Leveraging AI and Sensor Fabrics to Evolve Smart City Solution Designs

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ABSTRACT

Cities have entered the age of the sensor and located sensors everywhere over and under cities. The sensors monitor a host of factors that assess City operations and life such as air quality, noise, city services and traffic. Further, the sensors have "gone mobile" with announcements of situation aware mobile sensor platforms designed for city-level security and public safety. These wearable sensor platforms combine video, audio, and location data with Internet of Things (IoT) capabilities. However, the many sensors and functional platforms have not yet made the cities employing these many diverse sensors truly Smart. We are analyzing why the success toward the Smart city is limited, or late in coming. The explanations for the constrained effectiveness are assigned to many factors, but one of significance can be teased from a long-accepted explanation that associates data, information, and knowledge. Smart Cities need to effectively use the sensor data and the information assembled from these interpreted and organized data to create knowledge that serves the city and its people by answering and resolving key problems and questions. But the systems and analytic models needed to associate these data from many sensors have yet to be designed, constructed, and proven in the complex cities of today. Thus, the data (and information from the diverse sensors) lacks crucial integration and coordination for decisions and sense-making. While these sensor-based systems were, and in many cases are meeting some intended functionally discrete goals, they appear to be better described as data collection tools feeding centralized analytical engines. They are point solutions with specialized or targeted sensors feeding specialized solutions. This is a significant limiting factor in a city's drive to improve the quality of life and the efficiency of the services a city provides to its stakeholders. In this paper we present current trends in Smart City development, emerging issues with data and complexity growth, and proposes a mean to leverage the advancing technologies to address the integration problem.

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CCS CONCEPTS

• Computing methodologies~Reasoning about belief and knowledge • Computing methodologies~Reasoning about belief and knowledge;500 • Computing methodologies~Learning from implicit feedback • Computing methodologies~Reasoning about belief and knowledge;300 • Computing methodologies~Cognitive science • Computing methodologies~Learning from implicit feedback;300

KEYWORDS

Smart City, Artificial Intelligence, Sensors, Sensor Fabric

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1 Introduction

The concept of the Smart City is one of the major trends that appears to generate strong and continuing research and discussions as we have moved well into the 21st century. Humankind seems to be moving into rather that away from urban environments. This stimulates concentrated growth and requires the development of new technologies, processes and techniques for managing the complexity of metropolitan centers. One approach to address this is to employ sensors and collect data to support the proactive management of cities functions. The number and variety of Smart alternatives, creative ideas for sensors, deployment of mobile devices, and current sources of tested and operative sensor data are truly impressive. They include:

- carpets of sensors across a City for autonomous cars (driverless cars),
- apps car drivers crossing over a pothole,
- digital masterplans for City designs,
- structure sensors for sustainable buildings,
- landing posts (utility poles) connected to underground, optical wiring that could provide neighborhoods with LED street lighting,
- process parking transactions, and

- service and data lists serving as electronic neighborhood bulletin boards. [1]

Added to these devices are end-to-end platforms supporting the aggregation and correlation of near real and real time data streams. Mobile sensor platforms designed for city-level security and public safety operations, such as wearable sensors, combine video, audio, location data, and Internet of Things (IoT) capabilities, which can be centrally managed via cloud-based software to offer real-time "situational awareness". One example is a public safety solution by Flir Systems which provides a system of sensors that can be worn on an individual's body or mounted inside vehicles. It has features that deliver data from visible-video, audio, global navigation satellite system (GNSS), gyroscope, accelerometer and magnetometer sensors. This provides decision makers more information so they can respond to complex situations and evolving threats as they occur [2].

2 Sensor Objectives and Purposes

It is critical that Smart cities apply the swarms of available sensors wisely and strategically to benefit citizens with more rapid and higher quality outcomes. If Smart cities fail to provide clear social and economic benefits, the point of the sensor-managed city would become merely to serve as a revenue generating source for the various commercial organizations providing and managing the technology.

