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Design of Strain Gauge Anemometer for Work in Antarctic Conditions

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Abstract – **This paper describes the design 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. For convenience the collected data of the environmental parameters could be initially analyzed and visualized by specialized master system and end-user software tools.**

Keywords – **Strain Gauge Anemometer, Wind Speed, Wind Direction, Weather Station, Ultra-Low Power Management, Self-Monitoring, Dynamically Reconfigurable, Global Warming, Data Acquisition.**

I. Introduction

Monitoring of the ambient parameters is important task for a number of activities. This includes, but is not limited to, studying the weather and the climate, preparing whether forecasts, collecting reference data for other studies, for aviation and navigation purposes, etc. Each of those tasks requires specific monitoring and/or logging system.

Usually, to study the climate changes, is necessary to analyze data from long-term measurements of the environment parameters like temperature, barometric pressure, humidity, etc. The data from the daily measurements are then logged into sets of different time frames (in conditions defined by World Meteorological Organization [1]) and analyzed to define the tendencies in the climate changes.

At the same time collecting a reference data for other studies requires measurements to be focused on current weather conditions. In this case is used an equipment allowing real-time monitoring of environmental parameters – measurements are done continuously, and a suitable interface is provided for communication with the user and/or other systems. Data from these measurements can be then used as a reference in order to take into account possible errors in the further processing of data from other measurements taken in parallel or used as an input for other systems.

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.

In order to support a research of Bulgarian Antarctic Expedition it was requested to provide anemometric system which should be capable to sustain the work in Antarctic conditions. Specific problems taken into account are the wide amplitude of the wind speed and the specific temperature conditions, namely freezing and thermal shrinkage. Another issue is the high air infestation of small hard particles – primary ice, but also dust picked up during intensive winds.

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.

Sphere laser anemometer [2] has shown some promising results, but there is no data for ice protection, air density changes and power requirements.

Due to above constrains, an idea for strain gauge anemometer have appeared with design characteristics described in this paper.

II. Mechanical Design

Figure 1 presents the mechanical construction of the sensor, which consists of main pivot and covering coat.

Several considerations are made during mechanical design of the system:

- Measurement range;
- Uniformity of force distribution;
- Diagnostic and Calibration.

Main pivot is built of two pairs of strain gauge sensors with different sensitivity. This approach provides possibility to record wide range of wind speed by changing the resolution of the sensor.

Each pair contains two strain gauge sensors with perpendicular sensing axis, in order to detect wind direction from 360 degrees. Covering coat is designed to

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transfer wind force to pivot evenly despite of the wind direction. It also serves to shields the sensors from the environment.

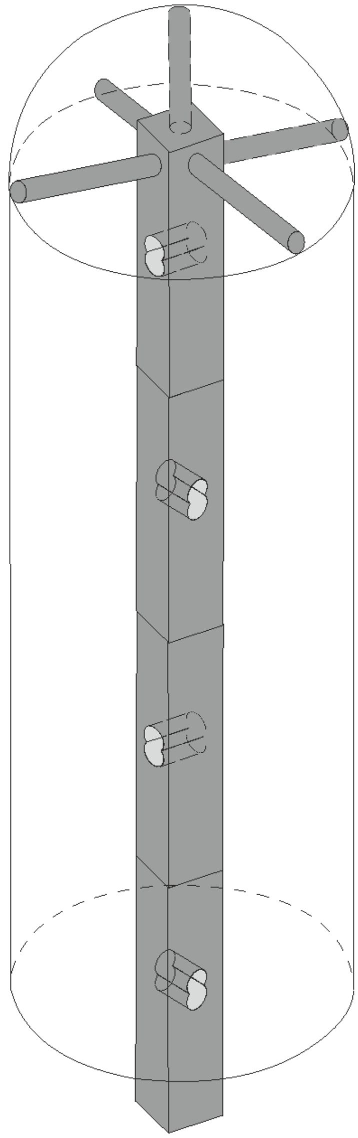

Figure 1 – Model of Strain Gauge Sensor

There are also two critical elements that require special attention during installation of the sensor – orientation of the sensor and mounting precision.

