MEDIUM-RANGE CONTACTLESS DATA TRANSFER OF TEMPERATURE AND HUMIDITY FROM AN OVERALL

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Abstract: Monitoring of life conditions both in inner and outer environment of protection overalls e.g. for firefighters becomes a demand of their producers thus a focus of development. Six temperature and humidity sensors were fitted on various places in ski suit for the first experiments. One extra sensor measures ambient condition on a surface of measuring unit box which is further equipped with 2-axis digital acceleration and inclination sensor. Data from these digital sensors are captured and collected with a microcontroller and are transmitted using commercial DECT module that enables communication at distance about 0.5 km in 1.9 GHz radio band. Data are received by the second DECT module and via USB interface chip are passed to a notebook where they are visualized on graphs and saved by a user application. Sets of data were collected during various motion and physical load of tester who wore the suit. Data are given on graphs for next evaluation.

1. Introduction

Intelligent textiles for special purposes (medicine, industry, military,...) can contain miniature sensors that continuously monitor life functions (e.g. temperature, humidity) and environment (occurrence of various gases and poisons, humidity, temperature, pressure,...).

Simple and cost effective sensors for life functions monitoring are being developed together with danger gas sensors. A part of development represents contactless communication, data acquisition and sensor signal processing.

The developed measurement system (Fig. 1) consists of sensors inside a suit, a measuring unit that captures data from sensors and transmits them to a base station where they are visualized and stored. All components of the system are described in next paragraphs.

2. Wireless Communication Platform

There are several wireless technology platforms that could be used for data transmission from a moving protective overall to a base station. Bluetooth represents mature solution but range would be short enough. In time of origin of the measurement system, GSM (mobile phone) modules were not be available as stand-alone solution and did not implemented GSM protocol stack inside. Beside this, GPRS mobile-to-mobile data transfer is not much supported by mobile operators and is complicated in the context of dynamic and non-public IP addresses. Standard radio transceiver modules for ISM (Industrial, Science, Medicine) bands (433 MHz, 868 MHz, 2.4 GHz) require a user to implement communication protocol including data coding and protection in his own microcontroller.

DECT (Digital Enhanced Cordless Telecommunications) is a highly successful wireless technology originally developed for cordless phone sets with range up to 300 m outdoor.

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The open DECT standard is accepted in more than 100 countries world-wide and offers competitive advantages for voice and data transmission. The DECT 1.88-1.90 GHz exclusive RF band eliminates interference. DECT makes possible to work more co-located DECT systems together.

We used small and ready-to-use **DECT module HW 86010** [2] from Höft & Wessel. It is a highly versatile and powerful engine for embedded DECT applications. The module has footprint only 53 mm × 37 mm and consumes about 40 mA from 3.3 V supply and about 50 mA in average from 4.7 V supply with peak RF output power 250 mW. It requires either two internal wire antennas (37 mm long) for receive diversity or an external antenna. The module performs complete radio and baseband processing of DECT signals including error-correcting data link protocols. Interfaces include full-signal RS-232 (3.3 V CMOS level) for serial data, PCM connection or analog for voice, I2C and analog input/output. General purpose digital I/Os and a bus interface make the HW 86010 easily expandable. Complete DECT protocol stack has been implemented as firmware running on the microcontroller of the HW 86010. The module has to be configured using RS-232 interface and e.g. terminal

