Documentation and Instruction Manual for the Horizontal Mobile Measuring System (HMMS)

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1 Introduction

The gradients of characteristic atmospheric quantities are immense at the transition from a dense forest to an open clearing, with heavy effects on transfer and chemical processes. In future forest ecosystems, the heterogeneity will increase due to damages by winds and pests with significant influences on the climate system, because it must be assumed that these heterogeneities increase the loss of trace gases. Therefore trace gas measurements should be the right facility to show possible effects. Tower measurements have often the problem with a sufficient spatial resolution. For this reason, more towers have to be build up to determine the quantities, which represent the exchange processes of an ecosystem (Oncley et al., 2009). Another possibility to achieve more information of gradients in heterogeneous ecosystem is to build a mobile measuring system.

For a heterogeneous forest ecosystem we build a horizontal mobile measuring system (HMMS). The HMMS measures in addition to meteorological quantities (temperature, humidity and short/long wave radiation) also trace gases (ozone and carbon dioxide). In the following chapters, you can find the technical description, the description of the software and the sensors.

2 Technical Description of the HMMS System

2.1 Drive mechanism

The drive mechanism of the HMMS is taken from a garden railway system of the manufacturer LGB (part of the Gebr. Märklin & Cie. GmbH). The scale of the railway system is 1:22.5, with a track width of 45 mm. The chosen locomotive is a replica of the German Federal Railroad (DB, in german: "Deutsche Bahn") Diesel hydraulic Locomotive with the Road No. 252 901-4 from the 1960s. The locomotive has two powerful 24 V DC engines and a length of 43.6 cm. It has an on board Multi-Train System (MTS) Loco Decoder which provides constant acceleration and constant breaking. The rails are made of massive, solid brass and the tie sections are made of plastic material. Every rail segment is 2 m long and they are connected with rail joiners, which are also made of brass. Because of the high electrical conductivity of brass, the rails are used for power supply of the engines and also for the power supply of the HMMS system. A detailed description of the HMMS power supply system can be found in chapter 2.3. Over the polarity the driving direction of the engines, respectively of the locomotive can be regulated. Further informations of the HMMS speed and position control system is shown in chapter 2.4.

2.2 Design

The weight of the original locomotive is around 3 kg. Due to the expected weight of the meteorological sensors on a separate railway carriage, the locomotive has to be weighted with approximately 10 kg extra weight, to guarantee static friction on the rails, especially on grades. A better solution is to combine the drive mechanism and the railway carriage of the meteorological sensors. This solutions leads to a total weight reduction of approximately 50 % in comparison with the first possibility, without a loss in the static friction.

To combine the drive mechanism and the railway carriage, the engines and the electrical system including the MTS Loco Decoder were removed from the locomotive. Afterward a base plate made of aluminum was mounted on the two engines. The plate has an downward-facing U-profile to increase the stability. A 3-dimensional model of the aluminum plate with its dimensions, mounted on the engines is shown in Figure 2.1.
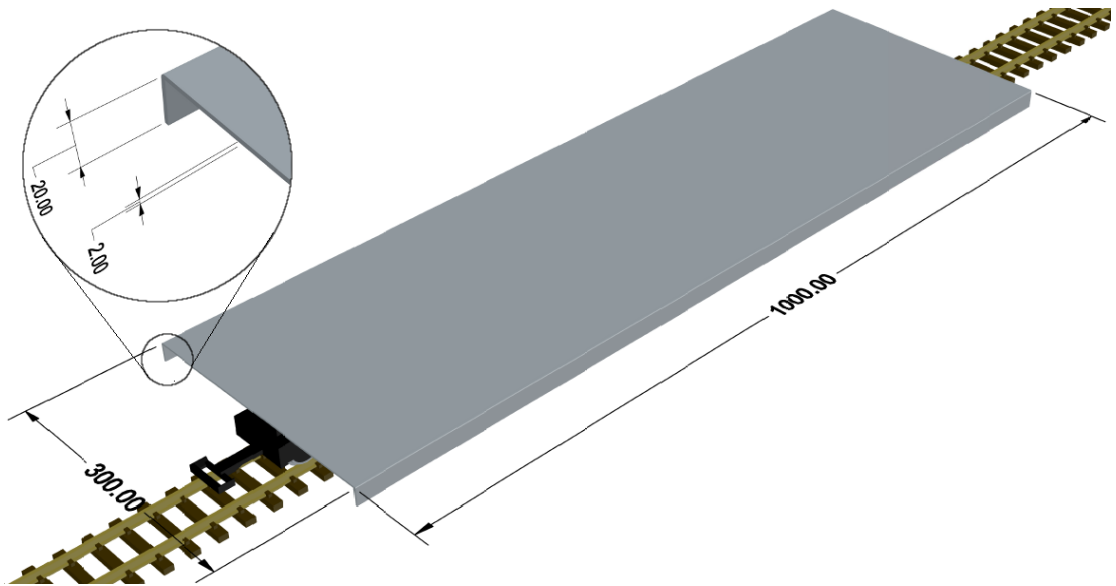
Figure 2.1: 3-dimensional CAD design of the HMMS aluminum plate mounted on the two engines. Specified dimensions are in mm.

2.3 Power supply

As mentioned in chapter 2.1 the rails are used for power supply of the whole system. Therefore the rails are fed with 24 V DC of voltage and a current of 5 A to supply the entire system with sufficient power. In spite of the high electrical conductivity of brass, the power must be fed approximately every 25 m to avoid the loss of power over longer distances. Spring-mounted Pick-Up Shoes (sliding contacts) on both sides of the two engines tapped the power from the rails.

The drive mechanism, respectively the engines needs 0-24 V DC with alternating polarity, which depends on the driving direction and the speed of HMMS. The sensors and the Micro PC needs 12 V DC with a constant polarity, which has the consequence that the HMMS has two different electrical circuitries. The different power consumption is solved with the aid of a DC-to-DC-converter which has a wide input range from 6-34 V DC and a high stabilized output ranging from 6-24 V DC, with a maximum current of 10 A (see Table A.1). Additionally the DC-to-DC-Converter protect the sensors against voltage peaks. The required constant polarity for the sensors in comparison to the alternating polarity for the engines is solved as follows: The rails are fed with 24 V DC without an alternating polarity, thus there is no longer a problem with the supply of the sensors. Temporarily breakdowns of the power supply are buffered with on board storage batteries. To switch between the direct power supply and the storage batteries a switching and loading module is also mounted on the HMMS (see Figure 2.3). The change of the polarity for the HMMS direction is solved with an analog throttle from LGB, which is mounted on the HMMS aluminum plate. The analog throttle receives a constant input voltage of 24 V DC from the rails and the output can be set via a controlled potentiometer, ranging from $\pm$ 0-24 V DC. The potentiometer can be controlled by the HMMS software (see chapter 3) which is running on a Micro PC and an analog input/output (i/o) controller (see Table A.2 and A.3). The power supply is shown in Figure 2.2.
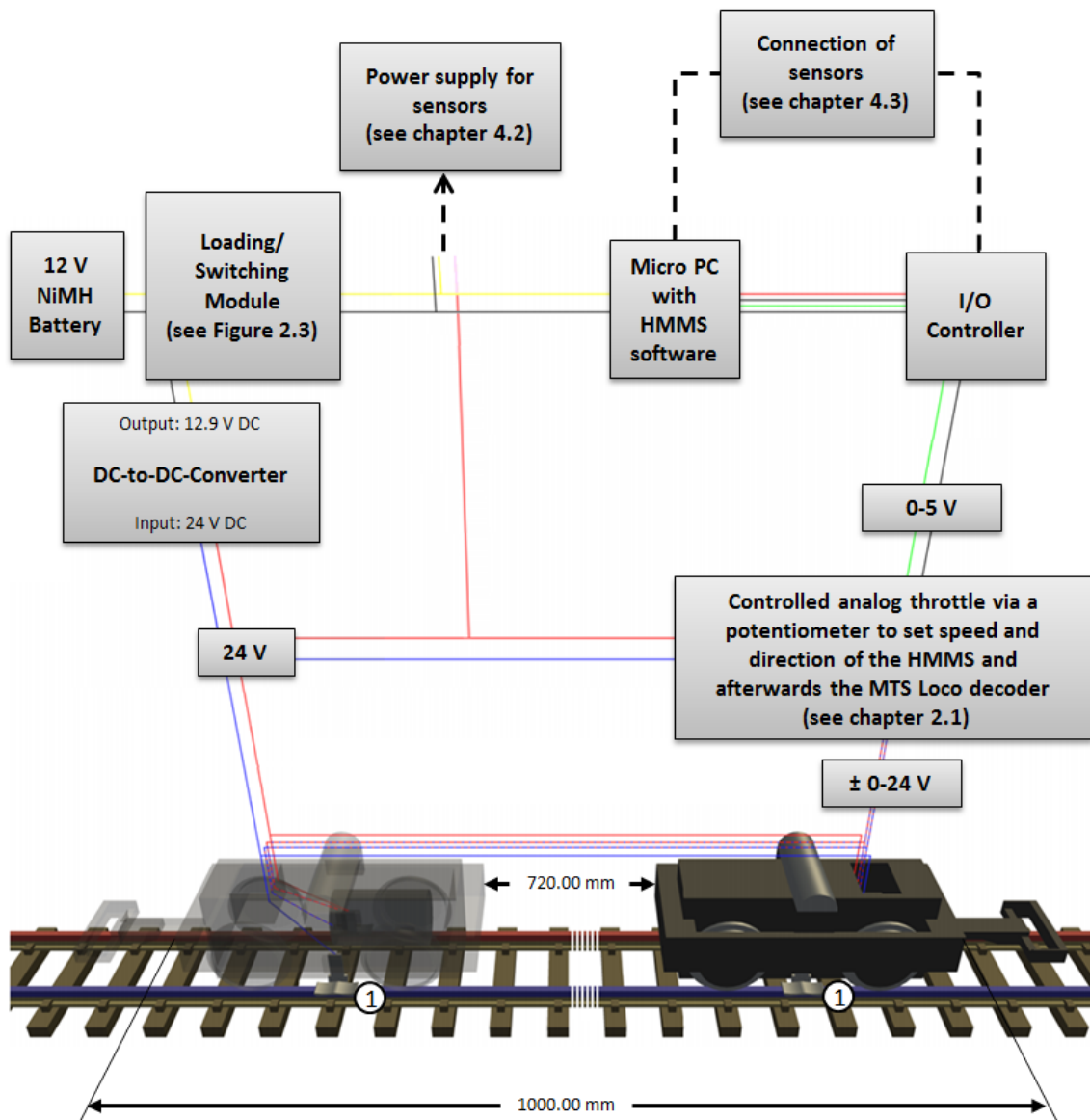
Figure 2.2: Schematic draft of the HMMS wiring. The rails are fed with 24 V DC with constant polarity. Sliding contacts tapped the power from the rails ①. The red/blue solid lines show wiring of the power supply with constant polarity (24 V DC). The striped red-blue solid lines show wiring of the engine power supply with alternating polarity (± 0-24 V DC). The yellow/black solid lines show wiring of the PC and sensor power supply (12 V DC). The i/o controller is connected to the Micro PC via USB (red/black/green/gray). The green/black solid lines show wiring between the i/o controller and the analog throttle (0-5 V DC).
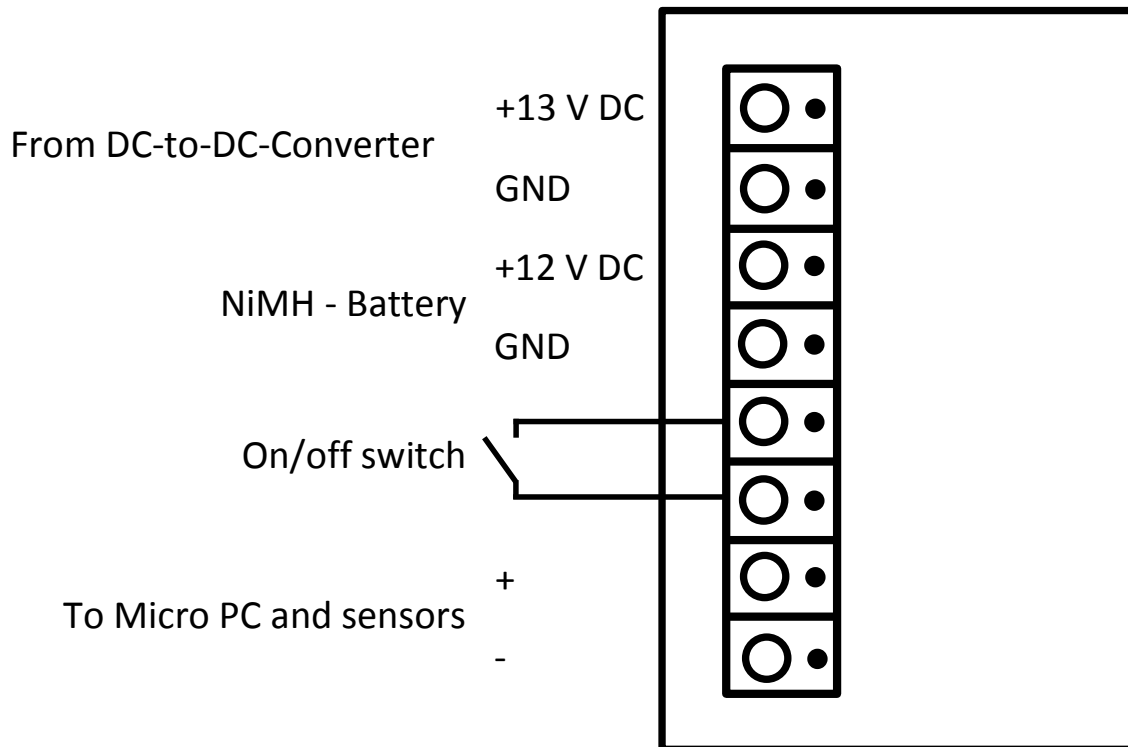
Figure 2.3: Top view on the components of the loading and switching module. The DC-to-DC-Converter has a programmed output of 12.9 V and the NiMH-Battery an output of 12 V, which is enough to supply the system with power. The on/off switcher can cut off the power supply of the 12 V DC electric circuit on the HMMS.

2.4 Speed and position control

The speed and position of the HMMS are controlled by the Micro PC, the HMMS software, the i/o controller, and a bar code scanner to determine the exact position. Over the software the speed and direction of the HMMS can be controlled via a analog throttle equipped with a potentiometer (see chapter 2.3). The i/o controller which is controlled by the software has an analog output between 0 to 5 V DC. The influence on the HMMS speed and direction of the different voltage outputs of the i/o controller is shown in Table 2.1.

For information of position, the HMMS is equipped with a bar code scanner (see Table A.4 for further informations). The used bar code scanner CLV412-1010 Raster

scanner from the company SICK AG reads Code 39 bar codes. The Code 39 is a alphanumerical code which defines 43 characters. 26 uppercase letters (A-Z), 10 numeric digits (0-9) and 7 special characters (-, .,$, /, +, %, and space). In this case the Code 39 is used to give the HMMS software information of the HMMS position and speed. Two Code 39 examples are shown in Figure 2.4. For position control the bar codes must be installed in ascending order in forward direction of the HMMS without any gap. Distances between two bar codes can be adjusted in the software. Over the distance and the elapsed time between two bar codes the software can calculate the speed of the HMMS. It is possible to pretend a speed profile via the voltage output of the i/o controller to achieve for example a constant speed over the complete HMMS line. Other variants are high speed at unimportant points and low speed at interesting points. Furthermore the two turning points (starting point and final point) of the HMMS line can be realized with the aid of the bar codes and the software. Every bar code can be specified as a turning point. The bar code scanner scans the bar code and the software reverses the polarity and the HMMS drives in the other direction. Compare with chapter 3.4.1 for the adjustments in the software. Should technical difficulties like crashes of the HMMS software, or "NO-READ" of the bar code scanner occur, the HMMS is equipped with a moving limit switch, which cuts off the power supply to the engines mechanically. The moving limit switch is mounted bottom side at the base plate and the switcher can move in both directions (see Figure 2.5). To move the switcher is also a good possibility to stop the HMMS for maintenance or changes in the software, because the HMMS stops within one meter without cutting off the power supply to the sensors and the Micro PC. Another safety precaution are currentless rails one both ends of the line. This can be realized via rail joiners made of plastic material instead of brass. The HMMS also stops within one meter. Please note that the power supply is exclusively hold up with the aid of the storage batteries. If the supply is empty, especially the Micro PC is directly turned off without a standard shut down, which can lead to data loss.

