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Research and Development of a Strain Gauge Anemometer

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Abstract – **This paper describes the examination, development, calibration process and initial experimental data of the prototype of anemometric device based on strain gauge sensors. The device relies on an ultra-low power micro architecture and adaptive power distribution mechanism. It is dynamically reconfigurable for working in real time transfer slave mode; and ultra-low power, fully autonomous, self-monitoring, long-term measurement mode.**

Keywords – **Strain Gauge Anemometer, Wind Speed, Wind Direction, Weather Station, Data Acquisition.**

I. INTRODUCTION

In order to support a research of Bulgarian Antarctic Expedition was requested to create an adaptive compact system that ensures all the necessary measurements to support experiments performed in real-time and able to autonomously provide series long-term measurements, by dynamically reconfiguring its working rate.

Development of the adaptive weather station is described in series of papers 0, 0, 0, and is mentioned here just for a background reference.

As an evaluation of the Adaptive Weather Station project, was set a requirement for development of anemometric system for work in Antarctic conditions.

Wind characteristics are typical example for environmental parameters that could require both long-term and real-time measurements. Tracking the wind speed and direction changes is specific and important task not only for the matter of weather and climate study, but also for a various everyday activities. In cases where conventional anemometers are not applicable, this task could be very challenging. Examples of such cases are places where wide temperature deviation exists and could cause freezing of the moving parts of the anemometer or blocking them due to infestation of small particles from dust and/or ice.

This task requires development of low-power anemometer without moving parts. Additionally, it should be able to communicate with external systems and provide data on-demand and as per the requirements of the real-time operation.

This particular set of conditions causes conventional cup anemometers to fail during long-term usage. Pitot tubes and sonic anemometers are also not convenient to use due to freezing and clogging risk.

Due to above constrains, an idea for strain gauge anemometer have appeared. This concept is unexplored solution for the problem and requires extensive research.

Purpose of the current paper is to present the development of the first prototype of this strain gauge anemometric system. The complete design of this system is presented in another paper 0, thus the focus here is on the specifics in realization of the initial prototype and the proof of concept.

II. DESIGN OF THE DEVICE

A. Sensors and Mechanical Design

Figure 1 presents the prototype of the sensor, which consists of main pivot, load cells, and covering coat.

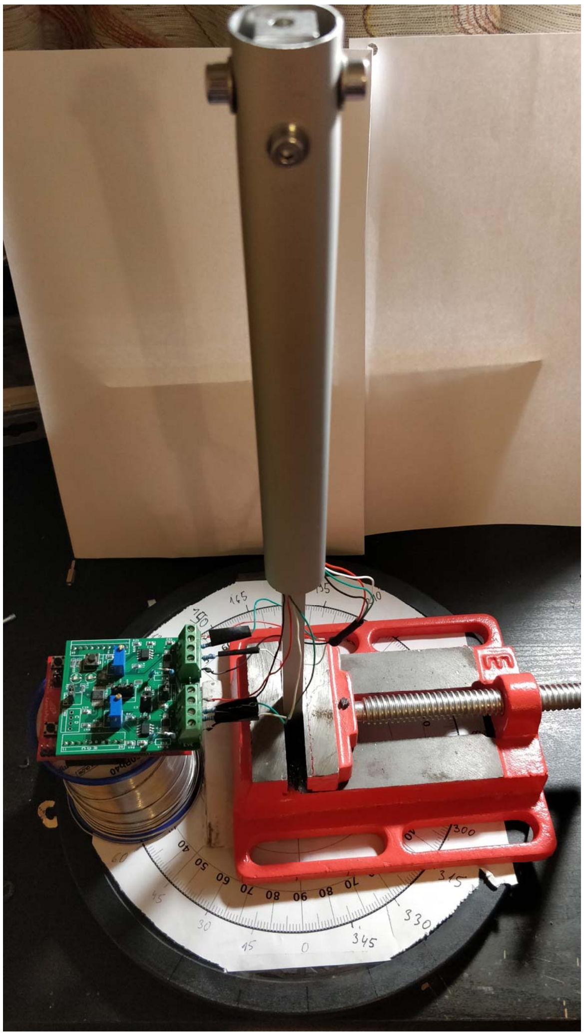

Figure 1. Prototype of the Device

Main pivot is built of a pair of load cells with perpendicular sensing axis, in order to detect wind direction from 360 degrees. Covering coat is designed to transfer wind force to pivot evenly despite of the wind

