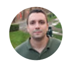
ISO-Standardized Smart City Platform Architecture and Dashboard

Article *in* IEEE Pervasive Computing · April 2017

DOI: 10.1109/MPRV.2017.31

4 authors:


Vladimir Zdraveski
Ss. Cyril and Methodius University in Skopje
22 PUBLICATIONS **98** CITATIONS
SEE PROFILE


Kostadin Mishev
Ss. Cyril and Methodius University in Skopje
14 PUBLICATIONS **97** CITATIONS
SEE PROFILE


Dimitar Trajanov
Ss. Cyril and Methodius University in Skopje
152 PUBLICATIONS **537** CITATIONS
SEE PROFILE


Ljupco Kocarev
Macedonian Academy of Sciences and Arts
410 PUBLICATIONS **14,564** CITATIONS
SEE PROFILE

ISO-Standardized Smart City Platform Architecture and Dashboard

The proposed platform, guided by the ISO 37120 standard for city services and quality of life, aims to acquire and process data from heterogeneous sensors and sources, implemented on the cloud. A prototype application was developed for the city of Skopje, Macedonia.

Vladimir Zdraveski, Kostadin Mishev, Dimitar Trajanov, and Ljupco Kocarev
Saints Cyril and Methodius University of Skopje

According to a United Nations report, 54 percent of the world's population lives in urban areas; by 2050, it could be 66 percent.[1] Managing urban areas is thus becoming one of the most important development challenges of the 21st century. Furthermore, forecasters predict there will be approximately 30 billion connected things by 2020.[2] These connected things (sensing devices) might include wearable sensors; smartphones; sensor-embedded gaming systems, such as music players; and in-vehicle sensor devices. Users carrying mobile sensing devices are becoming the source of a vast amount of varied data. At the same time, inherent user movement and ubiquitous connectivity are creating opportunities for dense spatial and temporal sensing.

Connecting devices thus has the potential to provide data that, after processing, could offer information and communications technology (ICT) solutions in the form of dashboards for managing urban areas. (For an overview of the state of the art in ICT platforms, see the sidebar.) The smart city concept aims to integrate traditional and modern ICT communication infrastructure (such as transportation and energy infrastructures) with the social infrastructure (intellectual and social capital) and online social networks to ensure sustainable economic development and a high quality of life. The concept includes smart urbanization,[3] smart energy consumption,[4] and smart usage of big urban data computing.[5,6] For example, researchers have designed an urban Internet of Things (IoT) system that supports the smart city vision by exploiting advanced communication technologies to provide added-value services for municipal administrators and citizens.[7]

However, a small set of smart applications for finding information using available municipality online data does not make a city "smart." Moreover, even when citizens owning IoT devices share or publish IoT data as reports, or as streams[8] that have been analyzed with continuous semantic mechanisms,[9] it's still difficult to claim the city is a smart one. Indeed, more comprehensive city factors should be considered and improved, such as city governance,[10] environmental issues,[11] and the role of the citizens,[12] and we need metrics of urban smartness and a shared definition of what constitutes a smart city.[13]

In May 2014, the International Organization for Standardization published the first international standard on city data, ISO 37120, which includes 100 indicators for city services and quality of life.[14] The standard was developed using the framework of the Global City Indicators Facility, which has been extensively tested by more than 250 cities worldwide.

Related Work in ICT

Here, we provide a brief overview of the state of the art in developing information and communications technology (ICT) platforms.

Platforms

ThingSpeak is an open cloud platform (available on GitHub) that enables connections between things and people (https://thingspeak.com). Its features include real-time data collection and storage, Matlab analytics and visualizations, alerts, scheduling, device communication, an open API, and geolocation data.

ThingWorx (www.thingworx.com) is a software development platform that combines the key functionality of Web 2.0 with search and social collaboration functionalities to build innovative applications that connect, store, and relate the activities and data from people, systems, and things, including connected machines, devices, sensors, and equipment.

NIMBITS (www.nimbits.com/index.jsp) is an open source platform for the Internet of Things (IoT) for connecting people, sensors, and devices on the cloud. It is software on a distributed cloud that can record and process time series data.

EVRYTHNG (https://evrythng.com) manages billions of intelligent IoT identities for your products in the cloud, giving each one a persistent, addressable web presence.

Paraimpu (www.paraimpu.com) is a social tool that aims to let people connect, compose, and share things, services, and devices to create personalized IoT applications.

SensorCloud (www.sensorcloud.com) is a sensor data storage, visualization, and remote management platform that leverages powerful cloud computing technologies to provide excellent data scalability, rapid graphing, and online analytics.

Arkessa (www.arkessa.com) enables organizations to monitor, manage, and control remote devices and facilities. It offers a secure and reliable wireless cellular communications system.

The Axeda (www.ptc.com/axeda) platform is a cloud platform to build and deploy enterprise applications, both wired and wirelessly. It enables the creation of business logic without programming and supports cellular, satellite, and Internet communication optimized for minimum transmission costs.

Xively (https://xively.com) offers a platform as a service that lets IoT devices connect to the cloud. It simplifies building and running a connected business.

Initiatives

There are many initiatives and organizations that aim to improve the city benchmarking and planning. The Centre for Advanced Spatial Analysis (www.bartlett.ucl.ac.uk/casa) is one of the leading forces in the science of cities. CASA is focused on generating new knowledge and insights for use in city planning and ideas in computer-based visualization and modeling.

The Senseable City Laboratory at MIT (http://senseable.mit.edu) develops and deploys tools to learn about cities and keep in step with industry partners as well as metropolitan governments, individual citizens, and disadvantaged communities.

QUT Urban Informatics (www.urbaninformatics.net) prefers the "people-first" approach and tends to merge the physical and digital layers of people networks and urban infrastructures by targeting across sociocultural, economic, ecological, and technological spheres.

The National Centre for Geocomputation in Ireland (www.maynoothuniversity.ie/national-centre-geocomputation-ncg) research focuses on the capture, storage, analysis, and visualization of spatial data and also works with secondary data sources—for example, analyzing crime patterns, house prices, and health data.

Dashboards

There are many existing dashboards for cities in the UK, including for Birmingham, Brighton, Cardiff, Edinburgh, Glasgow, Leeds, London, and Manchester (http://citydashboard.org/choose.php). There are also dashboards in other places around the world, such as in Dublin (www.dublindashboard.ie),[1] Amsterdam (http://citydashboard.org/amsterdam), and Chicago (www.cityofchicago.org/city/en/depts/cdot/dataset/cdot_performancemanagementdashboard.html). A more comprehensive overview of the benchmarking and dashboard initiatives employed by various cities appears elsewhere,[2] as does an analysis of how big data directly affects cities.[3]

Our Novel Platform

The aforementioned smart dashboards and platforms offer user friendly user interfaces and accurate data, but they're not based on an international standard, and they lack different viewpoints (temporal, spatial, and so on) for different types of users. To solve those shortcomings, we developed an ICT platform architecture based on the ISO 37120 standard that offers full data integration of various sensor networks, social networks, news, blogs, and other data sources to create a context-aware and energy-efficient IoT/big data/cloud platform. The platform architecture concept allows coordinated, holistic, and improved city planning and forecasting; real-time reporting on infrastructure conditions, predicting and preventing problems, and deploying resources more efficiently; and two-way communications between government and people and effective citizen engagement by contributing to and accessing real-time city data.

REFERENCES

1. G. McArdle and R. Kitchin, "The Dublin Dashboard: Design and Development of a Real-Time Analytical Urban Dashboard," *ISPRS Ann. Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 4, no. 1, 2016, pp. 19–25.

2. R. Kitchin, T.P. Lauriault, and G. McArdle, "Knowing and Governing Cities through Urban Indicators, City Benchmarking and Real-Time Dashboards," *Regional Studies, Regional Science*, vol. 2, no. 1, 2015, pp. 6–28.

