IoT based Schistosomiasis Monitoring for More Efficient Disease Prediction and Control Model

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***Abstract*—The urinary and intestinal schistosomiasis are a significant public health problem in Senegal with a prevalence rate varying between 0.3% and 1%. After malaria, bilharzia (or Schistosomiasis) is the second disease that calls for admission to hospital. In Senegal, treatment is based on "$Praziquantel$" that is not effective and may aggravate symptoms. In fact, schistosoma that transmits the illness lives in water points. Firstly, our proposed Sensors-Based Bilharzia Detection (SB^{2}D) architecture uses data collected by wireless sensors network that are deployed in natural environment. SB^{2}D is able to collect in real time different physical and chemical parameters such as solar irradiation, water temperature, water point pH and then predicts whether the environmental factors are favourable to bilharzia life cycle transmission. Secondly, event detection algorithms were developed in order to assess the transmission contamination risk when anomalies are detected. The obtained results show that *Support Vector Machines* (SVM) gives good anomalies detection rate compared to other anomalies detection test.**

I. Introduction

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.

An intestinal schistosomiasis epidemic in Richard Toll region after a newly built dams of $Diama$ and $Manantali$ on Senegal River and related irrigation projects is well known in Africa [2]. Actually, bilharzia life cycle is based on physical and chemical factors [3], [4], [5]. Physical factors include temperature, solar irradiance, water movement, water-level fluctuation and desiccation, depth of water; whereas chemical factors, such as salinity, ion balance, hydrogen-ion concentration, are measured within water point where intermediate hosts that transmit bilharzia are living.

Despite efforts made by World Health Organization and the Bilharzia local control programs, the number of patients infected remains constant in Africa. Bilharzia diagnosis, if the patients go to health centers, is performed by performing microscopic urine examination or faeces in order to figure out eggs presence. 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, a treatment can be done by chemotherapy or prophylaxis. According to chemotherapy approach, $Praziquantel$ treatment is efficient in situation of low outbreak and reinfection. Nevertheless, in case of high morbidity and reinfection, as observed in Richard Toll in northern Senegal, $Praziquantel$ has very low cure rates [1]. Furthermore, $Praziquantel$ has no impact on immature schistosome and eggs [1].

Recent studies 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 consist in:

- Using chemicals such as copper sulfate in order to kill the snails that act are intermediate hosts. This solution can break the ecosystem of water points.
- Improving sanitation and involving 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.

New generation of Micro-Electro-Mechanical Systems promotes the development of smart sensors that use energy efficiently and facilitate remote applications like tracking (e.g., animal or human tracking, traffic tracking, car or bus tracking) or monitoring (e.g, environmental monitoring, patient monitoring, animal monitoring, structural monitoring, inventory monitoring) [6], [7]. During last decade, IoT-based applications are widely used for surveillance and monitoring [8], [9], [10], [11], [12]. Therefore, we promote the use of Internet of Things (IoT) based applications that enable continuous and remote monitoring of water points.

The contributions of this paper are twofold. Firstly, the designed Sensor-Based Bilharzia Detection (SB^{2}D) architecture aims to remotely monitor the status of water points in order to determine environmental changes. The main goal is to stop bilharzia transmission cycle by forbidding water point access, for treatment, when the environmental factors are suitable. SB^{2}D architecture was deployed and tested in a natural environment. The proposed epidemiology tool uses data collected by a set of sensors, including pH water, water temperature, solar irradiance, in order to develop more-sensitive disease-prediction and control-model. SB^{2}D architecture is based on $GSM/3G/GPRS$ mobile cellular network and Web Services technology. It integrates a gateway router designed to connect sensors network to the Internet by using $Ethernet$ and *3G/GPRS* connectivity. In contrast to [9], sensors network embed *GSM* module to enable communication using $ShortMessageService$ (SMS). In fact, according to several Senegalese areas, where we plan to deploy SB^{2}D, we note a lack of $3G$ cellular network.