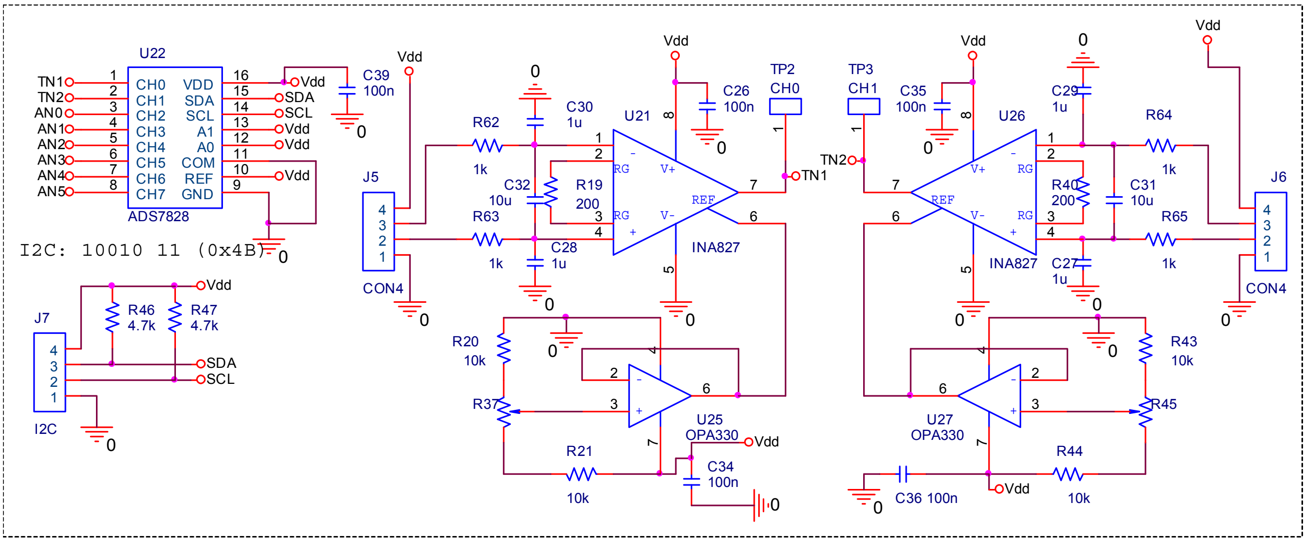

Figure 2. Prototype Front-end schematic

direction. It also serves to shields the sensors from the environment.

Each sensor (load cell) consists of four 1-kΩ ±10% strain gauges in a full-bridge configuration. The rated electrical signal output is 1.0±0.15 mV/V, thus requires amplification by an instrumentation amplifier before it can be used.

Mechanical connection between the two load cells, the covering coat, and main pivot requires special attention, as they are key elements in force distribution and any imprecision will affect the measurement data. Loose or too tight bond will also affect force distribution. In current version of the sensor building are used sets of studs and special designed bushes, but the construction require extensive research to be optimized.

It is important to note, that due to specific way of usage of the load cells (sensing axis are vertical), system is very sensitive to gravitational force. This may lead to deviations in the results and require precision in mounting of the sensor. A gyroscopic solution was proposed in the design paper 0, to ease the process of exclusion of gravitational force influence but further analysis is needed.

B. Front-End Design

As mentioned above, sensor is based on resistive bridge architecture with very low output signal, and works in very specific conditions and environment. This sets the major requirements for front-end system design:

- Noise and error compensation.
- Low level of the input signal;
- Polarity of the measured signal;
- Larger system integration characteristics;

Schematic solution for the front-end is presented on Figure 2.

