Fiber bundle sensor for detection of formaldehyde concentration in fish

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ABSTRACT

We experimentally demonstrate an optical fiber bundle based sensor for measuring formaldehyde concentration in fish. We show that when contaminated fish samples are shined with red laser light with about 630 nm wavelength, the intensity of the backscattered radiation increases linearly with respect to the formaldehyde concentration. Our sensor has a simple architecture, it exhibits good sensitivity, linearity and stability and it has been tested for formaldehyde concentrations ranging from 3% to 21%. Our sensor allows non-destructive, on-site measurements and will have applications towards the development of all-optical cheap and portable sensors for detection of pollutants and toxic chemicals in the food industry and in the agriculture sector, being potentially suitable for measurements in the field.

1. Introduction

Detection of pollutants and of substances which are noxious for human health, both naturally present and surreptitiously added in the food production and supply chain, will be a major trend in optical sensing engineering in the present century. The demand for more sensitive, precise and selective sensors is motivated both by the scientific and technological challenge and by the increasingly higher standards in health and safety set by governmental policies for their citizens welfare. Especially in developing countries where quality and safety controls are currently looser, the risks of people contamination, with potentially deadly consequences, is higher and hence more efficient and practical techniques are required.

One of the current social problems related to food safety in developing countries (such as Malaysia, Indonesia, Thailand, Bangladesh to name just a few) is indeed the addition of formalin to the most various kinds of food including meat, fish and milk. Formalin is a solution of formaldehyde in water. Formaldehyde is a chemical substance tremendously noxious for human health being the cause of a variety of illnesses including different forms of cancer and leukemia [1,2]. It preserves the apparent look of food samples making them look healthy and fresh even when they are not any more so. For this reason, rogue traders use formalin to illegally sell rotten food, causing a two-fold damage to people: the eating of rotten food itself and the ingestion of the highly noxious formaldehyde.

While sensing of formaldehyde in the gaseous state, released from some construction materials for instance, has been studied quite extensively both using electronics and photonics based sensing platforms [3–5], the research on sensing of formaldehyde in food is much less developed. In such research area, while chemical methods based on chromatography [6,7] and mass spectroscopy [8] are accurate, they require sample treatment and long time measurements which should be performed in dedicated labs; photonics, potentially opens room for cheaper and portable sensing platforms with applications for measurements in the field.

Besides works on opto-chemical sensing [9–11], some recent experiments have demonstrated the possibility of detecting formaldehyde and measuring its concentration in liquids exploiting the emission of fluorescence [12–14] or based on Raman spectroscopy, especially surface enhanced Raman scattering enabled by metallic nanoparticles [15–18]. In an alternative approach, attenuated total internal reflection in bent plastic optical fibers has been used to measure concentration of formaldehyde in milk [19].

We present here experimental results obtained with a fiber bundle sensor, about the optical non-destructive, on-site measurement of formaldehyde concentration in fish using a very simple detection scheme based on collecting the intensity of laser light reflected from the food sample, fish in our particular study, contaminated by formaldehyde.

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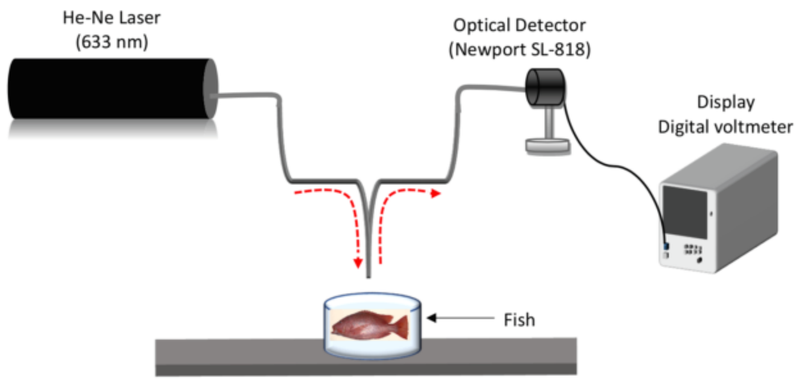

Fig. 1. Experimental setup.

