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A multiplexed FBG based sensor platform for flow and temperature measurements in the Baltic Sea

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ABSTRACT

In this paper a multiplexed multi-parameter marinized sensory array is described. This was deployed on the continental slope off the Keri Island marine observatory in the Gulf of Finland (Estonia). The sensor array is made up of 4 measurement stations which are connected in series. Across these measurement stations, a total of 16 temperature sensors, 4 attitude sensors (each consisting of 3 individual fiber sensors) and 16 flow sensors were successfully deployed. They were addressed over 1.1 km via 20 single-mode (SMF-28e) optical fibers contained in a single marine compliant ruggedized umbilical. The bio-inspired fiber optic flow sensors are designed to mimic the behavior of the superficial neuromasts naturally found as part of the lateral line sensory organ present in fish. The sensor is composed of optical fibers inscribed with Fiber Bragg Gratings glued together in a polymer matrix which are then encapsulated in a polyurethane shell. The sensors response has been tested in DC flows in a tow tank and have demonstrated the ability of measuring flow speed from 0.05 ms^{-1} to 2.5 ms^{-1}. The main aim of the deployment was to demonstrate the capabilities of fiber sensor technology for long-term oceanographic applications. The measurement period described lasted over two months and the sensor system performed well in comparison with data was gathered from commercial instrumentation available.

Keywords: Fiber Bragg Grating, Multiplexing, Flow sensing, Environmental sensing.

1. INTRODUCTION

There is increasing interest in monitoring and understanding flow interactions that take place near the seabed. This is increasingly important due to the expansion of structures that occupy this space, such as moorings, platform foundations, piers, and harbours. Understanding this flow becomes increasingly challenging near the sea bed[1] and around obstacles, and this interface is difficult to monitor using traditional techniques. The impact on costal environments around the world by the effects of human activities can affect costal erosion, sediment migration, flooding[2]. To address this gap in measurement data, the EU funded Lakhsmi project aimed to fabricate and demonstrate sensory arrays for large scale hydrodynamic measurements. At present there is no technology which permits the measurement of hydrodynamic parameters (flow magnitude, direction, and turbulence) in these boundary regions, with high spatial and temporal resolution at a reasonable cost. This work aims to provide a potential solution for this technology gap.

The underlying concept is to produce a passive, all-optical, sensor array that can be remotely interrogated via a rugged umbilical. A schematic outlining the general concept is shown in Figure 1, where multiple measurement 'stations' are serially linked by an optical umbilical. Interrogation hardware is located in a dry environment, in this case on land, and powered via solar charged battery packs. Remote communication was provided via a 5G (wireless mobile) modem that facilitated system control and remote data retrieval.

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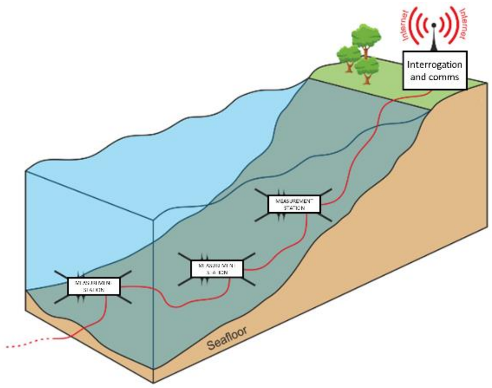

Figure 1: A schematic of the underwater sensory array. Remote access was afforded using mobile-data technology, and the system was powered via solar charged batteries.

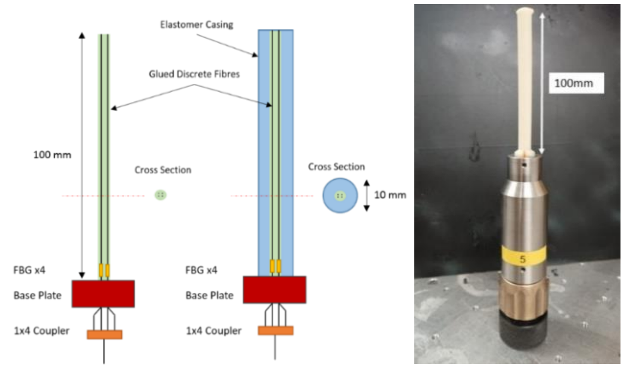

Figure 2: Left – schematic of the multifibre FBG based sensor to measure amplitude and direction of the flow induced deflection of the sensing stem.

