COGENT Labs

Philippines UK coLlaborative Partnership-System for Environmental and Efficient Drying: Factory Wireless Sensor Network (WSN) Deployment

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Cogent Labs

Contents

1 Introduction

Philippines UK coLlaborative Partnership-System for Environmental and Efficient Drying (PULP-SEED) is a British Council Newton Fund Institutional Link between Coventry University (CU), UK and the University of San Carlos (USC), Philippines.

The institutional link focuses on three areas a) technological advances in factory monitoring systems to enable creation of new process models and support follow-on automation; b) developmental activities to result in staff training for research skills at USC and lessons to be applied to CU; c) scoping industry-academia links and link-forming know-how at USC. All three areas will lead to social and economic impact either directly (factory workplaces and promotion of economic model to other factories) or indirectly (empowering the Filipino academics to create wealth and social benefit through high standard research).

The team working on this project is a multi-disciplinary group consisting of electrical engineers, computer scientists, and chemical engineers from both CU and the USC. Table 1 lists the members of this project.

Table 1: Pulp project team members

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This report presents initial monitoring results, forming part of the first focus area described previously "technological advances in factory monitoring systems to enable creation of new process models and support follow-on automation". The aim of this focus area is to make use of Wireless Sensor Network (WSN) technology to improve the yield and efficiency of existing mango waste processing, thus leading to increased viability and scale of operation. The outcome will therefore be to increase the viability of mango waste processing such that it can be scaled up to process all or most of the available mango waste currently being produced (current processing only takes waste from 1 of 36 plants in the region), thus leading to job creation and increasing social wealth in disadvantaged communities in the local region. Furthermore, it is envisaged that another positive outcome of this work will be to inspire other Filipino industries to make greater use of their academic institutions as a source of technological innovation.

2 Motivation

The Philippines produces around 1 million tonnes of mangoes per year, with more than half of this quantity being processed into products such as juices, dried fruits, fruit bars, candies and jellies. The mango processing industries use only about half of the mango fruit (by mass), with the remainder being waste such as the peels, seed husk and seed kernel. This mango waste is simply disposed of in open dumpsites and left to rot, releasing foul odours and potentially hazardous leachate. The waste is also a health hazard, as people scavenging dumpsites often eat the freshly discarded mango parts.

Recently, a start-up company, GEM, was formed out of the USC Department of Chemical Engineering that converts waste from the mango processing industry into useful products, using novel technology developed at USC. The company began operations in 2012 with initial seed funding of US$2 million. The company built its 2,500 m^2 facility in a one-hectare land area in Bangkal, Lapu-lapu City, Cebu.

The aim of this project is to make use of WSN technology to improve the yield and efficiency of existing mango waste processing, thus leading to increased viability and scale of operation. The application of Wireless Sensor Networks in the facility as a demonstration of their efficiency and usefulness can be shown in two areas:

1. Solar drying facility where direct solar energy is harnessed and used as an alternative power source for drying of raw mango waste peels and seeds. WSNs can be used to monitor the environmental and process conditions inside the facility such as temperature, humidity, light intensity and so on, in order to characterise and model its drying mechanisms and properties. The data and information gathered by the use of WSNs can help to further improve the design of the dryer and/or the design of the solar power generation system so as to achieve high productivity, yield and cost-efficiency. Further, WSNs can assist in studying the effects of direct solar heat on the characteristics and properties of dried products.
2. WSNs will be deployed in a prototype tunnel dryer used in the facility, which is used to dry the high-value products from mango wastes, such as mango flour, mango tea, pectin, and others. Data obtained with the help of WSNs will be used to study the effects of drying conditions and parameters in the product formulation and to describe drying mechanisms. Optimisation of process conditions and operating parameters can be achieved with the use of WSNs.

The basis for optimisation of processing will be through forming statistical models of the processes that incorporate empirical data. These models will then be used to optimise the process in terms of efficiency and quality of production through automation techniques.