2. Experimental setup

We used a Helium-Neon laser emitting in the visible at 633 nm to illuminate a fish sample through a 2 ports fiber bundle probe; the intensity of the light reflected from the fish was collected through the second port of the fiber bundle probe and measured by a Newport SL-818 optical detector connected to a digital voltmeter. The fiber bundle probe was attached to a support with micrometric movement, which allowed to finely control the distance between the probe and the sample. A schematic of the experimental setup is shown in Fig. 1.

3. Results

We have tested our sensor on two different kinds of fish popular in Indonesia: the snapper and the gouramis fish.

For each kind of fish we have immersed one entire fish in formalin for 1 h and then measured the output voltage of the detector by varying the distance of the fiber bundle probe from the fish, from 0 to 1 mm in steps of 50 µm. We have repeated the procedure for 8 different concentrations of formaldehyde in water ranging from 0% to 21% in steps of 3% (for each specie 8 different fish samples have been used, one for each formaldehyde concentration). We observed that the detector output voltage increased proportionally to the formaldehyde concentration due to an enhanced backscattering caused by formaldehyde.

As one could expect, the voltage response decreases instead with

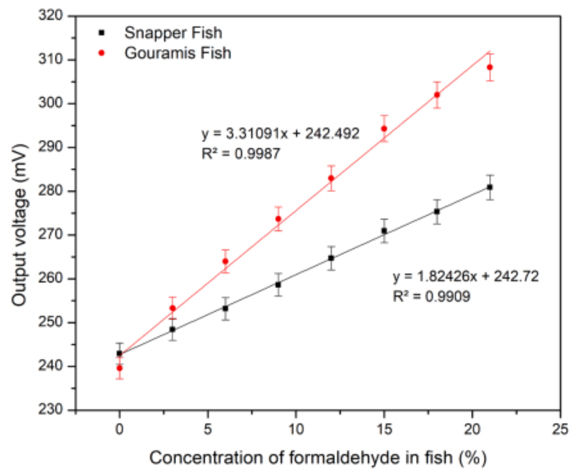

Fig. 3. Linearity of the sensor: output voltage versus formaldehyde concentration at zero probe-sample displacement for both snapper and gouramis fish (see legend). Dots represent averages over 10 different realizations of the experiment, while error bars represent the corresponding standard deviations. Results of linear fits are reported close the respective data sets.

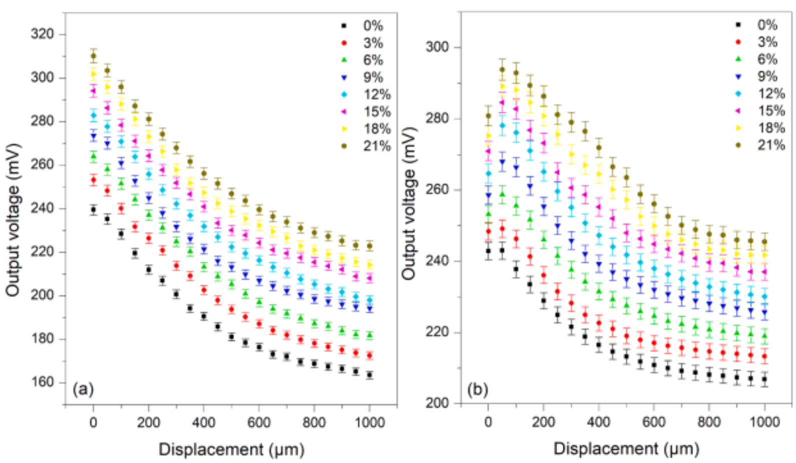

Fig. 2. The sensor output voltage is plotted versus the displacement between fiber bundle probe and fish sample for the snapper fish in (a) and for the gouramis fish in (b). Note that 0 displacement corresponds to the probe being in touch with the sample. Dots represent average over 10 realizations of the experiment, while error bars represent standard deviations.

