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A low-cost portable spherical directional anemometer for fixed points measurement

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ABSTRACT

We present a novel anemometric system, which could be also suitable for IC integration with MEMS technology. The proposed approach is illustrated at both the design and implementation level, and it allows reliable absolute and relative wind measurement to be obtained for both fixed point or moving vehicles, for instance, on boats. The solution here represents a low-cost, low-power, portable measuring system. The prototype makes use of a fully 3D-printable spherical structure, that acts as an air conveyor, and a differential pressure measuring technique. A preliminary feasibility study has been conducted, strengthened by computational fluid dynamic simulations, and the following measurements on the prototype that has been fabricated have shown promising results. As a result, the test campaign on the prototype has allowed to obtain reliable performance on the wind speed measurement in the range 0–20 m/s and a directional measuring range of 306° with a precision of about ±2.5% and ±3.5% for the wind speed and wind angle, respectively.

1. Introduction

Nowadays, both the validation of new leading technologies and the even more complex human needs that tend to improve the global wellness and safety, are encouraging the definition of novel electronic systems and devices with improved characteristics in terms of power consumption, usability, portability and integration. This phenomenon is particularly evident in sensors and instrumentation field, and this paper, in particular, focuses on anemometric systems since the accurate measurement of wind parameters is an important aspect for various activities and, so far, is usually performed either with mechanical or electronic systems. Despite hot-wire techniques or ultra-sonic anemometry being more reliable than mechanical devices and having no physical moving parts, they are not suitable for portable applications because of power consumption and size. Moreover, it is challenging to obtain a complete characterization of windy events with electronic systems, especially regarding the relative velocity (apparent speed) on a vehicle or the wind direction with compact systems. In addition, it is usually not possible to have all these capabilities embedded in a single device. Different solutions have been presented in the literature [1–10] dealing with the design of anemometric electronic system and researchers have focused attention on operations, time on costs, or on integrability. None of them are able to realize a complete, low-cost and portable anemometer; hence, that is the aim of this paper.

Mainly, anemometers are based on electromechanical or cup sensors and, up to now, this is the typical choice for fixed stations, and also in hostile environments [11–13]. Some alternative solutions rely on the use of pressure sensors or on the heat exchange with the air [3,8,9]; they are preferable for portable applications, but usually suffer from low accuracy in the wind direction estimation. Also, the same authors have already presented an interesting solution based on the use of hot wire sensors [14] and implemented a portable Constant Temperature Anemometer (CTA).

With respect to that solution, which accounts for thermal resistors (heaters) and thermistors with a negative thermal coefficient (*NTC*) on a ceramic substrate, the proposed one is a substantial evolution of the work conducted in [15] and is based on differential pressure sensors, as in [1], that combined with a suitable measurement technique, allows to obtain a more accurate estimation of both wind speed and direction with a reduced power consumption and simpler architecture. The proposed system is realized with a fully 3D-printable spherical structure that acts as an air conveyor and embeds suitable paths for increasing the sensors resolution. It shows a robust and low-cost design; the pressure differential sensor that has been adopted is the SDP31 (Sensirion, Switzerland). Differing from [1], in this anemometer, only two sensors are used

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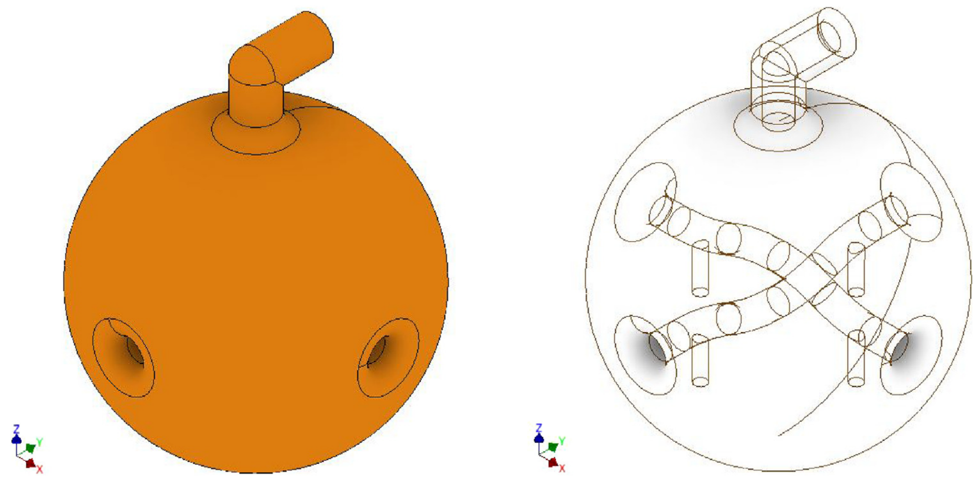

Fig. 1. Spherical structure design.