To meet the increasing need for innovative solutions to the problems of the urban environment, Smart City data and the resulting analytical outcomes from the sensors must consistently influence ongoing efforts to optimize overall city performance. This requires planning (for services like preventive maintenance, security, traffic flows…etc.), actual delivery of the services, and post-delivery monitoring. These services must be performed with a clear citizen-focused goals that minimize the costs of services and maximize the quantity and quality of the delivery of the services. This structured and coordinated purposeful decision making has been described and envisioned by cities and Smart city researchers for many years. Yet the underlying highly coordinated and qualitatively effective system has not evolved in a significant way. Since 2000 the vision has been of a city where an urban center is "…safe, secure environmentally green, and efficient because all structures--whether for power, water, transportation, etc. are designed, constructed, and maintained making use of advanced, integrated materials, sensors, electronics, and networks…" This city image predicts that the Smart City will be managed by computerized systems comprised of databases, tracking, and decision-making algorithms [3].

While the initial vision called for systems to be functionally focused or tailored for an application, it also called for a system with a design that would;

- make use of these building-block like components,
- provide an interface to the computerized "monitoring" capability for each given function, and
- have a full structure or service supplied.

Finally, the vision posited the system would somehow be integrated across all aspects of an urban center's essential infrastructure. The envisioned capability of these all-encompassing macro systems was that they would monitor and integrate all "…critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, and major buildings." Proponents and advocates of Smart cities asserted and often predicted that systems and structures would have the capacity monitor their own conditions and carry out self-repair. However, it was never clear how this transformation would occur. Even the physical environment including air, water, and surrounding green spaces will be monitored in non-obtrusive ways to maintain optimal quality levels [3].

The limiting factors in this early period of Smart City sensor application development recognized the limitation of sensors with embedded microprocessors and wireless communication links. A 2002 National Research Council report discussed the benefit of networked systems of embedded computers and sensors throughout society that could provide support for a greatly expanded information revolution. The report noted that a framework did not then (~2004) exist that could allow the distributed computing paradigm offered by smart sensors to be beneficially applied to structural health monitoring and control systems. The report cited the Tsing Ma Bridge monitoring system established in Hong Kong in 1997 with 280 sensors, including anemometers, temperature sensors, strain gauges, accelerometers, global positioning systems (GPS), displacement transducers, and level sensors as well as the Stonecutters Bridge monitoring system (Hong Kong) with over 1500 sensors to support the contention. The problem recognized was the algorithms in use assumed that all data would be centrally collected and processed. It was noted that the approach did not scale to systems with densely instrumented arrays of sensors required, and that practical and durable power supplies were still a challenge [4].

2.1 Today, and the Future of Sensor Data

It is important to comprehend the scope and scale of the sensor driven Smart City to fully appreciate the problem facing managers, system architects, data managers, and a host of others involved in making cities Smart. First, we need to catalog what sensors inhabit the Smart City environment, how much data is produced, and what it takes to process the data even before we try to make sense of the data and perform coordinated correlation and analysis activities. There are many ways of exploring and categorizing the Smart City sensors of today [5]. They encompass assessments of the breadth of the sensors placed around a City, the functional diversity of the sensors, the data generated and available from the sensors and the time sensitivity and locational volatility of mobile sensors.

As a starting point, consider the City of Barcelona which has been described as a city that can be categorized as being very "Smart." [6] Barcelona encompasses about 100 Km^2 and has about 1.62 million inhabitants. Functionally, city owned equipment includes 150,000 lampposts, 40,000 garbage containers, and 80,000 public parking spots. The cities data are collected by a sensor networks for energy monitoring, Noise monitoring, urban environmental monitoring (includes air, temperature and humidity measurements), garbage collection monitoring, and parking spots monitoring are all in operation. [6] The sensor data generated may be viewed by the amount, type, and frequency of the generated data. These data are then combined to obtain data estimates of daily sensor traffic [7].

This city has almost 1,800 sensors installed monitoring these energy, noise, urban lab, garbage collection, and parking at specific locations. Energy monitoring is conducted for municipal buildings and solar thermal installations. It provides energy consumption (electriCity meter, electriCity ambient conditions, gas meter, internal ambient conditions, and temperature) while the solar thermal installation ascertains solar thermal energy produced and consumed. Noise monitoring management detects noise and acoustic pollution (about 50 distributed sensors) in seven different city areas. Laboratory environmental monitoring assesses air, temperature, humidity, and some transportation issues (including people and bicycle flow) with about 50 active sensors spread through the various zones of Barcelona. Garbage Collection management obtains data about garbage and containers with hanging sensors. The refuse data are organized by glass, organic, paper, plastic and refuse through about 660 sensors. Parking Spots monitoring locates free parking spaces through approximately 500 sensors in one localized area of Barcelona. The monitoring service transfers and updates several data packets periodically during the day.

