Title: **Field trials of the MANITS system for water pumps in Sierra Leone and The Gambia**

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Abstract:

*Many hand water pumps across Sub-Saharan Africa break down prematurely and remain out of service for significant periods of time. This issue has been well documented, with reports suggesting that between 20% and 65% of hand pumps in a number of African countries are broken. It has also been reported that broken hand pumps in this region have represented between $1.2 and $1.5 billion of ineffective investment over the last twenty years. Regular post-construction monitoring of remote water pumps can help address these problems. However, in many instances traditional monitoring programmes require regular site visits to remote locations, which can delay the implementation of repairs and place heavy time and resource demands on supervisory bodies. In response there has been an emerging interest in the use of mobile phone based technologies to monitor water pumps. The authors describe a new monitoring system, called MANTIS (**M**onitoring & **AN**alytics To **I**mprove **S**ervice), which is intended to be a context-appropriate monitoring tool for hand pumps in developing regions. The paper introduces field trials of this system*

that have been conducted in Sierra Leone and The Gambia. The unit relays 'near real time' operational data from the water pump via an SMS (Short Message Service) server to an accessible on-line platform.

1 Background

Many hand operated water pumps in Sub-Saharan Africa prematurely break down and remain inoperable for significant periods of time. This problem is well documented (Harvey and Reed, 2006; Jiménez and Pérez-Foguet, 2011; Carter, 2016; Bonsor *et al.*, 2015), with previous studies reporting between 20% and 65% of hand water pumps in a range of sub-Saharan countries as being broken, or out of use (RWSN, 2010). Over the last 20 years, it is reported that these broken hand pumps have represented between $1.2 and $1.5 billion of ineffective investment across this region (USAid, 2016). Regular post-construction monitoring of remote water pumps may help address some of these problems. However, traditional monitoring programmes can require regular site visits to remote locations, which can delay the implementation of repairs and place heavy time and resource demands on supervisory bodies. As a result, there is an emerging interest in mobile phone based technologies for monitoring water projects.

Telemetry (or remote sensing) systems are widely used for monitoring various remote activities around the world. Many telemetry systems utilise mobile-phone networks to transfer data from a remote site to a central data hub. The key advantages of such telemetry tools relate to the relatively low costs and wide coverage offered by GSM (Global System for Mobile Communications) networks. The timeliness of these applications corresponds to the recent rapid growth in GSM network coverage, in addition to the arrival of low cost monitoring equipment. In terms of network coverage, the 'GSM per capita' coverage of the African population reached 76% in 2012 (GSMA, 2014).

A number of new technologies have been developed for monitoring hand water pumps within the context of Sub-Saharan Africa. The most notable of these are the Dispatch Monitor, SWEETSense, SMART pumps and MoMo projects. These systems utilise a range of often complex remote measurement approaches, including the use of accelerometers, pressure transducers or flow sensors (see Figure 1). The effectiveness, and operational performance, of many of these systems are currently being assessed through field-trial investigations.