The orientation of the sensor is important for the system, so it gets the correct values for wind direction. In general, this requires some attention from the operator. Considering working conditions, this could be quite an issue, which may lead to incorrect data logging. To avoid such a problem and to ease the task of the operator a tri-axial compass is added to provide the orientation of the sensor to the system on-demand – during calibration or during diagnostic process.

Due to character of the strain gauge sensing, sensors need to be mount absolutely perpendicular to its foundation. Any deviation may cause static errors due to gravitational force, which in that case needs to be included to final calculations. To help covering such an issue, a gyroscopic sensor is used.

In addition to those two sensors a tri-axial accelerometer is added to help detecting wind blasts.

III. HARDWARE DESIGN

The development of the hardware is based on constrains of working conditions and environment:

- Continuous data logging;
- Lack of energy sources;
- Extreme weather conditions;
- Unattended area.

These conditions set requirements for ultra-low power management architecture and self-monitoring mechanisms.

Thus the system is designed on the base of three main subsystems:

- Power and Reset Manager;
- Control subsystem;
- Front-end block and auxiliary sensors.

Figure 2 presents the device block diagram.

A. Power and Reset Manager

The Power and Reset Manager (PRM) is entirely hardware based mechanism which ensures system maintenance on board level. It consists of two main structures – power control module and off-chip reset distributor.

Power control module structure includes accumulator, battery charger, on-board power conditioners, and power switching mechanism.

Power switching mechanism is critical for the system. It provides adaptive power control that ensures the ultra-low power requirements. It also includes over charging and short circuit protection modules.

Specific point in the design is the provision of autonomous power supply for the device. This is critical for two reasons – first, this allows the device to work as a stand-alone system, making it more flexible for usage; and second, because this provide relaxation on power requirements for master system, when device is used in smart-sensor mode.

Off-chip rest distributor is logical-gate based circuit, which propagates different on-board reset sources to MPU. It includes voltage level supervisor, on-board watch-dog timer, temperature supervisor, and manual reset circuit.

B. Control Subsystem

The control subsystem is based on efficient ultra-low-power mixed-signal microcontroller (MSP432P401R [3]) and includes user control interface for direct work with the system, real-time clock, an additional internal watch-dog timer, and data memory.

Control interface subsystem is dedicated slave interface from device point of view. It is based on I2C and RS232, which allows the device to serve as a smart sensor for a larger system such as Adaptive Weather Station [4]. It