The resulting data generated per day are:

- Energy monitoring management (>3MB),
- Noise monitoring management (578KB),
- Urban Lab monitoring management (153KB),
- Garbage Collection management (480KB), and
- Parking Spots management (615KB).

About 5MB that is transferred through the Barcelona Smart City network. Barcelonas' data are particularly useful because they can be analyzed and extrapolated to estimate the generated data from similar services for an entire city. According to Barcelona's City statistics, there were 70,000 buildings, 40,000 containers and 80,000 parking slots in 2014. Sinaeepourfard et. al [7] estimated that there are 40,000 street corners. The number of sensors, and corresponding expected generated data (for a city-wide equivalent network) is about 8 GB per day from all sensors in the city. (This includes only data obtained from these identified sensors). The number of sensors needed would come to 321 million sensors for coverage of the whole city. Excluded are data from mobile devices, surveillance cameras, information from web services, etc [7].

3 Stationary and Dynamic Sensors and sensor platforms

Fast forward to today and we find ourselves entering a new era of robots with great capabilities — flying drones functioning in both natural and man-made environments. Initially drones were associated with defense applications but they are having an increasingly significant impact on civilian tasks such as transportation, communication, agriculture, disaster mitigation and environment preservation. The determinants of the drone effectiveness are due in part to the energy required to staying airborne, the perceptual intelligence required to negotiate complex environments, and the tools available for collection and reporting of data that may be useful. It has been predicted that there will be great use of autonomous drones for civilian applications [8].

Drones have significant functionality for diverse products including commercial inspections, photogrammetry and movie making. But drone makers have found it necessary to continuously improve and increase the number and capability of sensors, so they possess features that are necessarily protective of the sensing (drone) vehicle itself. Today consumer and professional drones are being constructed with obstacle detection and collision avoidance sensors. This technology began with drones equipped with sensors detecting objects in front of the drone and has progressed to drones from DJI, Walkera, Yuneec and others have front, back, below and side obstacle avoidance sensors including Stereo Vision, Monocular Vision, Ultrasonic, Infrared, Time-of-Flight and Lidar sensors (with only one drone with all 6 directions of obstacle detection today). To understand detected objects and then take action to avoid the obstacle - whether to stop, go around or above the object, is difficult manually. The operator must recognize and then take immediate and appropriate actions. Operating an autonomous drone require is more difficulty and requires an array of obstacle detection sensors including SLAM technology to interpret the images being scanned (by the sensors), GPS and GLONASS satellite navigation systems to know exactly where it is and maintain stable flight as well as software algorithms and software programming which includes mathematical modelling, algorithms, machine learning [9].

The resulting and notably impressive sensor technology of the drone generates potentially vast amounts of data. Functioning together, they include:

- Gyros and accelerometers (tilt controls) to determine position and orientation of the drone in flight.
- thermal sensing of changes in the movement of gas molecules passing over a small integrated circuit on-board camera
- Inertial measurement units
- GPS utilize multi-axis magnetometers
- Current sensors monitor and optimize power drain, detect fault, and safely charge internal batteries, conditions with motors or other areas of the system
- Gas engine mass-flow sensors employ an calorimetric principal utilizing a heated element to monitor air flow into small gas engines to maintain the proper fuel-to-air ratio at a specified engine speed.

All these sensors feed data into a central processor to maintain adherence to flight rules, air traffic control direction, and flight paths [10].

4 Inbuilt intelligence, self-diagnostics and repair.

The manufacturing response from sensor makers appears clear. The focus has been on the sensor itself. For example, the sensor community has begun to focus on built in intelligence. It is essential to reduce the huge volumes of generated data into actionable information for users, and commands given to actuators back out in the field. Sensors which simply convert physical variables into electrical signals must evolve into something more sophisticated to perform a technically and economically viable role. Manufacturers have responded with improvements to fabrication, adding integration and built-in intelligence. This facilitates IoT connectivity, improves predictive maintenance, enables self-diagnostics and repair and improves manufacturing. Manufactures have also improved the base functionality by sending calibration data to the MPU so that the sensor is automatically set up for any production changes and can identify production parameters that start to drift beyond acceptable norms. It can then generate warnings so preventative action can be taken.