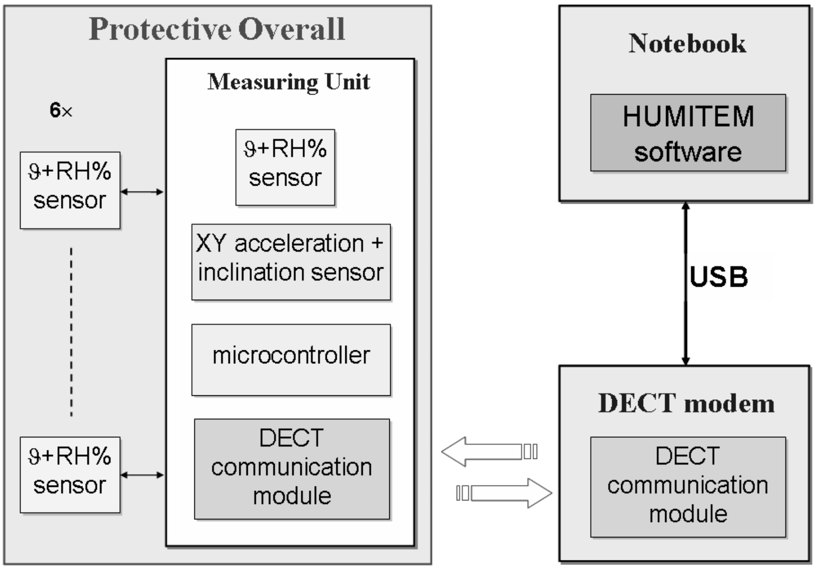

Figure 1: *Block diagram of measurement system*

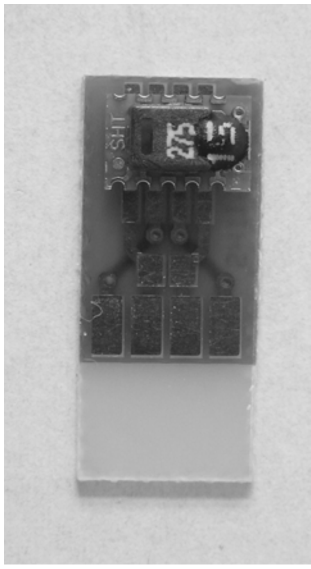

Figure 2: *SHT15 ϑ+RH% sensor and connecting PCB*

program on PC. Baud rate 38400 Bd was set on the module.

3. Sensors and Overall

As some inexpensive, miniature sensors specially designated for embedding in textiles had not been available yet, the **Sensirion SHT15/75 relative humidity and temperature sensor** [3] was employed due to high precision, excellent resolution and a 2-wire digital serial interface. It exhibits only ±0.3 K temperature error and ±2 % relative humidity error at 25 °C with 0.01 K and 1/25 % resolution, respectively.

The single chip device is supplied in either a surface-mountable 8-pin or as a pluggable 4-pin single-in-line type package that integrates temperature and humidity detectors and appropriate electronics. The SHT15/75 requires a voltage supply between 2.4 and 5.5 V and consumes less than 1 mA. Two-wire proprietary serial interface and communication protocol are similar but incompatible to wide spread I^2C so that a software interface in a microcontroller had to be designed. The 5-bit commands are sent into the device and 2 bytes of either 14-bit temperature or 12-bit humidity followed by 1 byte of the CRC polynomial are received.

As a real protective overall (e.g. for firefighters) tailored for an individual tester would be too expensive, tester's own older ski suit was adapted for first experiments. Six SHT15 sensors were sewed in the suit on various meaningful places as shown on Fig. 3. They were soldered on a miniature PCB to make possible wiring of a cable (Fig. 2). Sensors are covered with woven polypropylene textile that prolongs a sensor response at least [1].

Signals from/to sensors are lead by 4-wire ribbon cable of cross-section 5.1 mm × 0.9 mm to/from a connection board because supply wires and clock signal can be shared for all sensors so the measuring unit is connected using 14-wire cable only.

An accelerometer and/or inclinometer captures data that after data processing could provide information about type of motion (standstill, walk, run) or some accident (fall, still laying) of a person who has it fixed on his suit.

The **Analog Devices ADIS16201** [4] is a complete, dual-axis **acceleration and inclination** angle measurement system available in a single compact package. It provides factory calibrated and tunable digital sensor data in a convenient format that can be accessed using a serial peripheral interface (SPI). The SPI interface provides access to measurements for dual-axis linear acceleration in range ±1.7 g with 14-bit resolution, dual-axis linear inclination angle in range ±90° with 12-bit resolution, temperature, power supply, and one auxiliary analog input. The sensor offers many programmable features as digitally controlled sensitivity and bias calibration, sample rate, frequency response, alarm settings, self-test and low power mode that are set by writing commands to appropriate registers within a set of 28 control registers.