This project will have impact in the following areas:

- GEM will benefit from more efficient production processes and logistics based on the research collaboration outputs.
- The plant's current workforces are drawn from the local community. Therefore, enhancing the viability and profitability of the mango waste processing plant will provide a boost to the local community by enabling a larger work force.
- With the help of CU, USC will build a strong research and skill base in wireless sensing technology.

3 Objectives

To meet the aims of the project the following objectives will be set:

1. Analysis of the current monitoring process in place at GEM and the current situation including wastage.
2. Analysis of the monitoring requirements to diagnose quality and yield of mango waste processing.
3. Development of a prototype system for deployment in a mango solar dryer.
4. Development of an optimal drying strategy using both data collected from the WSN and a record of yields and quality of the resulting produce.
5. Development of automation techniques to manage the solar dryer environment to maximise yield and quality.

Figure 1: GEM solar dryer.

4 The Solar Dryer and Tunnel Dryer

This section details the mango drying process in the factory through the use of the solar dryer and the tunnel dryer. Both drying methods process three main mango by-products—mango seeds, mango kernels and mango husks. The process fully converts this raw material into useful products, leaving no waste at all.

4.1 Solar Dryer

The solar dryer (Figure 1) is a brick building with a transparent polycarbonate roof measuring 30m$\times$ 30m$\times$3m. Within the solar dryer there are 36 drying racks (5.55m$\times$ 1.15m$\times$2m) with 5 drying trays. The flooring of each tray is made from nylon netting to allow sunlight the penetrate lower levels

In the solar dryer wet mango waste is spread on the trays twice a day at 8am and 4pm. This can not be done at any other time due to extreme heat and risk to workers. The mango placed at 8am is usually fully dried by 4pm when the new batch is laid out. There is little drying during night time but the mango peels and seeds placed at 4pm will be ready for the following day.

A proposed conveyor system is under development as of this writing as a way to automate the spreading of mango peels and seeds on the trays when the workers cannot do it due to the heat.

4.2 Tunnel Dryer

The tunnel dryer (Figure 2) measures 11m$\times$ 1.5m$\times$1.5m and is made entirely of stainless steel. The tunnel has ramps on both sides to allow the racks to be loaded /unloaded into the dryer. On one side of the tunnel

Figure 2: Drying tunnel.

are ten 1 kW resistive heaters connected to a temperature control panel on the outside. The other side of the tunnel has 5 circulation fans, with 5 exhaust fans directly above to remove cold air.

To dry the mango waste, nine racks of the waste are loaded into the tunnel dryer and both ends of the tunnel are sealed. Once ready the dryer is switched on for four hours with a set point temperature of 65 °C. After 4 hours the dried product is unloaded and the workers check if the mango waste has dried. If not, the product is stirred on its tray to remix so wet layers are exposed for the next drying time. The mango waste will then undergo another set of drying for four hours until completely dry.

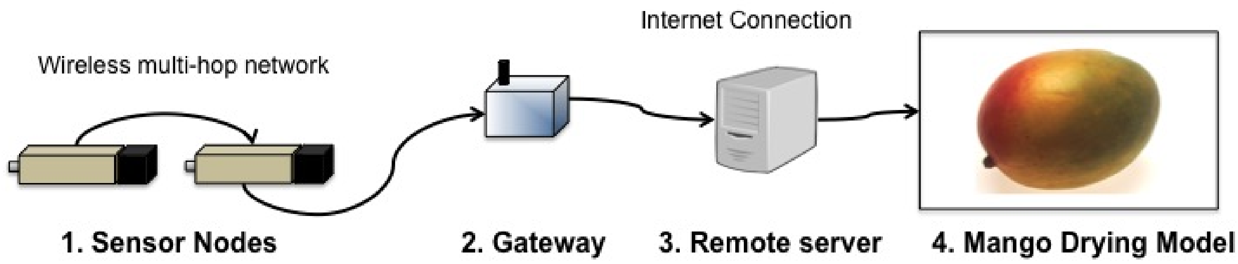

Figure 3: System overview.

[Picture required when final is built]

Figure 4: Sensor node hardware.