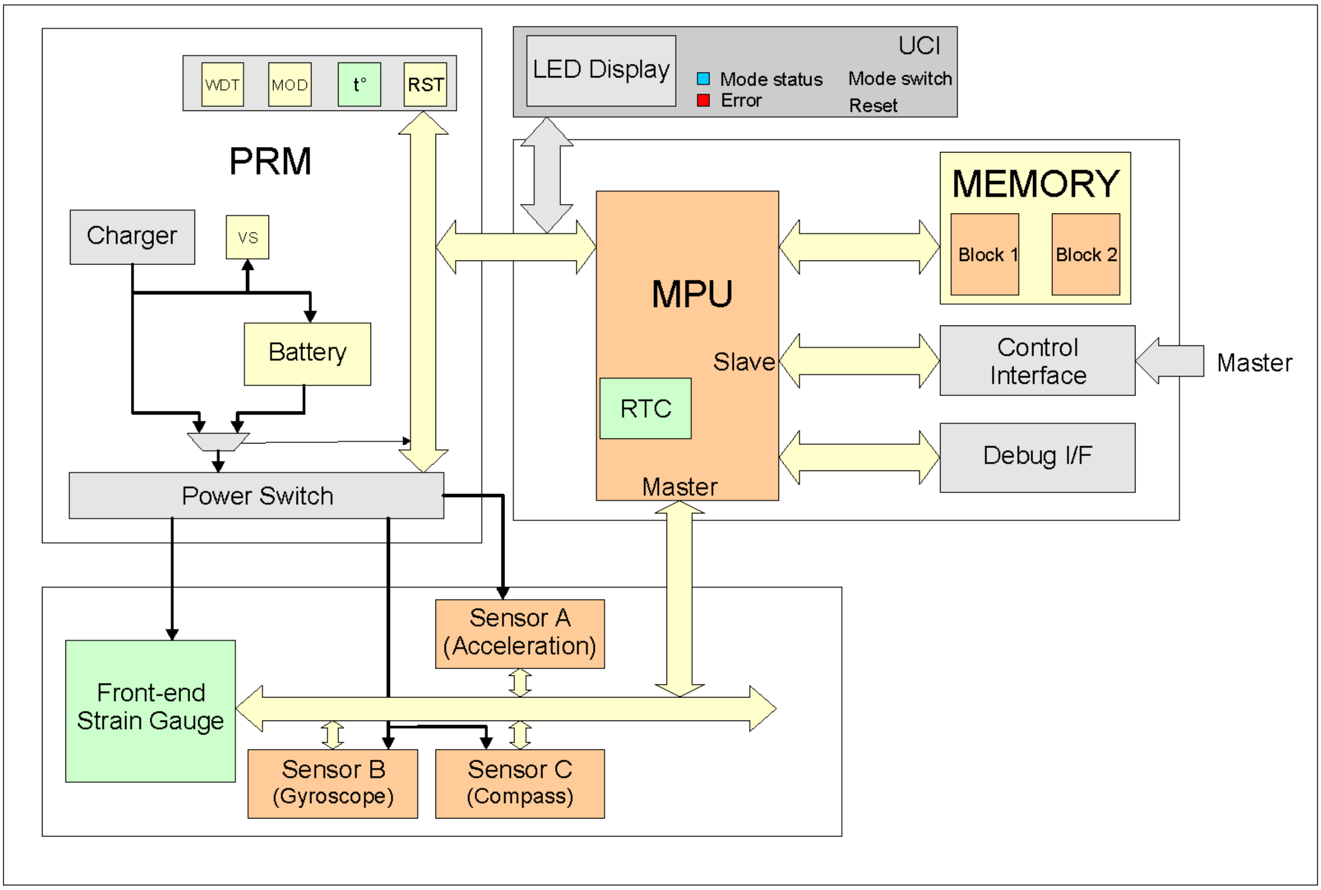

Figure 2 – Block Diagram

provides options for setup, control, and direct read of the memory.

Additionally there is a debug interface, based on JTAG, which allows programing and debugging the device during development and updating the firmware afterword.

Real-time clock and the internal watch-dog timer ensure the continuous operation of the microcontroller and the system. RTC provides time stamp required for the synchronization of the measured parameters with a global database. This is critical for the stand-alone mode, but also very useful for backing up the main system time during smart sensor mode.

User control interface is a simple direct control mechanism, which allows interaction with device on basic level to help setup modes, calibration, and real-time data observation.

C. *Sensor Subsystem*

The sensor subsystem includes front-end electronics, necessary for converting analog signal from strain gauge sensors, and the three auxiliary sensors (tri-axial compass, accelerometer, and gyroscope) described above.

Each subsystem is equipped with controllable power supply in order to cover ultra-low power requirements.

IV. Firmware Design

System management is executed by embedded software, including algorithms for determining the operating modes of the system (stand-alone or smart sensor), powering the sensors, synchronization, error detection, analysis and reconfiguration of the operating modes, the data logging and transmission.

Figure 3 presents the simplified block algorithm of the firmware. There are three main algorithms that build the firmware:

- Self-diagnostic,
- Power Management and
- Data collection.

A. *Self-diagnostic*

Self-diagnostic algorithm is executed during the first (diagnostic) system scan after restart. Its main task is to check the system health status and to configure appropriate working mode. It is executed in two phases.

Component detection – during this phase firmware is scanning all peripherals within the system. Each scan is performed for a predefined period of time (2x sensor's maximum response time); if a response does not appear during this time frame, the program cancels the scanning process, flag the sensor as unusable, and log an error message. Once detection scanning is completed a watch-dog timer (WDT) starts monitoring the system during its normal operation. Component detection is performed only once after restart, as this is high power consuming operation. If sensor fails during normal working mode, WDT will restart the system and the failed sensor is detected during new diagnostic scan.

Error detection – this phase is active during system's normal operation mode. It logs all errors/status that could appear – mode change, reset, manual scan requests, inappropriate user configurations (invalid input data, syntactic error, invalid command, etc.), data memory overflow, etc.