And also the sensors are directly turned off.

Table 2.1: The influence of the i/o controller output on the HMMS speed and direction.

Analog output [Voltage DC]	Direction and speed of HMMS
0	Backward direction with max. speed
0 to < 2.5	Backward direction with decreasing speed
2.5	Stop of the HMMS
2.5 to < 5	Forward direction with increasing speed
5	Forward direction with max. speed
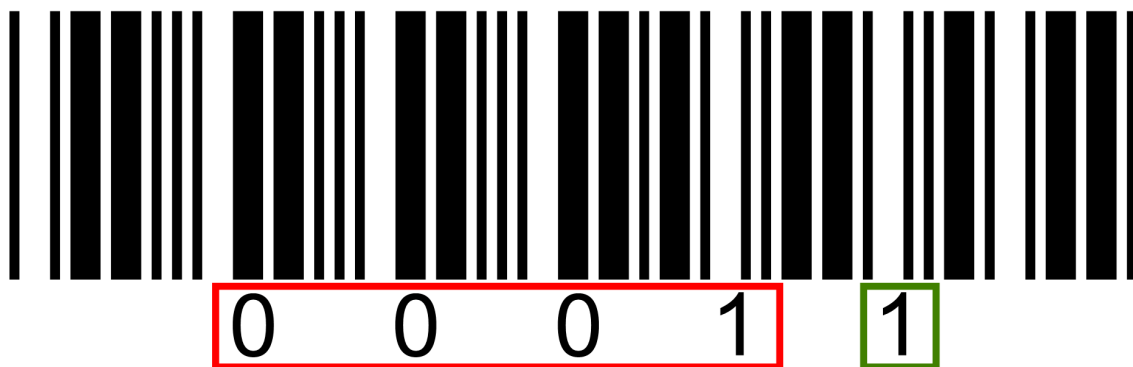
(a) Code 39 with the Position "0001" (red rectangle) and the checksum "1" (green rectangle)
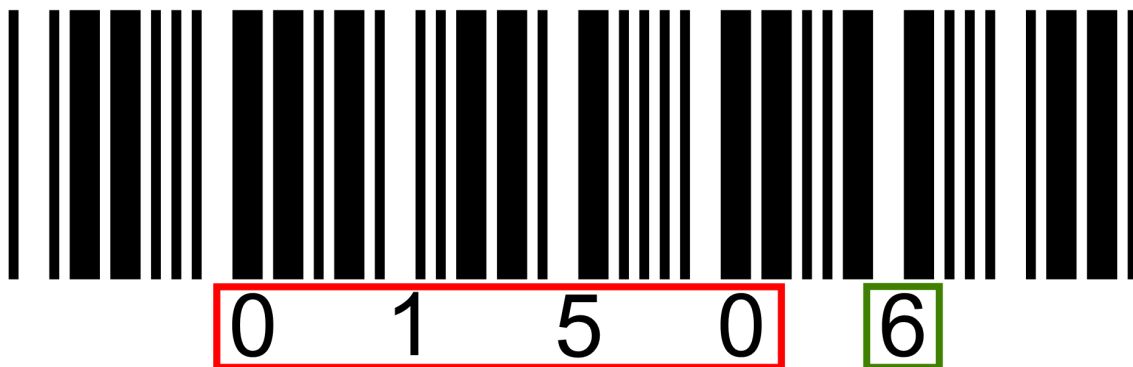
(b) Code 39 with the Position "0150" (red rectangle) and the checksum "6" (green rectangle)

Figure 2.4: Example of Code 39 codes, used for the determination of position with a bar code scanner and the HMMS software, to control speed and direction of HMMS.

Figure 2.5: Moving limit switch mounted bottom side at the base plate of the HMMS. The moving limit switch can be thrown in both directions and cut off immediately the power supply to the engines.

The HMMS is equipped with nine on/off switchers for the sensors (see chapter 4.1) and three on/off switchers for the power supply of the whole system (see Figure 2.6). One switcher for the 24 V DC, one for the 12 V DC and one for the drive mechanism of the HMMS. For further instructions see chapter 2.6.
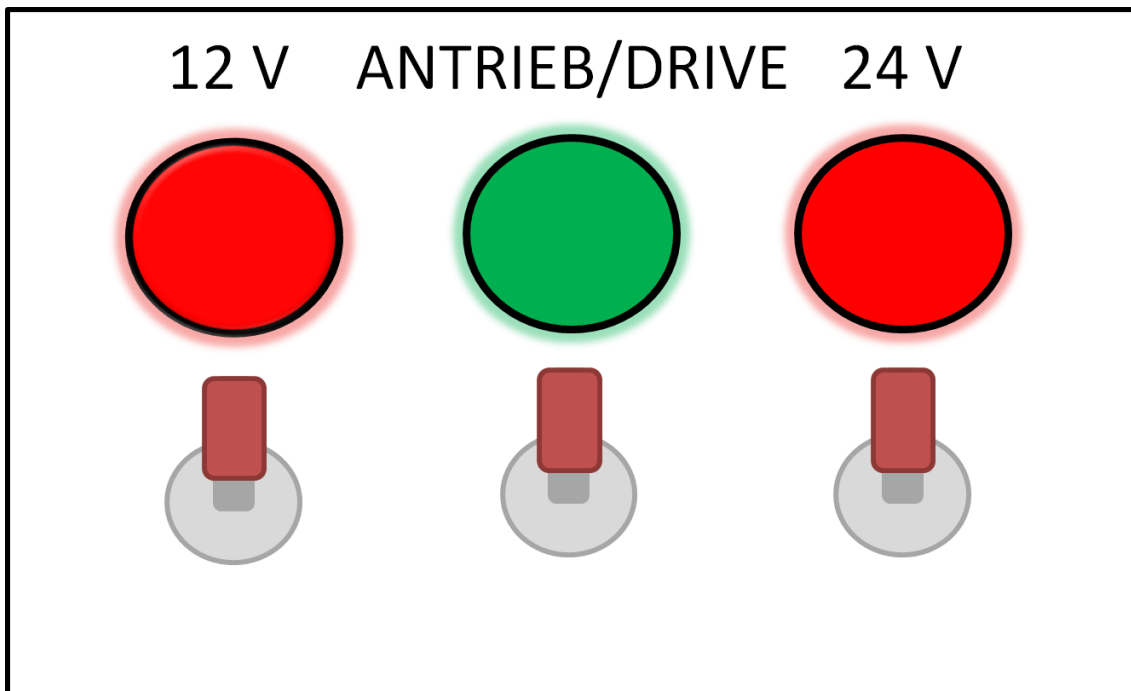
Figure 2.6: On/off switcher for power supply of the HMMS. Instructions for this on/off switchers can be found in chapter 2.6. Upward pointed switchers are on (this is indicated through shadows around the red or green Diodes).

2.5 Safeguarding

To protect the sensors and the electronic for rain and dirt a cover made of Makrolon® can be attached on the aluminum plate (Figure 2.7).

Because of the measuring height, the HMMS has to be protected from falls of heights. Therefore the HMMS is equipped with lateral holders made of aluminum. The holders are shown in a 3-dimensional CAD design in Figure 2.8.

In addition to the protection, the lateral holders can be used to put the HMMS on the ground without damages on the moving limit switch or the bar code scanner on the bottom side. Therefor the holders have bumpers made of plastic material.
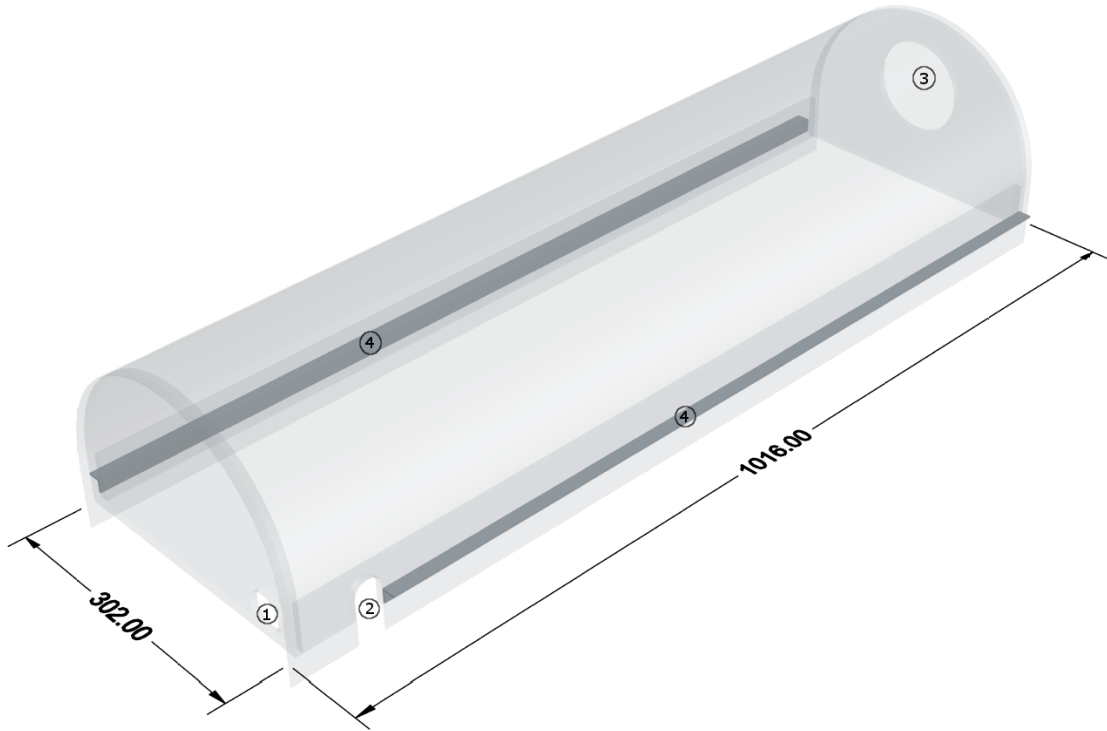
(a) Bird's eye view on the front left corner of cover.
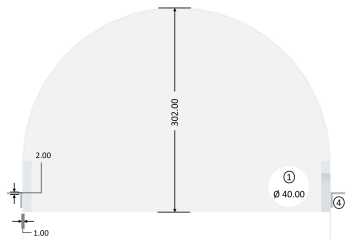
(b) Front view of cover.
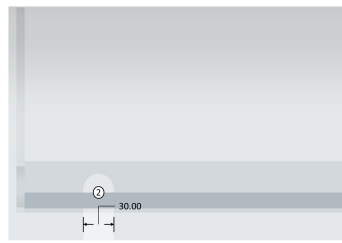
(c) Lateral view of cover.
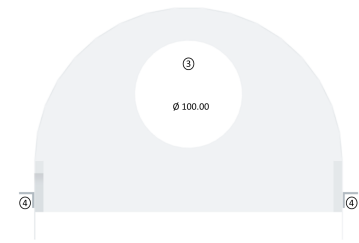
(d) Rear view of cover.

① Hole for HMP155 fan (see chapter 4)

② Hole for HMP155 sensor (see chapter 4)

③ Hole for case fan (see chapter 4)

④ lateral fixing of the cover with aluminum L-profile

Figure 2.7: 3-dimensional CAD design of the cover made of Makrolon® to protect the sensors and the electronic for rain and dirt. Specified dimensions are in mm. The encircled numbers are described below the sub-figures.
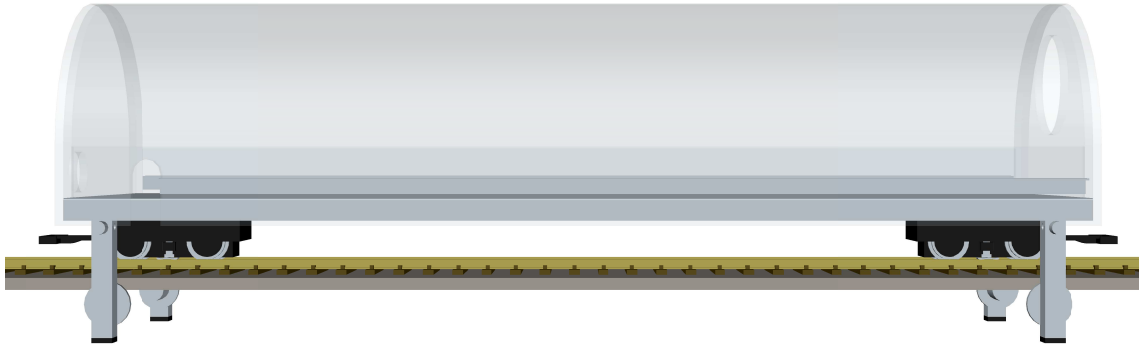
(a) Lateral view on the holders.
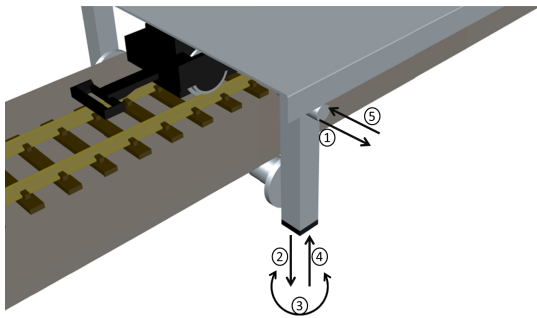
(b) Instruction to remove and rotate the holders about 90°.
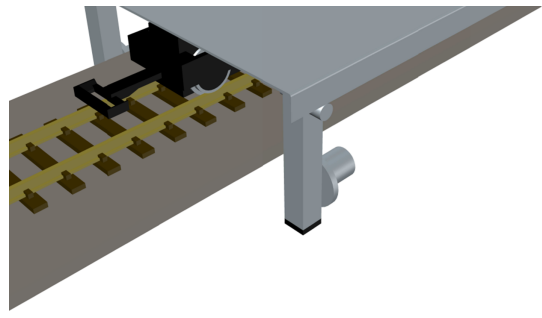
(c) Rotated holders, in order to remove the HMMS from the wooden substructure.

Figure 2.8: 3-dimensional CAD design of the lateral holders made of aluminum to protect the HMMS from falls of height. The rails are mounted on a 12 mm thick film mounted plywood plate.

To remove the holders follow the instruction in Figure 2.8b. The first step is to remove the splint pins (①). After removing the splint pins, the holders can be removed in a second step (②). After a rotation of 90° (③) the holders can be attached again (④) and locked with the splint pins (⑤). The result is shown in Figure 2.8c. In this position the HMMS can be removed from the wooden substructure and placed on the ground.

2.6 Instructions to start the HMMS

Important steps to start the HMMS correct:

NOTE: Don't switch the drive mechanism ("Antrieb") switcher to "on" till step 6. The HMMS would start otherwise immediately, with ignoring the speed profile and the turning points!

1. Switch on the 24 V. The DC-to-DC-Converter has now power.

2. Switch on the 12 V. Now the whole system has power. The Micro PC boots up without pushing the power button. Also the PC fans under and above the Micro PC and the Housing fan (⑯ in Figure 4.9) starts to ventilate.

3. Switch on the bar code scanner and wait for the LED indicator "Device Ready" and the acoustic indicator.

4. Switch on the sensors, mainly the sensors with RS-232 connection, to guarantee an unproblematic start of the software.

5. Start the HMMS software by clicking on "HMMS.exe". Wait for the initializing to finish without problems.

6. Switch on the bar code scanner in the software.

7. Now the drive mechanism ("Antrieb") can be switched on, because the HMMS software has adjusted the i/o controller to an output voltage of 2.5 V DC (compare Table 2.1).

8. Check the windows with the current measurement values. If every sensor updates his values in the adjusted sampling rate, go to step 9. If that is not the case, try turning the sensors off and on again.

9. Now the measurements can be started. For the software adjustments see chapter 3.

3 Description of the HMMS software

The HMMS software was programmed from the company GAF - Gesellschaft für Akustik und Fahrzeugmeßwesen mbH (Zwickau, Germany, contact see Appendix D)

3.1 System requirements

Table 3.1: The system requirements for the Micro PC to run the HMMS software.