Furthermore, by considering three popular machine learning-based approaches (*Random Forest*, *Artificial Neural Network*, *Support Vector Machines*) that achieve excellent performance [13], we build a detector which identifies outliers in collected data set. In fact, a correlation is noted between schistosome vectors, water pH, water temperature and solar irradiance [1], [4]. Therefore, there exist a couple of measured values within a fixed interval which means that conditions are favourable to bilharzia transmission life cycle. Indeed, when retrieved data from deployed sensors fall outside this interval there is no contamination risk. After calibration, proposed machine learning tools are able to detect anomalies that deviate from common statistical properties of a distribution and then trigger alerts. Consequently, local authority can quarantine involved water points for treatment.

The remainder of the paper is structured as follows. Section II and III illustrate bilharzia life cycle transmission and our designed metrics. In section IV, we introduce the SB^{2}D architecture and its methodology to use wireless sensors networks with Internet or mobile cellular network to monitor water point. Following that, Section V depicts the results of used anomalies detection tools. Section VI concludes this work.

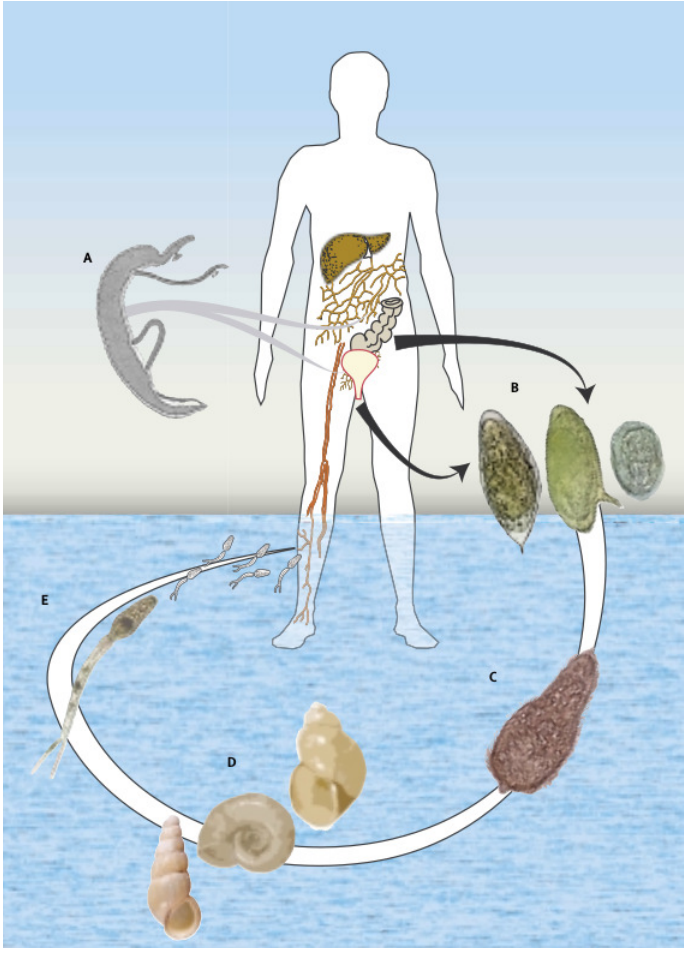

Fig. 1. Transmission cycle of Bilharzia.
Derived from Gryseels et *al.* [1].

II. The Bilharzia life cycle transmission

Fig. 1 illustrates a transmission cycle of schistosoma Mansoni. During the first step, eggs are excreted in the urine or faeces of an infected person. They are viable up to one week. For instance, three types of eggs, called respectively from left to right schistosoma haematobium, schistosoma mansoni, schistosoma japonicum, are depicted in Fig.1 with the tag labelled “B".

The ecosystems transformation create favorable habitats for the development of intermediate freshwater snails that host the miracidium released by the eggs on contact with water points [1], [14]. Miracidium (respectively snails) are illustrated by the tag “C" (respectively “D") in Fig.1.

Fig.1 shows three type of intermediate hosts snails. From left to right we have : Oncomelania, Biomphalaria, and Bulinus. In northern Senegal, in Richard Toll region, five types of freshwater snails (e.g., Bulinus Senegalensis, Bulinus Umbilicatus, Bulinus Globosus, Bulinus Truncatus, and Biomphalaria Pfeiffeiri) that can host the parasite are present [2].