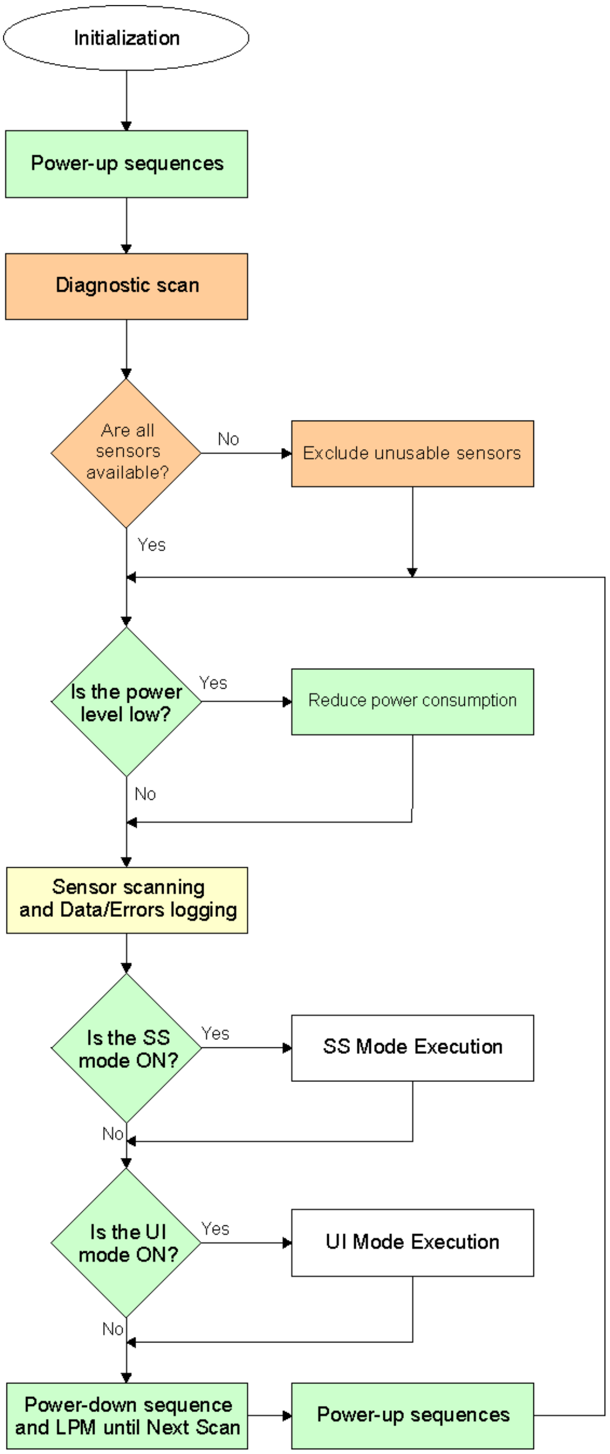

Figure 3 - Block Algorithm

B. Power Management

Power Management algorithm is executed immediately after initial initialization and have the responsibilities to perform power-up and power-down sequences necessary to prepare the peripheral devices for work, and to switch them off to save power. This program is in direct service of the data collection algorithm. Additionally, this program monitors the traffic upon the user interfaces and can change the working mode from user-controlled (UI Mode) and smart sensor mode (SS Mode) to stand-alone mode, if defined time of interface inactivity expires. And vice versus - if the user/system request control appears, it changes the modes back.

In cooperation with the Data collection algorithm, the Power Management also monitors the battery status, and can cut down the power exhaustive sensors, if the source drops below predefined thresholds, and keeps the system active for longer periods.

C. Data collection

Data collection algorithm is the main program that is running during normal operation mode. Its main task is to collect data from the sensors and record them in the embedded memory. It also provides vital data for Power Management and Self-diagnostic algorithms in order to keep them function properly. It is also responsible for user communication and all data exchange including acceptance of control commands and data conversion for real-time user usage.

V. Conclusion

This device is designed to extend the range of action of Adaptive Weather Station – system designed to support a research of Bulgarian Antarctic Expedition.

First prototype is under development and is expected to be send to Bulgarian Antarctic base on Livingston Island, during 26-th Antarctic expedition in the end of 2017.

VI. Acknowledgement

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