Right – final sensor prior to deployment.

2. OPTICAL SENSORS

A suite of sensors were developed to measure temperature, attitude of the sensor station, and flow conditions. Fiber Bragg Grating (FBG) technology was chosen because of the ease of multiplexing sensors, and well characterized strain and temperature response. The attitude and flow sensors were based upon differential strain measurement from several FBG combined to make a sensing stem that allowed deflection of the stem to be monitored. This allowed the effect of a test mass (for the attitude sensor) or the flow (upon the sensing stem for flow measurement) to be monitored. Temperature was monitored via strain isolated FBGs. The design of the sensor based upon earlier work[3] is shown in Figure 2 (left), with a complete marinized sensor shown Figure 2 (right).

3. THE SENSOR PLATFORM AND NETWORKING

A rugged sensor frame and platform was developed to house the optical networking components, and act as a support for the sensors. The frame is engineered to have 8 legs to aid deployment, in which the platform could land in different orientations depending upon the seabed profile and deployment sea state. A CAD rendering of the frame is presented in Figure 3 shows the location of the flow sensors and the umbilical feed through connectors at each end of the cylindrical body for the connection to subsequent CAT units. Figure 4 illustrates a in-situ image of early deployment tests of the sensor platform.

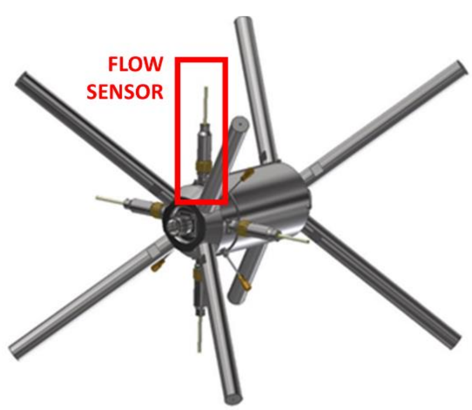

Figure 3: CAD model of measurement station with support legs angled at 30˚ to aid stability in high current flows.

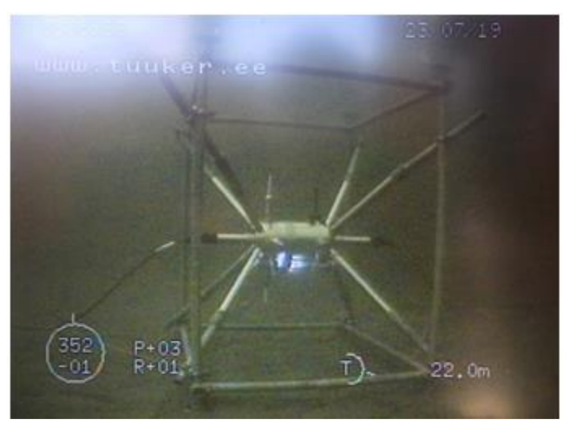

Figure 4: Early deployment tests, with an outer cage attached to assist with handling and stability testing.

The sensor platform is designed to be completely passive to avoid issues with subsea electrical connections. The optical power for the platform is provided by an SM130-700 interrogator from Micron Optics which is connected to the sensor platform via 20 single mode optical fibers incorporated in a single marine compliant ruggedized umbilical. A schematic of the overall layout of the array is presented in Figure 5 below, in which wavelength division multiplexing is housed in each sensor platform body to allow a total of over 80 FBGs to be individually interrogated. The interrogator can sample at 1kHz and incorporates a Micron Optics SM041 multiplexer to provide the additional channels required to address 20 umbilical fibres.