In fact, a given mirarcidia becomes a cercariae larvae within the snail. It should be noted that $4-6$ weeks after the infection, cercariae are released within water point (the tag labelled “E" in Fig.1). They can penetrate actively a skin through proteolytic secretion of a definite host up to 72 h [1]. Afterwards, cercariae transform into males or females schistosomes (the tag labelled “A" in Fig.1) and the transmission cycle start again. Note that infesting eggs are produced by females. Put simply, human host the virus and participate actively in the spread of schistosomiasis. Gryssels et *al.* argue that an adult schistosome lifespan varies between 3 to 5 years. Nevertheless, it is possible to reach 30 years [1].

III. Background on design metrics

A 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], [5].

According to bilharziasis life cycle transmission, solar irradiance plays an important role when eggs are released, by an infected person, on contact with water points. Indeed, diurnal light intensity has a great impact on the maturation of eggs [3]. Furthermore, more recent work [4] shows the correlation between the light intensity and the breeding of snails. Moreover, breeding includes following milestones: oviposition, larvae, and youth. Light intensity has a stimulating action on reproduction between adult snails and the growth of larvae and young forms. It is worth noticing that mean

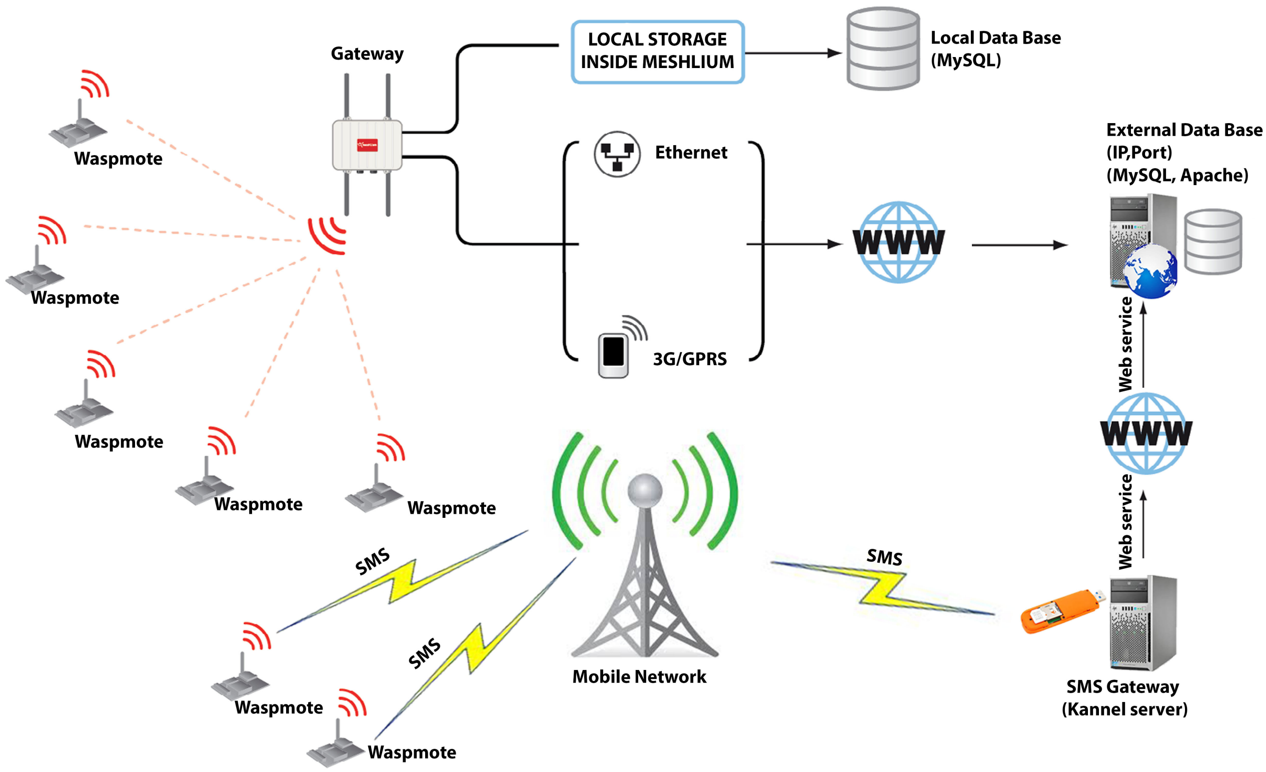

Fig. 2. SB^{2}D framework.

solar irradiation in Senegal is roughly equals to 242μmol/m^2/s [15] 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 8.2 is mandatory for an optimal conditions of development of most aquatic organisms [5]. For instance, the optimum water pH, according to favourable breeding conditions, for Bulinus snails (resp. Biomphalaria) lies between 6.0 to 6.5 (resp. 7.0 to 8.2) [3].