3. D. Offenhuber and C. Ratti, *Decoding the City: Urbanism in the Age of Big Data*, Birkhauser, 2014.

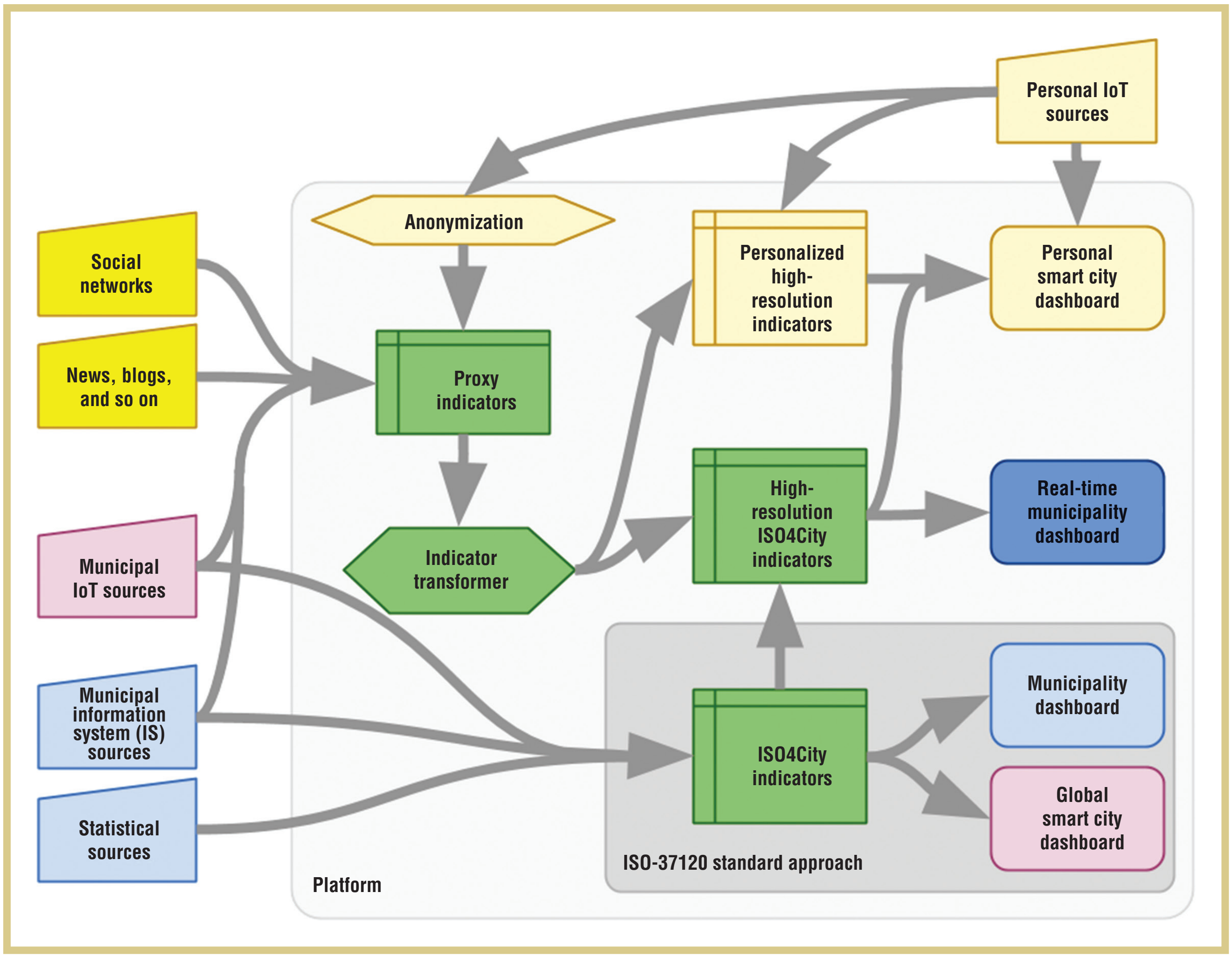


Figure 1. The platform architecture's dataflow diagram. Personal IoT sources integrate data from sensors on citizen-owned smart devices. Additional customization and contextualization is offered through a filter that develops personalized high-resolution indicators. Personal data can also be anonymized to produce proxy indicators, which the indictor transformer uses to create high-resolution ISO 37120 (or ISO4City) indicators.

This is a demand-led standard, driven and created by cities, for cities. It defines and establishes definitions and methodologies for a set of indicators to steer and measure the performance of city services and quality of life. The ISO 37120 indicators (also referred to as ISO4City indicators) are categorized under 17 themes related to city services and quality of life: economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, safety, shelter, solid waste, telecommunication and innovation, transportation, urban planning, wastewater, and water and sanitation. The indicators reflect quantitative data and measure a city's social, economic, and environmental performances, but we refer to them as "low-resolution" indicators, because they're static or slow changing (annual, quarterly, or monthly) quantities that merely show the city's average performance.

Here, we develop a concept for a platform that complements such indicators with "high-resolution" indicators, which can provide real-time temporal, spatial, and personalized input. Furthermore, our platform aims to provide methods for observing and measuring phenomena of common interest (such as traffic conditions, air pollution, and noise in urban areas) over large geographic areas, exploiting the inherent mobility of sensing devices. By combining data from social networks, news, blogs, and other sources, the platform can create a generic city footprint that could guide solutions and technologies to help build smarter cities.

Platform Architecture

Figure 1 shows our platform's core architecture, which is based on the ISO4City indicators as well as a more granular (temporal, spatial) set of high-resolution ISO4City indicators, which

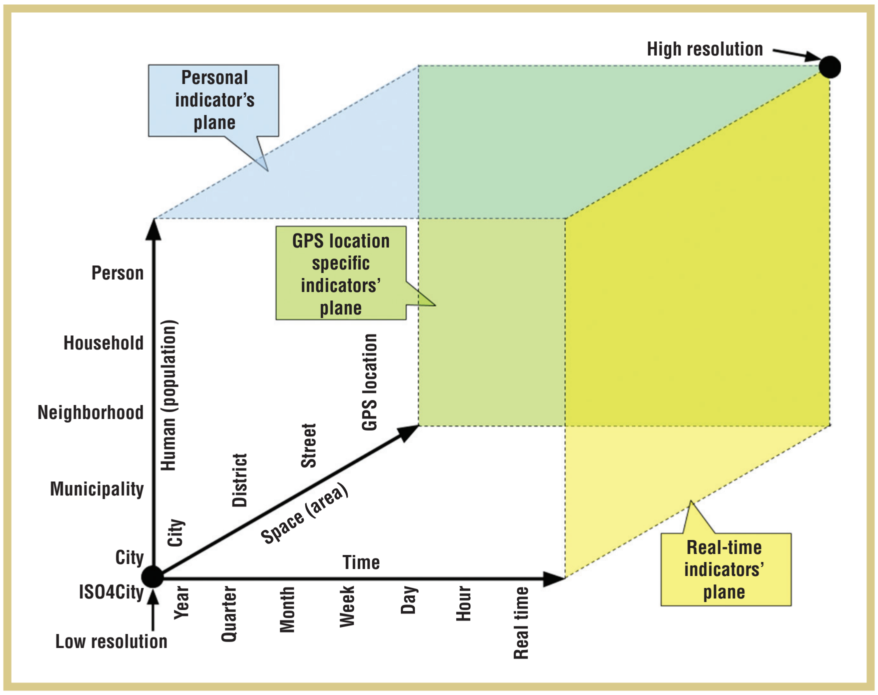


Figure 2. The 3D space of ISO indicators. The space has three axes: temporal, spatial, and human, showing the contrast between "low-resolution" and "high-resolution" indicators.

are used to create a real-time personalized dashboard for citizens and city planners.

The architecture can integrate data from several sources, arranged into four groups:

- *statistical and municipal-information-systems data*—that is, data from existing information systems owned by the authorities;
- *municipal IoT data*—that is, data provided by governmental, nongovernmental, or EU agencies that is continuously available or available in periodic reports, and data from sensors deployed by the city or owned by various vendors (such as data from mobile phone providers);
- *social data*—that is, data retrieved from social networks, blogs, newspapers, or news aggregating portals; and
- *personal data*—that is, data from sensors owned by citizens (such as wearable sensors, smartphones, or in-vehicle sensors).