The front-end module is designed with two identical channels for sensing both load cells. Each channel consists of input low pass filtering system and instrumentation amplifier.

Low pass filtering system is designed to reduce the input noise. It includes R62, R63, C32, C30, and C28 (R64, R65, C31, C27, and C29 for the other channel). C28 and C30 in conjunction with R63 and R62 form common-mode filters with a cutoff frequency of 159 Hz. C32 in conjunction with R63 and R62 form a differential filter with a cutoff frequency of 8 Hz, which further limits the noise.

Major issue of resistive bridge configuration is the stability of the supply voltage, as the output of any bridge is directly proportional to it. The circuit must either hold the supply voltage constant to the same accuracy as the desired measurement, or it must compensate for changes in the supply voltage. The simplest way to compensate for supply-voltage changes is to derive the ADC's reference voltage from the bridge's supply voltage.

The amplification of the signal is done using precise instrumentational amplifier 0 designed to work with strain gauges. The gain of this amplifier can be selected from 5 to 1000 via single resistor, which allows working with low supply voltages. Considering the requirements of the Adaptive Weather Station for a single 3.3-V battery supply and the rated output of the load cells mentioned above, load cell will provide only 3.3 millivolt signal at full load. This will require amplification of at least several hundred times for proper signal measurement.

Another specific requirement of the sensor is to work in both directions of pressure appliance. This is in order to provide information for the wind direction. To allow working in this mode with a single-supply source is necessary to offset the output signal of the amplifier to a precise mid-supply level. This is done via applying voltage on the reference pin of the amplifier. Offset schema allows precise trimming and provide low impedance at the reference terminal to preserve good common-mode rejection.

III. CALIBRATION

Essential part in realization of data acquisition systems is calibration of its sensors in order to achieve maximum accuracy.

On Figure 3 is presented the calibration graph of the load cell – applied force (represented as mass, thus excluding gravitational acceleration) as function of LSB. The capacity of the calibrated load cells is 1kg with safe overload of

