Networkable Sensor Station for DSN-PC System

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***Abstract*—Weather stations nowadays usually have significant computation capacity since they control their sensors, process the measured data and often are capable of IP-based communication with a central computer. This computation power creates opportunity to use these stations for calculation purposes. This was our goal during the development of Distributed Sensor Network for meteorological sensing and numerical weather Prediction Calculations (DSN-PC) system. Here the description of the latest version of the applied sensor node/station is presented.**

***Keywords*—weather station; distributed sensor network; meteorological sensing**

I. INTRODUCTION

The need for a central computer for weather forecasting calculations can be eliminated by the application of DSN-PC where the sensor stations themselves form a distributed computational grid (Fig. 1). This way they can exchange measured and computed parameters and do e.g. numerical weather prediction calculations cooperatively, so there is no need to collect data and make calculations by a central computer. This way the highest level of parallelization can be achieved [1, 2].

II. HARDWARE AND SOFTWARE IMPROVEMENTS

Previously we have introduced the hardware and software elements of the measurement board used for testing purposes [1, 2, 4, 5, 6, 7, 8, 9]. Since then the board construction evolved to get more accurate measurements, and housing was also constructed so that the station can be placed at outdoor locations (Fig. 2).

Regarding the housing (Fig. 2, 4), the 3rd plate from the bottom is closed (only the cable passes through) for the heat generated by the main board not to reach the sensors. The ones above are opened (have a large hole at their center) so that there is enough open space around the sensors. The top 2 plates are completely closed.

a./

b./

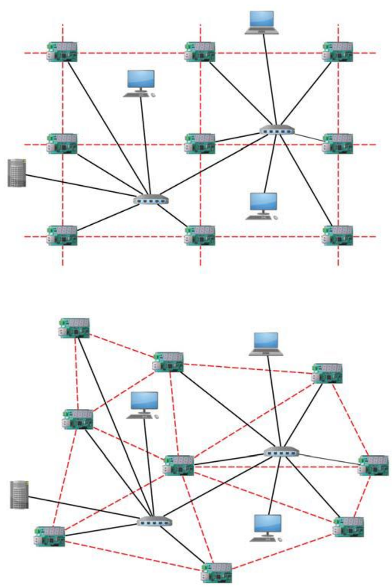

Fig. 1. The conception of DSN-PC sensor network, which forms the necessary grid for numerical calculations by using the nodes of the networked sensor stations not only for measurements and collection of data but for communication with their close and distant neighbors through the Internet and solve numerical weather prediction calculations by the Finite Difference Method (FDM) on a rectangular grid (a./) or by the Finite Elements Method (FEM) on irregular grid (b./) [2].

Fig. 2. The outdoor weather station.

The currently used sensor node capable of the measurement of 3 atmospheric parameters: temperature, relative humidity and pressure. It is built around a PIC18F67J60 microcontroller (μC) which has a built-in Ethernet-controller. The software is written in C and compiled with Microchip's PIC18 compiler. It is responsible for controlling the hardware elements, the measurement and the TCP/IP communication with other nodes and for making possible the numerical weather prediction calculations.

The TCP/IP communication is based on Microchip's open-source TCP/IP Stack library which was completely integrated into our firmware program code. UDP and TCP communication modes are both available for use, and the choice between them depends on the actual needs. TCP should be used in areas with poor network quality, but UDP is a better choice when the chance of packet loss is minimal. Nonetheless, UDP packet loss detection is manually implemented by us.

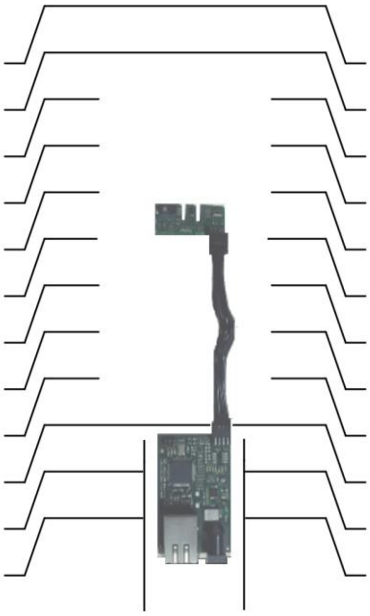

Fig. 4. Cross-sectional view of the weather station with the separated controller and sensor panels inside the housing.

The main development in the case of the latest sensor node/station is the separation and isolation of the base panel (power supply, Ethernet connector and μC) which generates a significant amount of heat, from the sensors that are very sensitive to such impacts (Fig. 3, 5). On the sensor board, the 3 sensors are also well separated which is especially important for the thermometer to work properly and provide accurate results.

The two boards can be interconnected by an 8-wire cable which should be long enough so that the heat cannot pass through.

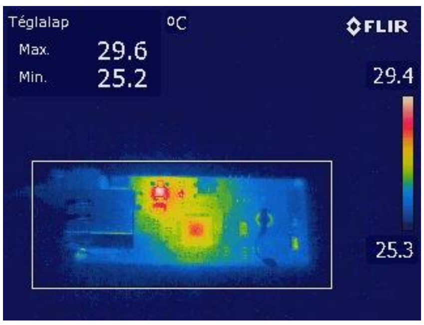

Fig. 3. Thermographic image about the controller panel of the DSN-PC board. The heat generator parts (μC and power supply) are clearly noticeable.

