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Switched Thermal Anemometer

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***Abstract*— A new experimental circuit arrangement for a thermal anemometer using a microcontroller as a control unit is described. The device uses a boost-configured self-heated thermistor as a flow detection sensor. Two different operating modes are presented: a sigma-delta constant temperature operating mode and a transient-temperature based operating mode. Both modes are compared and experimental results showing the performance in both cases are presented.**

***Index Terms*— Anemometers; air flow measurement; thermal sigma–delta; robot sensors**

I. INTRODUCTION

Searching odour sources with mobile robots is a problem with a large number of potential applications (e.g., the automatic detection of chemical leaks or illicit substances). This problem can be separated into three sub-problems: detecting chemical traces of the searched substance; tracking the generated odour plume until its source and identifying the source localization. Airflow represents the major phenomena in the transport of odour molecules in the atmosphere. It has been demonstrated by several researchers, from biological and from the robotics field [1], that anemotaxis (motion using the wind information) constitutes a fundamental complimentary strategy for the success of olfactory based navigation algorithms in atmospheric environments.

The measurement of the airflow direction with mobile robots has been addressed by several researchers in different ways. Chapman et. al [2] have built a biological hair inspired device constructed with a metal spring that oscillates and contacts four lateral supporting pins differently, depending from the wind intensity and direction. Russell and Kennedy [3] employed another mechanical-based anemometer that is based in a rotating vane actuated by a DC motor. In this device, the velocity of the vane depends from its direction relative to the wind. One of the most common methods to measure the airflow direction in mobile robots consists in the utilization of thermal anemometers placed around airflow deflecting structures [4] [5] [6].

Mapping odour fields is another related application, where gas concentration and airflow vector measured by fixed nodes from a sensor network might be fused with information gathered by mobile agents in order to estimate the spatiotemporal concentration of some chemical substance of interest [7].

In both situations the power consumption is a relevant issue. Autonomous sensor nodes are either supplied with batteries or use some method to extract energy from the environment, most commonly photovoltaic panels. Mobile robots are usually supplied by internal batteries. Depending on the dimensions of the thermal elements and the number of elements employed, the power dissipation can be a relevant factor that might be important to minimize in order to increase the energy autonomy of the sensing nodes.

II. THERMAL ANEMOMETERS

Thermal anemometers are based on the change of the heat transfer coefficient h from a heated surface to its surrounding environment when the velocity of the fluid around the surface changes. King [8] demonstrated in the beginning of the XX century that for hot wires this coefficient changes according to the following law:

$$h = A + B\vartheta^{n} \tag{1}$$

where A, B, and n are constants that can be determined by calibration (typically n$\sim$ 0.5).

Typically, thermal anemometers are operated with a constant thermal differential from the environmental temperature. In order to keep this differential constant, a negative feedback circuit with a linear amplifier is used to drive a Wheatstone bridge having the thermal element in one of its branches. The power losses in the driving circuit are frequently higher than the power dissipated by the thermal element itself. In order to minimize this power loss, a high frequency switched driver is proposed.

The use of digital modulators in thermal anemometers has received recently increased attention. For example, Makinwa [9] proposes a 2nd order sigma-delta modulator to keep a SOT-89 transistor at constant temperature and Almeida [10] simulated the behaviour of a sigma-delta constant temperature PTC anemometer. The solution proposed in this paper is based on a Boost architecture to heat the thermal element. This approach allows decreasing the power consumption and operating from low voltage circuits, even when low cost NTC thermistors, with high resistance at environmental temperature, are used.

III. AIRFLOW SENSOR

To validate the boost heating concept, some airflow sensor prototypes employing this principle were constructed (see Figure 1). These prototypes are based on a Microchip PIC18

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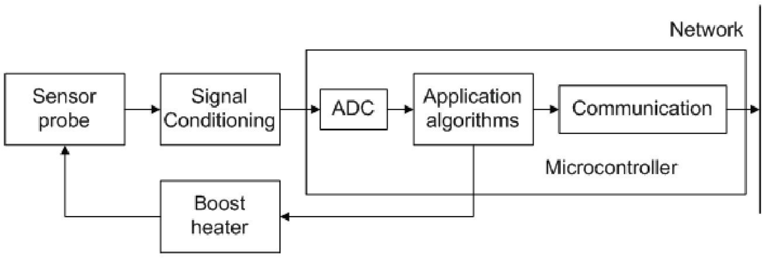

Fig. 2. Block schematic of smart sensor approach.