5 PULP WSN overview

The PULP system is a full end-to-end Wireless Sensor Network (WSN) environmental monitoring system targeted at collection of data from the drying environment. PULP is designed to gather sensor data (temperature, humidity, black bulb, air flow) and transmit that data to a central database where it can be viewed with a web-browser. This section details the hardware and software components of the system.

Figure 3 shows the an overview of the end-to-end system architecture. Data flows from the sensor nodes to a gateway, where it is transmitted to a remote server via the Internet and made available to user applications, such as a data analysis portal and further used to create a mango drying model. To reduce risk and development time, we opted to use off-the-shelf hardware and software wherever possible

5.1 System hardware description

Our sensor node combines the TelosB platform with a custom interface board (see Figure 4). The TelosB is based around an MSP430 F1611 CPU and a 2.4 GHz CC2420 802.15.4 radio. The TelosB also includes an integrated temperature and relative humidity sensor—the Sensirion SHT11. Our custom interface board provides input for one black-bulb sensor and one air flow sensor. Each sensor node is packaged in an off-the-shelf IP65 plastic enclosure with an slot for the air flow sensor. Nodes are affixed to the shelf supports using two cable ties.

The gateway was built using a Raspberry Pi 2 model B combined with a TelosB node.

5.2 System software description

This section describes the software components of the PULP WSN system. Figure 5 shows the system flow. A set of WSN nodes transmit their data. The sink node (connected to the gateway) receives packets from each individual sensor node and forwards these messages via USB to the gateway server. The gateway server receives these messages through the SerialForwarder program, which opens a packet source (in

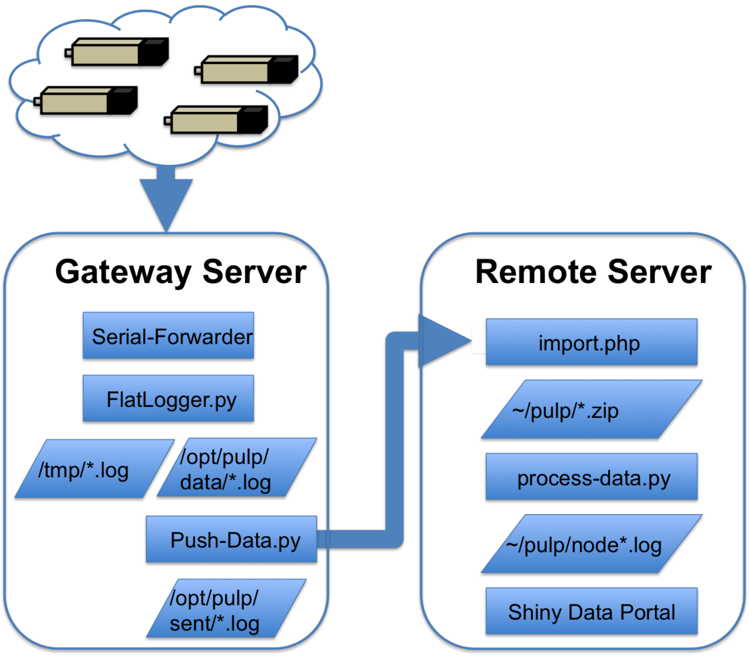

Figure 5: System flow diagram.

this case the USB-connected sink node) and lets many applications connect to it using TCP/IP streams in order to use that source. FLATLOGGER is one such application. FLATLOGGER receives packets from SERIALFORWARDER, extracts the relevant data, and logs the data to a flat file. Each hour a Push Data script is run which transmits the logged data to a PHP page on the remote server where it is archived. Finally this data can be interrogated and downloaded via a data portal hosted on the remote server.

The rest of this section will describe the key software components of the system.

5.2.1 Node Software

The node software was developed on top of the TinyOS WSN OS. TinyOS provides a network stack with a low power MAC (Low Power Listening (LPL)) and multi-hop tree formation/data collection protocol (Collection Tree Protocol (CTP)) that were used in the system we developed here.

Drivers were written for our interface board to sample both the black-bulb and air flow sensors. At the application level a traditional sense-and-send system was developed. Every 5 minutes a node acquires, and transmits temperature/humidity/air flow data, network information (time, RSSI, sequence number, parent node,), and battery voltage (51 bytes of payload total).

