A PORTABLE LAB-ON-A-CHIP INSTRUMENT BASED ON MICROCHIP ELECTROPHORESIS with CONTACTLESS CONDUCTIVITY DETECTOR WITH REPLACEABLE DETECTION CELL FOR ORNAMENTAL FISH FARMS APPLICATION

Kambiz Ansari1, Jasmine Yuen Shu Ying1, Peter C. Hauser2, and Nico F. de Rooij3

1Institute of Materials Research & Engineering, A*Star (Agency for Science, Technology and Research), 3 Research Link 11760, SINGAPORE
2Department of Chemistry, University of Basel, Basel, SWITZERLAND
3Ecole Polytechnique Federale de Lausanne, Institute of Microengineering, Sensors, Actuators and Microsystems Laboratory Samlab, Neuchatel, SWITZERLAND

ABSTRACT
Ornamental fish ponds require continuous control of water quality such as salt content (salinity), hardness (Ca, Mg), and ionic contents particularly nitrate and ammonium. Conductivity is considered as a parameter correlates with these parameters and sensitive to environmental conditions such as temperature. Therefore, a conductivity detector can be employed for control of water quality in aquaculture. In this paper we have developed a compact portable lab-on-a-chip instrument based on microchip electrophoresis and capacitive coupled contactless conductivity detection (C-D) optimized for conductivity measurements at different environmental conditions and quantitative analyses of anions in Ornamental fish aquarium water tanks. The instrument is battery powered with total dimension of 14×25×8 cm (w×l×h), and weighs 1.2 kg with a compact portable design based on microchip electrophoresis and dual capacitively coupled contactless conductivity detection (dC-D). The particular application of the system for Ornamental fish farms water quality monitoring for toxic ions of nitrate and nitrite were evaluated. Our multielemental fast reliable E-dC-D instrument has proven to be a perfect analytical sensor for quantitative and qualitative monitoring of fish water tanks. The results have shown an acceptable comparison with respect to the costly laboratory standard techniques and highly precise compared to calorimetric probes that currently popular in fish farm industry.

KEYWORDS: Capacitively coupled contactless conductivity detection, portable lab-on-a-chip, Microchip electrophoresis, Ornamental Fish

INTRODUCTION
Aquaculture is highly dependent on analytical techniques for monitoring and analyses of aquarium water. This is because the water should have the required ionic concentrations and temperature in order to be suitable for fishes to survive [1, 2]. The water in aquarium should maintain certain level of salinity (salt concentration), alkalinity, pH, hardness (Calcium and Magnesium), and concentrations of nutrients such as phosphorus, ammonium, and nitrate to provide the necessary health conditions for the aquatic system. Any sudden temperature fluctuation leads to intolerant conditions such as stress and shortage of oxygen for fishes. Therefore, measurement and control of ionic contents and temperature on a continuous daily-base practice are critical for successful aquaculture. Currently, colorimetric is the frequently used technique for water monitoring in aquaculture. Colorimetric relies on color shades that are arrays of printed color codes calibrated with respect to specific parameter of water. However, the measurements are indirect and relies on distinguishing of colors that may not be visible to human eyes so the read out can be affected by the light environment. Alternative methods are potentiometric and amperometric which are isoelectric membrane probes (ISE) to selectively detect a single parameter or ion [2]. So for multiple parameter measurements multiple probes are required. However, probes selectivity’s and detection limit are sensitive to sample/environmental conditions and their performances degrade overtime as their membranes are in direct contact with analyte solution.

Conductivity measurement is considered an indirect but precise parameter that is related to water ionic contents and its values have been used for measurements of salts, nutrients and other ionic impurities in the fish tanks water. Conductivity of water is also correlates with temperature such that a thermal compensation coefficient need included in all the measured parameters. This value for example, for raw water is 2%/°C while for estuarine salty water is 20%/°C. In addition the conductivity-temperature correlation can be employed as a way of controlling the thermal condition of water. Capacitatively contactless conductivity detection (C-D) is a multi elemental analyses detecting many ions in a single run less than a minute an advantage compared to single ionic probe based detection techniques. The contactless nature eliminates detector exchange due to degradation, double layer charge build up, signal interferences with high voltage electrophoresis and no maintenance resulting to low noise stable baseline ideal for reproducible analysis that maintains calibration for long time.

