A Physical Testbed for Smart City Research

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***Abstract*—City infrastructure is deteriorating, traffic management systems are becoming increasingly inefficient due to volume, and resources are becoming scarce. In the era of information and analytics, the idea of smart cities has been increasingly proposed as a solution to inefficient public services and resource management. While some cities have had success with beginning to transform into smart cities, the process has revealed significant barriers. One of which is the communication infrastructure necessary to create an interconnected network of sensors, actuators, and analytics systems. This barrier is discussed, and a physical testbed for smart city research is proposed. The current progress of the testbed development is reported, and a plan for continued work is outlined.**

I. Introduction

The world's population has been increasingly concentrated in cities with an estimated 15% rise in developed countries and an estimated 32% rise in developing countries between 1990 and 2050. A larger population further strains already insufficient transportation systems, communication infrastructures, water systems, and power systems [1].

To counteract these shortcomings, a movement has begun to establish cities that are able to self-manage in order to operate more efficiently. These cities have been termed smart cities. Smart cities have been defined in various terms [2]. A short and concise definition is: a city that is able to use technology to create networks comprised of both people and systems that work collaboratively to solve problems in governance, society, and infrastructure. Smart cities are able to achieve this by collecting information to make more informed decisions, efficiently allocate resources to improve operation, and to proactively resolve problems [3].

A large variety of city components can be integrated into the smart city concept. The broadest categories include transportation systems and management, water and waste monitoring, infrastructure inspection, and energy monitoring. However, the addition of more specific components directly improves the lives of city inhabitants and the relationship between the city and its people. Examples of these include small aerial vehicles for package delivery, connected surveillance systems for improved security, body cameras on law enforcement officers, a more accessible government for greater input by citizens, and connected wearable health monitors for improved health care [4].

The most significant inhibitors to real-world smart city research all fall into the area of information and communication technology (ICT) infrastructure. Three main areas of concern are: IT infrastructure, security and privacy, and operational costs [2]. Should a city be able to satisfy these requirements, research and development can further be inhibited by the lack of interconnection capabilities of current technology. The devices connected to a smart city need to adhere to a standard communication interface [5].

A solution to the previously stated problem is a physical testbed that can be used for smart city research. To our knowledge, this is a first-of-its-kind in the United States, and it will allow for the development of smart city systems that are closer to real-world testing than software-only simulation but without the negative aspects of real-world testing. This testbed will be a scale city complete with city blocks and roads. Sensor and actuator networks will be embedded within elements of the testbed that will allow them to be controlled via a city-wide control system.

II. Current Progress

While the smart city testbed is still new, multiple projects have been started to begin initial development. These projects have been of a smaller scope and have mainly dealt with city infrastructure. The current focus is on efficient traffic control systems and building-wide heating, ventilation, and air conditioning (HVAC) system control.

A. City Infrastructure

The testbed is designed to be modular to allow for easy reconfiguration. This allow smart city systems to be tested on a large variety of city layouts. It utilizes the same composition as a traditional city with blocks and roadways. Each city block is constructed as its own module, and these modules are connected via four-lane road modules. Special intersection modules are used to connect 4 road modules together. A power distribution system is used to electrically connect all modules. A variety of structures can be placed on the city block modules, such as multi-story buildings, industrial factories, residences, and utilities distribution centers.

B. Traffic Control System

The traffic control system uses a Raspberry Pi computer to control all of the lights at an intersection module. The control software is being designed in such a way that it can operate using a variety of timer-, sensor-, or remote-based control schemes. The goal is adaptability so it can be easily modified to simulate any type of current or future controller. In addition, the integration of smarter traffic management systems could be gradual instead of all-at-once. Therefore, smarter traffic control systems will need to be tested for cities that use a variety of traffic control schemes.

C. Autonomous Car

The autonomous car is being adapted from the DeepPicar [6] so that it can communicate with a backbone network. Both cars have the ability to navigate using image analysis, but the one used in the smart city testbed has the ability to also off-load analysis to a centralized server. This car will also be able to both control itself and receive commands from a remote system. This can facilitate testing of vehicle swarms with a central controller or systems that use a central controller with local car control as a failover.

D. Smart Buildings

The smart house is one of many types of buildings that can be placed on a city block module. It contains a sensor and actuator network to monitor the status of the house and control different elements of it, such as doors and windows. The actuators and sensors connect wirelessly to a Raspberry Pi that acts as a gateway to the backbone network. The smart house publishes data to a website that can then be viewed by a user connected to the smart city testbed. The smart house can also receive commands, such as opening or closing the windows and doors, via the same website. Having sensor and actuator networks embedded within buildings allows for finer control of its energy usage, such as monitoring room temperature and automatically turning off lights and HVAC systems in unoccupied rooms. By having buildings in the testbed, sensor and actuator networks can be quickly constructed to test building-wide control systems without the need to install these networks in real buildings.

E. Backbone Network

To allow communication among all of the nodes of the smart city testbed network, a backbone networking infrastructure is necessary. The backbone network consists of database servers to store the data received from the sensors, data analytics servers to process the incoming data, and web servers to present processed data to users and accept their commands. The network topology is similar to that recommended by Cisco [7]. The sensors and actuators of the smart buildings, autonomous cars, and traffic controllers reside in the street layer, the gateways within the smart buildings reside in the city layer, the analytics and database servers reside in the data center layer, and the web servers reside in the services layer. The analytics servers will be used to aggregate sensor data and use machine learning to more efficiently manage city resources. Having a full network infrastructure that resembles that of a real-world smart city means network vulnerabilities and security inadequacies can be tested without risk of crippling real systems. In addition, new network architectures can be researched without the overhead required of implementing them in real smart cities.

III. Conclusion and Future Work

The smart city testbed provides a low-cost way for researchers to develop novel technologies for use in smart cities without needing a city that meets all of the infrastructure requirements. Using this testbed also allows for full control of all elements within a city. The testbed can also serve as a platform for testing security vulnerabilities without risk of damaging or exposing current city-wide systems. This is something that would be difficult to conduct in a real-world city.

Future work can be broken down into four categories: infrastructure, traffic control, vehicles, and real-world collaboration.

The infrastructure will be expanded in both size and building complexity. Areas of the city will be zoned into residential, commercial, and industrial to further resemble real-world cities. With this comes the addition of office buildings, factories, and other commercial and industrial entities. In addition, power stations and water facilities will be added for research into the integration of connected utility systems into smart cities.

The traffic control system will be expanded so that traffic controllers at each intersection can communicate over a mesh network. They will also be able to coordinate with each other and a centralized traffic controller to allow for research into more advanced traffic flow methodologies that include coordination with public transport systems, such as buses.

More autonomous cars will be added for use in traffic management studies. In addition, autonomous quadrotors will be introduced, and coordination between aerial and ground vehicles will be studied.

Finally, a collaboration with the city of Richmond, Virginia will be begin the planning stages so that more developed smart city technology can begin to be transferred to the real-world.

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