European
Commission

WATERSPY

High sensitivity, portable photonic device for pervasive water quality analysis

PHOTONICS21

This project has received funding from the **European Union's Horizon 2020** research and innovation programme under grant agreement **No 731778**.

WaterSpy – revolutionising water quality analysis

During the last few years the growing public concern regarding the effects of water quality on human health urged the European Union, as well as it's individual governments, to update their water pollution control legislation to face the new challenges. The increased level of understanding of every step of water's route, from the water resources to the final consumer, revealed new potential contaminant sources. More than ever there is a growing need for continuous water monitoring, near real-time data collection and analysis.

In this context, pervasive and on-line water quality monitoring data is critical for detecting environmental pollution and reacting in the best possible way to avoid human health hazards. However, it's not easy to gather such data, at least not for all contaminants. Currently, water utilities rely heavily on discrete manual sampling and laboratory analysis in order to acquire this information. For the situation to be improved, portable and high-performance devices for pervasive water quality monitoring are required. Such devices should expand current limitations in detecting contaminants, transcending today's paradigms, and bridging different technologies available, allowing continues monitoring of harmful contaminants.

WaterSpy is a research project which aimed to address this challenge by developing water quality analysis photonics technology suitable for inline, field measurements. WaterSpy was funded by Horizon 2020, the **EU Framework Programme for Research and Innovation for 2014-2020**. The project was an initiative of the Photonics Public Private Partnership (www.photonics21.org).

WaterSpy technology was integrated, for validation purposes, to a commercially successful water quality monitoring platform, in the form of a portable device add-on. WaterSpy was used in the field for the analysis of critical points of water distribution networks.

The WaterSpy project consortium includes **10 partners** from 7 different European countries, coordinated by **CyRIC**, Cyprus Research and Innovation Center Ltd. The project was launched in November 2016. The WaterSpy journey ended on February 29th, 2020

Concept

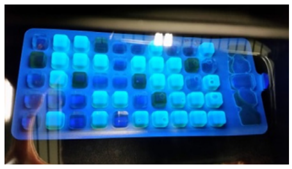
The current EC conservative legislation requires the measurement of only three microbiological parameters, namely heterotrophic plate counts (HPC) and the two bacterial indicators Escherichia coli and Enterococcus spp. WaterSpy aimed at developing a novel, compact, cost-effective photonic device, operating in the spectral range of 6-10 μm and suitable for pervasive water quality sensing. The approach is based on the following main pillars:

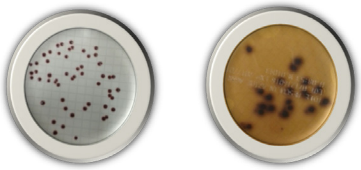
- The development of advanced Quantum Cascade Lasers (QCL) sources employing the Vernier effect photodetectors coupled with innovative, fast and sensitive Higher Operation Temperature (HOT) photodetectors, in order to detect the fingerprint regions of the selected analytes of high priority in freshwater.
- The use of ATR spectroscopy techniques to maximize the Signal-to-Noise Ratio (SNR).
- Targeted analytes are specific heterotrophic bacterial cells. Several novel techniques are employed for increasing Signal-to-Noise Ratio.
- Use of adapted light modulation, detection and signal processing concept supporting highest sensitivity and specificity levels
- Use of a novel sample pre-concentration technique, based on ultrasounds
- The integration of the photonic sensors into a portable device used for large area water quality sensing.
- The device requires about 6 hours for a complete sample analysis. With currently used systems, the same analysis could take up to 3 days.
- The WaterSpy technology was integrated, for validation purposes, to a water quality monitoring platform, in the form of a portable device add-on.
- Towards the end of the project, the WaterSpy device was tested at a pilot site: the Prato water treatment plant, which serves the city of Genova (approx. 580,000 inhabitants).

Traditional methods to detect E. coli, P. aeruginosa and salmonella in water

The benchmark methods used for the detection of E**. coli, P. aeruginosa and salmonella** are fully adjusted to the ISO regulations and usually include:

- 18 to 24 hr incubation, depending on the bacteria
- The use of a commercially available enzyme-substrate liquid-broth medium, in the case of Enterococci bacteria and E. Coli
- The Salmonella detection consists of a series of successive phases which include: Pre-enrichment, Enrichment, Isolation, Biochemical confirmation, and possibly, Serological confirmation.
- The Pseudomonas Aeruginosa detection requires bacteria colony growing on a nutrient medium (plate count method).