5.2.2 Gateway Software

During normal operation WSN data is collected by the TelosB sink node, aggregated at the Raspberry Pi gateway and transmitted hourly via the Internet to a remote server. In addition to hourly "pushes" of data, this use of an Internet connection allows for remote access and thus debugging in-situ. There are two scripts responsible for this operation:

FlatLogger The Flat logger component receives sensor data from the sink node (through the TinyOS serial forwarder), extracts the relevant data, and logs it to a flat file system. This data is initially stored in /tmp/ with a date and server timestamped log file (e.g., 2015_277_14-54_pulp2.log). These logs each contain 15 minutes of data. After 15 minutes of logging the data file is transferred to the /opt/pulp/data directory and new log file is created in /tmp/.

Push synchronisation The push synchronisation system provides a way to push logged data from the local data servers in Cebu to the remote server based in Coventry. Once per hour the push script compresses the data stored in the /opt/pulp/data directory and transmits the resulting compressed file to the remote server

5.2.3 Remote server software

The remote server is a virtual server hosted at CU. Interaction with the server is via a combination of PHP scripts for application use and a webpage-based interface for human users of the system:

import.php This PHP page receives files from the gateway server and stores them in the portal directory on the remote server.

process-data.py This script extracts the compressed files in the portal directory to allows the data to be used by applications such as the data dashboard.

Shiny Dashboard The web interface (pulp.coventry.ac.uk) to the remote server provides a way to interact with the monitoring system and to see live sensor readings as they are gathered. The key features of the web interface to the server are:

- All data types supported (i.e. temperature, humidity) can be displayed live.
- The health of the monitoring system can be displayed, including Packet Delivery Ratio (PDR), battery levels, etc.
- Logged data can be exported to the CSV (comma separated values) file format.

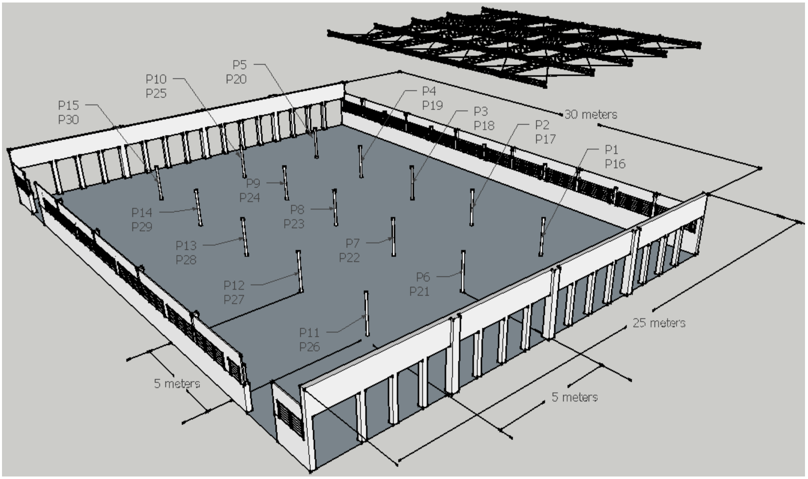

Figure 6: Solar dryer deployment diagram.

6 Deployment

From August 2015 our system[1] has been deployed in the GEM factory in Cebu, Philippines. The main goals of the deployment are to: i) validate the performance of our system in-situ, and ii) collect an archive of data for offline analysis which can be used to build the drying model.

The PULP system has been deployed in 2 areas of the GEM factory:

Solar Dryer The solar dryer is the factories primary method of drying out mango peel and kernels. A total of 30 nodes have been deployed in the solar dryer transmitting to a single server (Pulp1). 15 nodes (Nodes 1–15) have been deployed on a bracket at 2.13 meters height. The other 15 nodes (Nodes 15–30) have been deployed on a bracket lower down at 0.6 meters. The nodes have been deployed in a 5m×5m grid. Figure 6 shows the layout of this deployment, and Figure 7 shows a photo of the deployed nodes.