Type	System requirement
OS	Windows® XP, Windows® Vista, Windows® 7 (32-bit systems) with Microsoft Framework 3.5
Processor	Intel-CPU with min. 500 MHz
RAM	min. 512 MB
HDD	Software: < 5 MB, Data storage: depends on measurement period and sampling rate (for sampling rate of 1 second: ~ 25 MB/day)
Additional Software	National Instruments DAQMX 9.1.35.15

Connections	USB2.0 or higher
	     1 x NI-6211 i/o controller
	     1 x Mouse/Keyboard
	     1 x USB to Serial Port Adapter
	     1 x Bulk storage
	 RS-232 Serial
	     1 x Bar code scanner
	     1 x CO_2 sensor

3.2 Installation

For the installation of the HMMS software no explicit installation program is necessary. After installing a Windows® OS, the Microsoft Framework 3.5, and the National Instruments DAQMAX, the HMMS software runs on every PC, by copy the HMMS software in a folder on the PC. Whereas it is appropriate to log in as an administrator under Windows® Vista and Windows® 7 to have full access on the OS file system.

3.3 Software versions

Versions of HMMS software and the several changes/bug-fixes:

Version 1.0 (Feb 2011):   Internal version of GAF

Version 1.1 (02/28/2011):   First stable version

Version 1.2 (March 2011):   Changes:

- Implementation of ultrasonic sensor
- Implementation of ozone detector

Version 1.3 (04/18/2011):   Bug-fixes:

- Correction of long wave radiation sensors
- Correction of Ultrasonic sensor

Version 1.4 (04/28/2011):   Changes:

- Improvement of handling with the software

Version 1.5 (05/20/2011):   Bug-fixes/Changes:

- Fix of problem with bar code scanner

- Display the raw voltages of analog channels in the software
- Set the output voltage on 2.5 V with quit of the software (see Table 2.1)
- Start time stamp with ".000" seconds
- Delimiter in Table of HMMS speed: Now TAB or ; are possible

Version 1.6 (05/30/2011):	Changes: • Extension of output file
Version 1.7 (06/06/2011):	Changes: • Additional output file with raw voltages
Version 1.8 (06/21/2011):	Bug-fixes/Changes: • Correction of temperature measurement PT100 from the radiation sensors • Extension of output files • Software function extension: Number of runs
Version 1.9 (06/22/2011):	Bug-fixes: • Fix of fatal exception error by clicking the button "Fahren"
Version 1.10 (07/04/2011):	Bug-fixes: • Improvement of stability of the RS-232 signal reception (CO_2 and Ozone Sensor)
Version 1.11 (commissioned):	Bug-fixes: • Correction of the time stamp in the data files, using a sampling rate > 1 Hz

3.4 Functions

To ensure a smooth start of the HMMS software, the bar code scanner has to be already active (wait for the LED indicator "Device Ready" at the bar code scanner and the acoustic indicator). In addition the National Instruments USB-6211 analog i/o controller (see Table A.3) has to be attached to one of the USB ports of the Micro PC. After the correct start of the bar code scanner, the HMMS software can be started by clicking on the "HMMS.exe". Measurement values are displayed immediately in the start screen of the software (see Figure 3.1). The measurement values are updated corresponding to the adjusted sampling rate.
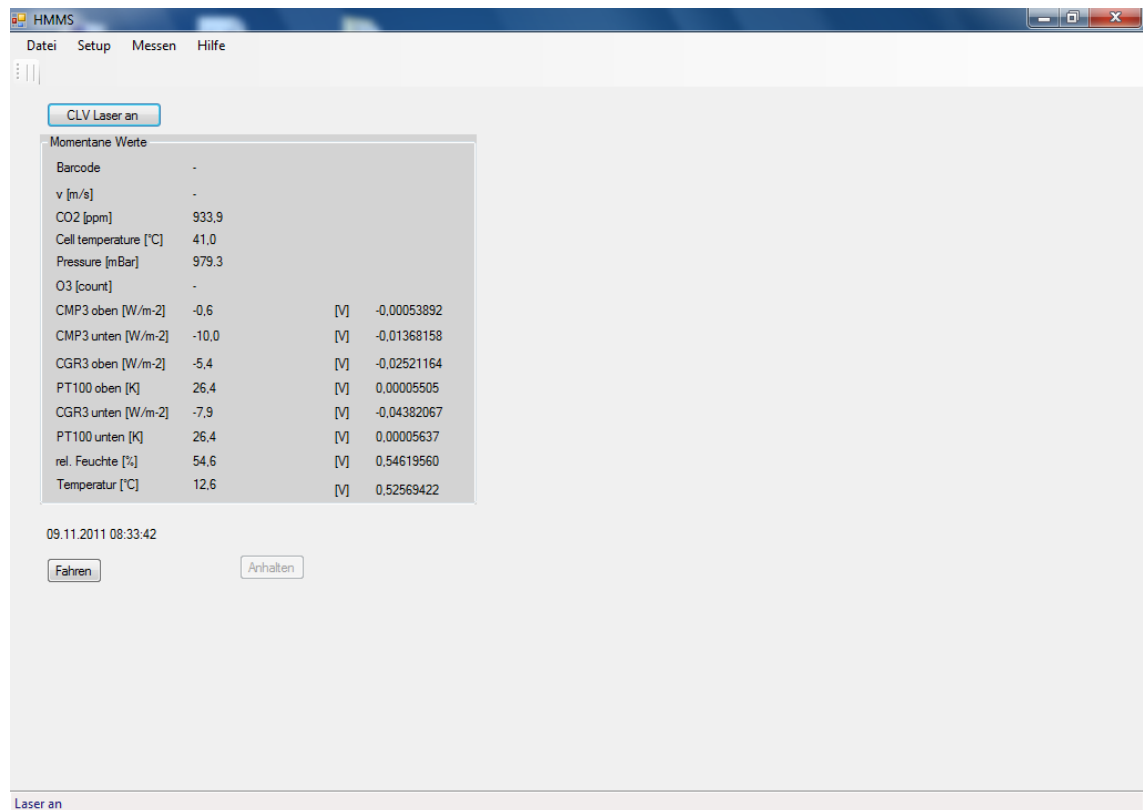
Figure 3.1: Start screen of the HMMS software. With the menu bar at the top. Via the button "CLV Laser an" the bar code scanner can be activated for the software. Via the button "Fahren" the HMMS can be started (but: compare with chapter 3.4.2). "Momentane Werte" show the actual measurement values, which are updated corresponding to the sampling rate.

The prior condition for full function range is to adjust the transfer factors and the RS-232 connections correct in the menu "Setup|Messung" (see chapter 3.4.1). The sampling rate can also be changed in this menu.

3.4.1 Setup

The menu "Setup" in the menu bar (see Figure 3.2) is divided in "Messung" for the setup of all sensors (see Figures 3.3 through 3.6). In the menu "Geschwindigkeit-sprofil" a profile of the HMMS speed can be specified (see Figure 3.7).
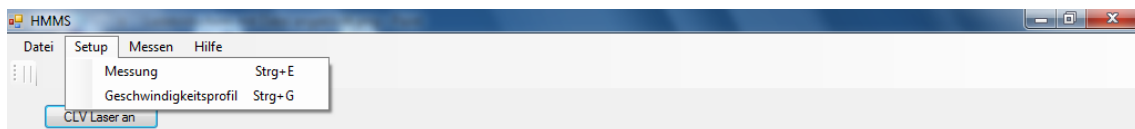
Figure 3.2: Clicked menu "Setup".
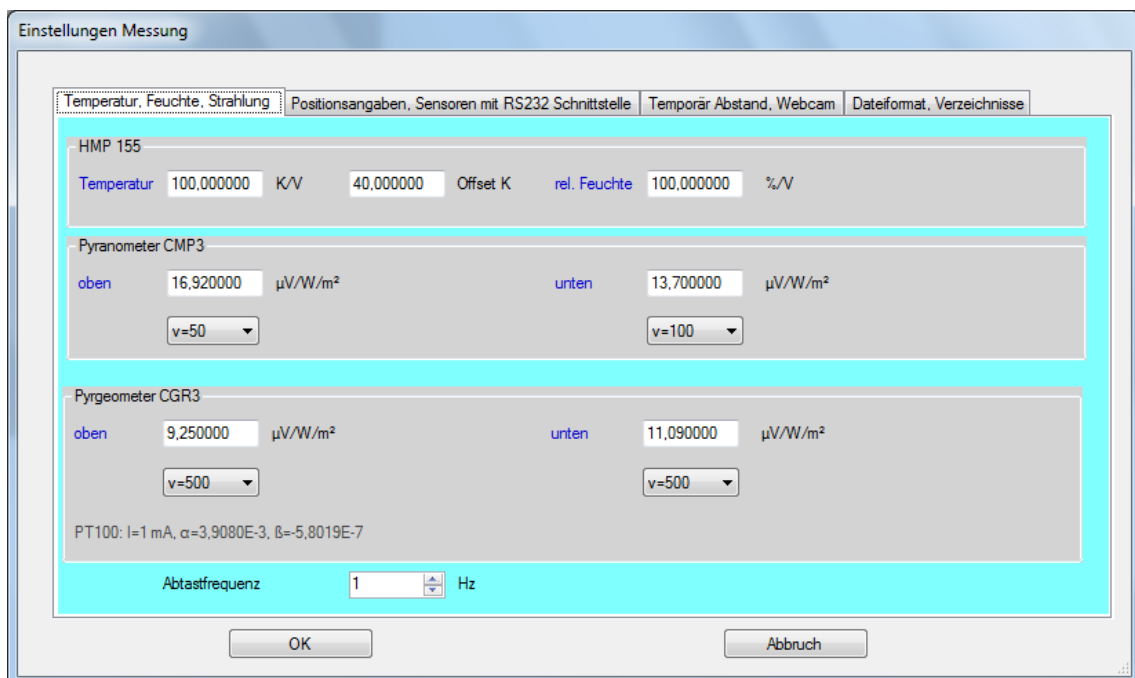
Figure 3.3: Setup for sensors with analog output (voltage) and the sampling rate.
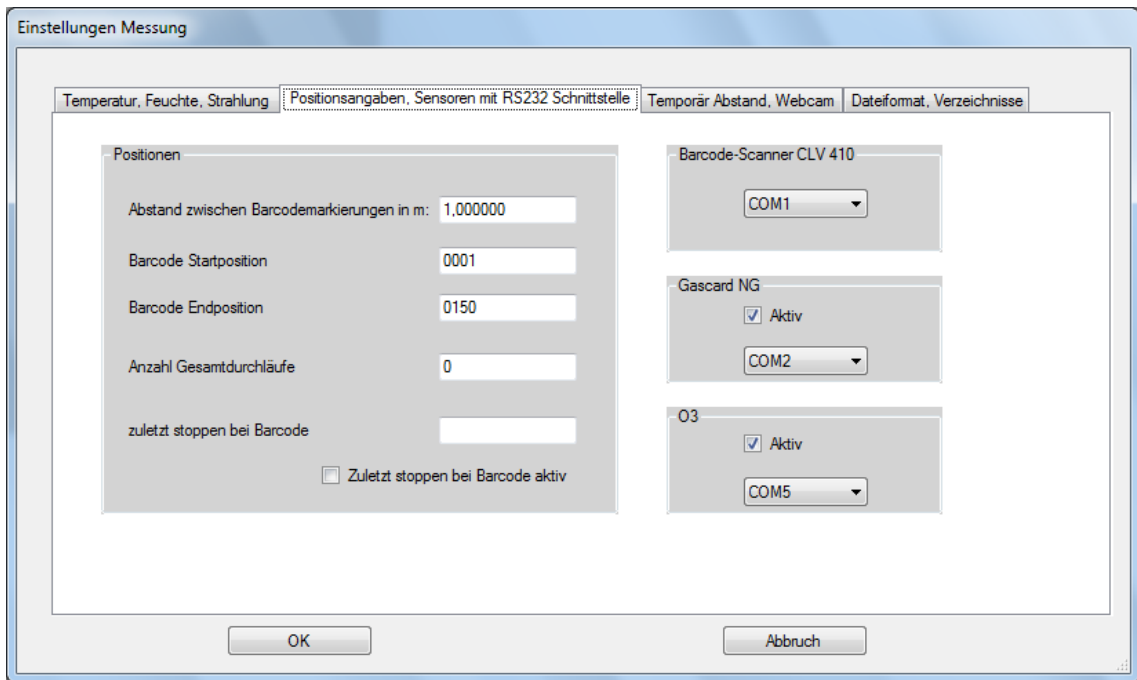
Figure 3.4: Setup for sensors with RS-232 connection.
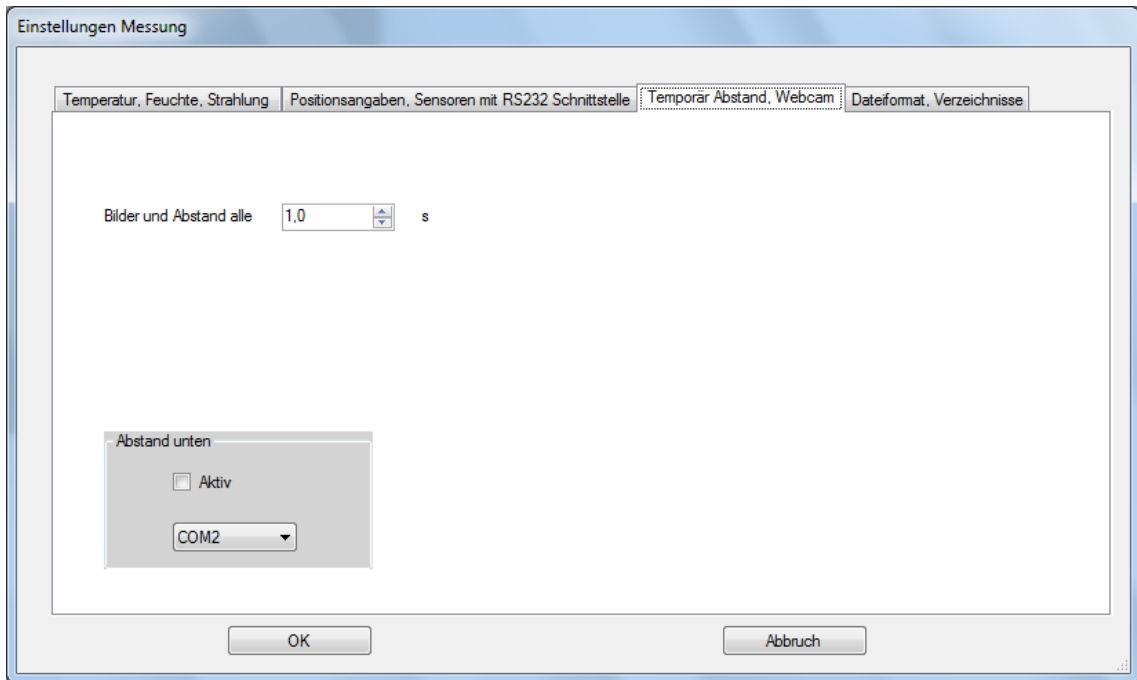
Figure 3.5: Setup for ultrasonic sensor (distance measurement) and for web cams.
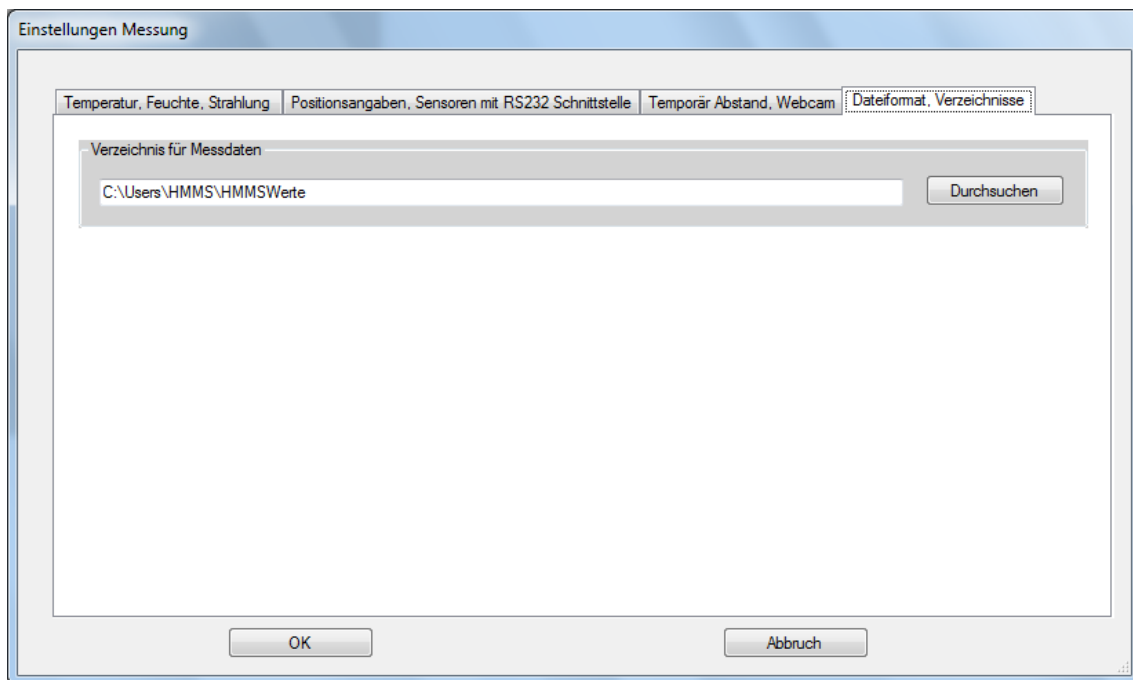
Figure 3.6: Setup for data storage directory.

