Development of San Marcos as a Smart and Sustainable City with the Support of Search-based Software Engineering

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Abstract. *The authorities of San Marcos' municipality (Mexico) have funded a project to develop it as a smart and sustainable place. This requires funding, technology, and expertise that they scarcely have, since they are afflicted by digital exclusion. To face the challenge, they have teamed up with Unijuí University and Santa Rosa city (Brazil) under Memoranda of Understanding (MOU) and with University of Cambridge under academic collaboration. In this paper, we (the team) discuss the main technical problems, technology used, results achieved and pending. Our strategy is to use low-cost technologies with optimised deployments to minimise maintenance and environmental costs.*

1. Introduction

In this paper we discuss a project funded by the authorities of the municipality of San Marcos (henceforth referred to as San Marcos) in 2022 to develop it as a smart, innovative, and sustainable place. San Marcos is located in State of Guerrero, Mexico and has 40 km of virgin coastline. It is home to 50,000 inhabitants, 12,000 of which live in San Marcos city— the municipal seat. The project includes the development of San Marcos city as a smart city and the 40 km of coastline as smart tourism destination. We have a team to meet the challenge: Santa Rosa contributes its 10 years of experience gained from its own development; Unijuí contributes technical know–how and shares its SmartLive Lab used for technology evaluation; Cambridge brings research expertise. We conceive smart and sustainable cities as places that offer conditions for integral human development. In our view, they are complex socio-technical systems, therefore, their development demands a multidisciplinary effort grounded in the intensive use of digital technologies. A smart city depends on communication networks, monitoring sensors, data-sharing repositories, methodologies, and algorithms (e.g. artificial intelligence) for urban analytics and end-user data-centric applications. It is common knowledge that the development of smart places is challenging and significantly harder in places like San Marcos municipality that are afflicted by digital exclusion [Alshamaila et al. 2024]. San Marcos suffers from a lack of public-private initiatives and economic, social, and technological constraints. The hurdles can prove to be too high to overcome unless innovative approaches are taken. The remainder of this paper explains the objectives of the project and the novel approach that we are taking to fulfill them in spite of the limitations mentioned above. In brief, we prefer open source (as opposed to cloud) technologies and open science. We welcome data-sharing and aim at reducing environmental costs through optimisation and biodegradable sensors. We have already achieved some results.

2. Objectives and strategies

Our goal is to redirect San Marcos' development from traditional and short-sighted to smart and sustainable. Specific short-term goal to fulfil by 2026 are to deploy antennas and sensors for testing and training. The strategy is to take advantage of open science and data-sharing to provide San Marcos with open source environmentally friendly technologies and to transfer technical skills to San Marcos to make it technically sustainable.

3. Technologies selected for reducing financial and environmental costs

We have selected LoRa (Long Range) antennas to leverage the experience gained from previous work in Santa Rosa. Additionally, LoRa is affordable; antennas cost from 350 to 500 dollars. Technical factors in favour include that it is a low-power alternative for Internet of Things (IoT) devices operating in unlicensed bands, such as the 902-928 MHz band in Mexico and Brazil. The use of Chirp Spread Spectrum (CSS) provides high resistance to interference and great range. A LoRa network includes antennas that capture radio signals from sensors and spreads radio signals to actuators. It also includes gateways that convert radio signals into digital data, forward them to central servers and transmit data in the opposite direction.

Communication coverage is more costly to achieve in regions afflicted by geographical (e.g. mountains) and urban (e.g. buildings) obstacles that block signal propagation. In places that suffer from digital divide, the lack of electrical grids and Internet aggravates the problem. In those places, antenna deployment is harder since they need to be placed at carefully selected locations; this effort demands proper software engineering techniques aimed at optimisation. San Marcos falls within this category. The optimisation of antennas is an (NP-hard) problem, i.e. a computationally complex problem with no polynomial-time solution for large inputs. The problem can be addressed with techniques that aim at near–optimal solutions like those used in Search-Based Software Engineering (SBSE) [Harman et al. 2008]. In San Marcos, we will use SBSE to solve other complex problems of design, testing and maintenance; examples are traffic management, deployment of video-cameras and waste collection. SBSE bridges the gap between theoretical research and practical engineering applications. To optimise antenna deployment, we have implemented *SmartSignal*, which is composed of a set of algorithms that use Simulated Annealing technique. This optimisation technique is derived from the simulation of a physical cooling process used to crystallise metals. *SmartSignal* can find the minimum number of antennas and their locations to cover a given area. We have coded it in GNU Octave (open source version of MatLab), it consists of 257 LOC and calls a Simulated Annealing library (*optim library*) to solve the NP-hard optimisation problem. *SmartSignal* is open source and available, with directions to run to replicate and validate, at GitHub[1] for the benefit of other cities interested in reducing the amount of hardware, energy consumed by their networks, and environmental costs. We favour low-cost open source experimental technologies rather than purchasing ready-to-use expensive technologies from dominant cloud providers. Thus, we store sensor data in an

[1]https://github.com/gca-research-group/lora-metaheuristic-model

open source ChirpStack Network Server deployed on Linux. We are manufacturing and testing biodegradable piezoresistive sensors in our laboratory; we can use them to monitor mechanical parameters such as pressure, tension, humidity, wearability, and temperature.