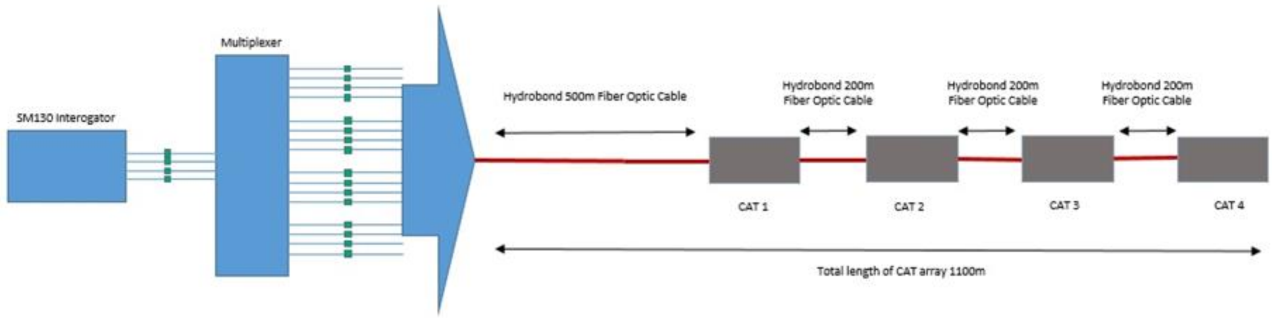

Figure 5. Optical multiplexing schematic, illustrating the use of a switched multiplexer on shore, to address the multi-fibre umbilical.

4. THE DEPLOYMENT

The system was deployed on 23rd July 2019 and recovered on 10th October 2019. The deployment consisted of 4 sensor platforms (16 optical flow sensors, 16 temperature sensors, 4 attitude sensors, and 4 self-contained electrical flow sensors for comparison) and the connecting cables (1.1 km total) was deployed using research vessel R/V Salme, a cable laying boat and a transport boat.

The umbilical was connected to an optical interrogator on the Keri Island, where data was stored locally as well as being transferred near real-time over the data link. In total 86 FBG gratings interrogated simultaneously providing data for 29 individual sensors. Around 97% data availability was obtained from this trial.

Reference measurements were made using commercially available sensors, located nearby: a reference ADCP was located close to the array towards the south-east. A glider was also deployed in the offshore area and was instructed to commence a mission in proximity of the array. The glider was recording vertical profiles of the temperature, salinity and turbidity. The actual locations of all the sensor deployments are shown on the map in Figure 6 below.

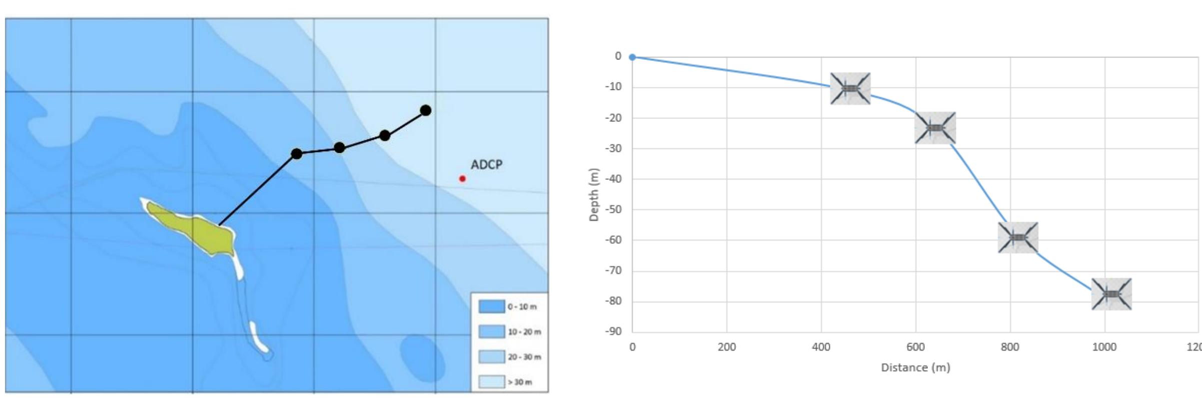

Figure 6: Left – actual locations of the underwater array (black dots) and the location of the reference ADCP (red dot). Right – depth profile for deployment.