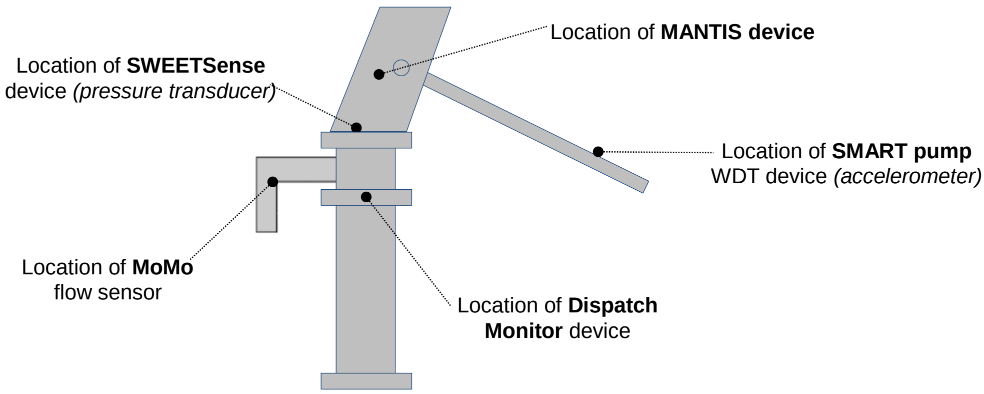

Fig. 1 Different systems for monitoring hand water pumps

The **SWEETSense Project** at Portland State University has generated a range of remote-sensing technologies for WASH (Water, Sanitation and Hygiene) projects (GSMA, 2014). The SWEETSense system has been field trialled on over 180 monitored hand water pumps in Rwanda (Nagel *et al.*, 2015). The SWEETSense system includes an accelerometer and a differential water pressure transducer (Nagel, *et al.*, 2015). This arrangement is designed to record water level in the pump's overflow basin as pressure. The system is powered by five AA type batteries, which have a design life of between 6 and 12 months (Thomas *et al*., 2015). Field trials were conducted over a seven-month period, and compared different pump management strategies, one of which utilised the pump monitors to observe the pumps' operational status, and report back to maintenance teams, via a SMART phone app, when repairs were needed (GSMA, 2014). Over the study period, the monitored group of pumps had a median time to successful repair of approximately 21 days, with a mean per-pump functionality of about 91%. In comparison, a benchmark group of pumps with a conventional maintenance strategy that did not utilise the pump monitor data – had a successful repair interval of approximately 152 days with a functionality mean of nearly 68% (Nagel, *et al.*, 2015). As such the study highlighted the system's potential to improve pumps operational performance. However, the field trials also highlighted a number of operational challenges. For example, some SWEETSense units struggled with extended exposure to fluctuating temperature, humidity and wet/dry cycles. It was reported that the unit's water-proof seal occasionally leaked, resulting in more sensor failures than had originally been anticipated. Similarly, the device's battery life was also observed as being shorter than originally hoped (Nagel, *et al.*, 2015).

The **SMART hand pump system**, developed by Oxford University utilises an accelerometer to measure pump handle movement. This device is installed within the pump handle and monitors pump usage via the handle's movements, which are detected by the accelerometer. The SMART hand pump system has been trialled on over 300 hand pumps in Kenya since November 2013 (GSMA, 2014). The system compiles hourly pump usage data, dispatched on a six-hourly basis. Data is relayed via SMS to an operational database in Nairobi. Outputs are graphically represented on a map layer, which indicates those pumps that are in frequent use. Any pumps that do not appear to be in regular use are assumed to be malfunctioning, and a technician dispatched to them in order to address the problem (GSMA, 2014). This system reportedly improved the average pump downtime (i.e. time until a repair was successfully implemented) from 27 days to 2.6 days (Nagel, *et al.*, 2015). These field trials, like those undertaken for the SWEETSense units identified a number of operational challenges. For example, this system relies on good GSM network coverage - but Behar *et al.* (2013) reported that during these trials the local GSM service was unreliable, to the extent that 40% of SMS messages were lost. The same study also reported that the success rate of the different transmitters varied significantly, and speculated that this may be due to reliability issues associated with the local diesel-powered GSM masts (Behar *et al.*, 2013).

The **WellDone project** has produced an open-source monitoring platform called MoMo (Mobile Monitor), which allows key stakeholders, such as governments and NGOs (Non-governmental organisations), on, to collect sensor data from infrastructure in remote developing world contexts (GMSA, 2014). The approach uses GSM enabled units that can be attached to hand pumps, pipes, and power systems. This application requires a flow sensor to be attached to the nozzle of the hand-pump. As with the SMART pump system, field data is sent back via SMS messages to a central database. This database can be monitored for daily service/usage levels for both water and energy infrastructure. A series of MoMo field trials are underway across Africa.

The **Dispatch Monitor system** has been developed by the ‘charity:water’ NGO and partner organisations**.** This system comprises a remote sensor unit and software system that processes data from the field and graphically represents this information upon a user interface. Field trials of this system are underway in Ethiopia (charity:water, 2015).

2 Methods

The **MANTIS** (**M**onitoring & **AN**alytics To **I**mprove **S**ervice) system represents a further step towards a ‘context-appropriate’ remote monitoring tool for water projects in the Global South. The MANTIS system was developed around five key principles (i.e. of simplicity, ease of deployment, longevity, low cost and minimal data collection), which sought to address the opportunities and challenges highlighted by previous studies (Swan *et al*., 2017). In terms of functionality, the MANTIS system infers the operational status of the water pump by monitoring pump usage patterns. The MANTIS system was developed through collaborations between Leeds Beckett University (LBU), Environmental Monitoring Solutions Ltd (EMS) and VisualWind Ltd (VW). The system is a self-contained, self-powered remote monitoring device for India Mark II and AfriDev water pump models. These models are the two most popular community hand-pump models across the globe (WaterAid, 2013). MANTIS units were installed upon India Mark II hand pumps at eleven locations in Sierra Leone and twelve locations in The Gambia (see Figure 2). These trials were supported by local representatives from the Rural Youth Development Organisation in the Bumpe Ngoa Chiefdom in Sierra Leone and the Glove Project NGO in the Gambia.

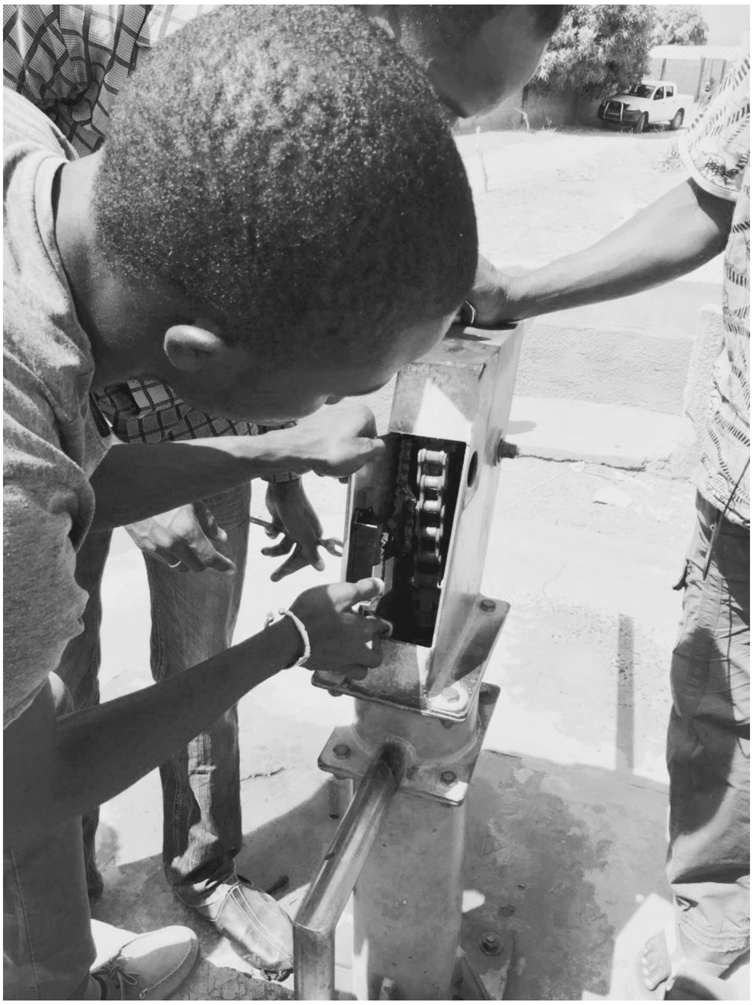

Fig 2. Installing a MANTIS unit in The Gambia

Operational data is conveyed from site, both on a routine basis and by exception to confirm inactivity and possible failure. This information can be processed locally with minimal power overhead. An operational battery life of greater than 5 years has been calculated based on the power consumption of the units. Succinct data packages are sent from the unit, via SMS messages and a SMS Gateway, in order to centralise information for access via an online user-interface (UI). The following example highlights the potential of this new technology.

3 Results

The MANTIS unit installed on a hand pump in Mbankan, Gambia recorded a dataset that contained the occurrence of a pump failure event (see Figure 3). Prior to the 14/05/2017 this pump exhibited a relatively stable usage pattern of between 5000 and 11000 operations per day. The pump usage then drops dramatically to less than 2000 uses per day; then gradually drops over the following 5 days to almost zero operations. This ‘unusual pattern’ was reported to local partners, who visited the site. These investigations revealed that the pump had failed on the 14/05/2017 due to a broken pump rod. The subsequent drop in operations therefore reflects fewer user attempts to use the pump, these attempts continue to fall in the subsequent days as the user community gradually become aware of the malfunction and begin to seek alternative water sources, by the 21/05/2017 most of the local community seemed to be aware of the problem as usage attempts virtually cease.

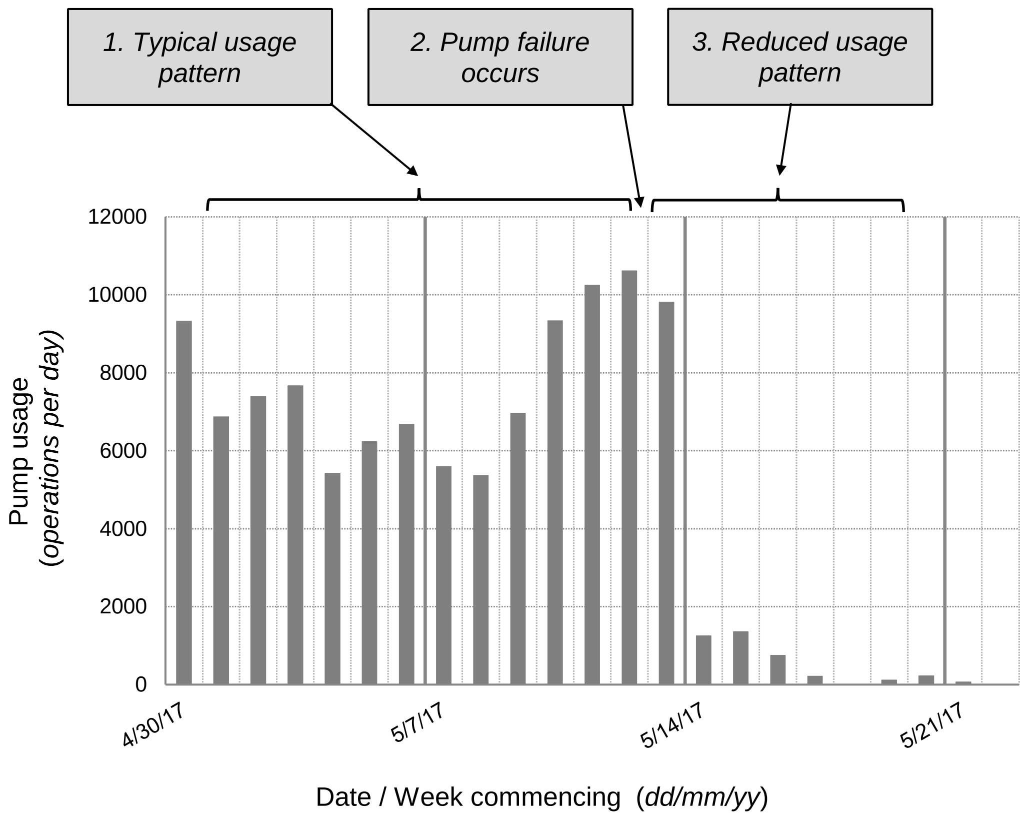

Fig 3. Pump failure event on India MkII hand pump in Mbankan, The Gambia

This demonstrates the primary objective of the MANTIS system (i.e. to indicate whether monitored hand pumps are operational). This process was achieved through monitoring and interpretation of simple pump usage patterns, with this analysis validated by local observations.

4. Discussion

It is intended that in future the simplistic information (i.e. pump usage patterns) collected from individual and proximate pumps could be analysed using rule-based algorithms (e.g. AI or fuzzy logic); enabling differentiation between signatures that indicate pump wear, increasing use, falling water tables, and inaction due to a completely receded water-table. However, in order to automate the process of detecting pump failures, or even more importantly of predicting when such failures are about to occur, it will be essential to establish when the usage patterns significantly deviate from a pump's normal operational range.

5 Conclusions

Many WASH projects are not visited after construction, and broken infrastructure is frequently not detected or addressed by relevant stakeholders. Broken hand pumps may go undetected for a significant period of time. This paper has highlighted the emergence of new telemetry tools for monitoring water pumps across Africa. These remote-sensing applications appear to have significant potential to improve both monitoring and maintenance strategies, and ultimately to increase the longevity of water projects. The primary aim of the MANTIS system has been demonstrated in the field (i.e. to indicate whether monitored hand pumps are operational by solely monitoring pump usage). This simplistic approach seeks to reduce both the unit's production costs and power requirements. Reducing power demand in turn increases the unit's battery life span, which in relation to the MANTIS system is calculated to be greater than 5 years. It is envisaged that in future the simplistic information (i.e. pump usage patterns) collected from individual and proximate pumps will be analysed to indicate different modes of failure.

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