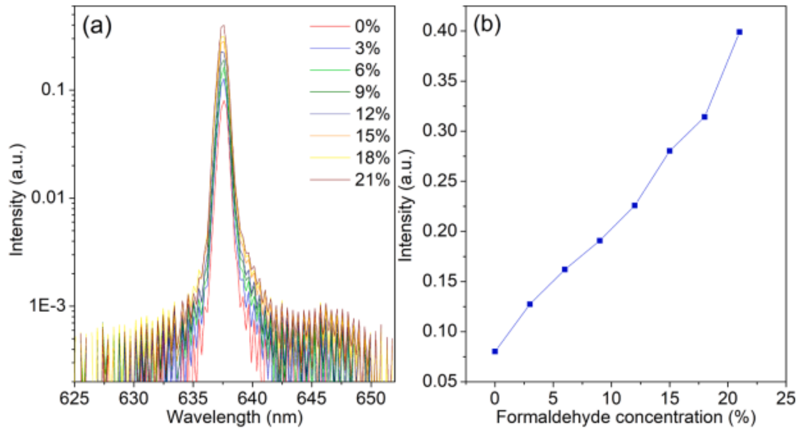

Fig. 4. The reflected light spectrum for various formaldehyde concentrations (see legend) exhibits an increase of the peak for higher concentrations (a). In (b) the intensity at the peak of the spectrum for various concentrations is plotted, the continuous line represents a guide for the eyes. The y-axes are in arbitrary units.

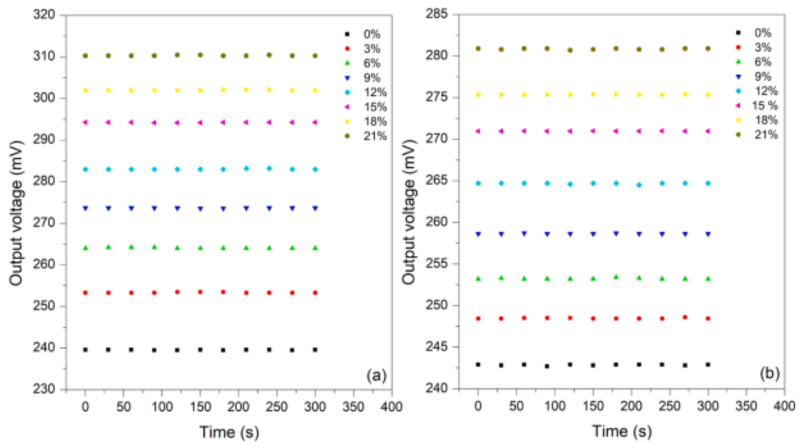

Fig. 5. Sensor stability: the output voltage is plotted versus time for various formaldehyde concentrations, in (a) the results are shown for the snapper while in (b) for the gouramis fish. The results are taken at zero probe-sample displacement.

increasing the distance between the fiber bundle probe and the sample, at fixed formaldehyde concentration, since more photons get lost through scattering on the fish surface (on the scales) when the probe is distant from the fish itself. This suggests that controlling the probe-sample distance is crucial for consistently comparing measurements of different concentrations. The detector output voltage has been shown for both snapper (Fig. 2(a)) and gouramis fish (Fig. 2(b)) by varying formaldehyde concentrations and probe-sample displacement.

The sensor response is linear with respect to the formaldehyde concentration for both fish samples tested, although the response for different fishes follows different slopes, this is possibly due to different constitution of the two fishes skins. The results are summarized in Fig. 3 where the detector voltage is plotted versus concentration for both fishes at zero displacement of the probe with respect to the sample.

We believe that the increase of reflected optical power for increasing formaldehyde concentration is due to a reduced absorption of red light by the water present in the formalin solution. Indeed increasing formaldehyde concentration in the formalin solution is associated to a decrease of water concentration in the solution itself with a consequent reduction of the absorption.