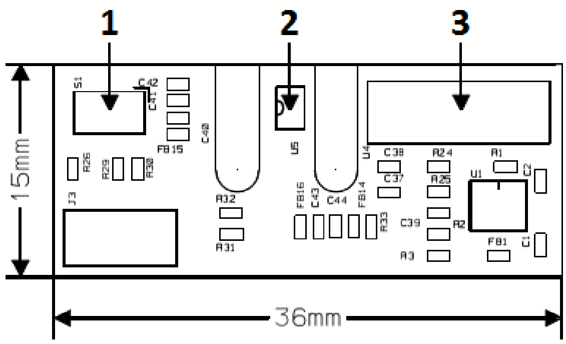

Fig. 5. Schematic of the separated sensor board with separated sensors on it. 1: MPL3115A2 barometer. 2: MCP9808 thermometer. 3: HIH-5031 relative humidity sensor.

The sensor nodes were tested under extreme weather conditions in a simple, ventilating plastic housing for 6 months, and no significant problems occurred during that period. We made great use of the Internet Bootloader capability of the node, by which we were able to upgrade the firmware on the microcontroller without having to access the programmer pins on the board directly. To make the upgrade procedure simpler we developed a Java application with an easy-to-use graphical user interface (Fig. 6) based on the open-source Microchip TCP/IP Discoverer application. It currently works on local network and is able to discover the connected stations and upgrade their firmware after selecting the proper .hex file. After reading and encrypting the selected file using XTEA encryption, it automatically uploads the file to the selected station. The file transfer is based on UDP-based TFTP protocol. UDP-based communication has a significant advantage in the case of the bootloader because it has little data- and program memory requirement. The upgrade procedure doesn't take longer than 1 minute.

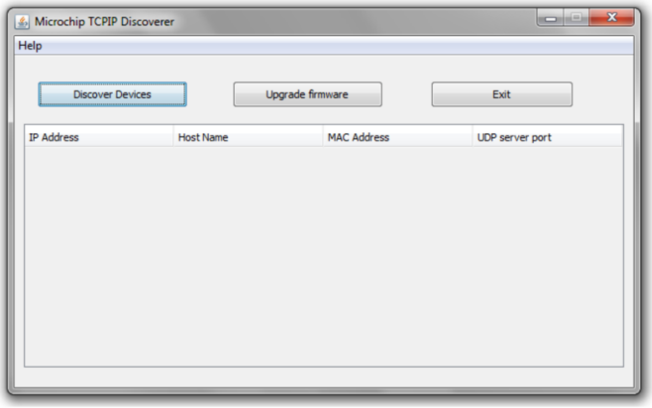

Fig. 6. The user interface of the firmware upgrade application.

For testing the distributed computing capability of the new sensor stations the finite difference (FDM, Fig. 1/a) vorticity equations weather prediction calculation method of J. Charney, R. Fjørtoft and J. von Neumann (CFvN) [3] have been implemented in our system with the basic equations [2,3] of

$$\eta_{ij} = h_{ij}\xi_{ij} + f_{ij} \tag{1}$$

$$\frac{\partial \xi_{ij}}{\partial t} = J_{ij}(\eta, z) \tag{2}$$

$$\Delta_{ij}\left(\frac{\partial z}{\partial t}\right) = \frac{\partial \xi_{ij}}{\partial t} \tag{3}$$

where

- $\xi_{ij} = \Delta z_{ij}$
- z_{ij} is the geopotential height of the 500 mbar level
- η_{ij} is the absolute vorticity
- h_{ij} and f_{ij} are constants
- $\Delta_{ij}\left(\frac{\partial z}{\partial t}\right)$ is the Poisson equation
- $J_{ij}(\eta, z)$ is the Jacobi operator

The boundary conditions are also considered during the term of prediction but in a possible worldwide network of DSN-PC the boundary condition may not necessarily be defined in the above way since the nodes of the network will provide them automatically through their directly measured and calculated data.

This equation system is solved in general by spectral methods however, in our system this would require from each DSN-PC node to collect data from all the other nodes of the investigated area, which would be difficult and would require large memory and processor capacities. Therefore, in our system an iterative FDM solution, calculated in a distributed way by the µC based nodes, was applied, that consists of the next steps:

$$z_{ij} \xrightarrow{(10)} \xi_{ij} \xrightarrow{(3)-(7)} \eta_{ij} \xrightarrow{(12)}$$

$$J_{ij}(\eta, z) \xrightarrow[\textit{for the whole field}]{\textit{n times iteration of } (8),(9),(11)} \left(\frac{\partial z}{\partial t}\right)_{ij} \tag{19}$$

During this procedure the nodes are communicating with their neighbors, exchanging data and solving the differential equation by applying finite difference scheme. Since the iterative solution of the finite difference scheme can be explained as the propagation of disturbances in the field of the investigated area, the data change and the finite difference iteration parts of the calculation for the different nodes in our case can happen not only in a regular way, but even randomly.

Time extrapolation is also needed to be done 24 times repeatedly for the whole forecast period and the solution can be found iteratively by solving the equations and extrapolating the motion forward in time with the suitable boundary conditions. During the simulation phase we made use of P. Lynch's MATLAB-code [10] that implements the original calculations of CFvN. However, it had to be redesigned to simulate distributed calculations.

III. CONCLUSIONS

We have succeeded to design, build and test a weather station in different weather and networking conditions. It consists of a housing with thermal insulation walls to separate the sensor (T, P, RH%) and the heat generator μC based controller panels with controller, computational, networking and Internet Bootloader capability inside. This station can be applied as a sensor node in our Distributed Sensor Network for numerical weather Prediction Calculations (DSN-PC) [1, 2] systems.

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