Capacitively coupled contactless conductivity detection (C-D) method combined with electrophoresis separation has shown high potential analytical method for simple, fast, multielemental, low cost analyses that can be miniaturized to a portable instrument and/or combined with other detection techniques [3]. The technology has been demonstrated successfully for applications in fields of environmental, and food analysis [4]. The simplicity of the instrumentation...
needed and possibilities of high level of miniaturization and integration into a low cost system have made them the ideal
choice for portable instrumentation. In this work, to address these dilemmas, a highly compact well engineered
replaceable C\textsuperscript{4}D cell in a cartridge format is devised which permits to interchange cartridges with variable electrode gap
sizes with well defined electrodes geometries encased in grounded housings with minimal noise level, maximal signal
protection and best possible elimination of stray capacitance. The detectors are designed in a plug and play format with
inbuilt input-output and ground connections that allow minimal signal distortion or loss.

In this work, a highly compact well engineered replaceable C\textsuperscript{4}D cell in a cartridge format is devised which permits to
interchange cartridges with variable electrode gap sizes with well defined electrodes geometries encased in grounded
housings with minimal noise level, maximal signal protection and best possible elimination of stray capacitance. Hence,
the user may select the cell depending on the requirements in terms of resolution or sensitivity of a specific analytical
situation. The dC\textsuperscript{4}D detection cells are designed in a plug and play format with inbuilt input-output and ground connec-
tions that allow minimal signal distortion or loss. The exchangeable cells are designed in dual top-bottom C\textsuperscript{4}D cell ge-
ometry that was reported previously. The cell are incorporated into a well developed compact all integrated portable ana-
lytical instrument. A detailed description of the exchangeable cells, instrument hardware and a demonstration of
applications are presented.

EXPERIMENTAL
Experimental analyses have been carried out to investigate the ability of portable C\textsuperscript{4}D for fish farm industry. The wa-
ter samples were obtained from local fish farm company (Apollo Aquarium Pte Ltd Singapore). The experiments were
carried out using acetic acid as buffer 40 mM acetic acid, 2 mM 18-Crown-6, 7.5 mM Histidine, at pH 4.05.

The portable E-dC\textsuperscript{4}D instrument is shown in figure 1.

![Microchip layout with dC\textsuperscript{4}D cell](image)

Figure 1: (a) Microchip layout with dC\textsuperscript{4}D cell: 1. Excitation electrodes, 2. Pick-up electrodes, 3. Shielded box, 4. Ground plane, 5. microchip (L= 10 cm, W=2 cm, t=125 \textmu m), 6. Cross microchannels with 50×50 \textmu m² square cross sec-
tions; injection channel (sample reservoirs: A → B) 1 cm long; separation channel (buffer reservoirs: C → D) 9 cm
long, 7. Imprinted reservoirs connected to microchannels 0.5 mm diameter, 8. Punched through holes into top lead for
fluidic inlets-outlets 2 mm diameter. (b) Optical photograph and schematic diagram of the E-dC\textsuperscript{4}D instrument with
hardware and electrophoresis components. (c) Schematic showing the detailed view of the instrument: 1. Plastic chip, 2.
dC\textsuperscript{4}D cell in cartridge format, 3. Pickup amplifier and its electronic circuit, 4. Signal generator, 5. Signal processing
Electrophoresis compartment.

![Exchangeable cells](image)

Figure 2: (a) Replaceable dC\textsuperscript{4}D cartridges of 0.5 mm, 1.0 mm and 2 mm detection gaps (the distance between the ex-
citation and pickup electrodes along the separation microchannel). (b) The top-bottom excitation and pickup electrodes
with ground plane in between. These components are positioned precisely within a small Faraday cage and isolated by
polycarbonate (PC).