The ADIS16201 requires a voltage supply between 3.0 and 3.6 V and consumes about 11 mA. It is available in a 9.2 mm × 9.2 mm × 3.9 mm special package (LGA). Because soldering of this package would be very difficult, a small evaluation board equipped with

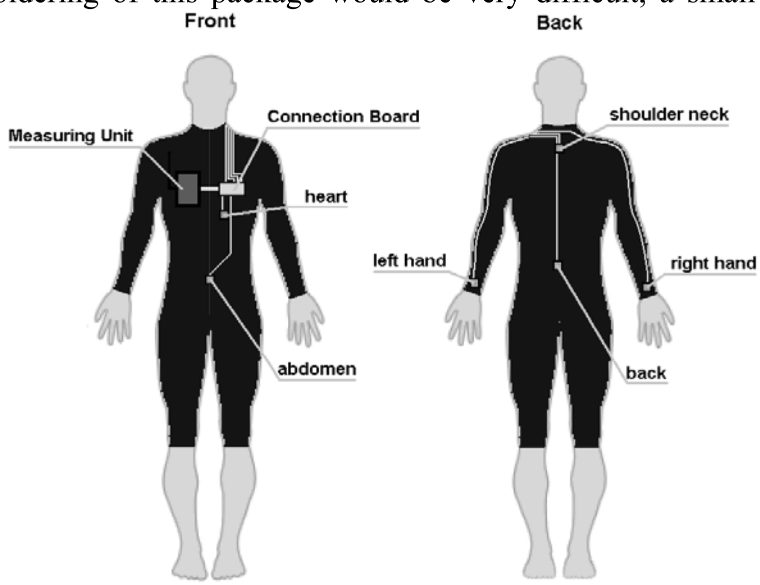

Figure 3: *Placement of SHT sensors and the unit in the ski suit*

Figure 4: *Measuring Unit*

connectors was purchased and adapted for a placement into the unit.

4. Measuring Unit

Measuring unit supplies the sensors, collects data by polling the sensors with sending commands and receiving responses using appropriate interfaces and communication protocols, converts sensors raw binary data to physical values and transmits them using the DECT module. Four LEDs, 3 buttons and a loudspeaker serve as a signaling interface. Four AAA NiMH accumulator cells with capacity 800 mAh can supply all devices for several hours. The unit is housed in a plastic box (photo in Fig. 4) with dimension 150 mm × 80 mm × 33 mm excluding the external antenna. The 7th temperature/humidity sensor is bonded in a through hole on the left side of the box to sense ambient conditions; the inclination/acceleration sensor is fitted inside the box in parallel with the shortest side. Another, irradiation sensor (photoresistor) is attached under through hole in a front side. Electronic parts including 3.3 V low drop regulator and the DECT module are assembled on single PCB.

The unit employs the **Atmel Atmega64L microcontroller** [5]. It is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega64 achieves throughputs approaching 1 MIPS per MHz. The ATmega64 provides the following features: 64K bytes of In-System Programmable Flash for code, 2K bytes EEPROM for persistent data, 4K bytes operational data SRAM, 53 general purpose I/O lines, 32 general purpose working registers, Real Time Counter (RTC), four flexible Timer/Counters with compare modes and PWM, two USARTs, a byte oriented Two-wire Serial Interface, an 8-channel, 10-bit ADC with optional differential input stage with programmable gain, programmable Watchdog Timer with internal Oscillator, an SPI serial port, JTAG test interface, also used for accessing the On-chip Debug system and programming, and six software selectable power saving modes.

The **SHT15 sensors** are connected to general I/O pins, the ADIS16201 sensor employs the SPI interface. Battery voltage and irradiation sensor signal are sampled by the microcontroller ADC. The DECT module communicates over USART No.0. USART No.1 can be used with necessary external level conversion for a connection to PC COM port.

Microcontroller firmware realizes data capture from sensors and ADC, a data conversion and an asynchronous full-duplex ASCII-character serial communication with the DECT module. LEDs signalize a measurement cycle, a sensor failure, a battery charge level and whether the communication is established. Sound alarm of communication drop-outs can be switched on/off.