Drying Tunnel Within the drying tunnel a total of 10 nodes (Nodes 31–40) have been deployed. Since the tunnel is made from stainless steel, the server (Pulp2) is placed outside of the casing, with the sink node passed through a hole cut out into the tunnel. Figure 8 shows the layout of this deployment, and Figure 9 shows a photo of the deployed nodes.

The remainder of this section will describe the conditions in the solar dryer and the performance of the WSN to date. Due to the poor PDRof the drying tunnel server this section will not discuss the tunnel environment.

[1]Note: Only base TelosB nodes have been deployed, since there was an issue with the interface board pre-deployment.

Figure 7: Deployed solar dryer nodes.

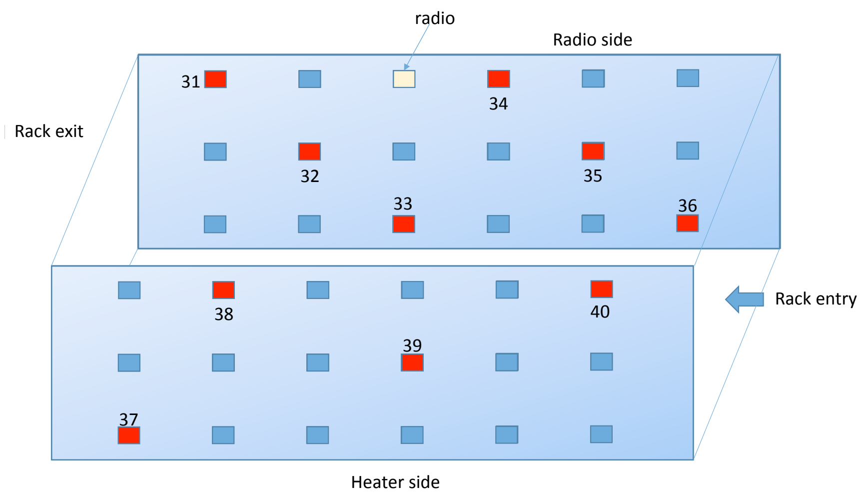

Figure 8: Tunnel deployment diagram (red squares represent node positions).

Figure 9: Deployed tunnel nodes.

6.1 Deployment performance

In our deployments, the network performance of the system was evaluated using two metrics: i) PDR (calculated as packets received versus the expected number of packets) and ii) the Received Signal Strength Indication (RSSI) for incoming packets to the gateway.

The tunnel dryer deployment has been in place for 60 days, obtaining a PDR of 18%. We believe the poor PDR is due the harsh radio environment within the tunnel dryer. This will be investigated on the next CU visit to the plant in November 2015.

The Solar dryer deployment has been in place for 64 days. Figure 10 shows the daily PDR for the deployment—over the 64 days the WSN has achieved a PDR of 58%. The data loss is associated with periods when factory workers have switched off the server from the plug socket. The workers need to be made more aware of this issue, and a socket protector will be installed. For all nodes the RSSI level was > -90 for at least 90% of the time.

6.2 The Solar Dryer Environment

The Philippines has a tropical climate with frequent and severe rainstorms. Within the solar dryer temperatures can rise to 65 °C and 85% relative humidity. There are large daily cycles where temperatures in the solar dryer can change by 30 °C and relative humidity by 60%. Between the nodes placed at the higher position (2.13m) and the lower position (0.6m) there can be a difference of 20 °C and 20% relative humidity. These effects are shown in Figure 11 and Figure 12. There does not seem to be a significant difference between nodes on the horizontal plane.

Figure 10: Heat map showing the packet delivery ratio of PULP1 (deployed in the solar drying greenhouse).