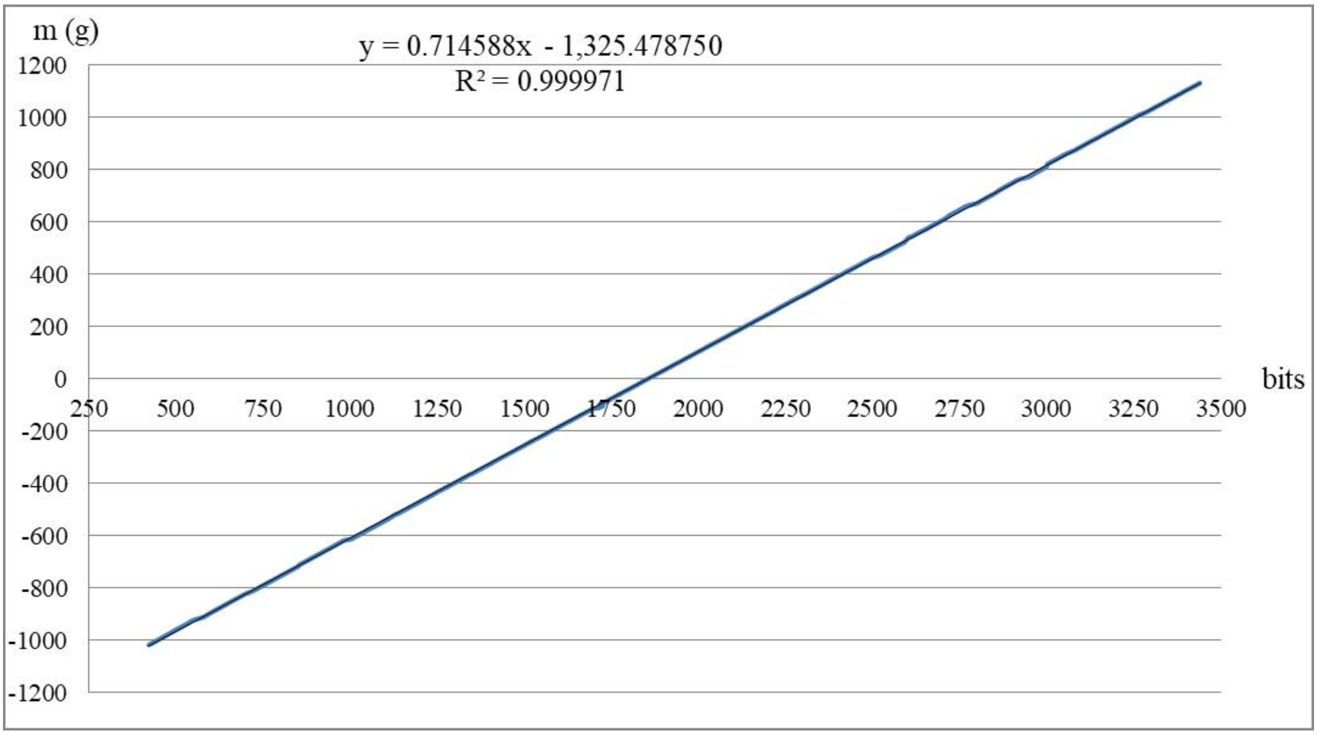

Figure 3. Calibration function

120%. Thus the calibration process is done in both directions with a little more than 1kg of total load.

The calibration of the front-end electronics consists of performing multiple measurements over set of calibration loads and defining the average value and standard deviation per each load. For building the calibration function are used total of 480 different load steps, acquiring data for loads as low as 0.5g.

As a result is achieved a linear equation that describes the measured load as function of the LSB:

$$y = 0.714588x - 1325.478750$$

Where the coefficient of determination is:

$$R^2 = 0.999971$$

This result premises the use of linear equation for obtaining the value of applied force, and calculating the wind speed.

As mentioned above, system is very sensitive to gravitational force. Any deviation from the vertical mounting of the sensor presumes shift in the tare due to senor's own weight. This dependency was experimentally examined and the result data is shown on Figure 4.

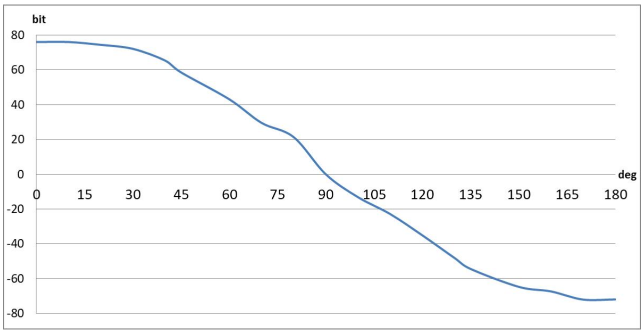

Figure 4 – Tilt graph

Resulting function is co-sinusoidal, as expected, and varies in range of ±75 bits. Some deviations are visible in the graph, which are result of the inaccuracy of the measurement equipment (primary variety of the angle setup). The test is done over the higher placed load cell (this is channel B), and some deviations in the maximums of the function is expected for the lower placed load cell (channel A), due to doubling the weight in the sensing zones.

IV. EXPERIMENTAL DATA

The concept of the sensor assumes that both load cells will work in correlation to provide sinusoidal function describing the velocity and direction of the wind speed.

First step of proving the concept is to test the systems behavior under relatively stable air flow from different angles and obtaining the sinusoidal function.

Initial experimental data from this test is shown on Figure 5. It is visible from the graphic that maximums of the functions in both load cells are in offset of 90 degrees form each other and the zero cross-points are in the tolerance of ±1 LSB, which is in the range of precession of the ADC.

Although the test method is not very precise - the measurement angles are not very accurate, source of airflow is not calibrated, and not very strong; the resulting function is definitely sinusoidal and corresponds to the theoretical expectations.

