Miljöförvaltningen

Göteborgs Stad

LoV-IoT – Air and water monitoring with Internet of Things

A project within IoT Sverige 2017-2020

2020-10-30

INTERNET OF THINGS SVERIGE

VINNOVA Sveriges innovationsmyndighet

Energimyndigheten

FORMAS

STRATEGISKA INNOVATIONS-PROGRAM

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Summary

Environmental monitoring lays the foundation of all environmental work. The status needs to be monitored to be able to put in necessary measurements to reduce the negative impact on human health and on the environment that the emissions have.

This report is a summary of the work done within the project LoV-IoT – Air and water monitoring with Internet of Things. LoV-IoT was an innovation and development project which explored the possibilities to complement air and water monitoring with the use of sensors and Internet of Things (IoT).

LoV-IoT was one of the projects within the strategic innovation program IoT Sverige. IoT Sverige is one of the 17 strategic innovation programmes funded by Vinnova, The Swedish Energy Agency and Formas.

For further reading go to the webpage “Rapporter från miljöförvaltningen” where all reports from the project are found. The reports are named as follows:

R2020:15	LoV-IoT Luft- och vattenövervakning med Internet of things – Integrering av projektresultaten i en kommun
R2020:16	LoV-IoT Luft- och vattenövervakning med Internet of things – Affärsplattformar
R2020:17	LoV-IoT Luft- och vattenövervakning med Internet of things – Utbildning och medborgarforskning
R2020:18	LoV-IoT Air and water monitoring with Internet of things – Air quality
R2020:19	LoV-IoT Air and water monitoring with Internet of things – Water
R2020:20	LoV-IoT Luft- och vattenövervakning med Internet of things – Dataplattform
R2020:21	LoV-IoT Luft- och vattenövervakning med Internet of things – Koncept för att använda sensordata för att validera spridningsmodeller

1 Background

The aim of this report is to give the reader a short sum up of all work done within the project LoV-IoT. LoV-IoT was an innovation and development project which explored the possibilities to complement air and water monitoring with the use of sensors and Internet of Things (IoT). The project started in September 2017 and ended in September 2020. The project had an overall budget of 26 million kronor. The project was funded by Vinnova, The Swedish Energy Agency and Formas to 50 percent.

The project was based on the public sector needs in environmental monitoring of air quality and water, with focus on storm- and waste-water infrastructure and operation. The purpose of the project was to explore the possibilities to complement the supervision using sensors and IoT.

2 Participating parties

A wide consortium was formed to take part in the project, all in all 16 organizations were participating. The City of Gothenburg was project leader and coordinator of the project, they together with the City of Uppsala were the representatives from the public sector. Three research institutes were among the partners; they were the Swedish Environmental Institute IVL, RISE, at the time RISE Acreo and RISE Interactive and Centro Mario Molina in Chile. Several smaller or bigger organizations from the private sector makes up the rest of the consortium, there were: Ericson, Hagström consulting, IMCG, Insplorion, Rent dagvatten, Swedish hydro solutions, Talkpool, Universeum, Uponor and Vinnter. Trafikverket was also projectparter, with a separate contract through IVL.

Figure 1Participating parties of LoV-IoT (Uponor and Trafikverket were also partners).

3 Results and deliverables

The project was divided into six work packages. Work package one was responsible for the project management. Work package two was responsible for incorporating the insights from the project into the City of Gothenburg. Work package three worked with communication, dissemination and replication. Work package four worked with air quality sensors and work package five with water sensors. The final work package, number six worked with IoT data platforms.

3.1 Work package one: Project management

The overall task of work package one was to manage the project and it was led by the City of Gothenburg. Reporting to Vinnova was done twice per year with both a financial report and a written report stating the status of the project.

Two times a year a meeting for the whole consortium was held. At the consortium meetings all participants could meet, and strategic topics were discussed such as security when using IoT or norm criticism. At these meeting guests were also invited for example other IoT Sverige projects.