For consistency, we performed further measurements in order to confirm that the increased concentration of formaldehyde in the formalin solution is indeed responsible for stronger reflection in general and hence to validate the general working principle of our sensor.

We put formalin solution in a transparent glass cuvette and shined the cuvette with a red laser emitting around 637 nm. We measured the spectrum of the reflected radiation for various formaldehyde concentrations by using a Thorlabs CCS200 - Compact Spectrometer with < 2 nm spectral accuracy. By keeping the laser emission power fixed, we indeed observed that more light was reflected for higher formaldehyde concentration. The results of the spectral measurements for various formaldehyde concentrations are plotted in Fig. 4. These findings supports the results shown in Fig. 2.

Our sensor also proves to be very stable. The sensor stability for various formaldehyde concentrations is illustrated in Fig. 5 where we show how the sensor output voltage is stationary in time at fixed concentration.

Table 1
Summary of the sensor features.

Sensor feature	Snapper fish	Gouramis fish
Sensitivity (mV/%concentration)	1.82	3.31
Linearity (%)	99.89	99.87
Tested range (%)	3–21	3–21
Resolution (%)	0.036	0.031

The sensor features including sensitivity, linearity dynamic range and resolution (defined as the standard deviation of the output voltage variation in time, as depicted in Fig. 5, divided by the sensitivity) are summarized in the following Table 1.

We have furthermore verified that moving the target fish in the x-y plane, at fixed distance from the fiber bundle probe, does not affect the sensor response.

4. Conclusions

In conclusion, we have proposed a novel fiber bundle based sensor to measure the concentration of formaldehyde in fish measuring the reflection of laser light. We observed that the intensity of reflected light increases proportionally to the formaldehyde concentration. The sensor is very stable and responds linearly to the formaldehyde concentration present on the fish surface. Our sensing technique is simple, low cost, it could be applied to detect, in a non invasive and non destructive way, formaldehyde concentration in different food samples, including milk and meat for instance, and it has furthermore the potential to be developed in the future towards a portable device suitable for applications in the field. Future works will include the study of the sensor performances depending on the laser wavelength and also its development towards selectivity in order to identify formaldehyde even in presence of other additional chemicals.

Acknowledgments

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GENERAL COMMENTS

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CLAIM

Take an arguable position on the scientific topic and develop the essay around that stance.

ADVANCED	The essay introduces a precise, qualitative and/or quantitative claim based on the scientific topic or text(s), regarding the relationship between dependent and independent variables. The essay develops the claim and counterclaim fairly, distinguishing the claim from alternate or opposing claims.
PROFICIENT	The essay introduces a clear, qualitative and/or quantitative claim based on the scientific topic or text(s), regarding the relationship between dependent and independent variables. The essay effectively acknowledges and distinguishes the claim from alternate or opposing claims.
DEVELOPING	The essay attempts to introduce a qualitative and/or quantitative claim, based on the scientific topic or text(s), but it may be somewhat unclear or not maintained throughout the essay. The essay may not clearly acknowledge or distinguish the claim from alternate or opposing claims.
EMERGING	The essay does not clearly make a claim based on the scientific topic or text(s), or the claim is overly simplistic or vague. The essay does not acknowledge or distinguish counterclaims.

EVIDENCE

Include relevant facts, definitions, and examples to back up the claim.

ADVANCED	The essay supplies sufficient relevant, accurate qualitative and/or quantitative data and evidence related to the scientific topic or text(s) to support its claim and counterclaim.
PROFICIENT	The essay supplies relevant, accurate qualitative and/or quantitative data and evidence related to the scientific topic or text(s) to support its claim and counterclaim.
DEVELOPING	The essay supplies some qualitative and/or quantitative data and evidence, but it may not be closely related to the scientific topic or text(s), or the support that is offered relies mostly on summary of the source(s), thereby not effectively supporting the essay's claim and counterclaim.
EMERGING	The essay supplies very little or no data and evidence to support its claim and counterclaim, or the evidence that is provided is not clear or relevant.

REASONING

Explain how or why each piece of evidence supports the claim.

ADVANCED	The essay effectively applies scientific ideas and principles in order to explain how or why the cited evidence supports the claim. The essay demonstrates consistently logical reasoning and understanding of the scientific topic and/or text(s). The essay's explanations anticipate the audience's knowledge level and concerns about this scientific topic.

PROFICIENT	The essay applies scientific reasoning in order to explain how or why the cited evidence supports the claim. The essay demonstrates logical reasoning and understanding of the scientific topic and/or text(s). The essay's explanations attempt to anticipate the audience's knowledge level and concerns about this scientific topic.
DEVELOPING	The essay includes some reasoning and understanding of the scientific topic and/or text(s), but it does not effectively apply scientific ideas or principles to explain how or why the evidence supports the claim.
EMERGING	The essay does not demonstrate clear or relevant reasoning to support the claim or to demonstrate an understanding of the scientific topic and/or text(s).

FOCUS

Focus your writing on the prompt and task.

ADVANCED	The essay maintains strong focus on the purpose and task, using the whole essay to support and develop the claim and counterclaims evenly while thoroughly addressing the demands of the prompt.
PROFICIENT	The essay addresses the demands of the prompt and is mostly focused on the purpose and task. The essay may not acknowledge the claim and counterclaims evenly throughout.
DEVELOPING	The essay may not fully address the demands of the prompt or stay focused on the purpose and task. The writing may stray significantly off topic at times, and introduce the writer's bias occasionally, making it difficult to follow the central claim at times.
EMERGING	The essay does not maintain focus on purpose or task.

ORGANIZATION

Organize your writing in a logical sequence.

ADVANCED	The essay incorporates an organizational structure throughout that establishes clear relationships among the claim(s), counterclaims, reasons, and evidence. Effective transitional words and phrases are included to clarify the relationships between and among ideas (i.e. claim and reasons, reasons and evidence, claim and counterclaim) in a way that strengthens the argument. The essay includes an introduction and conclusion that effectively follows from and supports the argument presented.
PROFICIENT	The essay incorporates an organizational structure with clear transitional words and phrases that show the relationship between and among ideas. The essay includes a progression of ideas from beginning to end, including an introduction and concluding statement or section that follows from and supports the argument presented.
DEVELOPING	The essay uses a basic organizational structure and minimal transitional words and phrases, though relationships between and among ideas are not consistently

	clear. The essay moves from beginning to end; however, an introduction and/or conclusion may not be clearly evident.
EMERGING	The essay does not have an organizational structure and may simply offer a series of ideas without any clear transitions or connections. An introduction and conclusion are not evident.

LANGUAGE

Pay close attention to your tone, style, word choice, and sentence structure when writing.

ADVANCED	The essay effectively establishes and maintains a formal style and objective tone and incorporates language that anticipates the reader's knowledge level and concerns. The essay consistently demonstrates a clear command of conventions, while also employing discipline-specific word choices and varied sentence structure.
PROFICIENT	The essay generally establishes and maintains a formal style with few possible exceptions and incorporates language that anticipates the reader's knowledge level and concerns. The essay demonstrates a general command of conventions, while also employing discipline-specific word choices and some variety in sentence structure.
DEVELOPING	The essay does not maintain a formal style consistently and incorporates language that may not show an awareness of the reader's knowledge or concerns. The essay may contain errors in conventions that interfere with meaning. Some attempts at discipline-specific word choices are made, and sentence structure may not vary often.
EMERGING	The essay employs language that is inappropriate for the audience and is not formal in style. The essay may contain pervasive errors in conventions that interfere with meaning, word choice is not discipline-specific, and sentence structures are simplistic and unvaried.