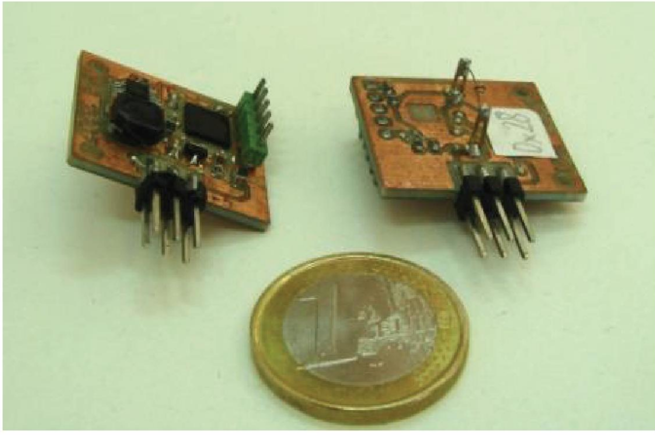

Fig. 1. Picture of experimental anemometer module.

Fig. 3. PWM impulses sent in packets.

microcontroller that interfaces through a serial bus with a higher level system. A block overview of the sensor configuration is shown on Figure 2. The transducer employed in these experiments was a small NTC thermistor (EPCOS B57540G0502). A five Volts power supply was used to feed the circuit. With a linear approach it wouldnt have been possible to heat this thermistor, but with the switched approach employed, the boost converter forces a current to flow through the thermistor increasing its temperature, independently of its cold resistance (see in Figure 3 the packets of PWM impulses generated by the microcontroller to the Boos driver). The amount of energy delivered by each packet of impulses depends from the PWM duty cycle and from the input voltage. Between each two packets of energy delivered, the system measures the thermistor resistance in order to estimate its temperature.

Two different airflow measurement strategies were developed. The first one is based on a constant temperature method and the second one explores the thermistor transient response.

A. Constant temperature mode ($\Sigma\Delta$)

This mode implements a simple $\Sigma\Delta$ digitalization where the thermistor is heated to some high temperature (in the current device the final temperature is set to $130°C$). After reaching the desired temperature, the system evaluates the temperature of the thermistor every $1024\mu s$ (called "packet period") and inserts or not another packet of energy depending on the current temperature being below or above the desired value respectively. A digital filter counts the number of packets inserted per 256 periods in order to estimate the airflow velocity. The operating algorithm is represented in Figure 4. An experimental example showing the generation of heating impulses to the thermistor is shown in Figure 5. In this mode the time needed for a single measurement is constant ($\approx 256ms$), but the energy consumption is higher than in the packet mode described in the next sub-section.

B. Packet mode

The packet mode of operation explores the transient response of the thermistor. In this mode, the thermistor is operated sequentially in two working temperatures and the transient time taken to reach each state is used to estimate the airflow: The lower temperature (in our case $\approx 70°C$) is used during a stand-by state. The second state corresponds to a temporary higher temperature of operation (in our case $\approx 130°C$). The number of constant energy PWM heating packets necessary to change the temperature of the thermistor from the lower temperature state to the higher temperature depends from the fluid flow velocity (as well as the time for cooling down from the higher temperature to the lower one).

The full cycle of measurement can be described by: stabilizing stand-by temperature, delivering and counting PWM packets of energy in order to reach the high temperature, waiting for cooling down until stand-by temperature. The operating algorithm is shown on Figure 6 and an example

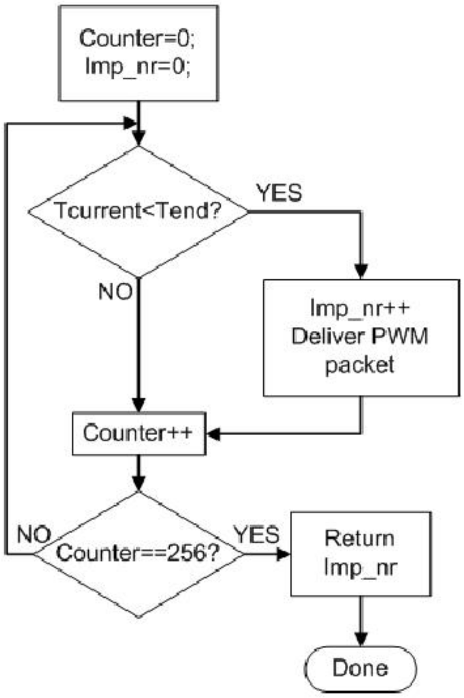

Fig. 4. Algorithm of simple Sigma-Delta conversion in Constant temperature mode.

