 μmol/m^2/s which means very high light intensity. It should be noted that July month belongs the dry season in Senegal where the temperature is very high.



(a) Water ph



(b) Water temperature

Fig. 6. Cumulative Distribution Function.

Figure 6(a) provides the CDF of the water pH. More than 60% of samples are a pH roughly equal to 7 that means a neutral water during this period. About 20% of samples have a pH value upper than 8. It should be noted that a favourable breeding conditions of intermediate hosts snails lies between 6.5 to 8.5 (Sect. 1).

Figure 6(b) provides the CDF of the water point temperature. 60% of obtained samples have a temperature less than 28 °C. In contrast, 40% of samples are upper than 28 °C which means an unfavourable breeding conditions. Indeed, the temperature should be warm enough (*i.e.*, between 25 °C to 28 °C) during a long period in order to enable the snail's maturation from oviposition to youth.

According to obtained results during the two early weeks of July, we can stipulate that the combination of physical and chemical factors are favourable to the breedings conditions of intermediate hosts snails with respect to a couple of days.

4 Conclusion

SBSD tool provides a potentially vital capability for use by disease control program managers, particularly in less-developed countries. This tool detects contaminated water source, and thus enables to take proactive decisions such as prohibit the infected area, or prevent the miracidium to infect the mollusc or the parasitic larvae to enter through the skin of humans. Therefore, we are able to stop the transmission cycle of schistosomes. We considered a high sampling rate.

For instance, we plan to analyze the measurement of one year, in order to find what is the appropriate sensing rate in order to reduce the amount of gathered data. In parallel, according to the Sensor-Based Bilharzia Detection project we aim to deploy the *SBSD* architecture in different water points located in the Richard Tool area. This deployment can help to reduce the infection rate and the morbidity with respect to the Schistosomiasis. An alert system should be designed in order to inform rural population. In such situation, we expect to use rural radio or and *SMS* as communication media.

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