3.2 Work package two: LoV-IoT in public sector

The overall task of work package two was to incorporate the insight from the project to the work of the city of Gothenburg. In order to achieve this, the project has worked actively by using relevant platforms and groups within the city to disseminate results and insights from the project. A reference group with representatives from relevant administrations within the city (Intraservice, Kretslopp och vatten and Miljöförvaltningen) met to join forces and discuss how the work with the project could be optimized to gain as much as possible for the organization.

Already during the project period, results and insights from the project has influenced serval plans and strategies in the city. The work with the project has had a clear impact on several groups at both the environmental administration and the administration for waste and water and how they work with IoT and sensors.

Through the work with the LoV-IoT project an improved and deepened understanding and collaboration between the involved administrations in the city has been achieved. This will have a positive impact on the future work related to air and water monitoring and IoT.

3.3 Work package three: Communication and dissemination

The work package three had four main tasks, the were:

- communication,
- dissemination and replication of the project results, both nationally and internationally,
- citizen science and education,
- businesses platform and businesses cases.

Communication

The project established early a webpage as an important part of the communication strategy. The webpage contains information about the project as well as contact information. To a large extent existing channels were used for external communication.

Businesses platform and businesses cases

A workshop on businesses platform and businesses cases with the project partners were carried out. From this work important insights were achieved, on what is important when working with IoT in public sector, and the importance of identifying a need where IoT and sensors can be a solution.

Citizen science and education

The project has explored working with IoT and sensors for citizens science and in education. As part of this work, three school programs on IoT and sensors were developed. These school program have been implemented at Universeum[1]. At Universeum the project has also been incorporated into the exhibition The Hub[2]. The Hub explores the digital technology of today and of the future.

Together with the non-profit organization "Luftdata" the project has organized several public events where the aim has been to educate in air quality, IoT and sensors. The events have been popular and generated positive publicity about the project. Three years has the project participated in the annual science festival. The project shared the instructions and experiences from the senor events at the science festival with Bradford University, UK and Lunds University, Sweden for replication and development of the concept.

Dissemination and replication of the project results

During the project period, the project has spread both nationally and internationally. The strategy has been to large extent to use already exciting platforms to disseminate the results from the project, but also to initiate new network where no relevant platforms exists.

[1] https://www.universeum.se/upplevelser/the-hub/#Skolprojekt
[2] https://www.universeum.se/experiences/the-hub/

The network and platform that being an IoT Sverige project enables has been important. Here project partners have been able to meet other parties in Sweden with interest in IoT in public sector.

The SCORE project host three-four times a year an open data forum in Gothenburg. The LoV-IoT project has been active in the planning of two forums and contributing with content and input.

The LoV-IoT project consortia has a Chilean partner, Centro Mario Molina Chile. Working together with a Chilean partner enabled a possibility for the project and for the project partners to work more in Chile. The collaboration with Centro Mario Molina initiated an IoT Sverige strategic project called: ”Innovationsplattform och samarbetsyta för kunskapsdelning och exportmöjligheter för IoT Sverige till Latinamerika”.

Miljöförvaltningen initiated a network for Nordic cities which are working with air quality sensors. The first workshop was held in Gothenburg in November 2019. At this workshop there were participants from cities in Finland, Norway and Sweden. The network will have a second workshop in November 2020 and due to the pandemic, this will be a digital event.

3.4 Work package four: Air quality sensors

The overall objective of the air quality part of the innovation project LoV-IoT, was to assess possibilities for using low cost sensor technology in flexible observational platforms for monitoring urban air quality. Available low-cost sensor and communication technology was evaluated, and an observational platform was developed using suitable components. To allow real time communication of high-quality data, calibration and post processing needs were assessed and integrated in the platform

The main lessons learned from this project are that low cost sensors potentially have many benefits, but it is important to understand the possibilities and limitations that this technology brings. This has been summed up in the following points:

- **Validate and post process the low-cost sensor data output to maximize data quality.** Data measured with low-cost sensors is commonly affected by biases such as systematic offset, influence by meteorological parameters, cross sensitivity to other pollutants and drift. To reduce biases and increase data quality, it is thus necessary to post-process the sensor data. This can be done by comparative measurements with reference instrumentation during representative ambient conditions. Based on these comparative measurements, correction algorithms can be developed and applied to increase data quality. We found post processing algorithms developed for each individual sensor using machine learning techniques was required in order to optimize the data quality.
- **Limit use of low-cost sensor technology to suitable applications where reliable and stable data quality can be assured**. The following suitable

applications for LCS technology were identified in the LoV-IoT project: in citizen science and for communication purposes, to complement and extend reference measurements, in studies with limited spatial and temporal extent, for identification of patterns rather than absolute concentrations, and for an initial rough measurement and indication, for example in an early warning system in situations when rapidly changing pollutant concentrations may occur.

- **Maximize flexibility and openness when integrating the sensor platform components to allow exchange of components**. With the rapid development of both LCS and communication technology, any sensor platform will rapidly be outdated, unless it is possible to exchange parts as new and improved alternatives are available. As low-cost sensor performance is still problematic, allowing exchange of components will ensure that the data quality can be improved as new solutions are available.

The LoV-IoT observational platform is focused on measurements of the pollutants that are most problematic in Swedish urban settings; nitrogen dioxide (NO_2) and particulate matter (PM_{10}, $PM_{2.5}$), as well as meteorological parameters, such as air temperature and relative humidity. Other components, such as CO_2 and SO_2, are also included in the tests, as well as noise sensors. The LUFT-NO_2 sensor under development by our LoV-IoT partner Insplorion, has been included continuously in the development and evaluation of our LoV-IoT sensor platform.

After testing and validation, the sensor platforms have been mounted in several different field settings in order to test their suitability for different applications as well as to assess the technology readiness level of the platform. The four main field applications that were assessed are:

1. Extending network of air quality measurement locations around major infrastructure projects. This has been a joint effort with the Swedish transport administration and has taken place at two main infrastructure projects in Gothenburg.
2. Extending air quality station network in Chile and assessing potential use of sensors in early warning systems. Sensor platforms has been evaluated in both urban and industrial sites in collaboration with Centro Mario Molina (CMM) in Santiago, Chile. Initial findings have been published by Tagle et al. (Tagle, Rojas et al. 2020).
3. Extend the current reference station network with additional measurement in locations of interest in Uppsala.
4. Mobil measurement by using public transport and measurements at bus stops

In addition to the development of the observational platform, additional, smaller sensor platforms have also been used in case studies as well as in LoV-IoT citizen outreach activities aimed to increase awareness of and interest in air quality.

3.5 Work package five: Water sensors

The innovation project is based on public sector needs in environmental supervision of water, with focus on storm- and waste-water infrastructure and operation. The main stakeholder is Gothenburg water board “Kretslopp och vatten” as well as the environmental departments in Gothenburg and Uppsala.

The project shows that massive deployment of low-cost sensors is an attractive method to collect data and get visibility of a vast infrastructure such as stormwater and sewage systems in a city. Dedicated IoT networks such as LoRaWAN give enough network coverage also down in wells and into the sewage system, low battery consumption for the communication enables long life length. The IoT devices supporting off the shelf sensing probes are relatively cheap which gives low total cost of ownership per measurement.

The project shows also that the main limitations are on the measurement probes, to get long life length, low maintenance cost and high measurement accuracy. Especially the sensors placed into the water are exposed to residue and harsh environment during maintenance operations such as pipe cleaning with high pressure water. Further, the measurement probes are typically more expensive than the communication and control units and have high battery consumption.

The outcomes of the project are insights and experiences how to deploy sensors in a city and to understand what measurements from more simple sensors can be used for. The main benefit that the city sees is predictive maintenance. To develop a solution for predictive maintenance you need at least a water level sensor and preferably also a turbidity sensor to predict how much load it has been on a system over time. This prediction can be used to alert the city water board that a system needs to be cleaned to keep its performance. Part of these ideas is further developed in the EU-Project SCORE-water.

3.6 Work package six: IoT data platform

Work package six in LoV-IoT focused on the central technical platform that work package four and five could use to store, manage, visualize and analyze data. The work package worked closely with work package four and five in order to make sure that data from the measuring stations were sent in a way that could be received and standardized. The platform used was Fiware that also supplied the data models.