Challenges and Objectives

The aspired solution is based on absorption spectroscopy beyond the 5 μm range; water itself is a very strong absorber of infrared light and special techniques have to be applied.

90-99% of bacterial cells detected in aqueous and terrestrial environments cannot be cultivated in the laboratory
("The great plate count anomaly").

It is difficult to gather pervasive and on-line water quality monitoring data, including all contaminants mentioned in EU Directives on water quality.

Meet the legal requirements for the concentration of contaminants, given in the EU directives on water quality.

The concentration of contaminants is very low, thus hard to detect.

Due to the very low acceptable concentration of contaminants, the sensitivity of the device has to be very high to catch up with current laboratory analysis.

1

WaterSpy focuses on detecting bacterial contamination.

2

Validate the cost-effectiveness and suitability of the proposed technology for large area coverage.

3

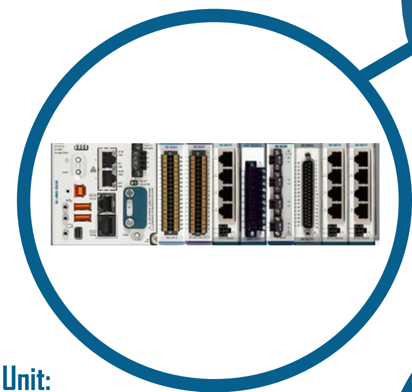
The device has to be compact, portable, energy-efficient & should perform measurements faster than currently available devices.

WaterSpy Modules

- Quantum Cascade Lasers
- Photodetector
- Pre-Concentration Module
- Incubator
- Main processing unit
- Acoustofluidic ATR cell
- Solution injection module
- TRITON

TRITON:

1. Feed 100 L sample for each test.
2. Receives measurement results for display.



Main Processing Unit:
It is responible for controlling all the WaterSpy modules, allowing data and results exchange.

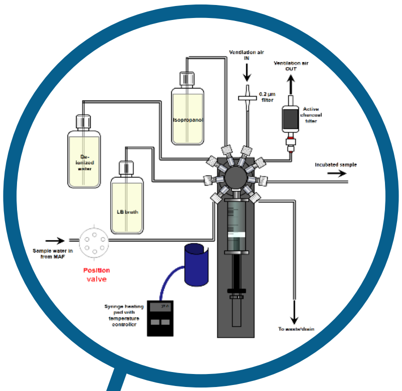
Photodetectors - QCL:

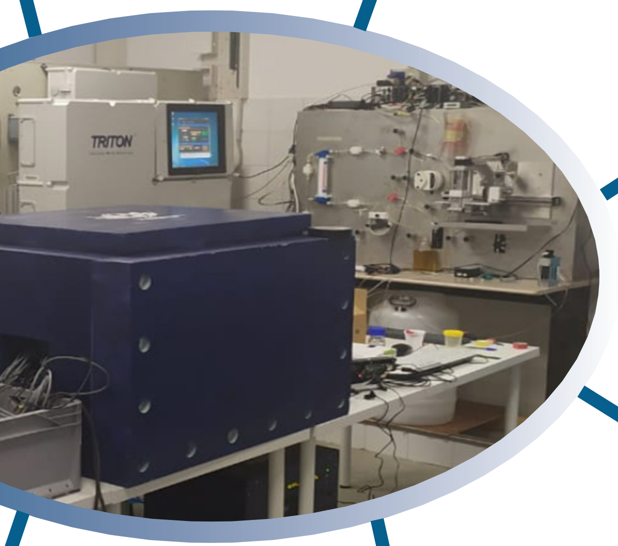
Enzyme subtrate is pumped into the acoustofluidic cell and the reaction is monitored using QCL based spectroscopy.

WaterSpy Device

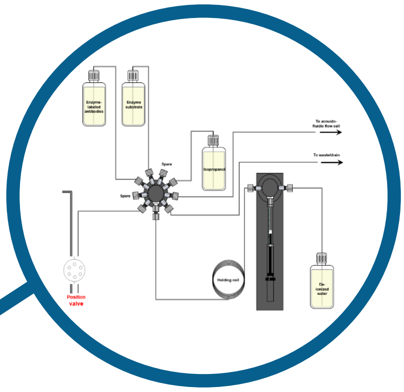
Pre-Concentration Module:
Ultrafiltration and MAF (monolithic affinity filtration).

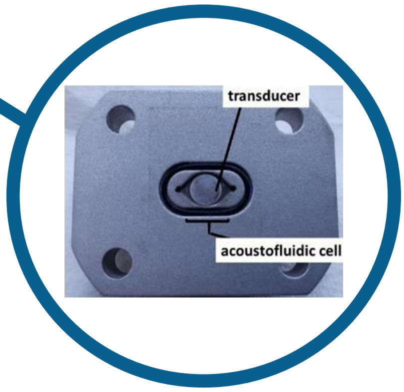
Incubator:
Perform incubation to multiply the bacterial population.





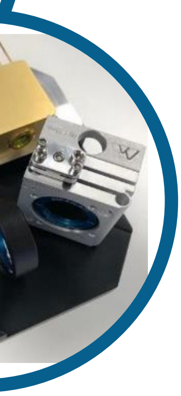
Solution Injection Module:
An automated process is used to inject the solutions with the anti-bodies into the acoustofluidic cell.

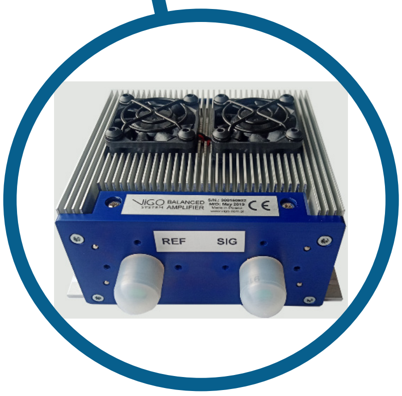




Acoustofluidic cell:

1. Incubated sample is pumped; bacteria are retained.
2. An enzyme-labelled antibody is pumped in, to interact with the retained bacteria to form a conglomerate.





Field validation

During the final stages of the project, the WaterSpy system was tested in the **Prato water treatment plant.** The facility is characterized by an average flowrate of about 1300 L/s; the treatment train includes several processes which can be summarized as it follows: pre-disinfection with sodium hypochlorite, coagulation/flocculation with aluminium polychloride, filtration through sand, disinfection again with sodium hypochlorite; treated water is supplied to about 198.000 inhabitants living in the city of Genoa.

At the site where the plant is located, raw water from two different supplying sources are treated:

- from the Brugneto artificial basin (25 Mmc.) supplying the homonymous aqueducts and
- from the water intake on the stream Bisagno, supplying the Civico Aqueducts.

The Prato drinking water treatment plant is the terminal part of the Brugneto supply system and consists of 4 open-air sedimentation units, a series of 12 indoor tanks for rapid sand filtration and a chlorine dioxide disinfection facility. The plant has an average flowrate of about 78,000 litres per minute (29.7 MGD).

Results

The fully functional WaterSpy device was thoroughly tested, using different initial setups (e.g. different concentrations of the analytes) to ensure reliability of the final results. Since the WaterSpy device is still a prototype, a number of modifications and adjustments were made via step-by-step developments and analysis. The main outcomes of the project can be summarized in the following:

1. The validations have shown that the integrated WaterSpy system is able to detect the targeted bacteria in drinking water, even at low concentrations. In fact, for E.coli the system is able to meet the strict regulatory requirements, while for Salmonella and P. aeruginosa further investigation is required, but results are promising.

2. A complete analysis with the WaterSpy requires about 6-7 hours, which is significantly faster with respect to conventional techniques that require minimum 18h (but usually more than 40h).

3. Improved design capability and understanding of the Vernier Quantum Cascade Lasers. ALPES's customized QCLs have already been improved to be market ready.

4. The novel balanced detector designed and developed by VIGO is also a major photonics result, unique at a global level. This is already part of the 2020 VIGO catalogue.

5. A new fiber coupler with an external lens was also produced in the project. This is not yet a commercial product, since more R&D is required, but it is definitely a wonderful achievement with commercial potential.

6. A new crystal structure orientation was also tested for the WaterSpy photodetectors. This technology can be used to deliver state-of-the-art detectors in terms of detectivity for niche applications.

7. A novel polarimetric setup for ATR spectroscopy measurements was developed and a patent application was also submitted.

8. A fully automated pre-concentrator for bacteria has been developed, exploiting CyRIC's novel engineering designs and TUM's know-how.

9. An automated sample incubation module was also delivered and is part of the WaterSpy device.

10. Significant advancements have been made in terms of ultrasound particles manipulation, within a fluidic cell used for ATR measurements.

Technological Impact

The main novelty of WaterSpy is in the development of the advanced, highly sensitive photonic elements for the identification of the target analytes. Advancements in the emitter and detector parts of the photonics sensors are integrated in a unique way, in order to develop a solution of unprecedented characteristics and clear commercial exploitation capabilities.

The device is complemented by novel subsystems that make possible the field use of the device and maximize the Signal-to-Noise (SNR) ratio in order to be able to detect single bacteria and meet the EC regulatory requirements.

The sensing elements (QCLs and detector) are integrated in a portable instrument for pervasive water quality sensing. Existing and new solutions will be integrated, in order to deliver a device that can be used in the field. The principles of cost-effectiveness and portability are key values of the WaterSpy system.

The participating companies will be given the opportunity to market a modular and configurable product, compatible with existing market solutions: WaterSpy will be compatible with AUG's water quality monitoring systems, but the main technology will also be adaptable for completely independent use. The system will also be expandable for the detection of additional contaminants in the future. The WaterSpy innovative developments address the existing market needs, not only in Europe, but also elsewhere in the world. WaterSpy is an application driven approach.

Societal Safety and Terrorist Threats

Terrorist threats do not only target individual citizens, but also the essential public infrastructures, such as water and waste water systems. Government, water utilities, state and local water agencies, public health organizations, emergency and follow-up responders, and academia, as well as the private sectors worldwide should take preventative measures against such threats.

WaterSpy, through the novel, compact and portable monitoring solution that proposes, will assist all the stakeholders to apply continuous surveillance against terrorism, prevent and prepare for terrorist attacks, minimize public health impacts and infrastructure damage, and also speed up the recovery after the attack.

Environmental Impact

Real-time monitoring of bacterial (and other) pollutants in the water network has significant environmental impacts, which have been proven by all the analysis done so far. By preventing the propagation of a pollutant, tons of water can be saved, which could end up in the environment and pose a significant threat, not only to people, but also to the animals and the environment.

The technology developed through WaterSpy could also be exploited after the project to detect additional water contaminants besides bacteria. For instance, a large group of harmful water contaminants have distinct fingerprints in the near and mid-IR spectral regions, such as Benzene, toluene and Xylenes isomers (BTX compounds), Vinyl chloride, Naphthalene, Mercury.