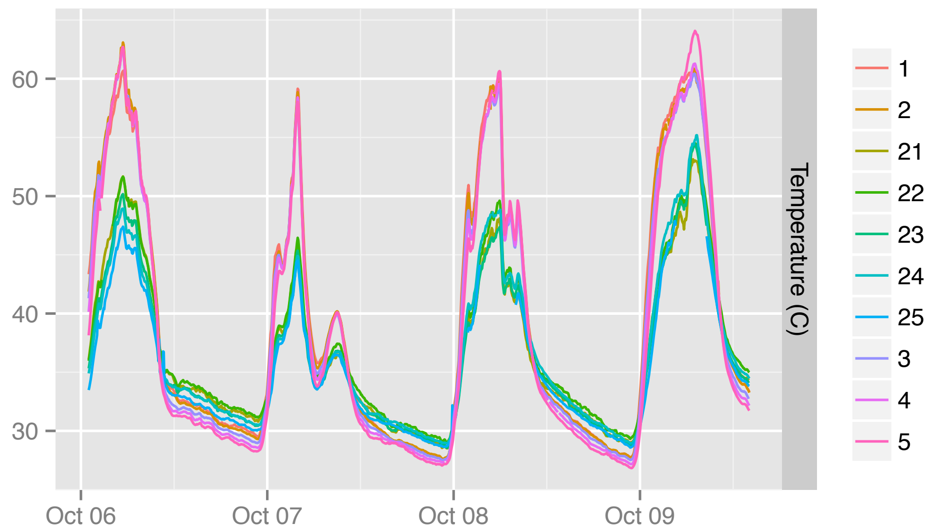

Figure 11: Temperature conditions in the solar dryer.

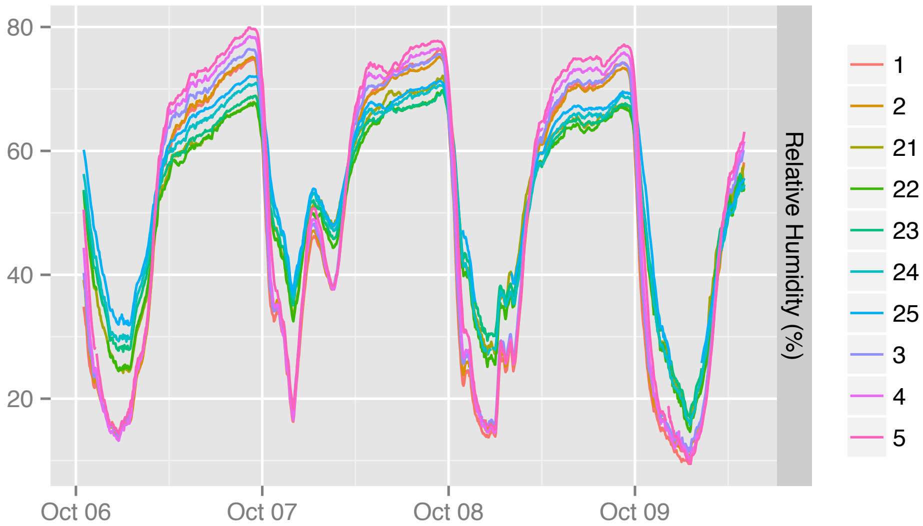

Figure 12: Relative humidity conditions in the solar dryer.

7 Conclusions

This report has presented the design and initial monitoring results of a WSN deployed within mango waste processing factory. Two servers and 40 nodes have been deployed in a solar dryer, and a tunnel dryer for a total of 64 days. The tunnel dryer deployment has not been as successful, in terms of PDR, as hoped, the harsh radio environment is expected to be the cause. The solar dryer was more successful, however, it suffered from frequent outages due to the factory workers have switching off the server from the plug socket. An initial analysis of the thermal environment, in the solar dryer, shows the temperature and humidity to be homogenous on the horizontal plane. However, on the the vertical plane it was observer there can be a difference of 20 °C and 20% relative humidity over 1.5m.

During the development of the sensor interfaces a problem was found with the interface board, therefore, in this phase 1 deployment only base TelosB nodes could be deployed. In the phase 2 of the project, it is envisaged these issues will be resolved and the nodes deployed by month 8.

The other focus of phase 2 will be designing and implementing an experimental method for collecting the ground truth of the drying model. This will be achieved through the frequent measurement of the mango waste during the drying process using a moisture analyser.

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