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Remote sensing, mobile applications and open data science tools for better monitoring of sanitation systems

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Abstract

Safely managed sanitation services, monitored by the United Nations 2030 Agenda for Sustainable Development, require data on treatment of excreta from sanitation systems. This data is not readily available for the majority of United Nations member states and has led to estimates being established mostly for those countries where conventional sewer-based sanitation systems are prevalent. Presented in this article is a decentralized portable treatment unit for the safe treatment of excreta and sludges from non-sewered sanitation systems. Data from daily operations is generated from a variety of sensors, each collecting approximately ten data points per minute. Innovative cloud-based methods and data science tools are implemented to collect, store and analyze data. A software platform was developed that offers real-time reporting and alerts to operators and supervisors, allows for remote operation and control, and provides a multi tier architecture that enables user interaction through a mobile or web interface. Key Performance Indicators and results from long-term analytics are presented to quantify the effectiveness of the treatment process and provide relevant information to improve daily operations.

1 Introduction

The United Nations 2030 Agenda for Sustainable Development measures progress in access to water, sanitation and hygiene services under Goal 6, a dedicated goal on 'ensuring availability and sustainable management of water and sanitation for all' [1]. Indicator 6.2.1 measures the "percentage of population with safely managed sanitation services" and indicator 6.3.1 measures the "percentage of safely treated wastewater". The methods for calculation require data on the collection, transport and treatment of sanitation resources, such as wastewater from piped sewers and faecal sludge from onsite sanitation technologies (pit latrines, septic tanks) [2]. In the vast majority of countries where onsite sanitation facilities are prevalent, estimates for indicator 6.2.1 could not be established by the most recent assessment of the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene. The report acknowledges that "The collection of reliable statistics on treatment and disposal of excreta is a prerequisite for safe management, so if countries do not have any data, it is not possible to estimate the proportion of on-site facilities which are safely managed." [2, p. 25]. In order to reach target 6.2 by 2030, based on current estimates, one million additional people per day will need to gain access to a safely managed sanitation facility [3].

Biomass Controls LLC technology portfolio offers complete solutions for the provision of sanitation services. This includes the Reinvented Toilet, first developed by Duke University and RTI International. The Duke Reinvented Toilet accomplishes the separation of liquid excreta (urine) and solid excreta (feces) for further treatment [4]. This technology incorporates the front-end and back-end of a complete non-sewered sanitation system, as defined by emerging ISO standards [5]. The Biogenic Refinery, the second product of the technology portfolio, provides a decentralized portable treatment unit for safe treatment of excreta and sludge collected from onsite sanitation at community scale. Both technologies address the specific requirements for communities and areas that are difficult to reach with conventional sewered treatment solutions. If implemented together, the technologies provide a complete non-sewered sanitation system, as illustrated in the sanitation service chain in Figure 1. Innovative cloud-based methods and data science tools are used to collect, store and analyze data along the entire chain. This allows monitoring of day-to-day operations, but also contributes to better national and global monitoring of safely managed sanitation services.

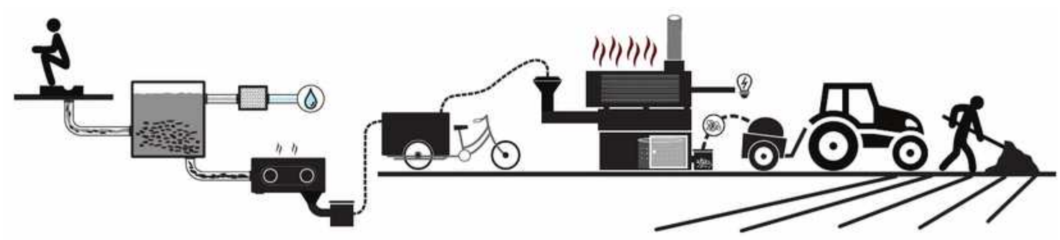

Figure 1: Biomass Controls solutions within the sanitation service chain.

Mobile applications and remote sensing are a novelty in the water, sanitation and health sector [6]. The majority of existing examples can be found in the drinking water sector. For example, the mWater platform, an open-source mobile survey application and data management tool originally focused on monitoring drinking water quality, but expanded to also provide the possibility for implementing sanitation surveys [7]. One example of using sensor technology is the Passive Latrine Use Monitor (PLUM), which uses a passive infrared motion detector to monitor latrine use [8]. kelv°n, a software platform developed by Biomass Controls LLC, offers real-time reporting and alerts to operators and supervisors, allows for remote operation and control, and provides a multi tier architecture that enables user interaction through a mobile or web interface [9].