Finally, water temperature play 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 water temperature 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]. Afterwards, when temperature ranges from $28°C$ to $30°C$, conditions are unfavourable. In such away, the breeding ceases [3]. Nevertheless, a temperature upper than $42°C$, during two hours, causes snail's death.

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

IV. Sensors-Based Bilharzia Detection SB^{2}D Framework

Fig. 2 illustrates our deployed SB^{2}D framework.

- A data acquisition module called *Waspmote* which can plug several types of sensors. Collected data are sent by a $Waspmote$ device either via $ZigBee$ [16] protocol towards a gateway or by SMS via GSM network towards a *Kannel* server which acts as SMS gateway.
- Our network infrastructure is formed by a $GSM/3G/GPRS$ mobile network and an $Ethernet$ network. The used gateway, called *Meshlium*, can send gathered data to an external data base by using its $3G/GPRS$ interface or $Ethernet$ interface. By default, an $Ethernet$ connection is used. If SMS option is considered, data are processing by the local mobile network operator and send to a $Kannel$ server. Afterwards, web services are used in order to fetch collected data and then store it in a *MySQL* data base.
- A storage system is formed by a local storage $MySQL$ data base within a $Meshlium$ gateway or and external data base that can be used either by $Meshlium$ to backup gathered data or by $Kannel$ server.

The module depicted in Fig. 3 enables to measure physical and chemical environment factors. Water temperature, water pH, and solar irradiation sensors are used during the first evaluation phase of the SB^{2}D. The data acquisition (*DAQ*) architecture is formed by a DAQ module which embeds different type of sensors.

Since wireless sensors networks are usually energy-constrained networks, DAQ modules use a 5 watt solar panel. An embedded battery is available in $Waspmote$ which is charged by our external solar panel. It is worth noticing that a Lithium Ion battery pack of $3.7V$ and $6600mAh$ is used in order to deal with insufficient sunlight. The used battery has an autonomy estimated to 18 hours.

In our context, *Waspmote* [17] equipment is considered as a DAQ module. A *Waspmote* is just an enhanced *Libelium* [17] mote which is used by wireless sensor network. Thence, our deployed sensors are *Waspmote* type and are directly connected to DAQ module. During deployment, two *Waspmote* devices have been used during our test. The first one embeds pH and temperature sensors, whereas the second one hosts a solar irradiance sensor.

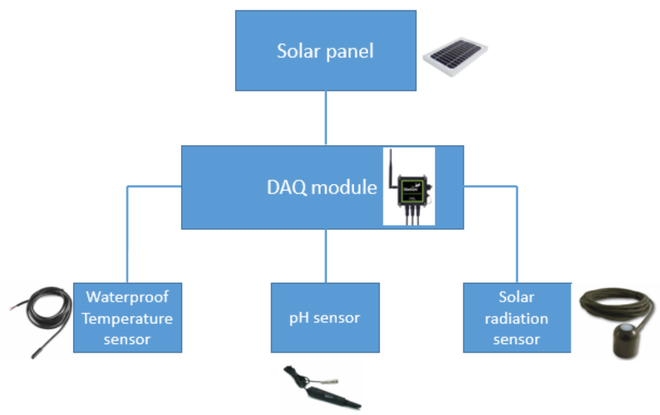

Fig. 3. Data Acquisition Architecture.