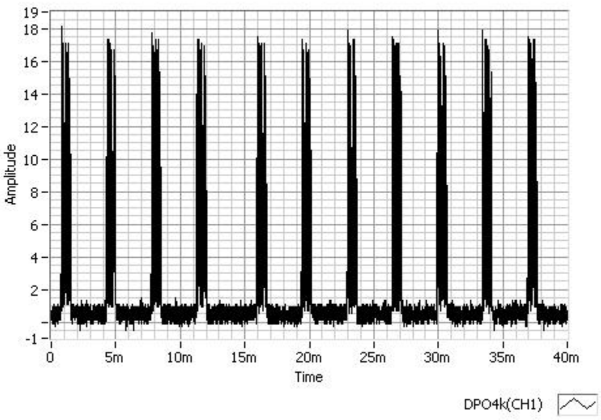

Fig. 5. Charts of heating impulses on thermistor in constant temperature mode.

chart of the heating process is shown in Figure 7.

C. Design

The sensor represented in Figure 2 was build with off-the-shelf elements. The sensing probe is a low cost thermistor from EPCOS B57540G0502. The nominal resistance on $25°C$ is $5k\Omega$, dissipation factor $\delta_{th} \approx 0.4mW/K$, Heat capacity $C_{th} \approx 1.3mJ/K$. The heating circuit designed is based on the standard boost converter (L_1, Q_2, D_1), see Figure 8.

Switch Q_1 is used to disconnect the power supply during the temperature measurement (voltage divider R_2, RT_1). This measurement is made with the microcontroller 10 bits analog to digital converter. The Zener diode D_2 (5.1V) is protecting the microcontroller input from the high voltage

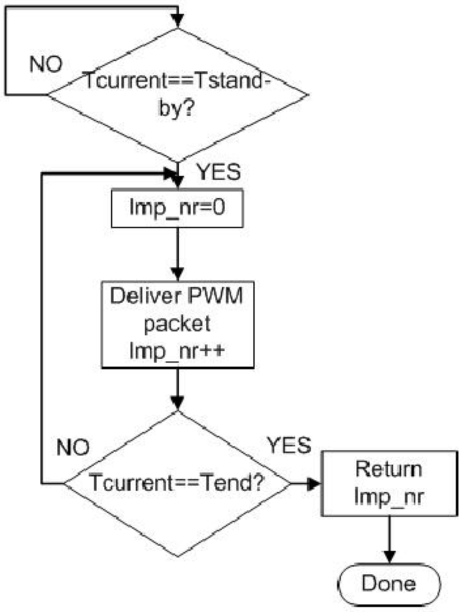

Fig. 6. Working principle of Packet mode measurement.

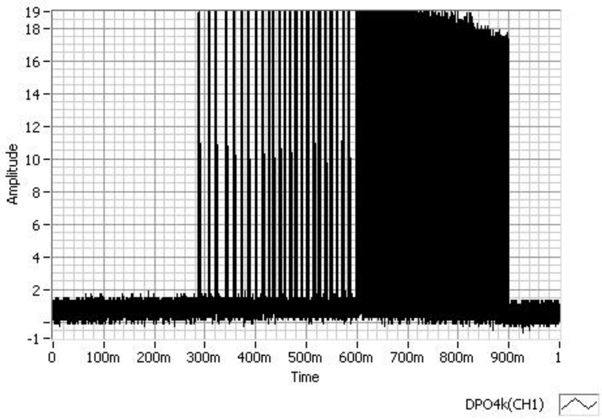

Fig. 7. Charts of heating impulses on thermistor in packet mode.

pulses produced by the boost converter. The microcontroller is the central unit responsible for generating PWM impulses to the boost converter, for measuring the thermistor temperature and to communicate with a master device. Two experimental modules are shown in Figure 1.

