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Fiber Optical Sensing System for Simultaneous Manometry, pH-metry and Bilimetry in Oesophagus

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Summary:
We present first development results of a portable fiber optic sensing device capable to perform simultaneously esophageal manometry, pH-metry and bilimetry. It will provide physicians a compact and reliable tool to perform exhaustive diagnosis in gastroesophageal reflux pathologies. Pressure measurement along the esophagus is performed with an array of optical fiber Bragg grating (FBG) sensors. The sensors for the measurement of pH and bile are based on the change of absorption caused by the parameter under investigation.

Keywords: fiber optic sensor, multi-parameter sensing system, fiber Bragg grating, compact interrogation unit, esophagus manometry, pH-metry and bilimetry

Background, Motivation and Objective

The esophagus transports food from the mouth to the stomach. Anatomically, it is an elastic tube of tissue with sphincters at both ends. The sphincters function to keep the tube empty from external (food) and internal (acid) intrusions. Swallowing and transport of food to the stomach is a highly coordinated neuromuscular event. Dysfunction of the peristaltic transport mechanism causes a variety of diseases like GERD, esophageal adenocarcinoma, heartburn or pyrosis, achalasia and nutcracker esophagus. When the clinical picture remains unclear, the functionality of the esophagus has to be examined with sensors ([1], [2], [3]). A clearly defined goal is to enhance the spatial resolution, the sensitivity, and the speed of these examinations as well as the comfort to the patient.

In order to have a correct clinical picture and to be able to perform a correct diagnosis, the measurement of more than one parameter in the gastroesophageal apparatus is necessary, mainly esophageal pressure, pH and bile. Within our project (started in Jan 2019) a device is under development, which will measure all three parameters with a portable device over 24h.

Description of the New Method and System

A principle of the sensing catheter with the location of the different sensors is given in figure 1. In table 1 the projects targets are compared to the state of the art.

Besides the innovation of the sensor combination an improvement of the single sensors in comparison to former results and an optimization of the interrogation units is under development. Within this article we present new results on manometer sensor modelling and the improvement of the catheter functionality. An improvement of the pH-sensors is actually presented in [5].

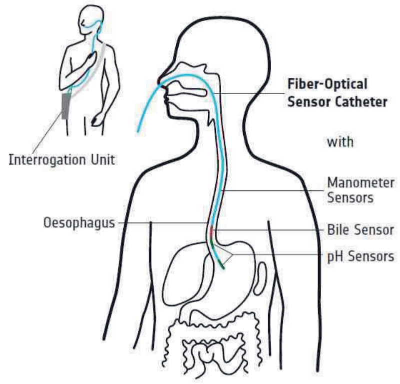

Fig. 1: Principle of the multi-parameter sensing system with positions of manometer- pH- and bile sensors within the measurement catheter.

Table 1: Comparison of different sensor characteristics, research targets and states of the art in gastroesophageal clinics application.

	Parameter	Project target	State of the art
Manometer	Pressure range	0-375 mmHg	0-200 mmHg
	Pressure resolution	1 mmHg	1 mmHg
	Spatial resolution	2.5 cm	10 cm - 1 cm
pH sensor	Measurement Range	1-8 pH units	1-8 pH units
	Accuracy	0.05 pH units	0.1 pH units
	Response time	≤ 20 s	10-30 s
Overall parameters	Diameter	< 4.8 mm	no combined catheter exist

Results

First feasibility tests have shown that optical fiber sensors are suitable for pressure measurements meeting the required stability of the compound material (Fig. 2) as well as the required response of the sensor head to pressure changes (Fig. 3).

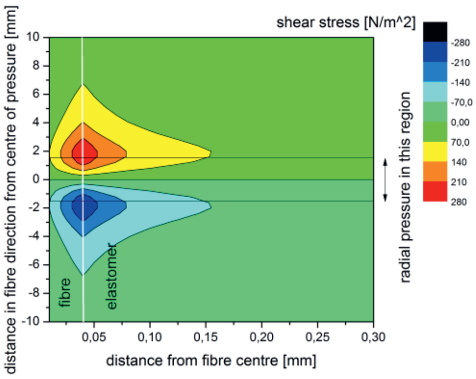

Fig. 2: Simulation of the shear stress at the fiber - elastomer interface with bare fiber with a soft elastomer as a pressure transducer.

A first transducer concept uses the conversion of radial forces into fiber elongation via transverse deformation (see e.g. [4]). Here the interface between fiber and polymer has to transfer high forces and needs a careful optimization. A calculation of shear stress under a pressure of 1 mbar over 3 mm length and 3 mm catheter diameter is given in fig. 2. To avoid sensor deconstruction, the design was chosen to get the shear stress significant smaller tensile strength of the elastomer and the interface allow.

An alternative transducer concept (based on a membran in direct contact to the FBG) is also under investigation. The sensor response to pressure is shown in figure 3. The test was carried out in a typical pressure range like in an oesophagus. Pressure changes within the region of some seconds. Sensor2 (red) shows the influence of an improved design in comparison to sensor1 (black). Sensor2 shows a sensitivity of ~0.58 pm/mbar.

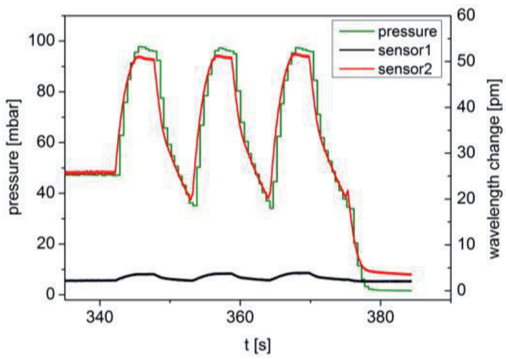

Fig. 3: Response to pressure change of different sensor designs.

Outlook

First measurement systems with combined sensors are planned to be tested at the end of 2020.

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