The work was conducted in close cooperation with project partners. In the beginning a wider selection of partners were involved while a smaller group were responsible to get Fiware up and running and data flowing. The work package mapped users and needs and used that as a basis for the development.

The technical platform used was Fiware that is open source, which was an important prerequisite for the City of Gothenburg. It also fit well with the project that had no budget for purchasing licenses. In the instances where

Fiware were not enough we used additional open source products to achieve our goals.

Data was transformed to conform to Fiware data models and we used two APIs for accessing the data. A third way to access data was through a visualization created in Grafana.

The diagnostics platform was an important deliverable and it was implemented to monitor sensor behavior and warn about unexpected behavior as well as creating one sensor specific and one general algorithm to try to increase the quality of the data.

There was interest in using our data from several parties. Since we did not publish it publicly no live usage happened but the fact that there is clear interest raised the city's awareness of the importance of sharing data. As a result the city now shares data from five high quality measuring stations, compared to only one before LoV-IoT started.

4 Publications and further projects

The project has resulted in both publications and more projects. These are presented in the following chapter.

4.1 Publications

The project has been disseminated along the duration of the project in numerous internal expositions and events. The project has been also disseminated through conferences and publications, and more publications are under preparation.

- From a City Perspective: Challenges with using Low Cost Particle sensors for citizens Science. Watne, Å.K, Lindén, L., Wanemark, J., Sjöholm, M., and Kolev, D. Poster, European Aerosol Conference 2019
- Tagle, M., F. Rojas, F. Reyes, Y. Vásquez, F. Hallgren, J. Lindén, D. Kolev, Å.K. Watne and P.Oyola,2020 Field performance of a low-cost sensor in the monitoring of particulate matter in Santiago, Chile. Environ Monit Assess 192: 171

4.2 Further projects

IoT Sverige goes to Latin Amerika/ IoT Sverige Exportplattform
The goal with the project was to internationalize IoT Sverige by creating a platform for exchanging experiences and solutions for innovation. The purpose was to systematically test Swedish solutions in international environments to be able to ensure and to create global relevance and interoperability.

SCORE-water[3] SCOREwater (H2020 Innovation Project) focuses on enhancing the resilience of cities against climate change and urbanization by enabling a water smart society that fulfils European Sustainable Development Goals 3, 6, 11, 12 and 13 and secures future ecosystem services.

NordicPATH[4] NordicPATH is a research and innovation project funded under NordForsk's Sustainable Urban Development and Smart Cities programme. It runs from April 2020 to March 2023.

City as a Platform[5] – CaaP is a strategic project that gathers 18 municipalities in Sweden (to begin with) that will explore, test, implement and collaborate on open IoT platforms to support community benefits in the cities.

OpenWaters[6] this project investigates the possibilities with open data and shared design for cross-sectoral cooperation and innovation in digital twins. The focus is water treatment.

5 Conclusions

Developing new methods is vital on the road of creating smart and sustainable cities. On this path sensors and IoT enables innovation and new solutions. The LoV-IoT project explored the possibilities to complement air and water monitoring with the use of sensors and Internet of Things. Sensors and IoT can enable development of environmental monitoring systems with real-time measurements and with high spatial resolution.

From the project we can conclude the following:

- low cost air quality and water sensors potentially have many benefits
- with low cost air quality sensors, it is important to understand the possibilities and limitations that the technology bring
- low-cost water sensors are an attractive method to collect data and get visibility of a vast infrastructure such as stormwater and sewage systems in a city
- collecting and sharing data via Fiware data platform was successful.
- there can be great gains from making environmental data open and easily accessible
- sensors and IoT can be a powerful tool used in education and citizens science for increasing awareness on environmental issues and digitalization

[3] https://www.scorewater.eu/#aboutus
[4] https://nordicpath.wp.nilu.no/about/
[5] https://www.ri.se/en/what-we-do/projects/city-platform
[6] https://www.ivl.se/projektwebbar/open-waters.html