V. SB^{2}D EVALUATION

A. 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 considered *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 [16] within the 2.4 GHz frequency and a transmission range equals to 7 km. $ZigBee-Pro$ 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 deployed *Waspmotes* kit are equipped with three types of sensors and collected data by our two *Waspmotes* are sent to a gateway *Meshlium*. It represents a gateway router for *Waspmotes* sensor networks. It is worth noticing that *Meshlium* is a Power over Ethernet network device. It receives in its local *MySQL* data base data that are sent by *Waspmotes's* via the $ZigBee-Pro$ protocol. Additionally, *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 Internet network and an external *MySQL* data base where raw data set are processing. It should be noted that $3\tilde{}G$ connectivity and SMS option have been tested successfully during a couple of days. Nevertheless, in order to reduce experiment cost Ethernet connection was considered.

Table I illustrates the general characteristics of the used sensors. For instance, the temperature sensor probe is an analog sensor. The obtained analog voltage needs to be calibrated with respect to the standard references of our temperature sensor which range from $-40°C$, $+125°C$. According to the pH sensor probe, a combination of electrode provides a voltage which is proportional to water pH; whereas the solar irradiation sensor gives the global radiation which is the sum of the direct and diffuse components of solar irradiation. One site calibration has been done before the beginning of measurements.

We consider a dataset obtained during a period of two weeks. Each frame sent by a *Waspmote* has 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 minute (resp. 2 minutes) for *Waspmote*_1 (resp. *Waspmote*_2). Moreover, the sampling rate is a tuning parameter. The frames sent by *Waspmote* are received by *Meshlium* from its $XBee$ $ZigBee$ radio interface.

Thereafter, a Sensor Parser software parses the frames and store the data in *Meshlium*'s data base. Finally, in each interval of 1 minute the received data are synchronized with an external *MySQL* data base 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.

B. Results

We computed the CDF (Cumulative Distribution Function) of solar irradiance and we found that more than 40% of measurements have an irradiation greater than 500μmol/m^2/s which means very high light intensity. In Senegal, July month belongs to raining season where the temperature is very high. At the same time, based on collected water point 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 8.2 (Sec. III). On the other hand, 60% of obtained samples according to water point temperature have a

(a) pH sensor probe

Sensor type	Measurement range	Response Time	Alkali error	Reader accuracy
Combination electrode	$0 \sim 14$pH	$< 1min$	$15mv$	up to 0.01

(b) Temperature sensor probe

Measurement	Sensitivity	Accuracy	Response Time
$[-40°C, +125°C]$	$10mv/°C$	$\pm 2°C$ (range $0°C \sim +70°C$), $\pm 4°C$ (range $-40°C \sim +125°C$)	1.65 $seconds$

(c) Solar irradiation sensor probe

Responsivity	Maximum radiation output	Sensibility	Spectral range	Accuracy
$0.200mV/\mu mol/m^2/s$	$400mV(2000\mu mol/m^2/s$	$5.00\mu mol/m^2/s/mV)$	$400 \sim 700nm$	$\pm 5\%$

TABLE I
SENSOR'S SPECIFICATIONS.

temperature less that 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.

C. Leveraging anomalies detection tools

Based on Caruana *et al* studies [13], we considered three supervised anomalies detection techniques such as *Random Forest*, *Artificial Neural Network*, *Support Vector Machines*) that gave better results amongst several other techniques. Therefore, we build a detector which identifies outliers in collected data set. Indeed, by using timestamps present in raw data set, a training set is formed by considering several samplings interval.

Afterwards, means of water pH, water temperature, solar irradiance are computed within a fixed interval of 10 minutes. We obtained 2160 samples that are clustered based on their timestamps within different sliding windows equal to either 1 hour, or 2 hours, or 3 hours, or 6 hours. We considered the sliding window approach since the tool should monitor in real time targeted water points. By so doing, we are able to collect the status of water point during a fixed interval and then run our anomalies detection test in order to figure out if the water point should be quarantined and/or sprayed. It should be noted that training set values (original data set) are normalized ("scaled training set") between 0 and 1.

Finally, we considered R language and environment [18] in order to apply our learning algorithms with respect to raw data set.

According to [3], [4], [5], maturation of eggs and favourable breeding conditions of intermediate hosts snails are possible if and only if water pH range from 6.5 to 8.2 and water temperature between $25°C$ to $28°C$, and solar irradiance upper than 242 μmol/m^2/s. Therefore, our learning algorithms should detect if all theses three conditions are realized. We use the classical false/true positive/negative indicators in order to characterize the performance of our Anomalies Detection Test (ADT).

