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Innovation Partnership IP 2016 0502
This Research is co-funded by the European Regional Development Fund (ERDF) under Ireland’s European Structural and Investment Funds Programmes 2014-2020
Adaptive Sensors Group

PI Dermot Diamond

Multidisciplinary Team of Analytical Chemists, Engineers, Material and Computer Scientists

Wearable Sensors

Environmental Sensors

Material Science
Environmental Sensors

Create cost effective sensors that can obtain accurate, real-time information about environmental status from the highly local to global scale.

This can only be realised through ‘deploy and forget’ models of use, in which the analytical platforms are:

i) capable of autonomous function for periods of months between servicing intervals;
ii) provide validated analytical data over this period,
iii) are relatively inexpensive to buy and maintain

• EU Copernicus programme invest almost €1 Billion 2014-2020

• Nutrient Challenge , Alliance Coastal Technologies (ACT)

• $210 Billion spent annually in the USA on impacts to drinking water quality and aquatic ecosystems

• Autonomous Nutrient platforms have the potential to offer higher resolution data in comparison to traditional methods
Autonomous Environmental Sensors

Current platforms

1. Evolutionary development, cost driven down, reliable, improved scalability

2. Revolutionary breakthroughs in materials science; hidden complexity, biomimetic platforms, all fluid handling integrated on chip, indefinitely self-sustaining

Cost/Complexity

Scalability ➔

Massively scaled deployments of the future
Nutrient Platform

A) Reagent, Calibration Standards, Waste

B) Electronics for Automation, Detection and Data Transmittance

C) Inlet System

D) Fluidic Handling

E) Fluidic Chip, LED, Photodiode

F) Battery
Nutrient Platform
Rapid Prototyped Components

Use of 3D Printing, Laser Ablation and Micro milling techniques for rapid Prototyping

- Parts quickly and easily manufactured in house
- Reduces manufacturing time
- Reduces cost
Nutrient Platform: Microfluidics

Microfluidics

- 2 Layer PMMA Microfluidic Chip (A,B), Optical Windows (C)
- Manufactured using Precision Micro Milling
- Bonded using Heat and Pressure at transition temperatures
- Mixing Channels Induces chaotic advection
- 3D Printed Alignment Rail for Kinematic Stability
Nutrient Platform – Colorimetric Chemistries

**Mixture (Reagent)**

\[(NH_4VO_3) + (NH_4)_6Mo_7O_{24}.4H_2O, HCl \text{ conc.}\]

**Sample**

\[KH_2PO_4\]

**Yellow Method** –

Vanadomolybdophosphoric Acid is formed when ammonium metavanadate and ammonium molybdate (mixture) reacts with phosphate (acidic conditions)

Increasing Nutrient \((PO_4^{3-})\) Concentration

Increasing Colour Intensity
Optical Detection on Microfluidic Chip Vs UV-vis Spectrometer

Phosphate (PO$_4^{3-}$) Detection

LED (375nm) Photodiode optical detection carried out on Microfluidic Chip

Phosphate (PO$_4^{3-}$) Detected 0-45µm on UV-Vis(375nm) and on Microfluidics

Increased Sensitivity when detected on Microfluidic Chip vs UV-Vis Spectrometer
Lab Validation

Validation carried out from the 25th of July to the 27th of October 2017

826 Measurements over 91 days

Nutrient Platform Phosphate (PO$_4^{3-}$) Detection

<table>
<thead>
<tr>
<th>Nutrient Platform (µM)</th>
<th>$S_{µM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.9 (n=139)</td>
<td>0.6</td>
</tr>
<tr>
<td>8.4 (n=71)</td>
<td>0.3</td>
</tr>
<tr>
<td>25.4 (n=408)</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Deployments

1: Milan WWTP, Italy

- **Water Type:** Waste Water after 2\(^{nd}\) stage processing
- **Number of Measurements:** 14
- **Date Deployed:** 4\(^{th}\) – 5\(^{th}\) May 2017

2: Lough Rea, Galway

- **Water Type:** Spring Fed Freshwater Lake
- **Number of Measurements:** 55
- **Date Deployed:** 5\(^{th}\) – 10\(^{th}\) Dec 2017

3: River Liffey, Palmerstown, Dublin

- **Water Type:** Freshwater River
- **Number of Measurements:** 224
- **Date Deployed:** 21\(^{st}\) Feb – 20\(^{th}\) Mar 2018
Deployment 1: Milan WWTP

Milano San Rocco WTTP
Sampling Point:
Output Water after Clarifier

Typical levels:
10mg/L Suspended Solids
15µM Phosphate (PO$_4^{3-}$)

Nutrient Platform Phosphate (PO$_4^{3-}$) Detection
Spring Fed Carboniferous limestone lake
55 measurements over 5 days
Deployment ceased due to regulator failure

<table>
<thead>
<tr>
<th>Grab Sample</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient Platform (μM)</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>UV-Vis (μM)</td>
<td>2.0</td>
<td>2.0</td>
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</table>
Deployment 3: River Liffey, Palmerstown, Dublin

• Sensor deployed on the River Liffey for 28 days (21/02/2018 – 19/03/2018)
• Measurements of Phosphate (PO$_4^{3-}$) detected every 3 hours
• Environmental Temperature, Rainfall and Water level recorded

A. Deployment Location
B. Sensor Deployed
C. Sensor Deployed by depth gauge
D. Temperatures reach -4.5°C

Beast from the East: Status Red snow alert in place until Friday
Varadkar says people ‘should not venture out of doors’ while the red level warning is in place


A. Water levels controlled by Leixlip Dam. Increasing water levels from the 5th Mar due to snow melt.

B. External vs Internal Temperature
External lows of -4.5°C.
Internal lows of 5°C.
Deployment 3: River Liffey, Palmerstown, Dublin

Nutrient Platform Phosphate (PO$_4^{3-}$) Detection over a 28 day period

636 measurements over 28 days recorded
Future Work

Smart Environment Integrated Sensing Network

Data Analysis:
Combination of in-situ and satellite data. Statistical Algorithms to develop test models

Real time information and predictive Models on water quality,

Development and Integration of Detection for Nitrite (NO$_2$) and Nitrate (NO$_3$)

Further optimisation and cost reduction of autonomous nutrient platform

In-situ Sensing: In-situ water quality
Acknowledgements

Dr Margaret McCaul, Prof Dermot Diamond and all in the Adaptive sensors group
Enterprise Ireland
National Centre for Sensor Research

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