Serial communication with the SHT sensors are software realized. Command is sent synchronously to SHT sensors all at once than microcontroller waits for “data ready” of all sensors that come asynchronously with approx. 15 % variation. Measurement takes about 210 ms for 14-bit temperature and about 55 ms for 12-bit humidity. Of course, possible bad idle level of DATA pin, missing acknowledgement bit and time-out of any sensor are treated. Reading of data is fulfilled again synchronously from all sensors together then compound serial data are split and transformed into binary values for individual sensors; next CRCs are checked. The SHT sensors polling are executed every 2.56 s. Firmware performs conversions from binary integer to floating point physical values as given in [1].

The **ADIS16201 sensor** is scanned every 10 ms. To reduce data flow, a maximum and minimum of both accelerations and a single sample of inclination values are passed every 160 ms only. Conversions from binary to physical values (‚g‘ as acceleration ratio, angle degree °) are fairly simple – linear scaling with a polarity offset.

Both physical values (including battery voltage) in ASCII strings and other messages (signals, errors) begin with 1- or 2-character prefixes that distinguish among them. Messages coming into the unit from PC have similar format.

The firmware written in C language represents about 1100 lines of source code and occupies 11 KB of code memory. Code Vision AVR C, Atmel AVR Studio and Atmel JTAG ICE mkII interface were used for development of the microcontroller application.

5. Data Acquisition

The measuring unit establishes communication with the second DECT module assembled in the USB/DECT modem that was made formerly. As a portability of measuring equipment was required, a notebook as a connected computer is considered. Notebooks equipped with COM port become rare nowadays so USB adapter converting asynchronous serial data between DECT module and the USB bus appeared suitable. It was realized with the commercial module ASIX UMS2 that uses a device from the FTDI family of chips. Driver provided by the chip manufacturer opens virtual COM port so programs running on a computer can handle the serial communication by standard way.

A user **application HUMITEM** was created to visualize measuring values (temperature, humidity, accelerometer, inclination and a state of the measuring unit) and to control the measuring unit. The application works with serial communication – process

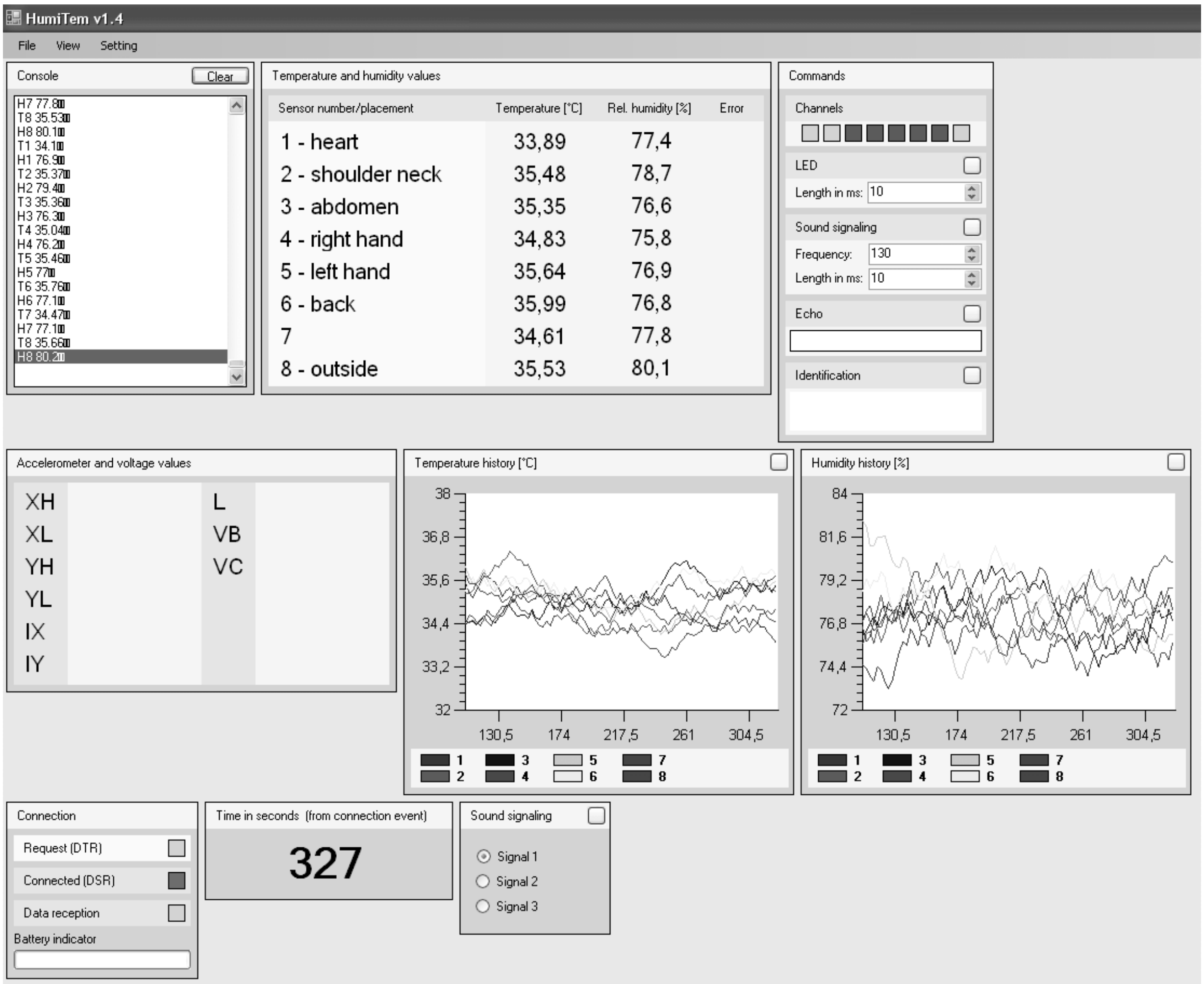

Figure 5: *Window of the HUMITEM application*

incoming serial data (parses ASCII strings) and sends ASCII commands to the measuring unit. The application stores measuring values (if enabled) into four separated files in CSV format (suitable for further processing in MATLAB or EXCEL); temperature and humidity values into the first two files, acceleration and inclination values into the third file and time marks into the fourth file.

The application main form is designed as a container of informative and control panels (Fig. 5). Every panel can be visible or hidden depending on user settings so only selected information is displayed. All incoming ASCII serial data are displayed in a console panel which is established mainly for debugging. After a line receives, serial data are parsed and relevant panels updated. Two panels display actual measuring data; first one presents values of temperature and humidity, second one presents values of acceleration and inclination. Temperature and humidity are also drawn as charts in another two panels, thus a value history is shown. Another panel indicates communication state (DSR, DTR, data receiving) and battery level of measuring unit. Also there is a panel there that displays time in seconds since successful connection.

The measuring unit can be controlled using two panels. The first panel provides selection of measuring channels, control of signal LED, invocation of sound of selected frequency and duration in the measuring unit, test echo and measuring unit identification. The second panel simplifies transmission of sound generating command by preset sound parameters. Simple remote sound signalization from a tester to an operator is available, too.

Last control panel provides appending of time marks with user-defined terms to a separate file. It allows marking of conditions and events during measurement chronologically.

The HUMITEM application was developed in C# for .NET platform using Microsoft Visual Studio 2005.

6. Experiments

The SHT15 sensors in the suit were calibrated by the Ahlborn ALMEMO 2390-5 Universal Measuring Instrument with the FH A646-E1C sensor that has uncertainty ±0.1 °C and resolution 0.01 °C. Differences between sensors values and reference temperature fell in interval –0.17 °C and +0.19 °C that corresponds to the sensors uncertainty. They were used for correction of data obtained during experiments. Data were processed in MATLAB by M-scripts.