A false negative is a sample that has been wrongly classified by the ADT as negative, and has therefore been wrongly unsuspected. A false positive is a sample that has been wrongly suspected by the ADT. True positives (resp. true negatives) are positives (resp. negatives) that have been correctly reported by the ADT and therefore have been rightly suspected (resp. unsuspected). The number of false positives (resp. false negatives , true positives and true negatives) reported by the ADT is $\mathcal{T}_{\mathcal{FP}}$ (resp. $\mathcal{T}_{\mathcal{FN}}$, $\mathcal{T}_{\mathcal{TP}}$ and $\mathcal{T}_{\mathcal{TN}}$).

We use the notion of False Positive Rate ($\mathcal{FPR}$) which is the proportion of all samples that have been wrongly reported as positive by the ADT, and we have $\mathcal{FPR} = \mathcal{T}_{\mathcal{FP}}/(\mathcal{T}_{\mathcal{TN}} + \mathcal{T}_{\mathcal{FP}})$. In addition, True Positive Rate ($\mathcal{TPR}$) is the proportion of samples that have been rightly reported as anomalies by ADT, so $\mathcal{TPR} = \mathcal{T}_{\mathcal{TP}}/(\mathcal{T}_{\mathcal{FN}} + \mathcal{T}_{\mathcal{TP}})$.

Table II illustrates the performance of used anomalies detection technique. Indeed, SVM outperforms RF and ANN anomalies detection test. In fact, SVM is able to detect 100% of anomalies according to over all sliding windows. Nevertheless, by considering only a sliding window of 3 hours, its triggers 0.84% of false alarms. In contrast, ANN test has wrongly reported as positives several samples according to all considered sliding window. As consequence, water point will be unjustifiably in quarantine, and thus not used by rural population according to their day-to-day life work. RF test exhibits good detection rate. However, 11.11 of anomalies are not detected when data are collected by considering a sliding window of 1 hour.

VI. CONCLUSION

Schistosomiasis (bilharzia), one of the most relevant parasitoses of humans, is confirmed by microscopic detection of eggs in stool, urine, or organ biopsies after the infection of patient. SB^{2}D tool provides a potentially vital capability for use by disease control program managers, particularly in less-developed countries. Sensor-based Bilharzia Detection 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

(a) Random Forest (RF)

Sliding windows (Data training set collection)	1 hour	2 hours	3 hours	6 hours
$\mathcal{FPR}$ (%)	0	0	0	0
$\mathcal{TPR}$ (%)	88.89	100	100	100

(b) Artificial Neural Network (ANN)

Sliding windows (Data training set collection)	1 hour	2 hours	3 hours	6 hours
$\mathcal{FPR}$ (%)	5.7	11.93	9.32	6.9
$\mathcal{TPR}$ (%)	100	100	100	100

(c) Support Vector Machines (SVM)

Sliding windows (Data training set collection)	1 hour	2 hours	3 hours	6 hours
$\mathcal{FPR}$ (%)	0	0	0.84	0
$\mathcal{TPR}$ (%)	100	100	100	100

TABLE II
PERFORMANCE OF ANOMALIES DETECTION TECHNIQUES.

find what is the appropriate sensing rate in order to reduce the amount of gathered data. In parallel, according to the Sensors-Based Bilharzia Detection project we aim to deploy the SB^{2}D architecture in different water points located in Richard Tool at northern Senegal. This deployment can help to reduce the infection rate and the morbidity with respect to 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.

Currently, we are tuning the fixed sliding windows. In fact, if considered window data collection is large, it can promote a huge number of infection if the status of water point is favourable to bilharzia transmission life cycle. Therefore, it is mandatory to find a trade off between data collection window and anomalies detection test.

Furthermore, prediction anomalies test such as $ARIMA$ model and $exponential smoothing$ should be considered in order to detect in real time potential risks of transmission of schistosomiasis. We plan to consider deep artificial neural networks that can provide significant results with respect to pattern recognition and machine learning.

We further aim at seeking the proteolytic enzyme that can be excreted either by miracidium or cercariae in order to built specific biological sensors with manufacturer.

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