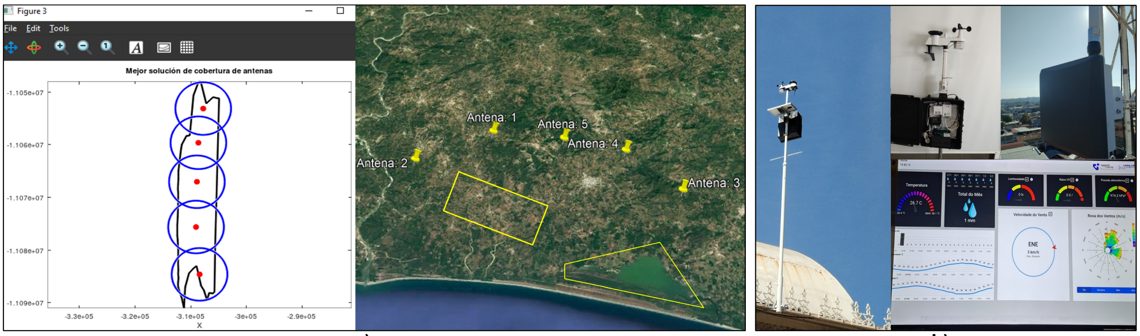
4. Benefits

The project will benefit biodiversity and reduce hazards. We will use sensors to monitor water levels (e.g. RAK12014), temperature, pollution, and other parameters of the 22 km^2 Tecomate Pesquería lagoon. It is home to several bird and fish species and, in our view, a candidate to join the list of Ramsar sites. Knowledge of water level variations can be used to anticipate its natural flooding cycle and evacuate affected villages [2]. Similarly, monitoring air particles can alert the authorities to wildfires that frequently affect the municipality during the dry season. Also, we can use sensors to monitor the rich biodiversity and weather conditions of the 40 km long coastline to produce maps (e.g. of native species) and attract eco-tourists. In San Marcos city, monitors can help with traffic management; noise sensors (RAK 18000) can be used to detect problems caused by about 7,500 motorbikes that roar through the streets. The project contributes to EDI (Equity, Diversity, and Inclusion) in several ways. For example, people from neglected villages without access to mobile coverage, mobile phones, or electrical grids can resort to LoRa to send messages. They can use devices such as the LoRa-based TTGO LoRa32 to request emergency assistance. We can use sensors (e.g. NEO-6M GPS Module) to monitor elderly and for incorporating people with disabilities into the labour market; there are about 550 of them that we regard as people with coolabilities (special talents), e.g. the enhanced imagination and creativity of individuals with ADHD.

5. Proposed solution and results

We suggest the use of LoRa/LoRaWAN antennas deployed at strategic locations determined by *SmartSignal*. We report here *SmartSignal's* approach and results. Firstly, the region under study is georeferenced using Google MyMaps. Secondly, we export, in Keyhole Markup Language (KML) format, the coordinates of the polygon that defines the geographical limits of the area to be signal-covered and the coordinates of the vertices of the geometric figures that delimit the obstacles and restrictions. The results are three files: city, obstacles, and restrictions. Thirdly, we use a text editor to convert the KML files into Comma Separated Values (CSV) format. Finally, we load these files into *SmartSignal* as input data in the main interface and run it. In *SmartSignal's* runs, we use the graphical interface (provided by Octave) that allows the user to import CSV files with coordinates, define antenna parameters, and observe the generated coverage. The use of *SmartSignal* is iterative and stochastic, differing from other techniques by avoiding converging on local minima. *SmartSignal* starts with an arbitrary initial solution, initially placing N antennas and a high initial temperature, then perturbation is applied. Interactions are used to lower the temperature and explore the best solutions [Harman et al. 2008]. A result is accepted when the new antenna arrangement improves coverage or cost reduction. Upon completion, *SmartSignal* generates a CSV file with the results. We then import this file into the Google Earth tool to visualise the coverage and antenna positions in a real geospatial environment. The result is a meaningful representation for non-technical people, such as municipal authorities. One of our results is shown in Figure 1.a The left side shows, in blue lines, the overlap of the coverage of the antennas. The right side shows the locations of the antennas and two obstacles: a mountain and the Tecomate Lagoon.

[2] We will build a digital twin of the Tecomate Pesquería lagoon.



a) b)

Figure 1. a) Antenna coverage. b) Weather station, gateway, and dashboard.

With the simulations (using five antennas of 5 km radius), we managed to cover 75% San Marcos' area and revealed that the antenna that we have deployed in San Marcos city is 5.8 km away from the nearest optimal location; we will relocate it. To master the technology, we have deployed a weather station with seven sensors that measure temperature, humidity, rainfall, luminosity, UV index, wind speed, and direction. To reduce expenses through resource sharing, we transmitted the data to a network server located in Santa Rosa instead of purchasing a brand new server for San Marcos. Figure 1.b shows the LoRa infrastructure that we have installed in San Marcos city. The dashboard shows plots of the data collected by the station.

6. Pending tasks

Pending is the deployment of a ChirpStack Network Server locally to store San Marcos' data and share it with our current and other collaborators. Testing of properties of the biodegradable sensors (e.g. lifespan and robustness to accidental exposure to the elements) is on our agenda. Our to-do list also includes the gradual deployment of additional antennas and sensors at locations suggested by our optimisation results (see Section 5). Additionally, we need to train more experts in data sharing and smart city technologies.

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