The **first experiment** was carried out on a strand walk of Liberec Dam Lake because there is relatively long sight distance there. The measuring unit and the suit worn on the tester, the PC program running on a notebook and the wireless communication for longer distance were tested in real condition there first time. Range of radio contact was determined as fairly reliable about 440 m when the tester was oriented face the operator stand, on the other hand the first communication drop-out occurred only in 140 m distance when direct sight disappeared and the antenna of the unit was shielded towards the operator's stand by tester's body. Some deficiencies both in firmware and software were detected in addition.

The **second experiment** was carried out in a very long basement corridor and on 4-level stairs in Building F of the university. The suit was conditioned hanging on a clothes hanger in the corridor over night. Some elevation stratification of temperature in a space was seen. Another, free SHT75 sensor connected to the unit measured out ambient condition at the beginning and at the end of the experiment – temperature changed from 19.0 °C to 19.3 °C, humidity was about 48 %. The tester dressed the suit and waited for steady state sitting on a chair. Then data for three type of tester's motion (walk, slow run, fast run) were collected following by relaxation on a chair again as both depicted in Fig. 6-9. On some places in the suit, temperature and humidity raised during relaxation probably due to missing air flow that had flown before due to tester's motion.

Inclination and/or acceleration data can make possible to distinguish type of motion as shown on slices of the record in Fig. 10-11. X-axis is assigned to a motion in forward-back direction (positive for turning forward down), Y-axis to the left-right direction (positive for clockwise rotation from the front view). Central values between minimum and maximum of acceleration were used.

Next part of the experiment consisted in fast run upstairs and moderate walk downstairs four times so heavy physical strain (but intermittent unfortunately) was simulated. Last time behavior of data was obtained during final relaxation.

However, detailed evaluation and discussion of captured data are beyond the scope of this article.