5. RESULTS

A section of flow sensor data is shown in Figure 7 below. In this case the data is for a period of 14 days in which the array records at 100Hz for 1 minute every 5 minutes and then generates 1 data point for that time window. The flow magnitu and flow direction data from the optical sensors has been overlayed with the reference data obtained from the ADCP which measured every 10 minutes. de

Despite the difference in measurement location there is correlation between the optical sensors and the reference measurement system, where differences in the measurements could be site specific. Both sensors show high variability in the flow direction, with consistency between the sensors suggesting that this is representative of the complex flow present

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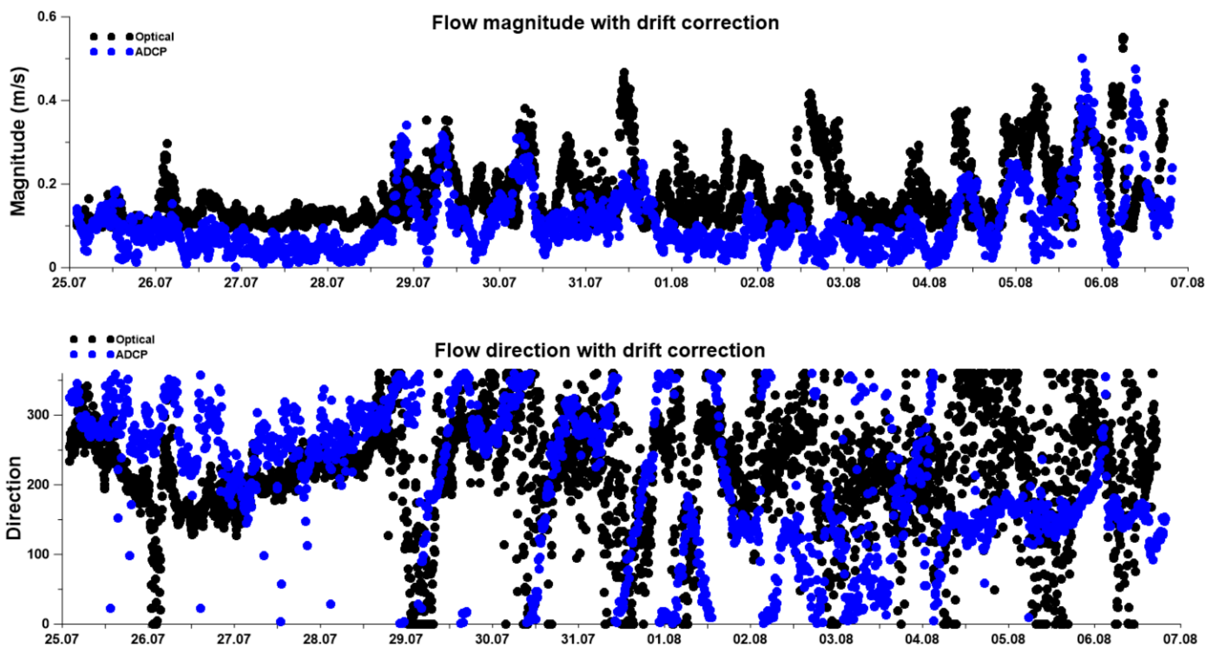

Figure 7. Time series of current speed and direction at 11m depth from the optical sensors (black) and the ADCP (blue).

6. CONCLUSIONS

In this paper we have described the concept and deployment of a multi-parameter sensor platform utilizing multiplexed FBG sensors. Novel flow sensors were deployed alongside temperature and attitude sensors to allow a range of seabed measurements to be realized. Reasonable correlation between the optical sensors and the reference measurements was observed when the difference in measurement location and complex flow regime are taken into consideration.

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