This 'report by exception' reduces both the load on the central computing resource, and the smart sensor's power requirements. Dual elements enable sensor self-diagnostics since drift in one of the sensor element outputs can be detected or the process can continue with the second measuring element. A Texas Instruments product example uses an ultra-low-power sensor to build a smart fault indicator for electric power distribution networks. The fault indicators reduce operating costs and service interruptions by providing information about a failed section of the network. Fault indicators, which are installed on the junctions of the overhead power-line network, send measurement data for power transmission lines wirelessly to the concentrator/terminal units mounted on the poles which then passes the data to the cellular network to relay real-time information to the main station.

The resulting Intelligent sensors can be remotely programmed with suitable parameters every time a product change is required. Sensors can self-calibrate by using a patented combination of an ASIC and an array of MR (magneto resistive) sensors. This accurately and reliably determines the position of a magnet attached to moving objects such as elevators, valves or machinery. The output and the MR sensor sequence determine the nearest pair of sensors to the center of the magnet location. The output from this pair is then used to determine the position of the magnet between them. This non-contacting self-diagnostics feature technology can provide enhanced product life, reduce downtime levels, and increased durability. Similar manufacturing goals to integrate all the elements into a single discrete device and adding intelligence and communications capabilities to the basic device provides further evidence of manufactures continuing response to IoT's needs [9].

5 Challenges using Smart City sensor data

Beneficial and game changing uses of the Smart city data requires more than just additional sensors and enormous data streams. As the evolution of drones shows, sensors must work in a coordinated and strategic manner to address deep problems in Smart cities. This effectiveness can be achieved by constructing a fabric that unifies a city. Such a fabric will require both organizational changes addressing city decision making and technical developments. Some suggestions for organizational and technical (but not combined) Smart City solutions must include technical architectural models such as the IBM Smart Cities technical architecture which helps to making sense of the data; not as previously assumed, people do not only want efficiencies but seek differentiation and some way of attracting Smart talent to create economic development [1]. Providing a consistent fabric of city management presents the dual challenge of technical complexity and legislative and ethical controls.

City managers must also deal with the impedance mismatch between the rate of change in technological capability and the legislative and legal systems ability to adapt to the availability of new technologies. Consider the long history of collecting sensor information from remote flying vehicles that can be traced back to the use of satellites and the limitation placed on these data by U.S laws. Images and information available from remote-sensing satellites was potentially valuable to both commercial and news media. Ready to make major use of new near real-time aerial and satellite information (which in the early 1980s offered resolution of less than 10 meters), potential consumers had to deal with licensing restrictions placed on any US company wanting to put a camera into orbit by the US Land Remote Sensing Commercialization Act of 1984 [11]. Technical capability blocked by legislative control.

The technical challenge for Smart Cities is to find ways of combining streaming and collected data with Smart City performance goals, concepts, and architectures. The progress assessment for this high level of coordination among the various architectures and their related data do not provide yet any comprehensive model which allows for consistently integrating all expected Smart Cities functionalities. Currently, things such as accepted standardization or data collection globalization are limited or simply do not exist. In addition, the increasing speed of developments in technology and innovation to Smart city data sources challenges city managers to consume and analyze data while citizens and stakeholders demand immediate service delivery and benefits [3].

6 Integration and Fabric Development Baby Steps

Most smart cities are evolving the underlying infrastructure as they deploy more services and build collaborative integration. Smart city integration of services requires highly reliable, highly performant networks, both fiber and wireless, as well as elastic compute and storage. Such complex tools are difficult to develop and slow to implement. Solutions that can more rapidly advance the integration required are necessary, if they exist. This paper suggests that the need to implement and enforce governance across all deployed solutions and services can be more rapidly addressed if the Smart cities create and provide or more likely procure use of a Cloud Fabric.

Service Fabric itself is an application platform layer. As the hosting platform the fabric provides an abstraction layer over the underlying infrastructure, helps manage the lifecycle of deployed services, and removes most external dependencies while unifying the deployment, management, and upgrade models [12]. The fabric host is a virtual integration space as long as it provides continuous monitoring; records the underlying metrics of operational use; delivers notifications required by the hosted solution and hosting system's status and health; and may be used to provided mandatory, certified components supporting a unified governance model.

It is assumed that there will be no "earthquake–like" fabric development and deployment model. The fabric (or multiple smaller focused fabrics) will grow or evolve through prototyping, agile integration of Smart development projects, and coordinated devops solutions. Once the integration challenges have been effectively addressed, Smart Cities will be able to confront the volume and speed of the real time data sensors continuously produce.