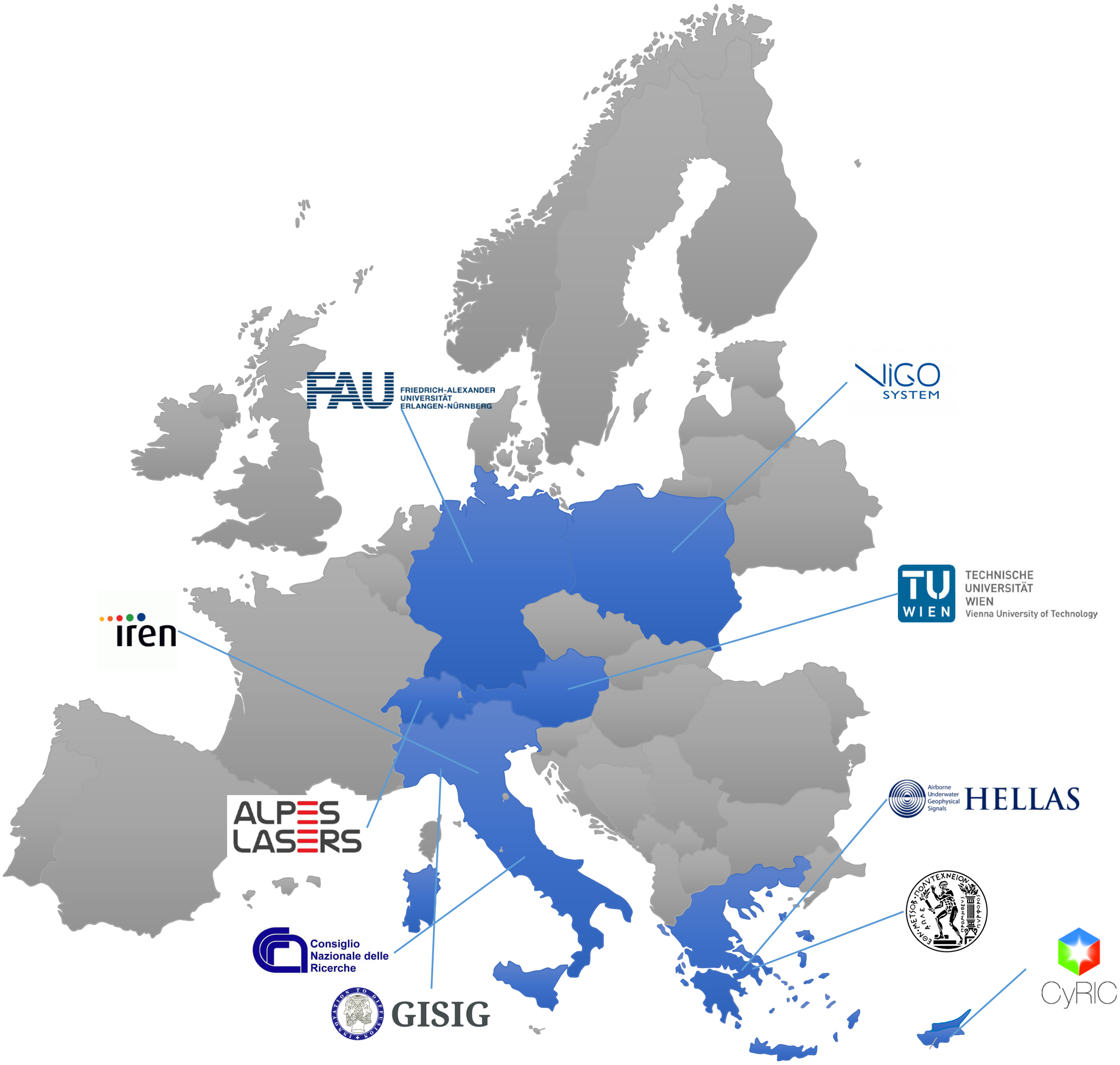
Social Economical Impact

Quality of Life, Health and Safety of the Citizens.
In the history, waterborne contaminants caused illnesses and death of citizens and farm animals, resulting in significant social impacts, such as lawsuits, and distrusts by the citizens over the governments and water utilities. Water quality incidents also significantly impacted the healthcare systems, local labor forces, the well-being of affected citizens and their families, and have been responsible of millions of Euro loss. It has also been proven that adverse health outcomes are associated with ingestion of unsafe water, lack of access to water (linked to inadequate hygiene), lack of access to sanitation, contact with unsafe water, and inadequate management of water resources and systems.

Pathogenic microorganisms remain one of the mostly regulated hazards for drinking water and recreational water in Europe. In some less developed regions, waterborne gastrointestinal diseases have been one of the leading causes to the child morbidity and mortality in some countries. Viruses (rotavirus, calcivirus, and hepatitis A virus) are responsible for 70- 80% of infectious diarrhoea cases in the developed world, according to the referenced WHO study. Some of the biological agents used in terrorism cause similar health disorders to the ones mentioned above and other can even cause other more catastrophic health hazards. By providing the capability to detect biological agents in the Water network, WaterSpy will effectively contribute directly to increased health and safety of European citizens.

WaterSpy target audience

WaterSpy consortium



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