"Setup|Messung|Temperatur, Feuchte, Strahlung" (Figure 3.3):
Calibration factors and offsets for the temperature, humidity and radiation sensors can be set. Furthermore a amplification factor for the radiation sensors can be adjusted (possible entries: 50, 100, 200, and 500). For detailed information see chapter 4.1.2. The sampling rate for all sensors can also be changed in this menu (possible entries: 1 – 5 Hz).

"Setup|Messung|Positionsangaben, Sensoren mit RS232 Schnittstelle" (Figure 3.4):
"Barcode Startposition" and "Barcode Endposition" are important informations for the automation of the HMMS. Without this informations there are no turning points for the system. With "Abstand zwischen Barcodemarkierungen" the distance between two bar codes can be set in meter. Be sure, to install the bar codes as mentioned in chapter 2.4. With the points "Anzahl der Gesamtdurchläufe" and

"zuletzt stoppen bei Barcode" the total runs of HMMS can be activated. 10 total runs means 10 turnovers at the start point and 10 turnovers and the endpoint for the HMMS. CO_2[1] and Ozone sensor[1] are not necessarily for full functionality and can be deactivated if they are not needed.

"Setup|Messung|Temporärer Abstand, Webcams" (Figure 3.5):

Ultrasonic sensor[1] and web cams (max. two) can be activated or deactivated. And the frequency of pictures and distance measurement can be adjusted.

"Setup|Messung|Dateiformat, Verzeichnisse" (Figure 3.6):

All measurement data are saved in this directory.
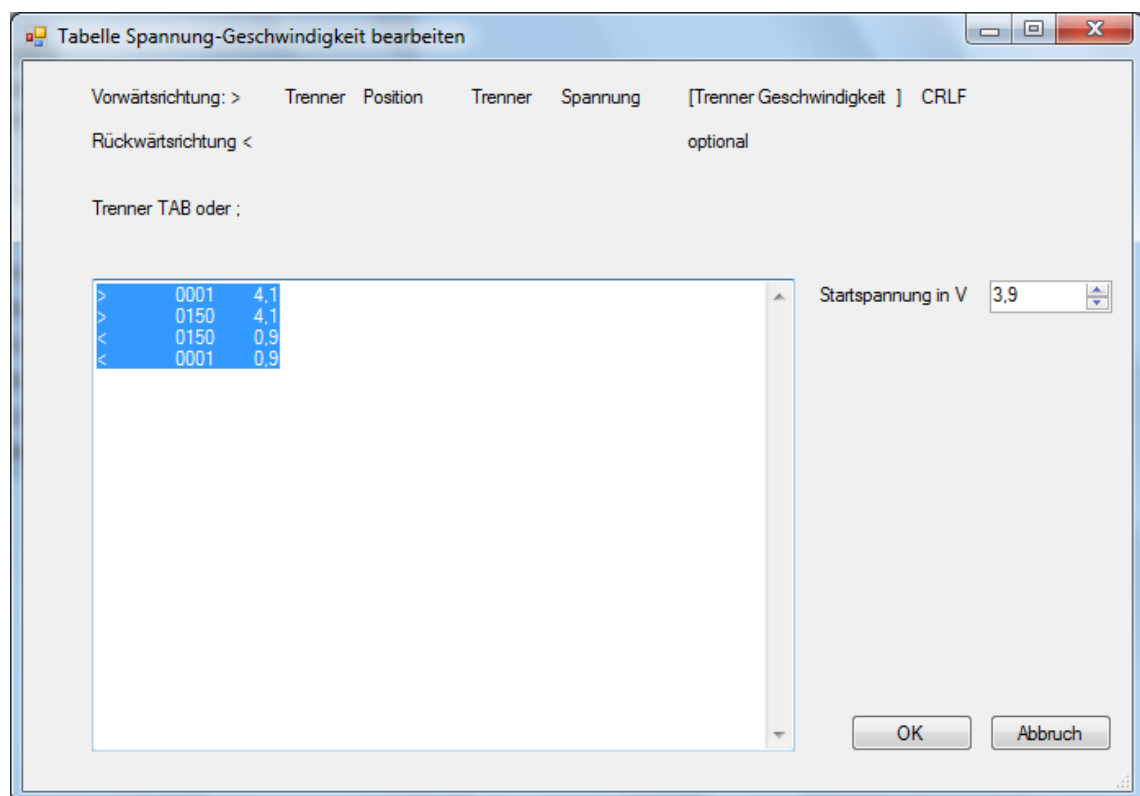
Figure 3.7: Speed profile of HMMS.

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[1]The baud rate as well as the handshake of the sensors connected via RS-232 are controlled trough the software.

"Setup|Geschwindigkeitsprofil" (Figure 3.7):
In this menu the speed of the HMMS can be adjusted in a table. Changes of speed between one and the following bar code is therefore possible.
Example like in the menu:

Direction[1]	Delimiter[2]	Position	Delimiter[2]	Voltage
>		0001		4.1
:		:		:
>		0150		4.1
<		0150		0.9
:		:		:
<		0001		0.9

"Startspannung" is the starting voltage of HMMS. This voltage is effective till the HMMS reaches one of the turning points (start- or endpoint). After scanning the bar code at the turning point the speed profile will be activated. To generate a speed profile, the menu "Messen|Geschwindigkeitsmessung" can be taken (see chapter 3.4.2).

All adjustments will be saved in the file "HMMSsetup.xml" by default. This file can be found in the same directory of the "HMMS.exe". With start of the software the file will be loaded automatically. There is also a possibility to save and load other setup files over the menu point "File" (see Figure 3.8). This can maybe be used for different speed profiles.
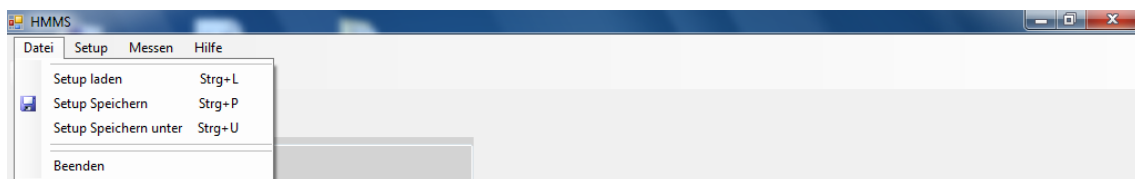
Figure 3.8: Clicked menu "Datei".

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[1]forward direction: >; backward direction: <
[2]TAB or ; possible

3.4.2 Measurement

The menu "Messen" in the menu bar (see Figure 3.9) is divided in "Messdaten in Datei" to start measurements with the HMMS (see Figure 3.10). In the menu "Geschwindigkeitsmessung" a profile of the HMMS speed can be measured (see Figure 3.11). And in the last menu "Dokumentation mit Webcam" the HMMS makes pictures with one or two web cams and a distance measurement (see Figure 3.12). The first click of one menu point activates the function, the second click deactivates it again.
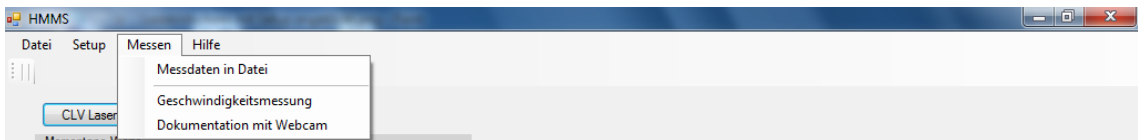
Figure 3.9: Clicked menu "Messung".
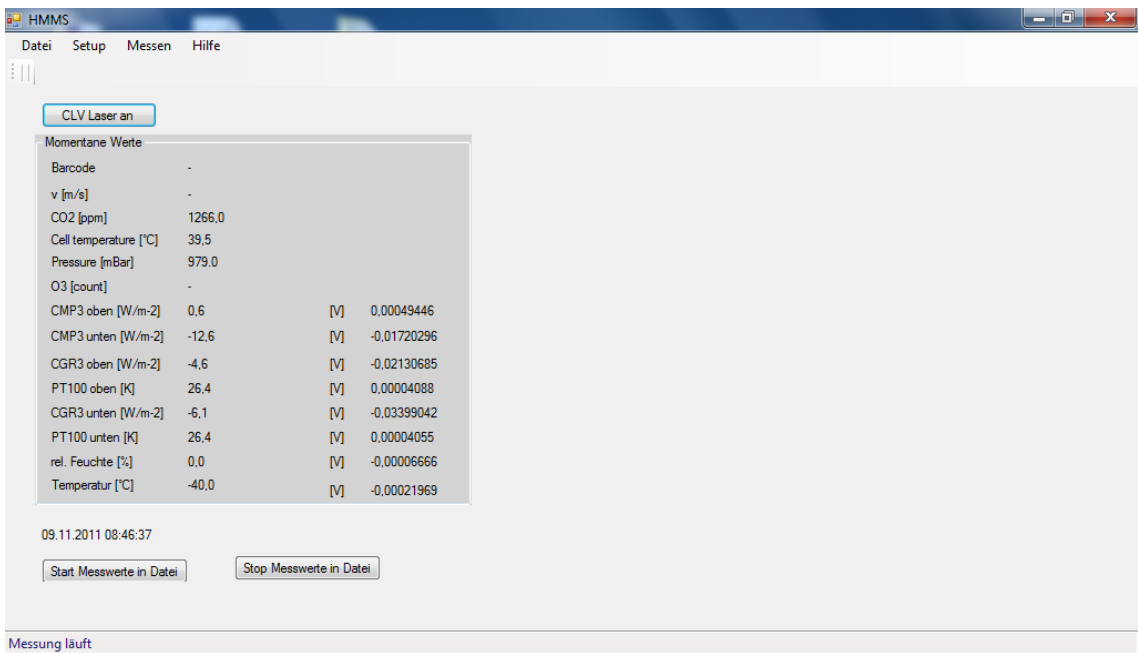
Figure 3.10: Software with activated menu "Messung|Messdaten in Datei".
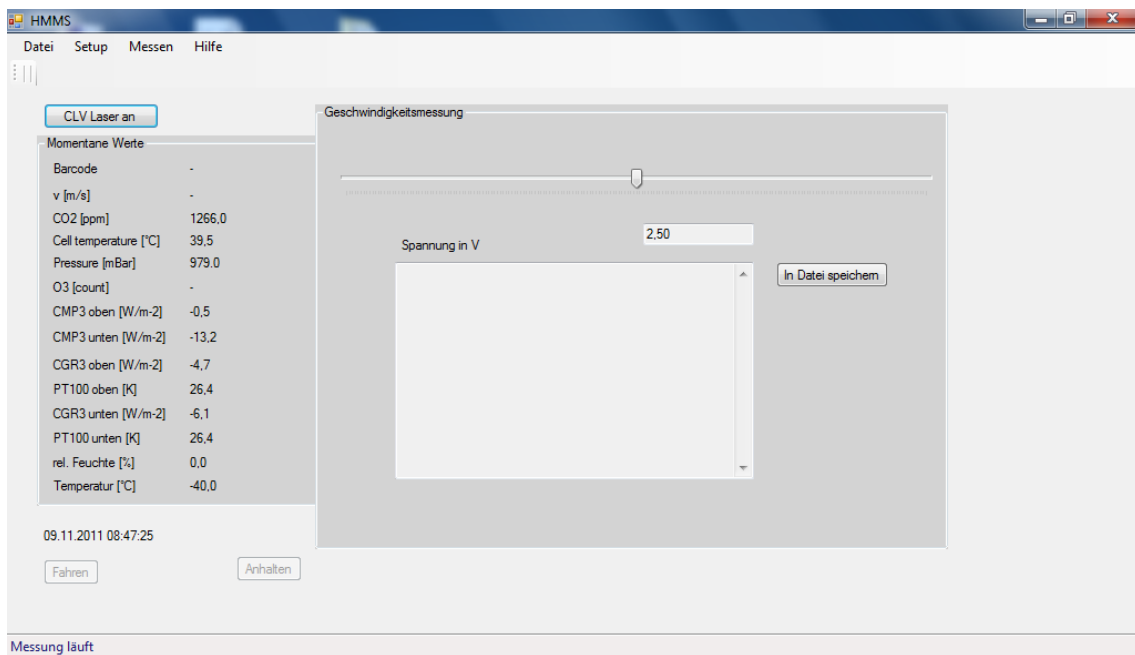
Figure 3.11: Software with activated menu "Messung|Geschwindigkeitsmessung".
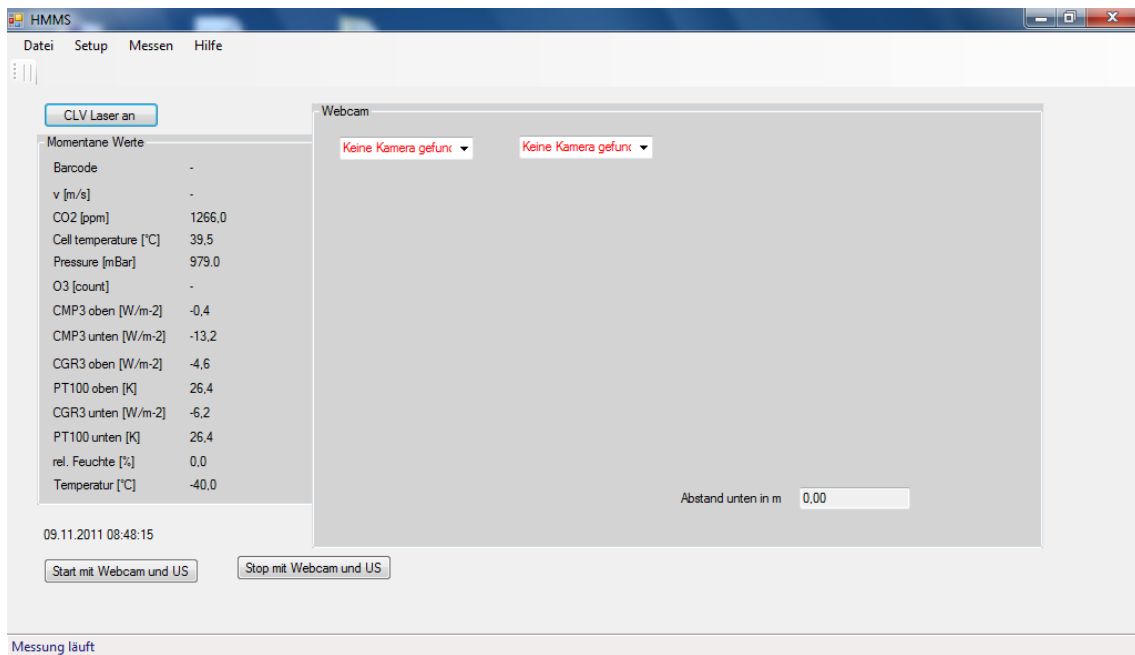
Figure 3.12: Software with activated menu "Messung|Dokumentation mit Webcam".

"Messen|Messdaten in Datei" (Figure 3.10):

With the button "Start Messwerte in Datei" the measurements can be started. The HMMS begin to drive and two data files will be saved in the directory specified in "Setup|Messen|Dateifomat, Verzeichnisse" (see Figure 3.6). One file is with raw voltages and the other with calculated values (see Appendix C). Dependent on the adjusted sampling rate, the data files will be updated every second or faster (max. with 5 Hz). The button "Stop Messwerte in Datei" stops the measurements and closes the data files. To reduce the disturb signal (random noise) of all incoming analog signals, an averaging over 10 % of the time between two measured values take place.

"Messen|Geschwindigkeitsmessung" (Figure 3.11):

The speed of the HMMS can be changed via a sliding controller for the output voltage. The bar code scanner scans every bar code and via the duration between two codes the speed of HMMS can be calculated. After a completed run, the speed measurement can be saved in a file. For the right format of the speed profile see Figure 3.7 and the instructions below.

NOTE: An older specified speed profile is not in use in this menu. As a consequence direction of motion, as well as the speed of the HMMS must be done manually over the sliding controller!

"Messen|Dokumentation mit Webcam" (Figure 3.12):

The software can handle with one or two web cams. Accordingly to the adjusted frequency in "Setup|Messen|Temporärer Abstand, Webcams" pictures will be saved in data-format: jpeg. The directory is the same like in Figure 3.6. The filename contain informations of time and position.

3.5 Remote access via VNC and WLAN

The HMMS can be controlled via remote access from another PC. Therefore the free UltraVNC software is installed on the Micro PC. To obtain access, the UltraVNC Server must be running. See Figure 3.13 for the adjustments. On the other PC the UltraVNC Viewer must be started. The WLAN Module is the Allnet Wireless LAN 54/108 Mbit Access Point. It is a small and lightweight module with a sufficient transfer rate and transmission range. The module is connected via Ethernet to the Micro PC and can be turned off and on by a switcher (see Figure 4.10).
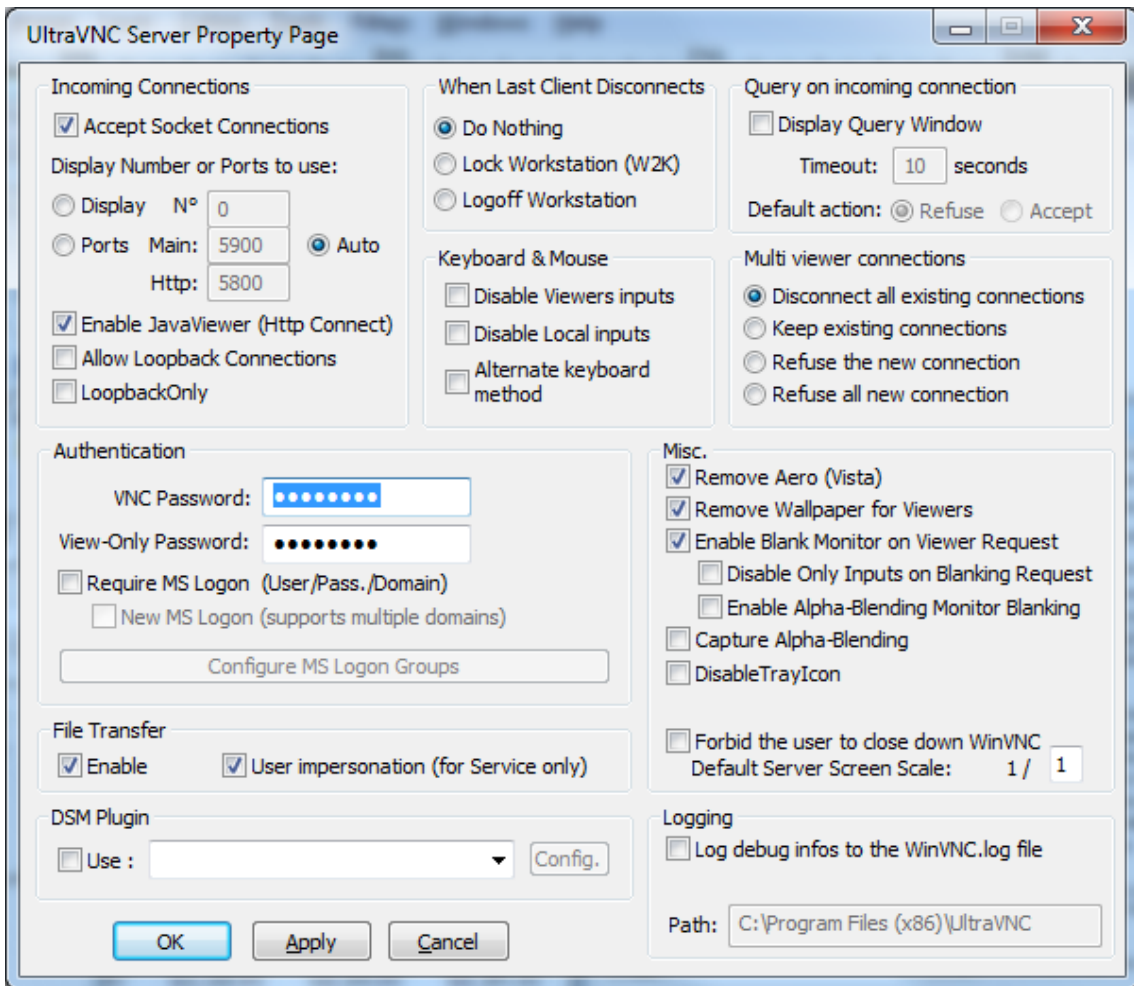
Figure 3.13: UltraVNC Server properties for remote access of the Micro PC.

4 Sensor system of the HMMS

The limited revenue load of around 10 kg on the HMMS base plate (see chapter 2.2) is a major challenge for the choice of the correct sensors. Those must be lightweight and small, but otherwise they should have a high measurement frequency in order to measure possible changes in quantities with a acceptable response time, without great delay times. The delay time of a sensor is given by the so-called time constant. The time constant is a measured variable in seconds and corresponds to the time a measurement system needs to reach 63 % of the final value after a change in the input size (Foken, 2008). The change of a measured variable and the delayed response of the sensor leads to an error in the measurement. This error is called a dynamic error. The dynamic error is not a big problem for static measurements, but for mobile measuring system it might cause a smearing of the measured value along the measuring transect. And the slower a sensor responds to changes of a quantity, the greater will be the smearing in the transect and finally in the time series. To keep the dynamic error and the smearing as low as possible is among the sensor weight a primary goal for the correct choice of the sensors. The dynamic error of the sensors on the HMMS, depending on the individual time constants and the speed of HMMS, is discussed in greater detail in chapter 4.4. In the following chapter 4.1 the applied sensors are specified with all modifications. In chapter 4.3 the wiring and data collection of the different sensors are discussed in detail.

4.1 Applied sensors on the HMMS

The following sections describes the sensors which are installed on the HMMS. A overview of the sensors is given in Table 4.2 at the end of the section. And the Figures 4.8 and 4.9 show the HMMS with the sensors.

4.1.1 Temperature and Humidity sensor - HMP155

For measurements of temperature and relative humidity the HMMS is equipped with a HMP155 from Vaisala, with a PT100 temperature and a HUMICAP® 180R humidity sensor. The configuration code of the HMP155 is: "A2GB11A0A1A1A0A". Please find the form for the configuration code and the specifications of the HMP155 in Appendix B.1.

To avoid heat accumulation on the sensor and to obtain the lowest possible time constants, the two sensors of the HMP155 are installed in a "thies tube". "Thies tubes" are double-walled protection tubes which protect the sensors for radiation. The company Adolf Thies GmbH & Co. KG use this tubes for their psychrometer. In order to get the HMP155 head with the sensors in the tube, the sensor housing is detached. Hereupon the circuit board is exposed. The tube is ventilated with an air flow of $\sim$4 ms^{-1} with the help of a computer fan. Figure 4.1 shows the plastic body ① with the "thies tube" ②, the fan ③ and the exposed HMP155 ④, mounted in the body. To achieve the high air flow, the diameter batter significantly between the sensor and the computer fan. A sintered PTFE filter (see ④ in Figure 4.2) which protects the sensors (see ① and ② in Figure 4.2) for dirt and moisture is removed to achieve a faster response time. The individual time constants for the temperature and humidity sensor with all this modifications can be found in chapter 4.4. Both individual time constants are smaller compared with the time constants given by Vaisala. The original time constants can be found in Table 4.2.
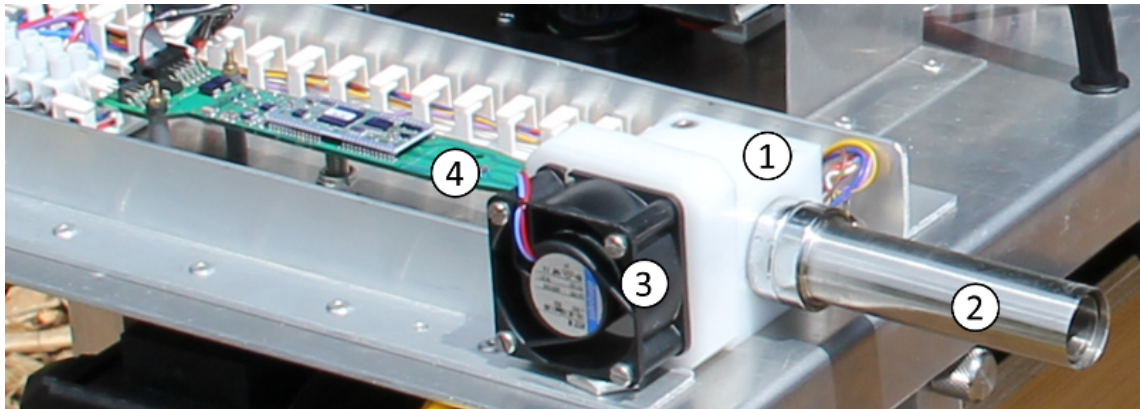
Figure 4.1: View on the HMP155 temperature and humidity sensor from Vaisala. With ①: body made of plastic material, ②: double-walled "thies-tube" for radiation protection, ③: computer fan for ventilation and ④: exposed HMP155 circuit board.
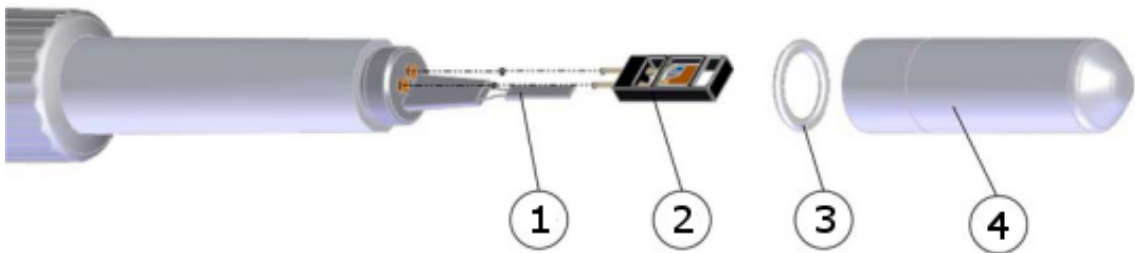
Figure 4.2: Schematic HMP155 with the PT100 temperature sensor ①, the Humicap® 180R humidity sensor ②, an o-ring ③ and the filter ④ which protects the sensors for dirt and moisture. The o-ring and the filter are removed at the HMP155. The picture is modified from the User Guide of the HMP155 (Vaisala Oyj, 2008).

4.1.2 Long-wave and short-wave radiation - CGR3 and CMP3

Furthermore, the HMMS transport four radiation sensors at the front site. Two pyranometer of the type CMP3 from Kipp & Zonen for the short-wave downwelling radiation, mainly emitted by the sun (global radiation) and the short-wave upwelling reflected radiation. And two pyrgeometers of the type CGR3 from Kipp & Zonen for the long-wave downwelling infrared radiation, mainly emitted by clouds, aerosols, and gases and the long-wave upwelling infrared radiation (see Appendix B.2 for the

specifications of both sensors). For exact measurements of the long-wave radiation, the two CGR3 are provided with PT-100 temperature sensors to measure the temperature of the sensor housing. The measurement of both radiation sensor types (CMP3 & CGR3) based on the principle of the temperature column.

The sensors are mounted on 0.4 m long extension arms on both sides of the HMMS. Because of the width of the HMMS, the sensors are 1.0 m erased from each other. This leads to a reduction of the influence of the route and the HMMS itself in the measurements. In forward direction the two CMP3 sensors are mounted on the right side (① in Figure 4.3) and on the left side the two CGR3 sensors (② in Figure 4.3). NOTE: Be aware of the correct positioning of the sensors. The arms are mounted on both sides at the top faced sensor for the downwelling radiation (see also Figure 4.3). For orientation there are short tape pieces with different colors attached at every connection cable near to the sensors. Look in Table 4.1 for the four different tape colors.

After measurements the two arms can be rotated by 90° and retracted to reduce the width of the HMMS (see Figure 4.4). For the rotation you have to open the winged screws at the bottom side of the arm holders.

Because of the small output voltages of the radiation sensors in the mV range and the low sensitivity of the NI i/o controller in the range from $0 - 1$ V, the sensors are equipped with amplifiers to increase the output signal. Possible factors of amplification are $100/200/500$ fold[1]. The amplifiers are self-constructed from the electronics workshop of the University of Bayreuth. For any problems or questions use the ELUB No. 5/361/1. The schematic attachment of the amplifiers is shown in Figure 4.5. The factor of amplification can be adjusted on the amplifiers via a jumper. (see also Figure 4.5). The factors of amplification for each sensor, as well as their individual sensitivity can be found in Table 4.1. These both values must be adjusted in the HMMS software in the menu "Setup|Messung|Temperatur, Feuchte, Strahlung"

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[1]The factors of amplification for the short-wave downwelling radiation differ from the other three amplifiers, because of the higher output voltage. The factors are $10/20/50$.

(see Figure 3.3) for each of the four sensors, in order to get correct measurement values.

Figure 4.3: Front view on the HMMS. In forward direction the two short-wave radiation sensors Kipp & Zonen CMP3 are located on the right side ①. And on the left side the two long-wave radiation sensors Kipp & Zonen CGR3 ②.
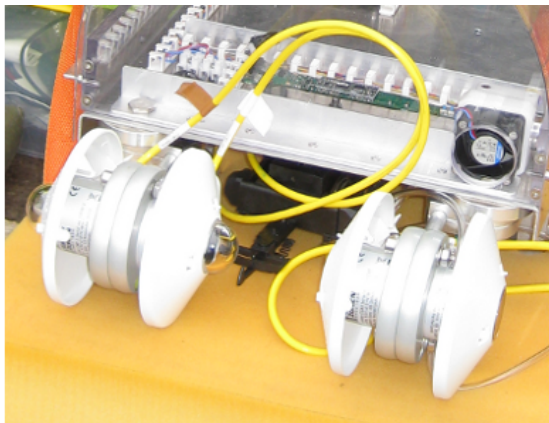
Figure 4.4: Retracted radiation sensors, ready for transport.
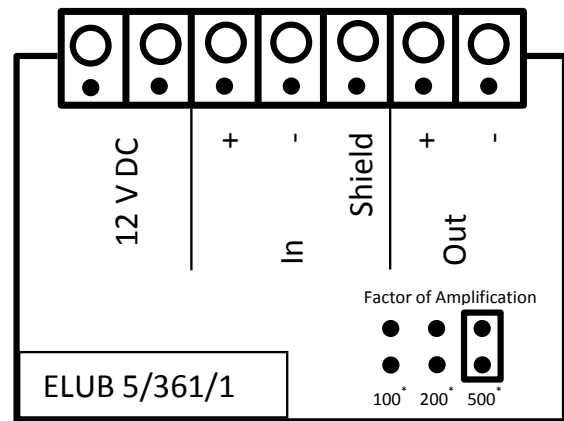
Figure 4.5: Amplifier for radiation sensors with factors of amplification of 100/200/500. *Factors are 10 times smaller for the amplifier of the short-wave downwelling radiation.

Table 4.1: Overview of the four applied radiation sensors.

Type	Parameter	Sensitivity [$\mu V/W/m^2$]	Factor of amplification	Color of tape
Short-wave radiation (CMP3)	downwelling upwelling	16.92 13.70	50 100	brown white
Long-wave radiation (CGR3)	downwelling upwelling	9.25 11.09	500 500	green blue

4.1.3 CO_2 concentration – Edingburgh Instruments Gascard® NG

For CO_2 concentration measurements the HMMS is equipped with an Edinburgh Instruments Ltd. OEM Gascard® NG closed-path (single cell) infrared gas analyzer with a measurement range of 0 – 1000 ppm. The Gascard® NG is a very tall gas sensor with the dimensions 160 mm x 100 mm x 40 mm and a weight of only 300 g. See Appendix B.3 for further informations. Especially the warm-up time named in Table B.3 is important for correct measurements.

The sensor has no sensor housing, therefore the cover, described in chapter 2.5 is absolutely required, to protect the sensor head and the electronic for humidity and dirt.

For the gas flow, a vacuum pump is used from the company Fürgut GmbH, with the identification DC24/16F. This pump is a 24 V DC pump, which has a flow rate of 3 L/min. Using the pump with 12 V DC leads to a reduction of the flow rate to 1.2 L/min, which is needed for the Gascard® NG. The inlet of the CO_2 is located on the left side of the HMMS, and has a 12 cm long tube, made of aluminum. This tube can be screwed off from a aluminum block, which switch the direction of the inlet through the base plate into the HMMS (see Figure 4.6). From there a flexible tube leads to the sensor.
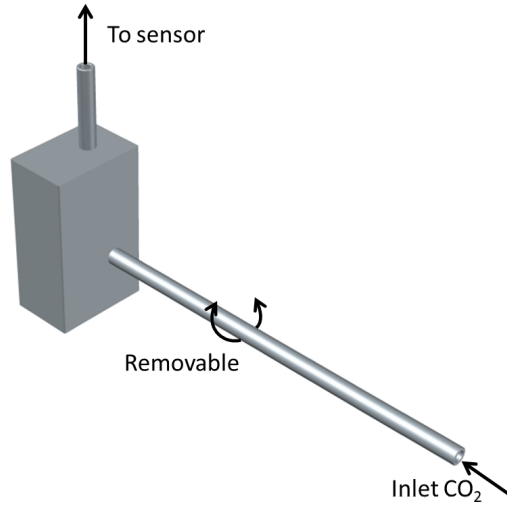
Figure 4.6: 3-dimensional CAD design of the CO_2 inlet. The inlet is mounted on the bottom left side of the HMMS base plate. See Figure 4.9, ⑨.

The overall tube length of the inlet is 50 cm and has a diameter of 3 mm. The flow velocity is calculated as follows:

$$\dot{V} = c \cdot a \tag{4.1}$$

With $\dot{V}$ as the flow rate in m³/s, the c as the middle speed in m/s and A as the cross-section area in m². The outcome of the repositioning to c is:

$$c = \frac{\dot{V}}{a} \tag{4.2}$$

With the values:

$$c = \frac{1.2\dfrac{L}{min}}{\pi \cdot (1.5mm)^2} = \frac{2 \cdot 10^{-5}\dfrac{m^3}{s}}{\pi \cdot (1.5 \cdot 10^{-3}m)^2} = 2.8\frac{m}{s} \tag{4.3}$$

The inlet tube length of 50 cm and the flow velocity of 2.8 m/s leads to a time delay of 0.2 s. In this theoretical calculation is no friction considered.

4.1.4 Ozone concentration - Enviscope Fast Ozone Detector

As a further variable the HMMS measures the ozone concentration. Therefore the HMMS carries an ozone detector from the company enviscope GmbH. The ozone detector was an item on loan from enviscope and was in use during the EGER project in summer 2011 (see chapter 5). After the project, the detector was dismounted and returned to enviscope.

The ozone detector is a fast sensor with a maximum measuring frequency of 50 Hz. Because of the big dimensions 133.4 mm x 214 mm x 231 mm (H x W x D) and a weight of approximately 3 kg, enviscope gave us a modified version, without the sensor housing and front panel by which the operational control is realized. This leads to a reduction of the sensor size to 70 mm x 100 mm x 175 mm and the weight to 1.6 kg, without the loss of accuracy and handling. The modified sensor is shown in Figure 4.7.

The measuring principle of the ozone detector is a chemiluminescence detector. Therefore the detector has a measuring chamber, in which the sample air react with a organic dye (e.g. Coumarin), applied to a detector plate. The reaction leads to a emission of photons at a wavelength of ~ 500 nm. The photons are detected by a photo-multiplier.

In addition to a 12 V DC supply for the sensor, the detector needs a higher voltage (15 ... 60 V DC) for the heating of the chamber. Therefor 24 V DC from the engines of the HMMS are tapped to supply the heating of the detector.

Because of the size and weight reduction, the fan, which is integrated in normal case, is also removed. Because of this, the HMMS has a second pump to guarantee the right sample air flow. The pump is a 24 V DC vacuum pump with the identification DC24/80L from the company Fürgut with a flow rate of max. 9 L/min. If the pump operates with 12 V DC, the flow rate decrease to ~ 3 L/min, which is the recommended flow rate for the ozone detector. At the detector two 30 cm long black Teflon® tubes are mounted, with a diameter of 3/8", or ~ 9.5 mm. The tubes have

to be black and therefore lightproof because of a possible offset in measurements caused through incident sunlight into the chamber. Because of the high frequency measurements, the time constant of the sensor is negligible and the flow velocity is after equation (4.2):

$$c = \frac{3.0\frac{L}{min}}{\pi \cdot (4.75mm)^2} = \frac{5 \cdot 10^{-5}\frac{m^3}{s}}{\pi \cdot (4.75 \cdot 10^{-3}m)^2} = 0.7\frac{m}{s} \tag{4.4}$$

This leads to a time delay of 0.5 s. This is also a theoretical value without friction.

Figure 4.7: Picture of the modified enviscope fast ozone detector. With ①: Power supply cables (12/24 V DC) and RS-232 connection, ②: 3/8" inlet, ③: 3/8" outlet, ④: Teflon® tube, ⑤: Aperture for the insertion of the organic dye, and ⑥: Quick-release knob.

Table 4.2: Overview of applied sensors on the HMMS sensors. Please find detailed descriptions of the sensors in the chapters 4.1.1 to 4.1.4 and in Appendix B. The acquisition is described in chapter 4.3 and the individual time constants in chapter 4.4.

Parameter	Sensor	Accuracy	Time constant (τ_{63}/τ_{95})	Connection	Remark
Long-wave upwelling radiation	CGR3, Kipp & Zonen	<15 W m⁻²	-/< 18 s	Two-wire	Amplifier used (Factor: 50 fold)
Long-wave downwelling radiation	CGR3, Kipp & Zonen	<15 W m⁻²	-/< 18 s	Two-wire	Amplifier used (Factor: 100 fold)
Short-wave upwelling radiation	CMP3, Kipp & Zonen	<15 W m⁻²	-/< 18 s	Two-wire	Amplifier used (Factor: 500 fold)
Short-wave downwelling radiation	CMP3, Kipp & Zonen	<15 W m⁻²	-/< 18 s	Two-wire	Amplifier used (Factor: 500 fold)
Temperature	HMP 155, Vaisala	± 0.1 K	< 20 s/-	Four-wire	Radiation shield and ventilation
Relative humidity	HMP 155, Vaisala	± 1 %	< 20 s/-	Four-wire	Radiation shield and ventilation
CO₂ concentration	Gascard NG 1000ppm, Edinburgh Instruments Ltd.	± 40 ppm	~1 s/-	RS-232	Vacuum pump with 1.2 L/min flow rate
O₃ concentration	Ozone detector, Enviscope	± 0.01 ppm	≪ 1 s/-	RS-232	Vacuum pump with 3.0 L/min flow rate
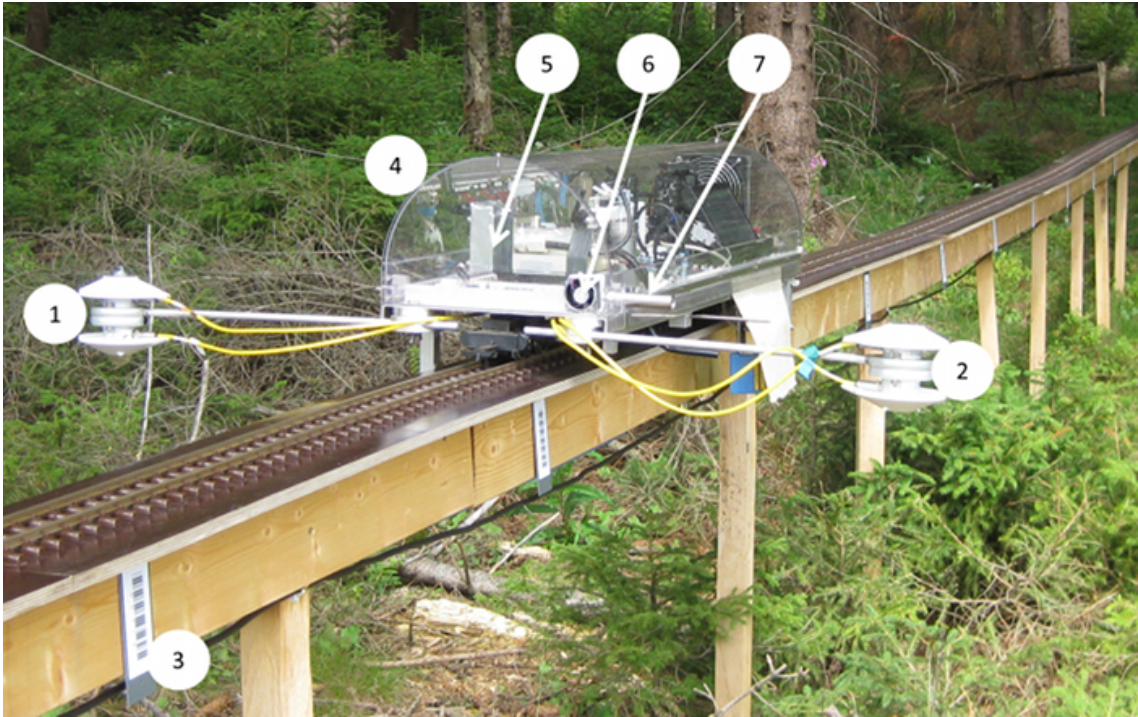
Figure 4.8: Front view on the HMMS. Specification of the numbers are in Table 4.3.
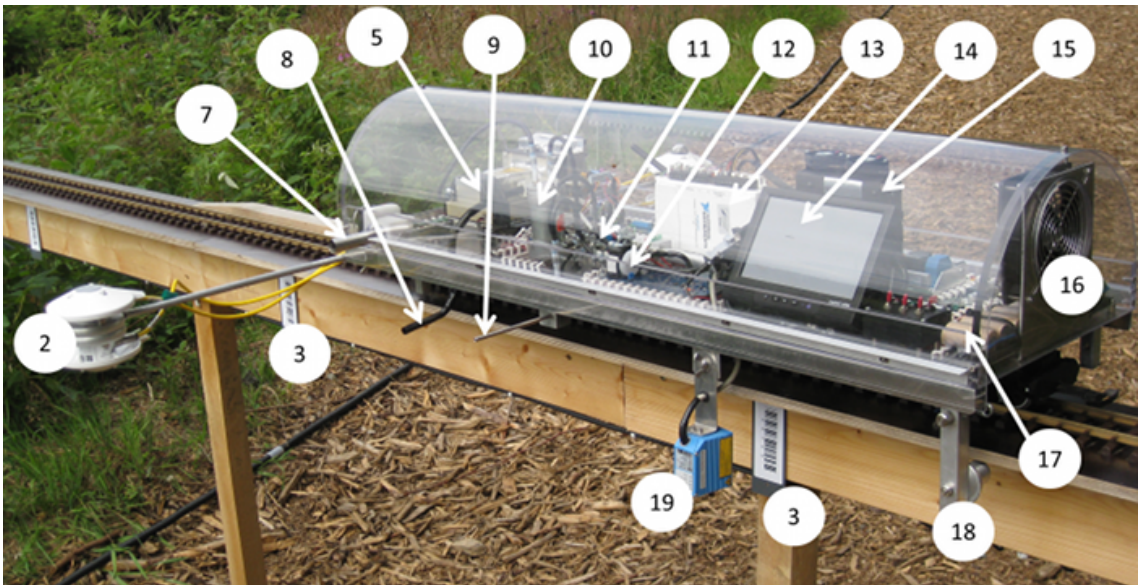
Figure 4.9: Lateral view on the HMMS. Specification of the numbers are in Table 4.3.

Table 4.3: Specification of numbers from Figures 4.8 and 4.9.

Number	Description
1	Short-wave up- and downwelling radiation on a 0.5 m long beam
2	Long-wave up- and downwelling radiation on a 0.5 m long beam
3	Code 39 bar code
4	Cover to protect the HMMS for rain and dirt
5	Enviscope Ozone detector
6	Fan for ventilation of the HMP 155 temperature and humidity sensor
7	Inlet for HMP 155, shielded
8	Inlet for Ozone detector, made of Teflon$^{®}$
9	Inlet for CO_2 sensor, made of Aluminum
10	Pump for Ozone detector
11	Pump for CO_2 sensor
12	Edinburgh Instruments Ltd. Gascard NG CO_2 sensor
13	National Instruments i/o controller
14	7"-TFT Monitor
15	Micro PC
16	Fan for cooling the entire system
17	On board storage battery
18	Lateral holder to protect the HMMS for downfalls
19	Sick CLV412-1010 bar code scanner

In spite of the lightweight sensors and conducted modifications, the HMMS has a total weight of $\sim$ 17 kg. With this weight, the HMMS is not that lightweight, but the engines has enough power to drive the HMMS with the requested speed of $\sim$ 0.5 ms^{-1}, even over inclines and declines of up to 8 degrees.

4.1.5 Temporary sensors

In chapter 3.4 temporary sensors are mentioned, like web cams and an ultrasonic distance measurement. The web cams are Logitech HD Webcam C310 with a max. resolution of 1280 x 710 dpi. For the system requirements have a look in Appendix B.5. The Micro PC doesn't fulfill the max. requirements to make HD videos, but high resolution pictures are possible. These pictures can be used to monitor the vegetation along the transect.

For the ultrasonic distance measurements the SRF02 sensor from Devantech Ltd. is used. It is a lightweight and small sensor with a TTL level (transistor-transistor logic). With a transformer module the TTL level can be transferred to a RS-232 signal. Detailed specifications can be found in Appendix B.6. The SRF02 sensor can be used to measure the vegetation height in reference to the measuring height. For the use of this sensors, there are not enough connection possibilities at the Micro PC. For the wiring of the temporary sensors see chapter 4.3.

4.2 Power supply of the HMMS sensors

Chapter 2.3 describes the power supply system on the HMMS and the two electrical circuits with 12, resp. 24 V DC. Figure 2.2 illustrates the wiring of the HMMS power supply system with a reference to the power supply wiring of the sensors. Besides the heating of the ozone detector (see chapter 4.1.4), which is fed with 24 V DC, all other sensors are fed with 12 V DC. Except for the radiation sensors, there is no explicit supply necessary. Because of the high number of current consumers, there is a power distribution on the HMMS. This distribution is solved via nine on/off switchers for sensors, pump, bar code scanner, and WLAN module. They are mounted lengthwise on the right side of the HMMS in forward direction. The on/off switchers are labeled but in case the labels peel of, you can find the right order in Figure 4.10. This Figure also describes the power supply of the sensors. Three cables leads to the switcher box of ozone. One with 12 V DC (yellow), one with 24 V DC (pink) and one ground cable (black) for the diodes. From the switcher box of ozone leads the yellow, the black and the three cables for the ozone sensor, the ozone pump and the heating to the next box and so on. Please find all cable colors for each part in Table 4.4.
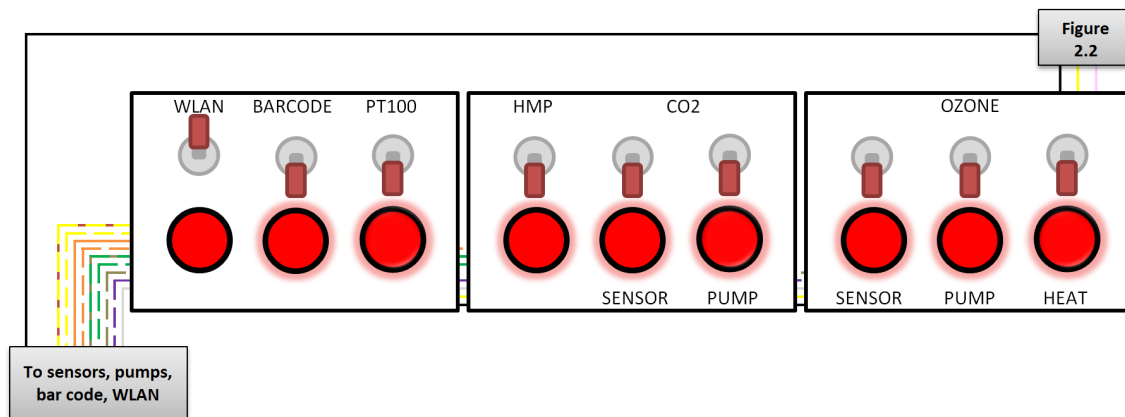
Figure 4.10: On/off switchers for the sensors, pumps, heating, bar code scanner and WLAN module. Downward pointed switchers are on (this is indicated through shadows around the red Diodes). Please find the cable colors in Table 4.4.

Table 4.4: Specifications of the cable colors shown in Figure 4.10. Permanent means: As soon as the power supply of the HMMS is on (see Figure 2.6); on/off means: The power supply can be switched to on or off through the switchers shown in Figure 4.10.

Cable Color	Current Consumer
yellow	permanent 12 V DC supply for all sensors
pink	permanent 24 V DC supply for the ozone detector heating
black	permanent ground cable
transparent	on/off 24 V DC supply for the ozone detector heating
purple/white	on/off 12 V DC supply for ozone pump
brown/white	on/off 12 V DC supply for ozone detector
green/white	on/off 12 V DC supply for CO_2 pump
green/brown	on/off 12 V DC supply for CO_2 sensor
orange/white	on/off 12 V DC supply for temperature/humidity sensor
orange	on/off 12 V DC supply for PT100
yellow/red	on/off 12 V DC supply for bar code scanner
yellow/white	on/off 12 V DC supply for WLAN module

As mentioned there is no explicit power supply necessary for the radiation sensors. Therefore there are no on/off switchers available. But for the right radiation measurements, the PT100 module needs power supply. The PT100 module produces a constant current of 1 mA, which is needed for the PT100 measuring principle. The module is shown in Figure 4.11.
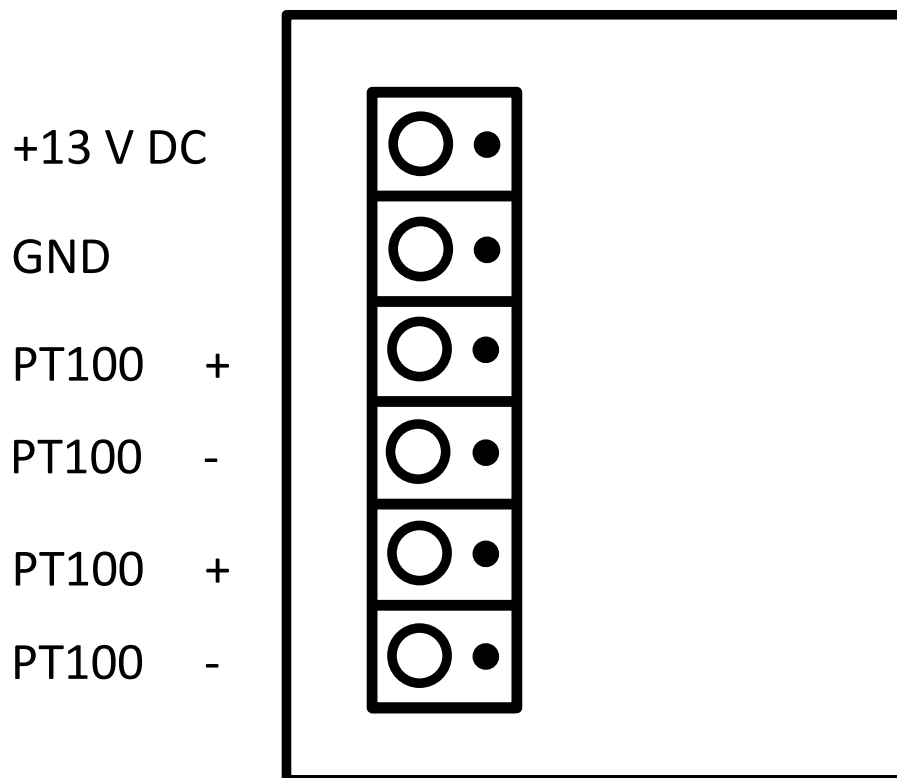
Figure 4.11: PT100 module which produces a constant current of 1 mA for the two long-wave radiation sensors. This module is needed for the PT100 measuring principle.

The fan of the HMP155 (see chapter 4.1.1) starts to ventilate when the on/off switcher of the HMP155 is turned on. Also the fan under the ozone detector starts when the on/off switcher for the ozone detector is turned on.

4.3 Measured value acquisition via i/o controller and RS-232

Figure 2.2 references in addition to the sensor power supply system of the HMMS (see Figure 4.10) also the connection system of the sensors. The sensors are connected via analog signal (i/o controller) or RS-232 to the Micro PC. Figure 4.12 shows the connection system of all sensors. In red color the parts are mentioned, which are

absolutely necessary for full functionality of the HMMS. Without the plugged-in USB receiver for the Keyboard/Mouse combination, the Micro PC doesn't start. And without the bar code scanner (connected via RS-232 to Micro PC) and the i/o controller (connected via USB to Micro PC) the HMMS software won't work. The blue rectangles show the standard sensor wiring. The two shortwave radiation sensors, the two long-wave radiation sensors, with their extra PT100 temperature measurements, the HMP155 temperature and humidity sensors are connected via analog signal to the i/o controller. For the detailed connection setup of the different input channels of the i/o controller have a look in Figure 4.13 (please note the legend). Beside the eight input channels, one output channel is taken for the control of the HMMS speed (see chapter 2.4). The ozone detector and the CO_2 sensor are connected via RS-232. The CO_2 sensor has a direct connection to the Micro PC. Because there is no third RS-232 port, the ozone detector is connected via a USB-to-Serial RS-232 converter.

In case of the measurement type "Documentation with web cams" (see chapter 3.4.2) some changes in the wiring has to be done. This is shown in Figure 4.12 by the orange rectangles. The CO_2 sensor and the USB-to-Serial converter with the ozone detector must be disconnected.

NOTE: Don't forget to deactivate the sensors in the HMMS software (chapter 3.4.1). For the CO_2 sensor, the ultrasonic distance sensor can be connected directly with the Micro PC. After disconnecting the USB-to-Serial converter two USB ports are available for the two web cams.

As a last connection, the WLAN module is connected via Ethernet to the Micro PC (green rectangle).

The handshakes and adjustment of the baud rate between the HMMS software and sensors, connected via RS-232 works automatically. Also the USB connected parts (web cams, i/o controller) are detected automatically from the HMMS software.
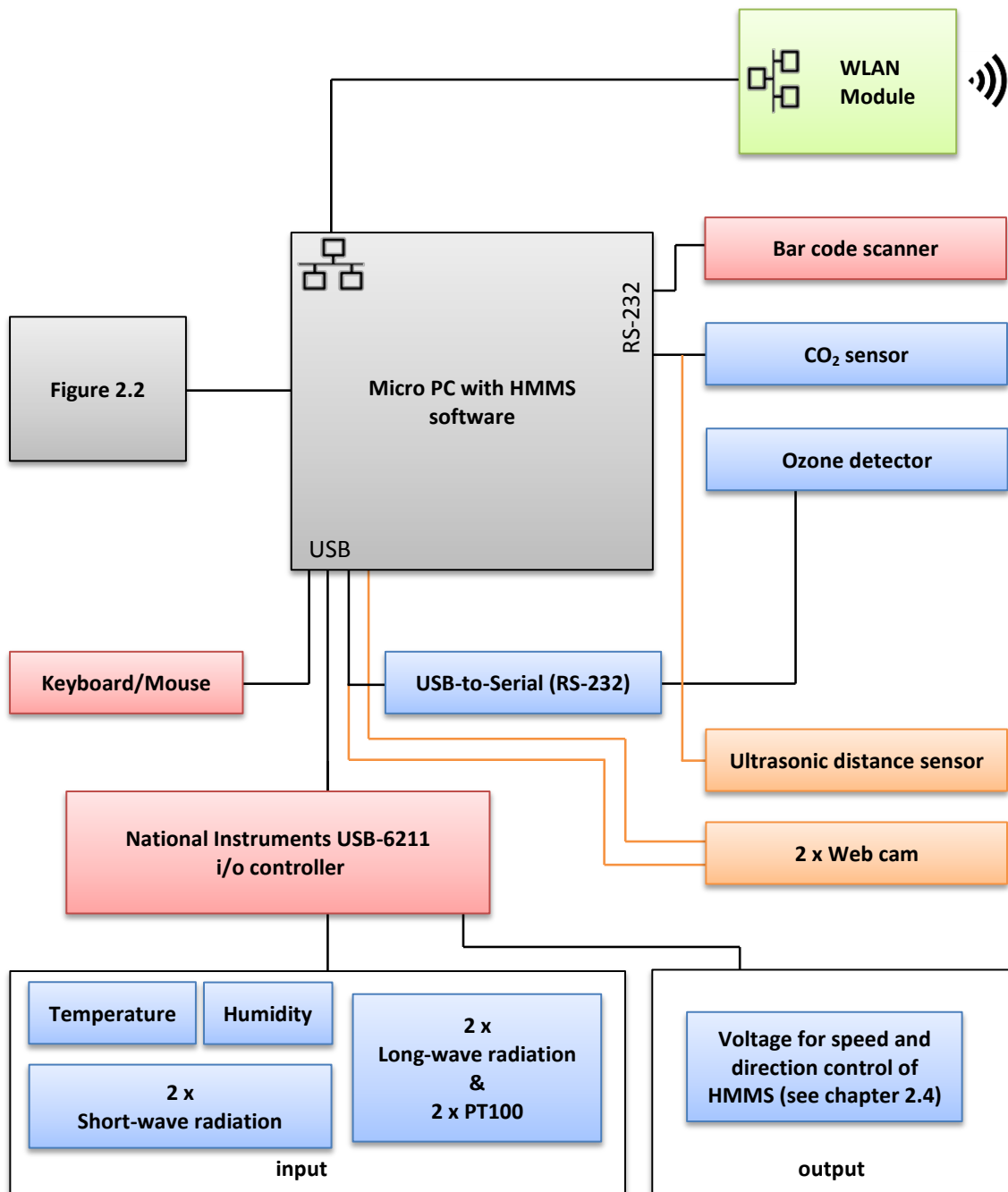
Figure 4.12: Sensor connection system of the HMMS. Red rectangles are necessary parts for the HMMS. Blue rectangles is the standard sensor wiring and orange rectangles show the temporary sensor wiring. For a more detailed description please look in the text above.
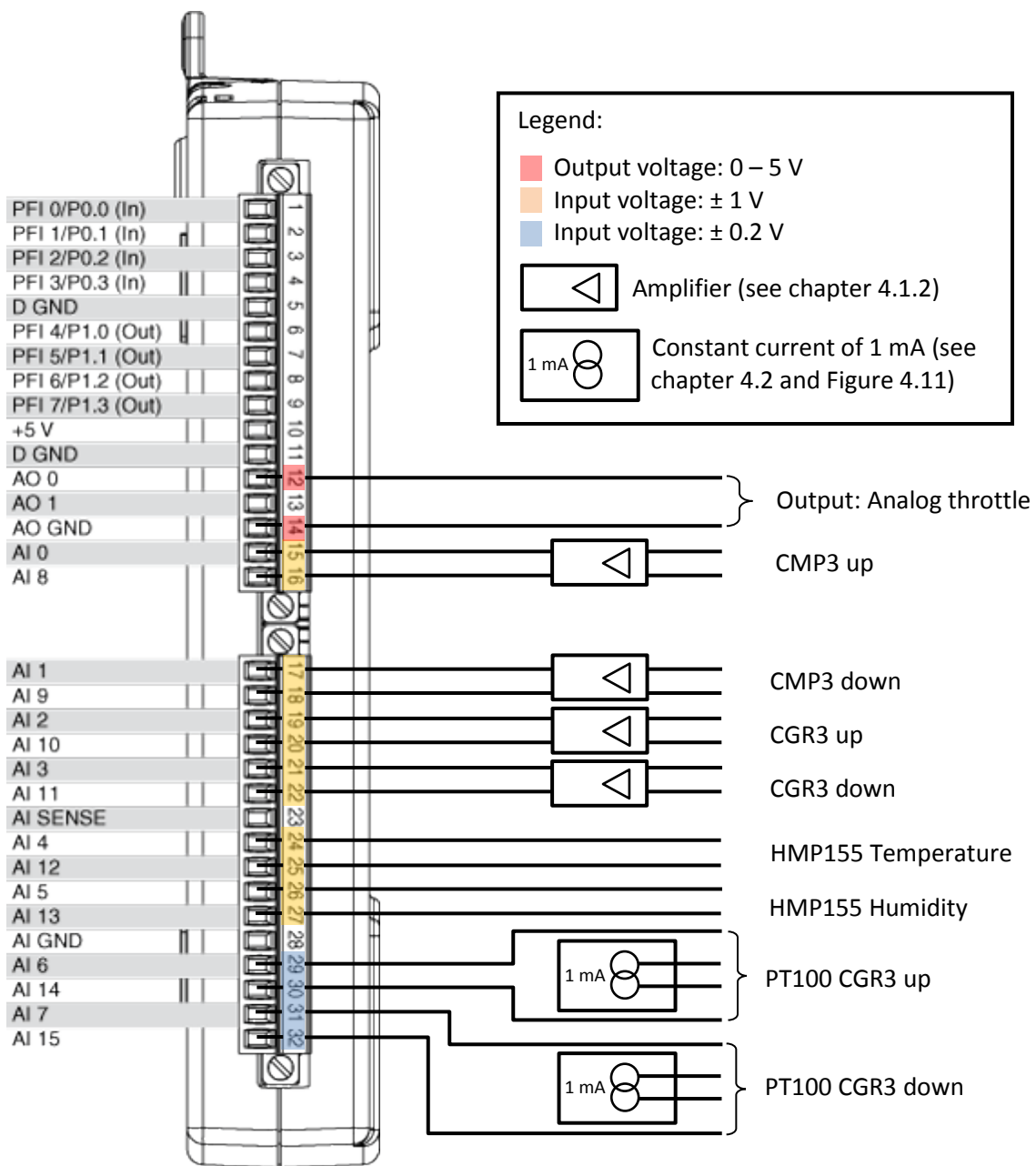
Figure 4.13: Attachment of the analog sensors at the NI USB-6211 i/o controller. Modified graph from (National Instruments Corporation, 2011). See in the legend the different in- and output ranges. For description of the sensors see chapter 4.1.

4.4 Individual response times of the sensors

In the beginning of this chapter the two major challenges for the sensors of the HMMS are named. The weight and the response time. The more important challenge was to choose the sensors with regard to the response time, to minimize the dynamic error. The higher the response times, or the higher the speed of the HMMS, the higher the dynamic error. The manufacturer informations of the response times of all sensors are given in Table 4.2. Please note, that the response times in the table differ. In some cases the given response time τ is τ_{63}, where 63 % of the final value are reached, in other cases it is τ_{90}, where 90 % of the final value are reached. Because of the modifications of some sensors (see chapter 4.1) individual time constants τ_{63} and τ_{95} were determined. They are shown in Table 4.5. The individual time constants do not differ remarkable according to manufacturer values. Except of the temperature sensor. This time constant could be reduced through the good ventilation. The ozone detector has no individual time constant because of the high measurement frequency of 50 Hz. Therefore the time constant is $\ll 1$ s.

The Figures 4.14 through 4.18 show in each case a example for a change of the measured value over time, after a change in the input value. Because of the averaging, the values in Table 4.5 can differ from the τ_{63} and τ_{95} markers in the graphs.

Table 4.5: Averaged individual time constants τ_{63} and τ_{95} for each sensor, except for the ozone detector, because of his high measurement frequency of 50 Hz. Figure 4.14 through 4.18 show one time series. Small meanderings to time constants in this table are possible.