The data from municipal information systems, municipal sensors, and social networks is used to measure proxy indicators of the ISO4City indicators. A proxy indicator represents an indirect measure that approximates or is related to a phenomenon in the absence of a direct measure. Thus, proxy indicators, derived from real-time processes, let us measure city indicators in greater detail.

Additional customization and contextualization is offered through a filter that uses the personal IoT sources to develop more personalized high-resolution indicators. The "personal IoT sources" component shown in Figure 1 integrates data from personal IoT sensors—that is, sensors in citizen-owned smart devices—and shares it with the platform. Personal data is then transformed into personalized high-resolution indicators, either directly or through the anonymization process producing the proxy indicators. This personal IoT component enables easy development of new cartridges (data adapters) to support the integration of different classes of IoT devices. A discussion of the privacy and security issues related to the integration of personal data appears elsewhere.[15]

The idea of increasing the resolution of existing indicators and introducing new (related) indicators has resulted in a 3D discrete space (presented in Figure 2) with the following axes and discrete values:

- *temporal*: yearly, quarterly, monthly, weekly, daily, hourly, and real-time values;
- *spatial* (by area): values based on the city, district, street, or GPS location (latitude, longitude); and
- *human* (by population): values based on the city, region/municipality (1/10 of the city population), neighborhood (1/10 of the municipality population), household, or person.

Thus, for the economic indicator "city's unemployment rate," we can consider, for example, the indicator "household unemployment rate in a district." Or, instead of the energy indicator, "total residential electrical energy use per capita," we could define a new indicator, "monthly electrical energy use per household in a street." Based on the proposed architecture, platform users obtain current information at each city location per person for a particular indicator (or set of indicators). Note that not all indicators have three dimensions. Moreover, some indicators are well-defined only if measured annually and for the whole city. The set of high-resolution indicators is a base for near real-time monitoring of vital city processes.

Figure 3 shows the application layer architecture, which consists of an integration interface to the data gathering module (the ICT platform), the core intelligence reasoning logic (the reasoner), a security block for authentication, and a user interface (front end) accessed via web and mobile applications, web services, and secure services for edge