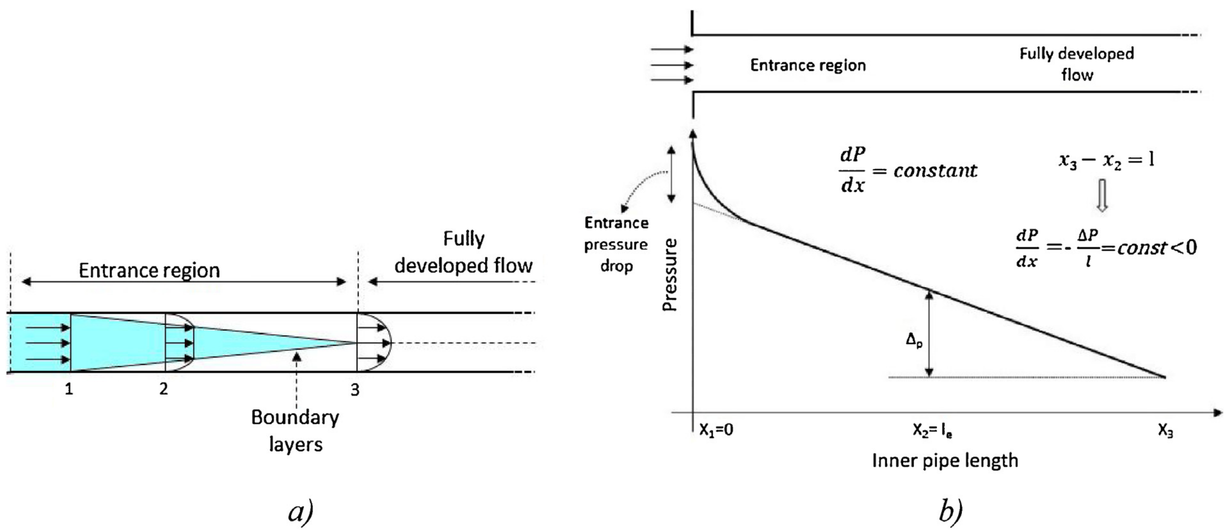

Fig. 2. a) evolution of the air flow through a pipe. b) pressure drop trend in a pipe.

and they are placed on two orthogonal directions, in order to map and define the coordinates of the wind direction. The system is suitable to operate in natural environments from -40 to + 85 °C and allows for an accurate measurement of both absolute and relative wind speed, making it particularly suitable to be adopted also on vehicles, like boats. In this paper, a preliminary theoretical analysis is presented, as well as massive computational fluid dynamic simulations, in order to validate the analytical model and provide a design guideline. Consequently, follows the prototype implementation and tests, in order to prove the strength of the theoretical studies and to give a method of characterization of the device. Finally, a conclusion paragraph summarizes the achieved results.

2. The Proposed System Architecture: theory of operation

The proposed directional anemometer system architecture is formed by a solid sphere structure of 7 cm diameter, crossed by two cylindrical sectional channels of 6 mm in diameter, not intersected, orthogonal to each other and therefore, directed along the *x* and *y* axes of the local coordinates, (see Fig. 1) and of a pair of differential pressure sensors. The structure has at the top a further duct, dimensioned as a Pitot tube, directed along an eventual vehicle motion direction and therefore used to measure the speed of movement of the vehicle (e.g., boat).

The goal is to calculate the vector components *Ux* and *Uy* of the air velocity vector, which runs over the sphere and passes through the tunnels, so as to derive the resulting velocity vector, in the *XY* plane, defined as:

$$\vec{U} = A \cdot U_x \cdot \hat{x} + B \cdot U_y \cdot \hat{y} \quad (1)$$

The resulting vector is then added to the velocity of motion, in order to compute the actual wind speed by means of the formulation of an analytical model of the structure, based on fluid-dynamic considerations of the air flow that develops inside the ducts, and then comparing it with the computational fluid dynamic (CFD) simulations.

First, it is necessary to account for the Reynolds number, in order to determine if the flow inside the ducts is laminar or turbulent. This number is proportional to the ratio between the inertial forces and the viscous forces of the fluid [16] and is defined as:

$$Re = \frac{\rho V_{av} D}{\mu} \quad (2)$$

where ρ is the air density [kg / m^3], μ is the dynamic viscosity of the air [kg / (m*s)], V_{av} is the mean air velocity inside the duct [m / s] and *D* the diameter of the air duct [m]

According to Reynolds studies, the status of a flow can be generally classified in the following ways: