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A cost-effective approach for a SHM system

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ABSTRACT: The work presents a system for the continuous monitoring of the structural parameters of a building. The system gathers data via a bus connected to several sensors. The resulted data will be automatically uploaded to a webserver in order to make it instantly available anytime. The building has been designed using passive house tools and is being built according to passive house guidelines. While researching the market for monitoring hardware several problems were encountered during the process of selection. Most of the available hardware was very expensive; they usually formed a closed system with little possibility for external interfacing through 3rd party hardware or software. As such, a monitoring system was assembled from independent components. The core monitoring system consists of a Web Energy Logger that connects to several sensors through multiple inputs. Since the WEL needs an internet connection, a router with a USB port was chosen to interface to a 3G modem that ensures the data gets sent to the server for storage. In addition local display of the collected measurements was desired and the monitoring of the internet connection was necessary in order to ensure its reliability since it was observed during trials that it tended to sometimes disconnect, all of this leading to the development of an inexpensive module fulfilling the above requirements.

1. INTRODUCTION

During the design and build phase of an energy efficient house the need arose for a cost effective monitoring system, necessary in order to validate the theoretical design. After several turn-key options were assessed the decision was taken to build a system based on units that were separately available, as well as units that had to be assembled from scratch with the plan of attaining lower cost in comparison to a commercially available ready-made system and the downside of higher labour input and a longer implementation period.

2. SYSTEM COMPONENTS

The need to make data available online and the physical measurements that had to be taken lead to the following composition:

1. *Central unit*

   1.1. Data collection unit

Commercially available under the Web Energy Logger [WEL] name the data collection unit consists of a low power embedded computer featuring a TCP/IP stack and an interface board that manages actual data collection via following channels: a 1WIRE bus, 6 counter inputs, 8 state inputs, 2 analog inputs and the possibility to interface with IP power meters.

The WEL collects the measurements from the sensors every minute and posts the data to a webserver provided by the manufacturer of the unit. The service offers the possibility to display trend graphs for collected data and to download all data in spreadsheet software friendly form.

1.2. Internet connection

The need to provide a low cost option for an internet connection lead to the use of a commercially available router featuring a USB port that was in turn connected to a 3G WWAN access modem offering a flat rate internet access. The router in turn provides an ethernet connection to the WEL. Because of the unreliability of the low cost 3G WWAN access an internet connection monitoring module was set-up as the WEL has several status outputs providing information regarding the connection to the data upload server. The module is configured to reset the power to the router anytime a connection time-out is detected and also provides local data display, very useful during the setup of the system (Fig. 1).

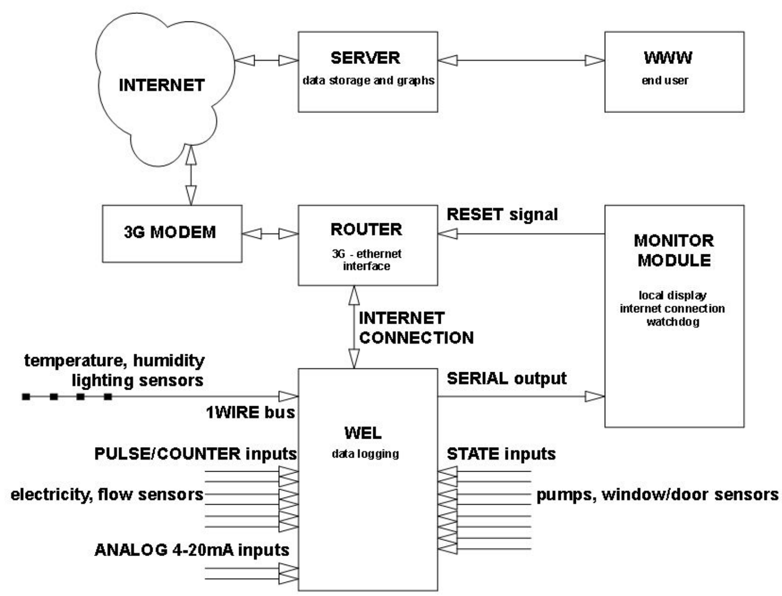

Figure 1. Monitoring system schematic

2. *Ambient/energy flow sensors*

The main strength of the datalogger is the great number of sensors that can be interfaced via the 1WIRE bus. Its main weakness is the reduced number of other inputs. As such, for certain sensors, interface units had to be used in order to convert their output to 1WIRE readable format.

2.1. Temperature

Low cost temperature sensors were used, readily available at electronic component suppliers, providing a digital serial bus compatible signal.

2.2. Humidity

The humidity sensors that were chosen provide a DC linear voltage output.

Thus an interface circuit had to be used in order to provide the digital data necessary on the serial bus. The circuit consists of an A/D converter that is compatible with the digital serial bus and respective support circuitry.

2.3. Atmospheric pressure

The sensors used provide an output signal similar to the humidity sensors and a similar signal converting device was used.

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2.4. Air flow

The airflow sensors are actually differential pressure sensors that feature a DC square root extracted voltage output characteristic

. They are connected to pitot-static tubes in the ventilation ducts. The square root characteristic is useful as it enables less processing of the data in order to derive the airflow rate. Further on an A/D converter that is compatible with the digital serial bus and respective support circuitry was used to connect the sensor.

2.5. Solar radiation

Silicon pyranometers with amplified output are used to collect solar radiation data. The output provided is a DC linear voltage that had to be interfaced with the serial bus in a similar manner.

2.6. Heating agent flow

For heating agent flow volume meters were used and interfaced directly with the impulse counting inputs of the WEL.

2.7. Wind speed and direction

The anemometer used provides an impulse output that can easily be directly connected to the WEL. The wind direction vane has DC linear output that was interfaced with the serial bus through an A/D converter.

2.8. Electricity energy meters

Electricity energy meters with impulse output were directly interfaced to the impulse counting inputs of the WEL.

2.9. State sensors

The state sensors consist of on optocoupler input connected in parallel with the device to be monitored for function, through a rectifier/current limiting circuit. The optocoupler output is connected to the state inputs on the WEL. A galvanic separated solution was chosen in order to avoid problems that could stem from different circuits connected to a common ground.

3. *Structural health sensors*

As availability of MEMS accelerometers is becoming better and their cost decreasing due to rising use of such devices in hand-held equipment the option of including them in the monitoring system arose. The problem lay in the different use of the information they offer. As such an intelligent type of interface module was built in order to gather data via the accelerometers and make it available on the 1WIRE bus. The module continuously takes acceleration measurements, stores minimum/maximum values and calculates an average of the values. Every minute as the bus is polled data is read anew and new values are stored and calculated.

3.1. MEMS accelerometers

The MEMS device selected is a LIS302DLH accelerometer commonly used in mobile phones and computers in order to detect movement or free fall of the device. The datasheet states a typical sensitivity selectable between 1, 2 and 3.9 mg/digit, values usually well below the noise and an output data rate selectable between 50, 100, 400 and 1000 Hz. For our application a working mode with a sensitivity of 1mg/digit and an output data rate of 50 Hz were selected as offering best resolution and sufficient sample density in order to explore even higher frequencies of oscillation.

3.2. Interface

As the accelerometers provide an I2C or SPI compatible output, it was necessary to convert the signal to make it compatible with the serial bus. Also as the bus is polled once per minute in the case of significant events the information density reported would be rather lacking for a further analysis to be pursued. As such a type of intelligent interface was designed. Comprised of a low power RISC microcontroller it reads data at a rate of 50 Hz from the accelerometer and stores the information in a ferromagnetic RAM (FRAM) for later retrieval. At 50 Hz storage rate 1Mbit of memory offers ca. 1 hour of data storage. Combined with a 10^14 read/write life cycle the arrangement offers many years of continuous operation before failure could occur.

In addition to storing the information the interface unit stores minimum, maximum and average values that are reported every minute as the bus is polled. The unit is also programmed with a threshold value that enables certain ranges of data to be protected from being overwritten until access to the unit is possible and the locally stored data can be downloaded and further analysed.

3. CONCLUSIONS

Within a limited budget and using mostly consumer grade off-the-shelf availabel products it was possible to design and build a monitoring system that reports environmental and structural parameters. Further developments include research towards synchronizing multiple sensors on the same network – necessary to align readings in time – in case of an event that triggers local data retention.

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