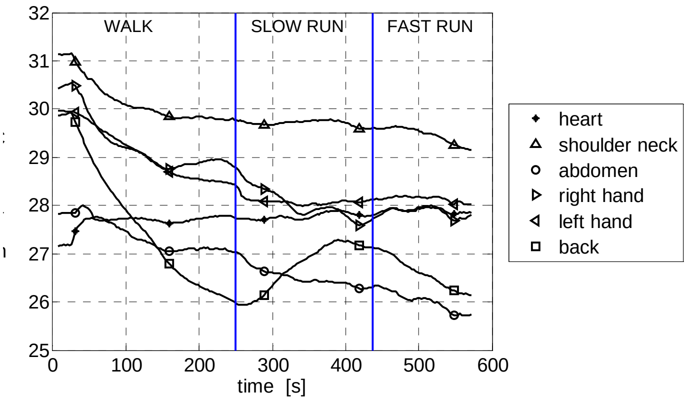

Figure 6: *Temperature during motion*

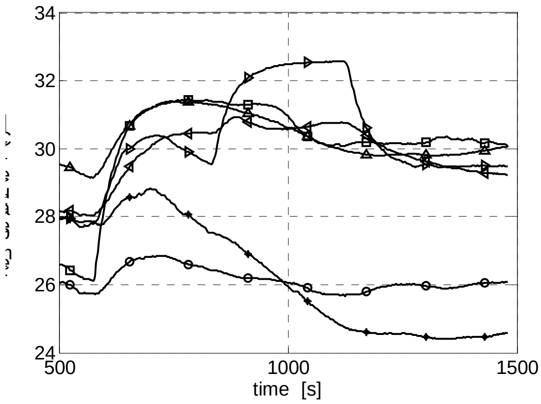

Figure 7: *Temperature during relaxation*

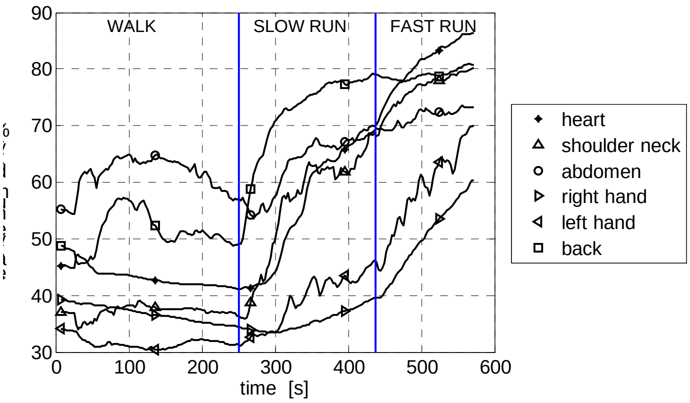

Figure 8: *Humidity during motion*

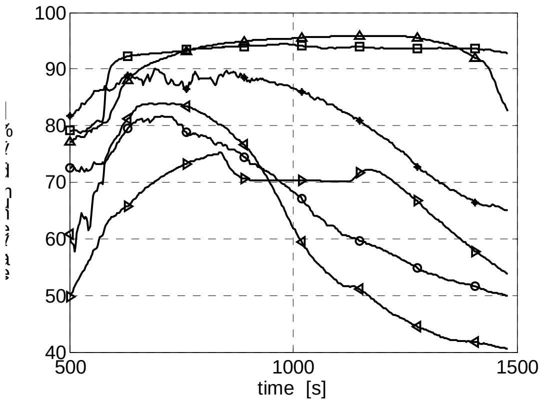

Figure 9: *Humidity during relaxation*

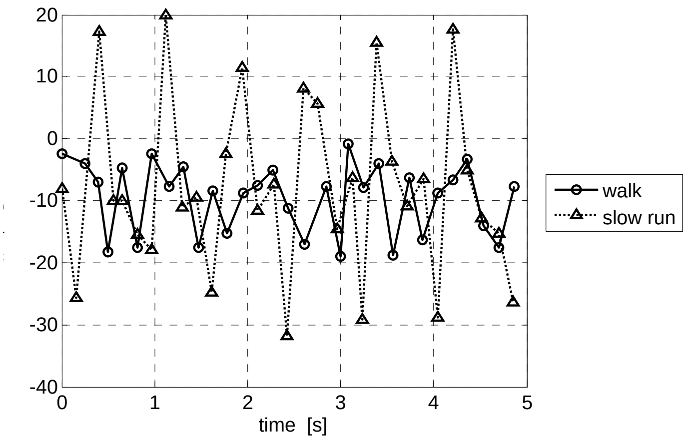

Figure 10: *Inclination in Y-axis*

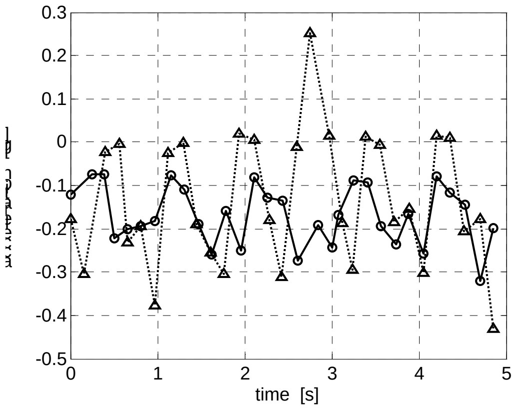

Figure 11: *Acceleration in Y-axis*

Conclusions

The whole measurement system has been developed. Sensors, electronics, firmware and software work well and fulfill expectation.

Temperature obtained by the SHT15 sensor that is built in the unit side cannot be used as ambient because of significant increase about 4 °C due to unit self-heating.

Radio link range has not achieved a value over 1 km that was promised by the HW86010 module supplier if the synchronization window in the DECT RF protocol would be set wider and the external antenna would be used.

Transfer rate of inclination and acceleration should be doubled to make possible capturing also fast run motion according to the sampling theorem. Of course, sensor of acceleration along the third, vertical Z-axis could be useful. Data of inclination and acceleration can be further evaluated e.g. using FFT to determine a footstep frequency.

Less expensive, flatter temperature/humidity sensors and wider range communication platform are necessary for final usage in e.g. firefighters' or soldiers' protective overalls.

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Acknowledgement

This work was supported by the Research Centrum "TEXTIL II", Code 1M4674788501.

Thanks to Mr. Josef Vojtěch, the voluntary suit tester, former representative of Czechoslovakia in nordic combined race.