7 The future of AI is Assistive, not Artificial, Intelligence

Decision makers across all role of city management rely on available information to make their decisions. The introduction and growth of sensors and the proliferation of available data can strain available information handling processes. The sheer volume, as discussed above, may obfuscate or overwhelm the demands of the integration effort, and its context. We believe that Smart city systems will likely evolve in several stages beginning with functionally successful stand-alone solutions. We the expect to see a development of more tightly integrated automated systems. We then expect to encounter cities that incorporate collaborative sensor networks, and finally we see the city systems evolving into autonomous and assistive tools that well manage the Smart cities of our future. Obviously, this evolutionary framework can be altered by the strategy and relative benefits (and needs) of the functionality being introduced in a specific urban center.

The following discussion helps us better understand and visualize what must be accomplished by these systems. For example, consider at the all too common scenario; when an unaccompanied driver is attempting to rapidly enter a busy roadway.

In a city using highly **integrated** technologies and operator may be provided video alerts due to movement within a predefined zone. They might receive the density and speed data for the roadway traffic and be able to make a rapid adjustment to the road signals to slow if not stop traffic. Today these independent systems are integrated by the driver/user. Providing the situational awareness to the operator is a significant improvement to previously fielded 'dumb' systems.

If we could create a more **collaborative** environment by hosting the individual system components on a shared fabric the operator would not need to seek secondary systems. The video detection would proactively display nearby, managed, systems. It could share location and state of those systems and likely reduce the speed so an operator could react to the potential danger.

An **autonomous** system would be permitted to take some additional action within the bounds of governance, policy, and law. Detecting the motion path and potential threat to the person the autonomous system might proactive change nearby stop lights to yellow to slow ongoing traffic while alerting the operator in parallel with the change. The operator may choose to override the autonomous choice or may ask the autonomous solution to provide options before either the system or the operator takes action.

Ultimately, Smart cites can evolve their systems to become **assistive** partners in the management of the city. The great ability is that a cloud fabric-based solution can to act in parallel. It could consider the alternatives available and diverse needs of multiple and different users. What is required is that the cloud fabric-based solution consider an exceptionally large array of alternatives in a relatively small amount of time, and that it correlate a large historical model of past behaviors to provide decision makers proactive suggestions. The solution migh take note of consistent pedestrian motion paths and consider a history of pedestrian-vehicle accidents. Finally, it might suggest adding fencing to block foot traffic) as well as reactive alerting for the passing traffic.

We believe the next generation of Smart city assisted intelligence and decision support systems will leverage data science, machine learning, and context awareness. It will both reactively and/or proactively provide decision makers statistical analysis supported by machine learning. The systems will predict, engage, and prevent outcomes (as determined by the Smart city stakeholders and decision makers) while leveraging a full feedback loop to continuously evaluate and improve performance.

8 Conclusions

The balancing and allocation of benefits of the Smart city among the stakeholder parties is an important decision that can lead to increasing or decreasing total cost (and benefit) of a specific project. We do not propose that the systems make arbitrary decisions. Such decision can affect the overall relationship between the Smart city inhabitants. Common benefit assessment processes are based on experiential knowledge and are considered subjective or perhaps simply implicit and "good." Smart cities will require fuzzy adaptive decision making models for selection of benefit allocations which transforms the linguistic principles, likes and preferences, and experiential expert knowledge into a more usable and systematic quantitative-based analysis. Cities may use fuzzy logic qualitative approaches and analytic hierarchy process (AHP) adaptive capabilities to evaluate the allocation of benefits and determine where and when to distribute each benefit a specific use or user group to achieve the highest overall level of benefits.

This paper has discussed an explanation for the constrained effectiveness of the Smart city revolution. It argues that unassociated (stove-piped) data, information, and knowledge are limiting the effectiveness of the Smart city of today. Smart Cities need to use the sensor data and the information assembled from these interpreted and organized data to create knowledge that serves the city and its people by answering and resolving key problems and questions. But the systems and analytic models needed to associate these data from many sensors have yet to be designed, constructed, and proven in the complex cities of today. Thus, the data (and information from the diverse sensors) lacks crucial integration and coordination for decisions and sense-making. While these sensor-based systems were, and in many cases are meeting some intended functionally discrete goals, they appear to be better described as data collection tools feeding centralized analytical engines. They are point solutions with specialized or targeted sensors feeding specialized solutions. The paper concludes that a fabric to integrate the sensors and data for the Smart city can resolve this problem

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