There are still additional source of errors in the characteristics, like imperfections in the sensor's mechanical construction mentioned above, that require enhancement for providing even better results.

A simple test is done to study the potential error from the effect of lengthening the arm of force appliance for the lower placed load cell (this is channel A from the diagram).

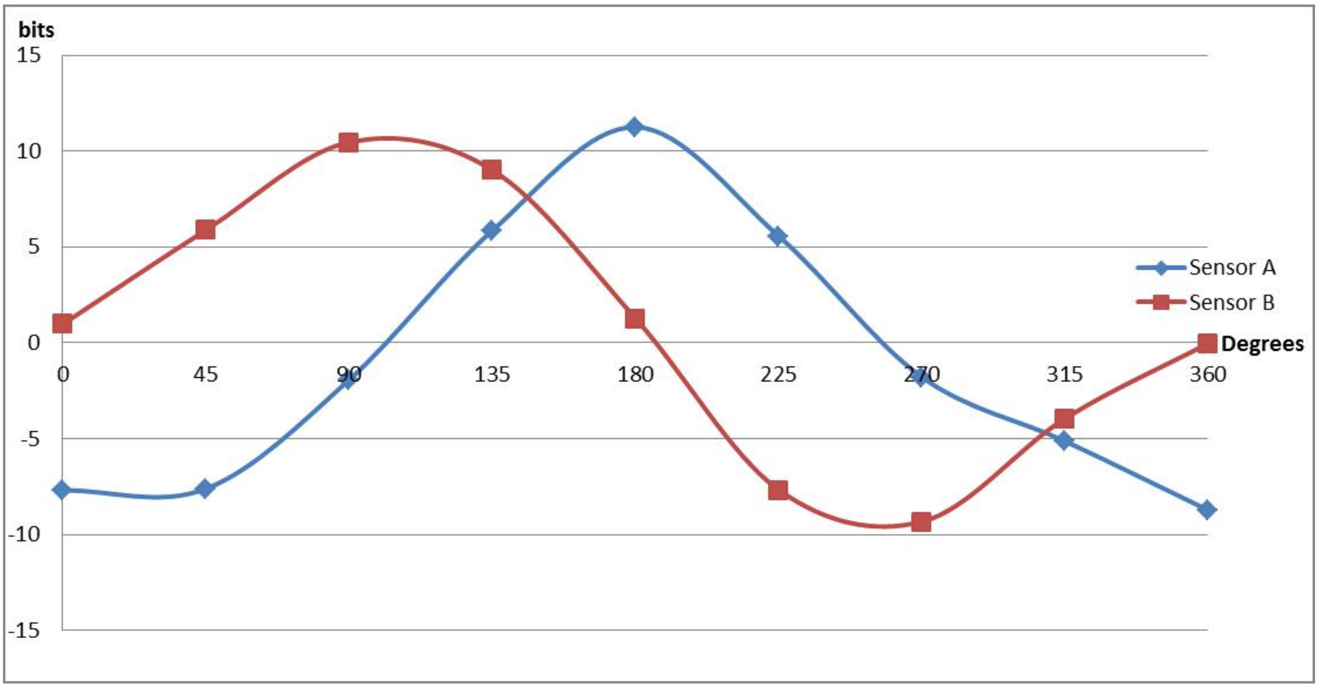

Figure 5. Experimental data

Initial results shows very insignificant changes in the measurement data (lower than 1 LSB over 50g of load), but an extensive research over full range of the load cell is necessary to determine if additional correction in the sensor function is required.

V. CONCLUSION

Development and tests of the initial prototype verify the expected results and prove the concept of the design.

To obtain the final version of the sensor characteristic function is necessary to do extensive tests with precise variations in the wind speed and directions.

As an evaluation of the project is planned to enhance mechanical characteristics of the sensors, study and compare other front-end solutions, and examine temperature characteristics of strain gauges in order to provide a function for temperature compensation.

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