This paper presents the hardware and software for the provision of safely managed non-sewered sanitation services. Results of long-term analytics will be presented and we will discuss the applicability of the presented software, its availability and the possibility to apply it to case studies different from those presented in the study.

2 Material and Methods

2.1 Duke Reinvented Toilet

The Duke Reinvented Toilet is a novel toilet, which accomplishes four primary functions: (1) separate solids from liquids, (2) disinfect and reuse liquids, (3) dewater, dry and combust solids, (4) convert thermal energy into stored electricity (planning phase). The processing of the solid materials uses a combination of mechanical and thermal energy. The Reinvented Toilet can be provided as a household unit for 10 users or as a communal-purposed containerized solution with multiple toilets [10]. As of February 2018, a test unit is installed at CEPT University (Ahmedabad, India) and additional prototypes are planned for sites in Coimbatore, India and Durban, South Africa.

2.2 Portable Biogenic Refinery

The portable, modular Biogenic Refinery provides value-added pathogen free treatment products, such as biochar, thermal energy and water through pyrolysis and combustion processes. It can handle input products with moisture contents as high as 85% and can process quantities up to 10 m^3/day. As of February 2018, four units are installed in India (Bangalore, Narsapur, Wai, Warangal), one cold climate unit in Kivalina, Alaska, and three additional research units are operated from Putnam, Connecticut.

2.3 kelv°n Software

The kelv°n software infrastructure was developed as a cloud-based web application. It provides a human machine interface, displayed on a touch screen, where the operator is prompted with instructions during the four phases of operation (start up, boost, run, shutdown) of the Biogenic Refinery, and is shown displays of sensor outputs, and motor statuses. Additionally, Android and iOS mobile applications are available to assist with monitoring and operations. The software provides safety checklist procedures to the operator, which need to be followed and checked off for the Biogenic Refinery to be operated. An Intelligent Biofuel Controller was developed which communicates operating conditions to the kelv°n architecture, and receives commands from both onsite operators and remote personnel. The controller is equipped with LED alerts and alarms, which help the operator to identify problems as they occur. Additional data, such as information about the characteristics of the input product, is collected through this user interface.

2.4 Data Assimilation

The kelv°n web application provides data visualization capabilities to create interactive plots. The plots can be downloaded in any common format, including the raw data that are displayed. Data is generated from a variety of sensors, each collecting approximately ten data points per minute. The data is stored in a standard relational cloud database technology that provides a flexible and dynamic data management platform.

2.5 Open Data Science Tools

Open source data science tools are used for data analysis, knowledge management and reporting to increase reproducibility, collaboration and communication [12]. R Statistical Software and the RStudio Integrated Development Environment are used for data analysis [13, 14]. Daily automated descriptive and exploratory analysis are performed and performance reports produced for the customer. These reports are written in R Markdown, which provides a literate programming environment that ensures full reproducibility of results [15]. Shiny, a web application framework for R, is used to develop reactive and interactive data products to close the feedback loop with the customer [16]. Git and GitHub are used for version control and organization of files and projects [17].

2.6 ISO/IWA Standard Document

'ISO 30500 - Non-sewered sanitation systems’ is an international standard currently in development for onsite off-grid sanitation solutions. To support the development of such solutions, a standard document (IWA 24:2016) titled “Non-sewered sanitation systems — General safety and performance requirements for design and testing” has been published by the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) [5, 19]. The treatment technologies presented here offer solutions that comply with and support the metrics and intent of these standards.

2.7 Key Performance Indicators

KPIs are developed to quantify the performance of the Biogenic Refinery, identify compliance with emerging ISO standards and provide relevant information for comparison of different sites. KPIs are clustered around parameters for emission control, combustion efficiency, thermal efficiency, process reliability, and electricity consumption and generation. A total daily score of 100 can be achieved with 10 KPIs, each a scoring from 0 to 10. A score of 5 in each category indicates compliance with emerging ISO standards.

3 Results

3.1 Biogenic Refinery

On average, 100’000 data points are generated per system and day of operation. Data for one year of operation was analyzed for the Biogenic Refinery based in Putnam, Connecticut. Presented as a heatmap in Figure 2 are the results of eight KPIs that are currently calculated.

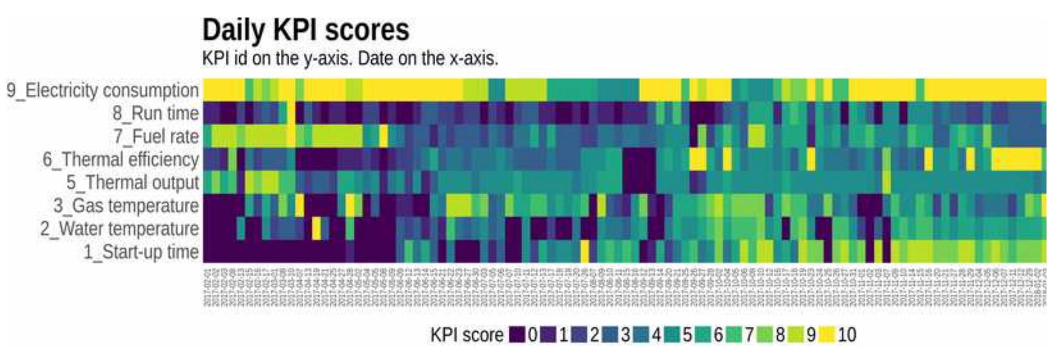

Figure 2: Daily scores for eight KPIs over 105 days between 01.02.2017 and 01.02.2018.

Figure 3 presents the sum of daily KPI scores. Currently, eight KPIs are being analyzed and the maximum achievable score is 80. The goal is to achieve a score of 5 for each individual KPI, as this would translate into compliance with safety and technology standards. It provides a normalized benchmark, which allows for appropriate comparison to improvements as hardware, firmware, technology and overall performance improves.

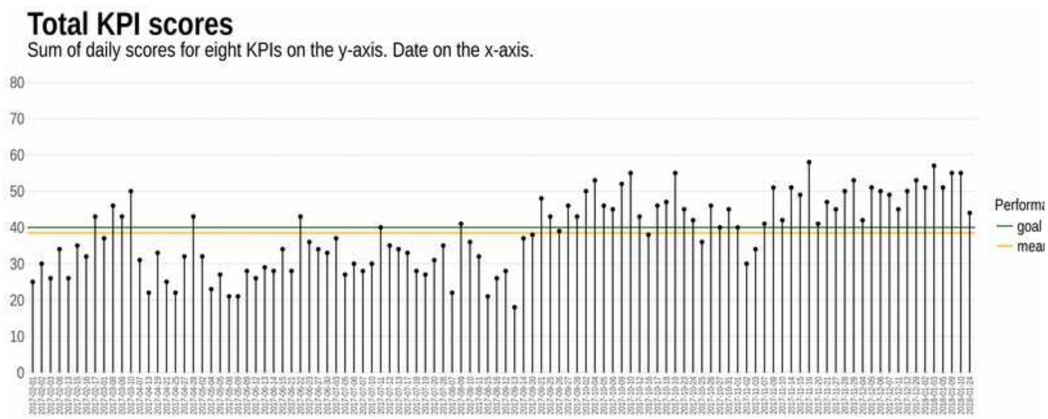

Figure 3: Sum of daily KPI scores over 105 days between 01.02.2017 and 01.02.2018. The green line indicates the performance goal and the orange line indicates the performance mean over all days.

In Figure 4, the performance of two systems, GI#1 and GI#2, is compared to each other. In this plot, dates are shown on the y-axis, systems are on the x-axis and KPIs are split by facets where the KPI id is displayed on top of the individual facets. With an increasing number of technologies being implemented, this comparison becomes valuable for the manufacturer and system operators. The presentation of the data allows for a quick comparison between systems and supports the identification of performance improvements in one system that might also be relevant for another system.

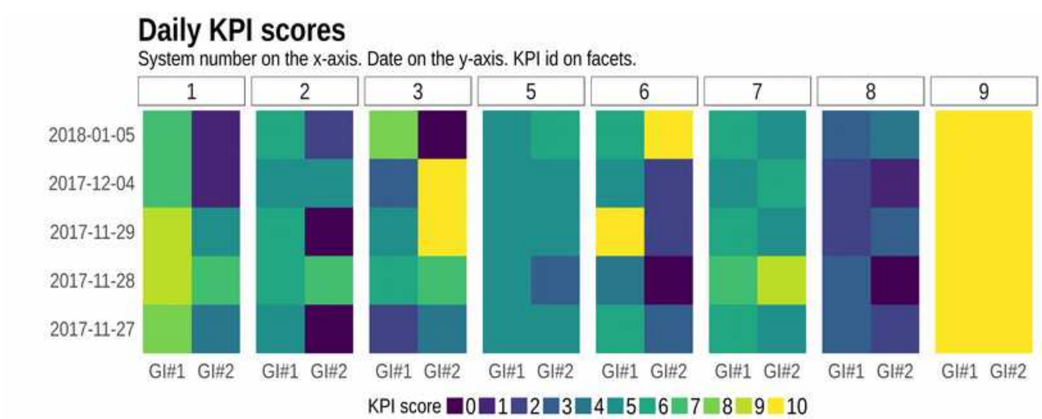

Figure 4: Comparison of eight KPIs for two systems over five days.

The three illustrations lay out a simple and accessible way of providing feedback to the operator and manufacturer of the Biogenic Refinery. Dates with strong and poor performance can easily be identified and immediate actions can be implemented from three different perspectives:

- Firmware: each data point is related to a specific system software. Updates are documented and provide a backward identification of how a change in the code has led to an improved or decreased performance.
- Hardware: adapting the system hardware and testing new technologies can lead to numerical performance comparison and improved or decreased performance can be quantified.
- Operator: the operator plays an important role in maintaining a good performing system. Day to day performance between systems operating on the same firmware and hardware helps to evaluate where support in operations is required.

3.2 Duke Reinvented Toilet

The presented kelv°n software infrastructure has been tested with the Duke Reinvented Toilet technology. KPIs related to thermal processes have proven to be applicable, while it should be noted that it will be critical to develop additional KPIs relevant to the system processes and to ensure all outputs meet emerging ISO standard criteria.

4 Results

4.1 Applicability

The results presented in this paper show the potential of using a new IT platform and architecture to process and store flows of repetitive data in real-time. Powerful analytical tools make it possible to extract knowledge from the data. The knowledge generated through KPI measurements was identified as an effective tool to demonstrate system compliance to the emerging ISO standard and monitor critical performance areas.

Parameters are transferable to other thermal and faecal sludge processing technologies, allowing for standardized comparison across solutions within the industry with comparable performance requirements. By providing a rapid, quantitative evaluation of performance for a variety of processing technologies, this tool is crucial to ensure key performance objectives are monitored and met for product value, functionality, and sustainability in circular economy markets.

The use of open data science tools make the software equally applicable to other sanitation systems than those presented in this study. The IBC and respective sensors can be readily implemented in other thermal treatment processes and first trials are ongoing with the Reinvented Toilet. Further, the controller can be adapted to also apply to systems with liquid effluent as a by-product. Sensors can be introduced to measure if treatment complies with standards for discharge of treated effluent.

4.2 Availability

The software and hardware presented in this paper is readily available to be used in other sanitation systems. For example, an increasing number of organizations provides sanitation services, where excreta are collected on a regular (daily to weekly basis), often in cartridges or container-based solutions, such as Sanergy Inc. in Kenya or SOIL in Haiti [20, 21]. The presented refinery technology could provide additional treatment solutions and the software is available to be tailored to the needs of the organizations.

4.3 Possibility

While Machine to Machine connectivity is at a very early stage of integration in the sanitation chain [6], there are great possibilities of expanding the infrastructure presented here to provide smart solutions for sanitation service provision. For example, number users per toilet and filling status of the container can be monitored. Once the container is nearly full, collection service providers can be informed and routes for collection can be planned efficiently. Information about the quantities of collected resources can then be communicated to the treatment infrastructure, which in return can predict quality and quantity of value-added end-products. There is a need to develop more cost efficient solutions for smart sensor integration in sanitation infrastructure [6].

5 Conclusions

Data Management Plans. The software infrastructure presented here can be implemented in any thermal treatment system and the kelv°n software platform provides a starting point for a much broader development of monitoring mechanisms in the sanitation sector. However, with more such technologies becoming available, there is a need to develop appropriate Data Management Plans and domain-specific protocols, following FAIR data principles [21]. Standardized templates would result in shorter Data Management Plans, reducing the time needed to review and evaluate them, as well as the time needed for researchers to create them [22].

Smart sanitation, mobile and digital applications. For now, mobile integration in the sanitation service chain remains limited, but the potential role it could play is being acknowledged more widely [6]. For example, the Toilet Board Coalition have entered an agreement with the Pune Municipality in India to become the world's first smart sanitation city and several organizations that provide container-based sanitation solutions have started to apply various information technologies to improve service delivery [23]. From the perspective of treatment technologies, the data and KPIs presented here are the first step to smart monitoring and Biomass Controls is dedicated to expand on this experience by working together with excreta collection and transportation service providers, which will support the efforts of closing the gap for "reliable statistics on treatment and disposal of excreta" [2, p. 25].

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