RESULTS
The analytical performance of the portable E-dC\textsuperscript{4}D instrument is presented in: water quality control with the analysis
of cations in standard water sample (figure 3a), and for analysis of water in aquarium fish tanks (figure 3b). The exper-
iments were carried out at different times of the day to investigate the influence of temperature on the performance of the
system as well as the required sensitivity for toxic ions in water tanks. The comparisons between analysis of pond water
samples from several farms using traditional techniques and dC\textsuperscript{4}D portable instrument are presented in table 1.
Figure 3: Electrophoretic analysis and conductometric detection of NH$_4^+$, K$^+$, Ca$^{2+}$, Na$^+$, Mg$^{2+}$ and Li$^+$ cations in a standard mixture containing 50 µM of each ion. Operating conditions: microchip 8.5/7.0 cm total/effective length; electrolyte solution, 30 mM MES/His, 2 mM 18-crown-6 pH 6; (b) Electropherogram of anions Cl$^-$, NO$_3^-$, SO$_4^{2-}$, NO$_2^-$, in pond water used for ornamental fish farms. Buffer acetic. Electrophoresis conditions: Injection voltage of 0.5 kV for 1 s and the separation voltage 4 kV. C$^4$D detector: C$^4$D detector: Sine waveform of 300 kHz 20 Vpp; electrode gap, 1 mm; electrode width, 2 mm. (c) Ornamental fish aquarium water tanks. Inset shows the fish farms the tests was carried out.

Table 1. RSD (n=6) of migration time (RSD(t$_M$)%), peak height (RSD(PH)), and peak area (RSD(PA)), correlation coefficients ($r^2$), and LOD as determined by microchip E-dC$^4$D separation of inorganic and organic anions in fish farm pond water samples (in mg/L)

<table>
<thead>
<tr>
<th>Anion</th>
<th>RSD (t$_M$)%</th>
<th>RSD (P_H)%</th>
<th>RSD (P_A)%</th>
<th>$r^2$</th>
<th>LOD, µg/L</th>
<th>Concentration of anions in apple juice, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine (Cl$_2^-$)</td>
<td>0.98</td>
<td>0.44</td>
<td>1.99</td>
<td>0.9993</td>
<td>12.5</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Itrate (O$_2^-$)</td>
<td>2.11</td>
<td>1.03</td>
<td>3.71</td>
<td>0.9802</td>
<td>12.5</td>
<td>0.82</td>
</tr>
<tr>
<td>Itrate (O$_3^-$)</td>
<td>2.14</td>
<td>2.38</td>
<td>1.93</td>
<td>0.9997</td>
<td>25</td>
<td>35.4±1.5</td>
</tr>
<tr>
<td>Sulphate SO$_4^{2-}$</td>
<td>1.80</td>
<td>0.49</td>
<td>1.54</td>
<td>0.9990</td>
<td>37.5</td>
<td>16.8±1.5</td>
</tr>
</tbody>
</table>

CONCLUSION

The analytical performance of a portable microchip based capacitatively coupled contactless conductivity detector instrument is evaluated for fish farm pond water analysis. The water quality of aquariums was controlled onsite on daily base practice and prove to be a reliable instrument. The portable system was tested in the fish farms at different times of the day. Although the temperature varies within 4 to 5 °C the instrument performance remain relatively stable and acceptable for the required detection limit of 500ppb. Organic and inorganic anions in water samples were separated using similar background electrolyte solution His and acetic acid. The quantitative analyses were carried out in single multi elemental analysis less than 90s. Inorganic cations and anions in water samples were separated using one common electrolyte solution.

REFERENCES


CONTACT
*Kambiz Ansari, tel: +65 68727536; mahabadik@imre.a-star.edu.sg