IV. Results

Considering the energy efficiency aspects, both approaches consumed far less than a linear-based approach (the gains depend from the regime of operation, but consumptions of less than 30% than the base cases were common). Considering the target application for the developed modules, their angular response is very important, in order to combine several modules around a robot and estimate the airflow velocity and direction [11]. This section presents that angular response obtained with tests performed on a small wind tunnel, with several air flow velocities. The ambient temperature was constant and equal to $25°C$.

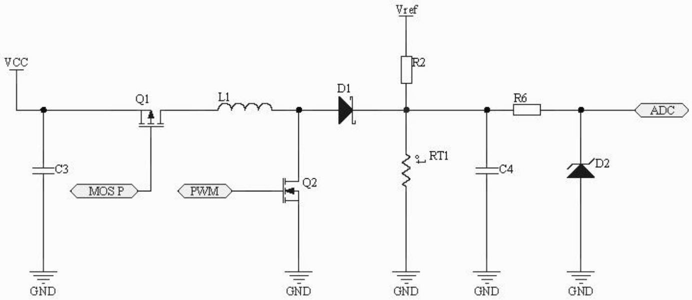

Fig. 8. A simplified schematic of the anemometer.

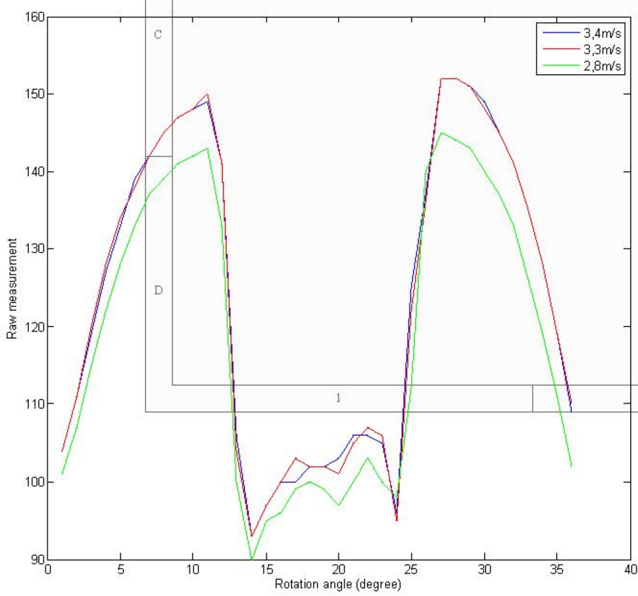

Fig. 9. Series of testing measurement in wind tunnel while rotating sensor (Constant temperature).

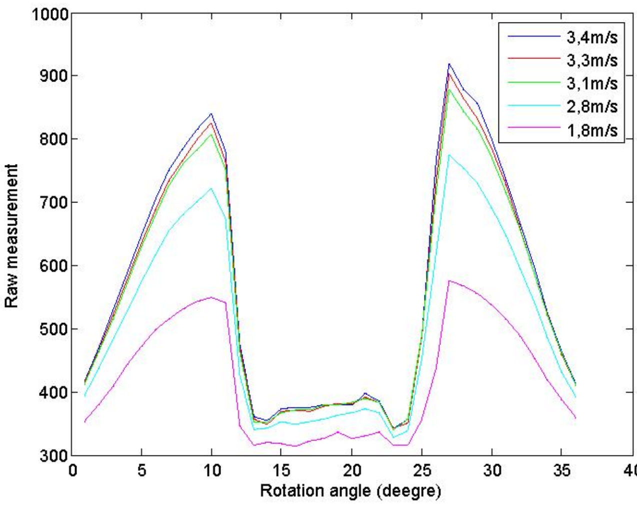

Fig. 10. Series of testing measurement in wind tunnel while rotating sensor (Packet mode).

V. Conclusion

A boost-based driver for a thermal anemometer was presented. The proposed approach has two main advantages relatively to the common driving circuits: better energy efficiency and ability to drive high resistance thermal elements from a low voltage supply. A modular system based on the utilization of smart thermal elements was implemented. Each element can measure the airflow on its surface with an accuracy of about 0.1 m/s in a range from 0.1 to 5 m/s. The fusion of data provided by multiple sensing elements placed around a solid body allows estimating the average intensity and orientation around that body. The system presented can be employed by mobile robots to implement navigation strategies guided by the wind direction.

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