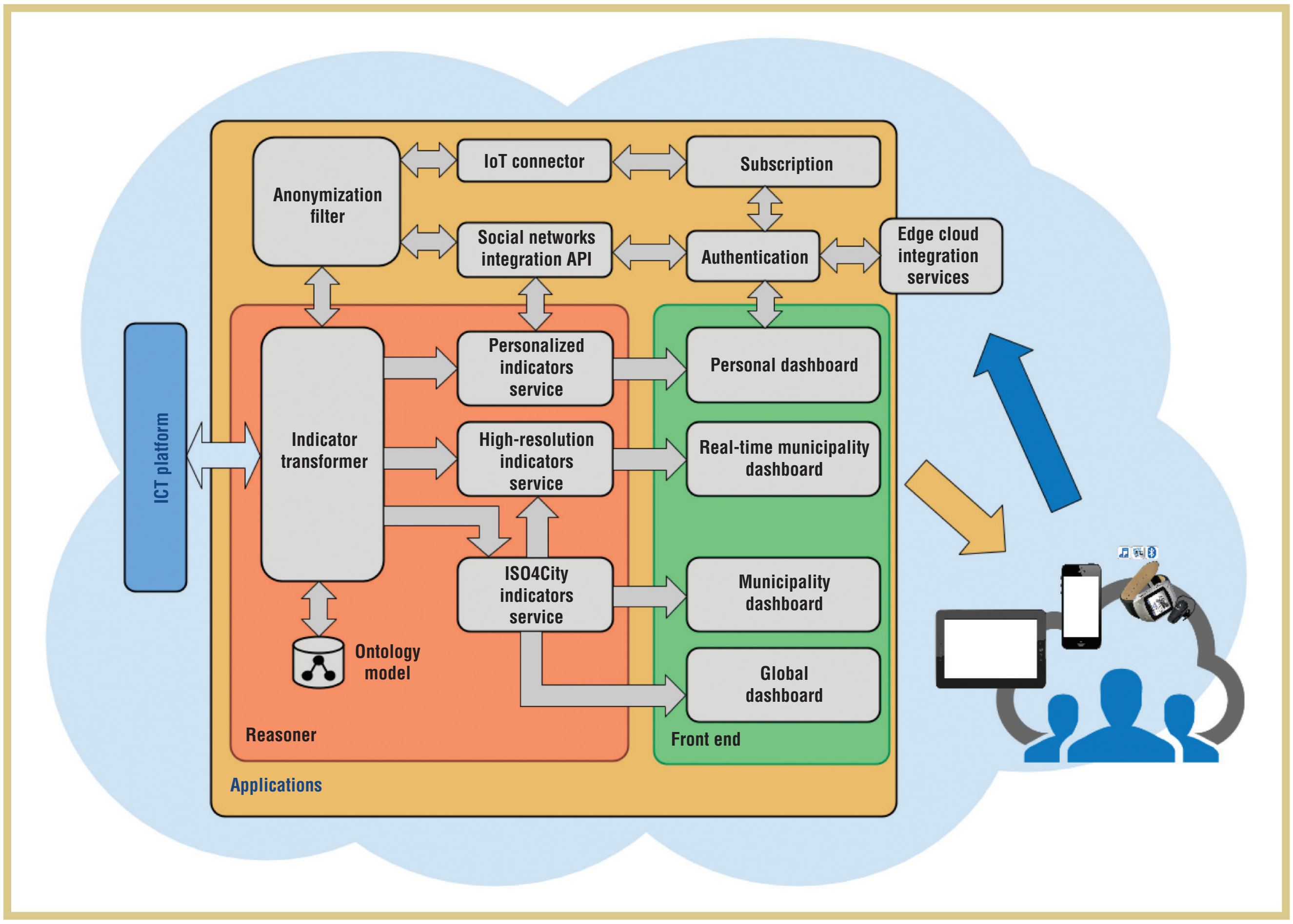


Figure 3. The platform's application layer architecture. The data is transformed by the indicator transformer, forwarded to the different groups of indicators, and then presented at the front end. The data anonymization filter is applied to the personal data.

cloud and IoT integration. The "social networks integration" API connects citizens to social network accounts and ranks users based on their involvement in improving city services and quality of life. The API can share scores continuously (daily or weekly) and provide tips to enhance city services and quality of life, thus motivating and empowering citizens to actively participate using the platform.

As Figure 3 shows, in the reasoner, the ontology model represents the semantic data model required for data-to-indicators transformation and reasoning rules, which have resulted from our research into indicator resolution improvement and personalization. The indicator transformer basically orchestrates the collection of data from various interoperable services of the ICT platform and passes it through the following indicator services (as JavaScript Object Notation or Java objects):

- The *ISO4City indicators service* processes the data and forwards it to users via the global and municipality dashboard.
- The *high-resolution indicators service* simply inherits the ISO indicators and increases their resolution using additional citizen-generated data as well as semantic knowledge gained through systems reasoning—that is, through the machine-learning approach.
- The *personalized indicators service* integrates the citizen's personal data (gathered directly from social networks or via the anonymization filter and data platform) to personalize the indicators data in accordance with the citizen's personal preferences.

Transformed in this way, the data is available at the front end for different user types, such as citizens interested in details about their nearby environment, municipal leaders who are concerned with the scope of the city, and global and foreign users who might be interested in the general living conditions of the city or the city's ranking.

A Feedback-Based Data-Acquisition Framework

As a result of open data access and open government partnership programs, there are several public datasets of

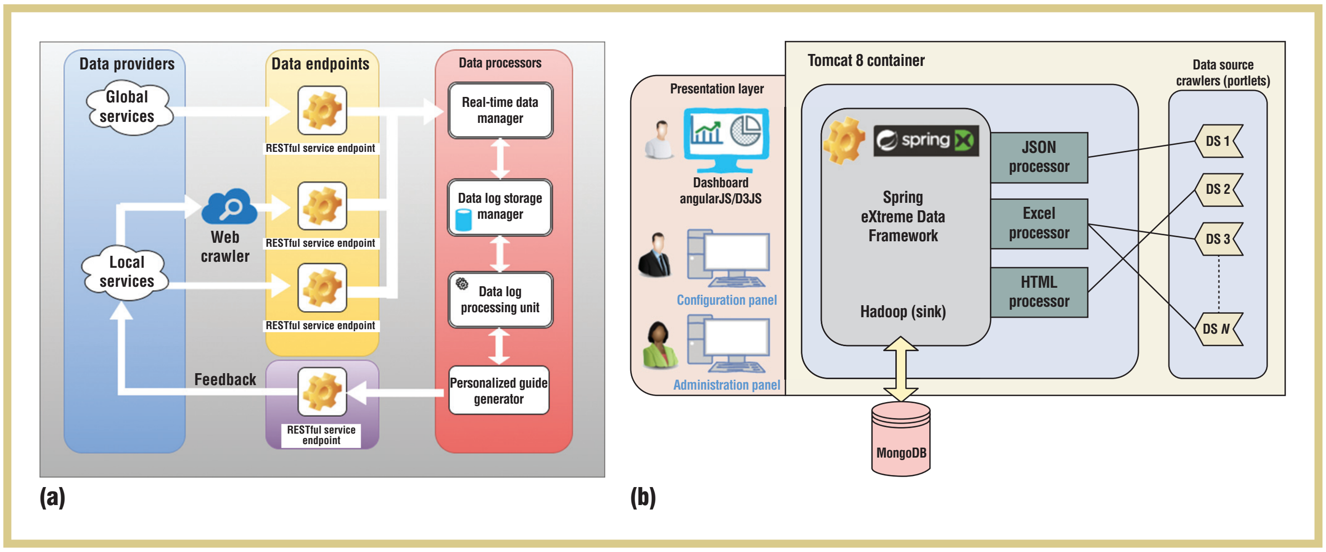


Figure 4. The feedback-based data-acquisition framework: the (a) system architecture and (b) Java implementation.

general public interest on the web that have at least a two-star rating for open data standardization. Global services, such as Facebook, Flickr, Foursquare, and weather forecast services, already provide structured Representational State Transfer (REST), but many data services offer nonstructured or semi-structured data whose preprocessing is more complicated, so we need to provide natural language processing (NLP) methods and advanced data-crawling techniques.

Our platform lets crawlers and data acquisition modules search a verified set of public-data site locations and extract new information, or update previous records with fresh data, and save the information in a local relational database. The local database is wrapped by high-level platforms (such D2RQ) for accessing relational databases as virtual, read-only RDF graphs, increasing the level of open data standardization to a possible five-star rating by linking open data with other datasets using appropriate ontologies. Linked open data, sensor network data, and data from social networks and blogs are all highly integrated in our prototype solution, resulting in a context-aware realization of the necessities for an ideal personal assistant that could act as a daily city guide.

Depending on the local services data format, we implement either an HTML processor or a REST service processor (see Figure 4a). We use the HTML processor (shown in red in Figure 4a) as a backup solution when REST services (shown in yellow) aren't available. The HTML processor outputs a RESTful service (shown in purple) that takes care of any data format incompatibilities. The intermediate REST layer provides endpoint interfaces to the real-time data manager, which implements interdependent periodical (Cron) tasks invoking the endpoint data services, optimizing the schedule and order of execution. By triggering a new data refresh, the real-time data manager saves the outdated information in a data log storage manager, which implements an interface for data persistence to the NoSQL database.

The intelligence in the framework is provided by the data log processing unit, which implements knowledge-based decision-making algorithms accessing the indicators' log saved in the data log storage manager. The algorithm's decision type then depends on the gathered data resolution: the decision can be user-aware, household-aware, neighborhood-aware, municipality-aware, or city-aware. The generated decisions are sent to the personalized guide generator, which sends the appropriate decision to the appropriate subject.

Figure 4a presents feedback generation based on the data input sent to the local authorities in a form of action recommendation to improve the quality of life in a city based on the current habitants' input, sensor-measurement data, social networks, and local information and blogs. Such real-time feedback helps local authorities and stakeholders assess and manage risks, make informed decisions, and better collaborate with citizens. Furthermore, the system can provide useful information to users. For example, for someone planning a roadtrip, the system might merge the planned trip information with weather forecast and air quality data, consequently suggesting that the user bring an umbrella and take the route with the least air pollution.

Prototype

We have developed our prototype implementation (see http://skopjeinfo.b1.finki.ukim.mk) following open standards and using open source technologies on an enterprise software framework, available in the Java Spring platform (Spring MVC), as shown in Figure 4b. Spring beans and aspect oriented programming (AOP) are suitable

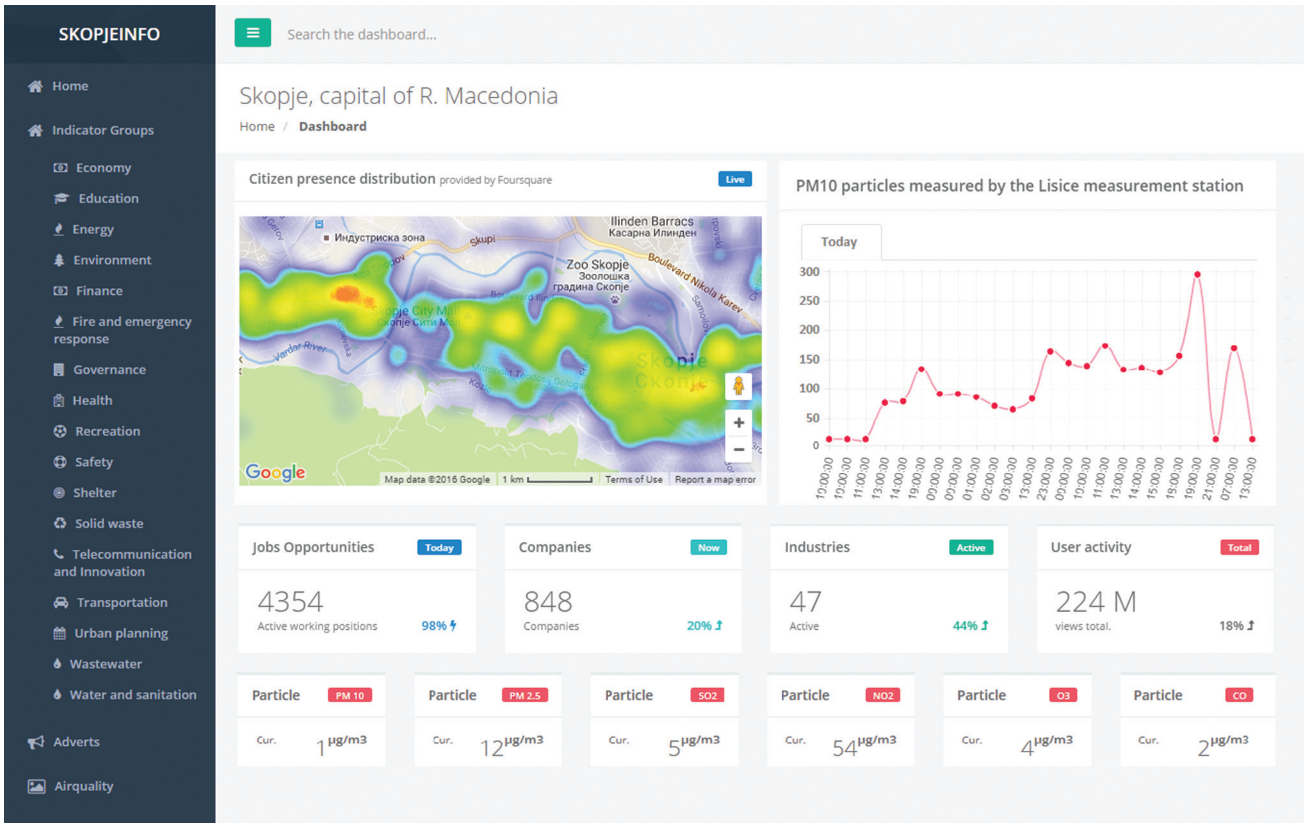


Figure 5. Our prototype ISO-standardized smart city platform and dashboard.

for modular software development and for implementation of our smart city application.[16] Spring services serve as a foundation for the indicator services offered via our prototype, and Spring controllers help integrate the information for presentation on the dashboard. Spring XD is a project that enables fast development of data-driven applications (http://projects.spring.io/spring-xd). It can be integrated with Project Reactor Streams, RxJava Observables, and Spark Streaming.

We used Spring XD to develop the data acquisition module. The data gathered from processors is preprocessed using the Hadoop file system, which optimizes the large dataset analysis, enabling a distributed and scalable working environment. The data preprocessing includes data redundancy removal, data filtering, data aggregation, and data simplification. The output is stored in a nonrelational database such as MongoDB, ideal for heterogeneous data objects. The indexing of the nonrelational database is done using the Apache Lucene framework (https://lucene.apache.org), a powerful open source solution with advanced integration mechanisms, thereby providing a scalable real-time search module.

We implemented our dashboard using novel client-side rendering JavaScript-based technologies, such as React (https://facebook.github.io/react) and AngularJS (https://angularjs.org), and we added advanced UI charts made in D3JS (https://d3js.org) and added advanced chart drawing libraries. In some cases, we implemented data caching mechanisms to improve the application response time and overall system performance.

We enabled the platform using existing public services in Skopje, Macedonia (see Figure 5). Several of the services are made available by the Faculty of Computer Science and Engineering at Saints Cyril and Methodius University of Skopje, including the Green Route application, which provides information to travelers about the quickest, cheapest, and most environmentally friendly routes to destinations in the capital. It also shows real-time traffic congestion and air pollution (http://skopjegreenroute.mk), using data taken from sensors installed by the city's local authorities at the main road junctions and at the most congested traffic routes in the city. Air pollution data is gathered from several air quality measurement stations in Skopje, which measure CO, O3, NO2, PM2.5, and PM10. For visitors or tourists in search of more general information about Skopje, our prototype can retrieve information from the DBpedia SPARQL endpoint, applying the concept of linked open data to efficiently link related datasets. The prototype can also pull the weather data from local public forecast services to provide forecasts and calculate the most efficient route given current weather conditions. Because our prototype can provide personalized data, use GPS locations, and present almost real-time feedback, it offers higher resolution indicators than current ISO indicators.

The prototype also offers employment data, pulled from an existing solution, PRVmk (http://prv.mk), implemented in partnership with the Agency of Employment of the Republic of Macedonia. PRVmk aggregates job advertisements in one place from all sources throughout Macedonia, enabling a user-friendly mobile and web interface for job listings. Currently, almost 10,000 active users are seeking employment through our application. PRVmk takes a user's basic information and skills as input parameters and then outputs suggested active job advertisements.

Disaster risk reduction is also considered in our prototype with two separate applications—one for reports on natural disasters and another that provides accident and crime reports. In collaboration with Skopje's Centre of Risk Management, we developed a public service that provides access to detailed information about dangerous events, including earthquakes, floods and fires, and potential hazards such as violent thunderstorms and heavy snowfalls (http://cuk.finki.ukim.mk). The system informs mobile application users in real time about potential and existing dangers.

In collaboration with the Ministry of Internal Affairs, we also developed a smart application that fetches information from the documents published by the Ministry and classifies them into appropriate event types, extracting metadata information from raw text using advanced NLP algorithms. It then presents the events on a Google map and classifies them as a traffic accident, robbery, violent offense, drug-related event, and so on. Our platform also provides detailed statistics about the rate of event occurrence, grouped by regions or municipalities, for different seasons of the year (http://crimemap.finki.ukim.mk).

the AUTHORS

Vladimir Zdraveski is a PhD student and a junior teaching and research assistant in the Faculty of Computer Science and Engineering at Saints Cyril and Methodius University of Skopje. He also works as a part-time Java back-end developer at Wildbytes, Macedonia. His research interests include digital system, design with HDL, electronic design automation tools, power grid optimization, the Semantic Web, web technologies, enterprise software, operating systems and computer networks. Zdraveski received his MSc in computer networks and e-technologies from Saints Cyril and Methodius University of Skopje. Contact him at vladimir.zdraveski@finki.ukim.mk.

Kostadin Mishev is a system engineer and lab assistant in the Faculty of Computer Science and Engineering at Saints Cyril and Methodius University of Skopje. He also works as a software engineer at the Regional Social Innovation Hub. His research interests include web and mobile solutions, linked and open data, and cloud computing. Mishev has an MSc in computer networks and e-technologies from Saints Cyril and Methodius University of Skopje. Contact him at kostadin.mishev@finki.ukim.mk.

Dimitar Trajanov is a professor and head of department of information systems and network technologies in the Faculty of Computer Science and Engineering at Saints Cyril and Methodius University of Skopje. He is also the leader of the Regional Social Innovation Hub. His research interests include the Semantic Web, data science, big data, open data, social innovation, entrepreneurship, and technology for development and mobile development. Trajanov received his PhD in computer science and engineering from Saints Cyril and Methodius University of Skopje. He is a member of the National Committee for Innovation and Entrepreneurship, where he is working on creating strategies and legislation to encourage innovation and entrepreneurship in the Republic of Macedonia. Contact him at dimitar.trajanov@finki.ukim.mk.

Ljupco Kocarev is a full professor in the Faculty of Computer Science and Engineering at Saints Cyril and Methodius University of Skopje. He is also a research scientist at the University of California, San Diego. His research interests include networks, nonlinear systems, and circuits; dynamical systems; and mathematical modeling, including computational biology. Kocarev received his PhD in physics (nonlinear science) from Saints Cyril and Methodius University of Skopje. He is a member of the Macedonian Academy of Sciences and Arts. Contact him at lkocarev@manu.edu.mk.

Our platform can also help gather citizens' input using the crowd-sourcing platform, My Municipality (http://moja-opstina.mk), an online tool provided by the United Nations Development Programme (UNDP) and the Faculty of Computer Science and Engineering. It aims to gather opinions from citizens to help address and prioritize local government issues. The social networks Flickr and Foursquare also take part in the dashboard, providing additional information. The Flickr API provides a gallery of the most popular photos taken at frequently visited places in Skopje, while the Foursquare API is used to generate a real-time pulse heat-density map of visitors in public places.

By implementing the ISO 37120 standard for city services and quality of life, we have presented an ICT cloud architecture for a standardized smart-city dashboard that enhances the ISO 37120 standard in terms of new sub- or proxy indicators related to existing core indicators. In addition to web applications, in the future, we plan to develop mobile applications for the most popular platforms (Android, iPhone, and Windows phone) as well as for advanced smart devices (such as smart watches and smart TV) that represent the user cloud and personal IoT block. These applications will not only bring the platform closer to the citizen by adopting a personalized approach to the ISO 37120 standard but also allow citizens to share their sensor data, making the platform a powerful tool for improving city services and the quality of life.

REFERENCES

1. *World Urbanization Prospects: The 2014 Revision*, Dept. Economic and Social Affairs, United Nations, 2014; https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf.
2. A. Nordrum, "Popular Internet of Things Forecast of 50 Billion Devices by 2020 Is Outdated," *IEEE Spectrum*, 18 Aug. 2016; http://spectrum.ieee.org/tech-talk/telecom/internet/popular-internet-of-things-forecast-of-50-billion-devices-by-2020-is-outdated.
3. R. Kitchin, "The Real-Time City? Big Data and Smart Urbanism," *GeoJournal*, vol. 79, no. 1, 2014, pp. 1–14.
4. H. Bulkeley, P.M. McGuirk, and R. Dowling, "Making a Smart City for the Smart Grid? The Urban Material Politics of Actualising Smart Electricity Networks," *Environment and Planning A*, vol. 48, no. 9, 2016, p. 1709–1726.
5. G. McArdle and R. Kitchin, "Improving the Veracity of Open and Real-Time Urban Data," SSRN, 2015; https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2643430.
6. D. Arribas-Bel et al., "Cyber Cities: Social Media as a Tool for Understanding Cities," *Applied Spatial Analysis and Policy*, vol. 8, no. 3, 2015, pp. 231–247.
7. A. Zanella et al., "Internet of Things for Smart Cities," *IEEE Internet of Things J.*, Feb. 2014, pp. 22–32.
8. A. Vakali, L. Anthopoulos, and S. Krco, "Smart Cities Data Streams Integration: Experimenting with Internet of Things and Social Data Flows," *Proc. 4th Int'l Conf. Web Intelligence, Mining and Semantics* (WIMS), 2014, article no. 60.
9. A. Sheth, C. Thomas, and P. Mehra, "Continuous Semantics to Analyze Real-Time Data," *IEEE Internet Computing*, vol. 14, no. 6, 2010, pp. 84–89.
10. A. Meijer and M.P.R. Bolívar, "Governing the Smart City: A Review of the Literature on Smart Urban Governance," *Int'l Rev. Administrative Sciences*, vol. 82, no. 2, 2016, pp. 392–408.
11. K.H. Yim et al., "Strategic Planning for The Smart-Green City through Urban Governance," *Int'l J. Built Environment and Sustainability*, vol. 2, no. 3, 2015; http://ijbes.utm.my/index.php/ijbes/article/view/81.
12. L. Berntzen and M.R. Johannessen, "The Role of Citizen Participation in Municipal Smart City Projects: Lessons Learned from Norway," *Smarter as the New Urban Agenda*, Springer, 2016, pp. 299–314.
13. V. Albino, U. Berardi, and R.M. Dangelico, "Smart Cities: Definitions, Dimensions, Performance, and Initiatives," *J. Urban Technology*, vol. 22, no. 1, 2015, pp. 3–21.
14. *ISO Std. 37120:2014, Sustainable Development of Communities—Indicators for City Services and Quality of Life*, Int'l Standards Organization, 2014; www.iso.org/iso/catalogue_detail?csnumber=62436.
15. C. Perera et al., "Big Data Privacy in the Internet of Things Era," *IT Professional*, vol. 17, no. 3, 2015, pp. 32–39.
16. C. Walls, *Spring in Action*, 4th ed., Manning, 2014.