Sensor	Time constant τ_{63} [s]	Time constant τ_{95} [s]
Short-wave radiation	< 4	< 16
Long-wave radiation	~ 4	< 16
Temperature	~ 13	< 30
Humidity	~ 19	< 38
CO_2 concentration	< 1	< 2
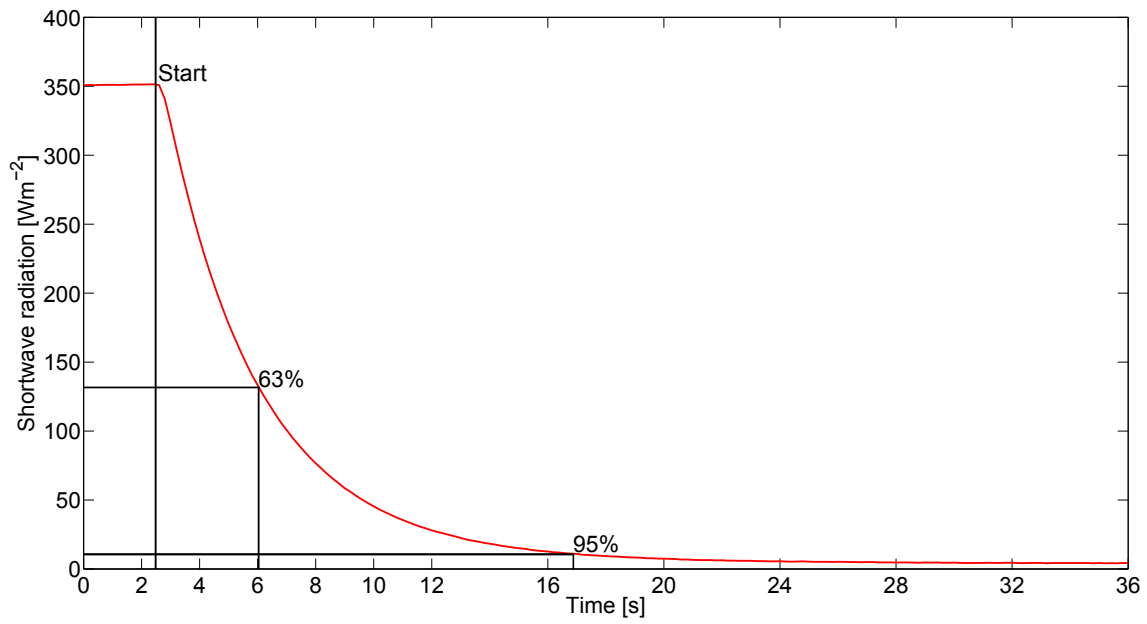
Figure 4.14: Time series after a change in the input value with the marked individual time constant τ_{63} and τ_{95} for the measured value short-wave radiation.
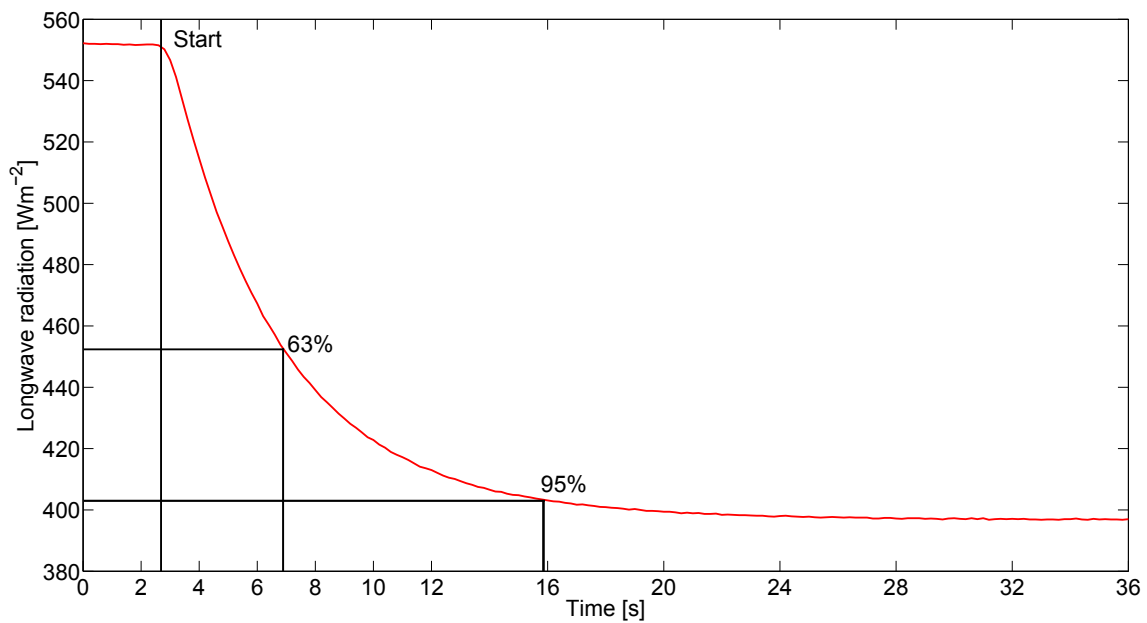
Figure 4.15: Time series after a change in the input value with the marked individual time constant τ_{63} and τ_{95} for the measured value long-wave radiation.
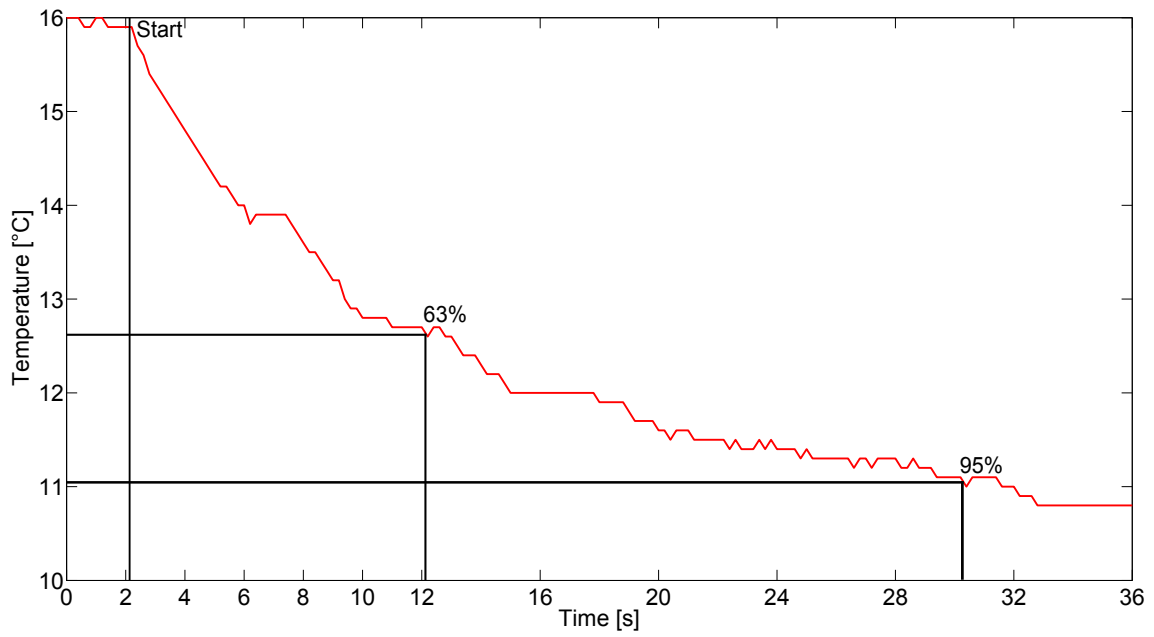
Figure 4.16: Time series after a change in the input value with the marked individual time constant τ_{63} and τ_{95} for the measured value temperature.
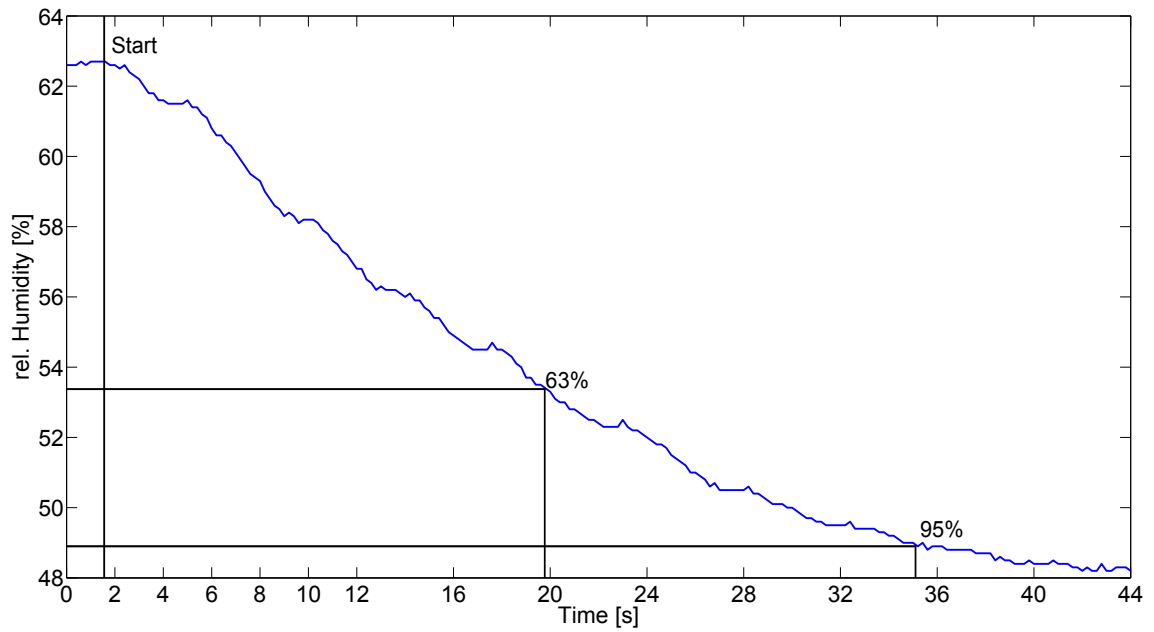
Figure 4.17: Time series after a change in the input value with the marked individual time constant τ_{63} and τ_{95} for the measured value humidity.
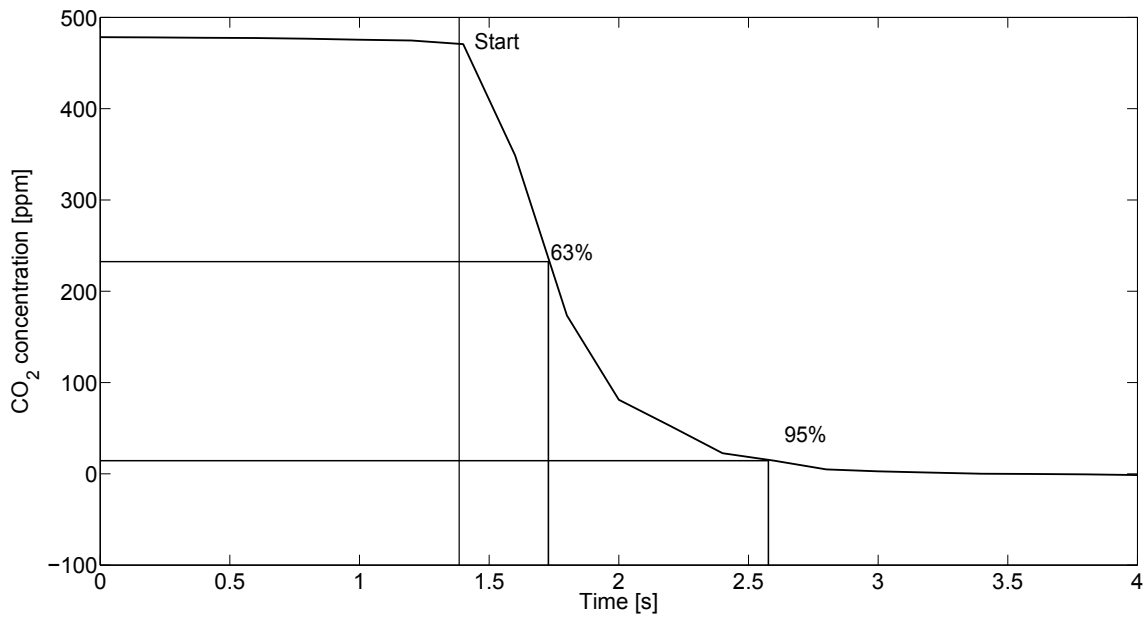
Figure 4.18: Time series after a change in the input value with the marked individual time constant τ_{63} and τ_{95} for the measured value CO_2 concentration.

As mentioned before, the time constants of sensors don't play a big role for stationary measurements, in contrast to vertical or horizontal mobile measurements. The dynamical error describes the overall error of a measuring system (e.g., Foken, 2008), but the resulting error caused by the time constants is not the whole dynamical error. Additional to the time constant error, there is often an error caused by lag-times. The lag-time error in combination with the time constant error leads to a bigger dynamical error and therefore to a longer adaption period after a change in the input value (see Figure 1 in Mayer et al., 2009).

In this case, there is an additional lag-time error for the CO_2 sensor and the ozone detector. The lag-time is generated by the inlet tube length and the prevailing flow velocity in the tube, which leads to a time delay of this measurements (see chapter 4.1.3 and 4.1.4). The lag-time in sum with the time constant leads to overall time delay of 1 s for the CO_2 sensor and ~ 0.5 s for the ozone detector. Figure 4.19 shows the dynamical error as a function of the HMMS speed and the time constant τ_{63}.
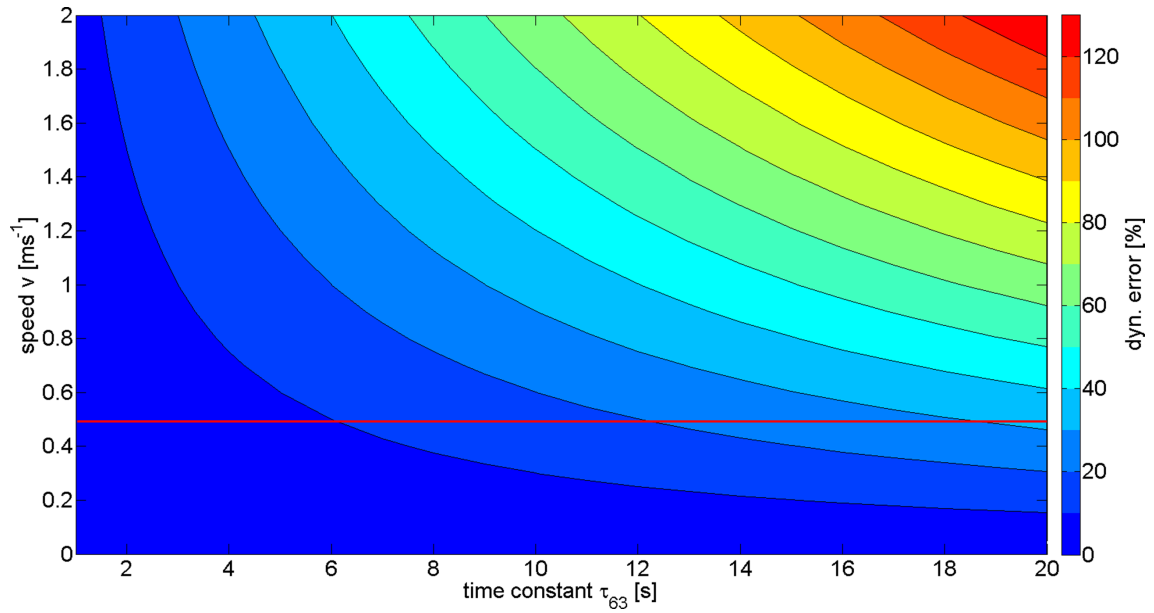
Figure 4.19: Dynamical error as a function of the HMMS speed and the time constant τ_{63}. The red line indicates a HMMS speed of 0.5 ms^{-1}.

Looking at the red line in Figure 4.19, which indicates the requested speed of the HMMS, it can be summarized that the dynamical error increases with τ_{63}. The humidity sensor, which is the slowest sensor, has an dynamical error > 30 %.

For short transects with nearly linear horizontal gradient the correction of the dynamical error can be done according to the previous investigations by Mayer et al. (2009), based on Foken (2008). The simple correction scheme after Mayer et al. (2009) will be the correction procedure for the HMMS measurements.

5 Application of the HMMS

5.1 EGER introduction

In the joint effort of the third intensive observation period (IOP3) of the EGER project (**E**xchan**GE** processes in mountainous **R**egions, DFG PAK 446), the diurnal cycles of energy, water, and trace substances in the soil-vegetation-boundary-layer system of a disturbed ecosystem was studied in summer 2011. As a result of the hurricane "Kyrill" the dense spruce forrest at the FLUXNET (Baldocchi et al., 2001) site (DE-Bay) at Waldstein in the Fichtelgebirge Mountains (near Weißenstadt, north eastern Bavaria) has a huge clearing. Current landscape studies suffer poor description of scale transitions and interactions especially in the case of such heterogeneities The investigations during IOP 3 focused on the resulting forest edge of the Kyrill event and the interaction between the remaining forest and the clearing. For this perpose the HMMS was built.[1] The transect passes 75 m in a dense spruce forest and 75 m on an open clearing (see Figure 5.1) vertical to the forest edge. Besides the HMMS measurements there were turbulence flux measurements installed above the forest canopy (canopy height: 27 m) and under the forest canopy along a transect vertical to the forest edge. Further turbulence flux measurements were installed on the clearing and on a transect parallel to the forest edge. Additionally scintilometer mearurements were conducted parallel to the forest edge and a measurement of atmospheric chemistry on the clearing.

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[1]The funding of the HMMS was realized by the University of Bayreuth and the Max-Planck-Institute for Chemistry, but not within PAK 446.
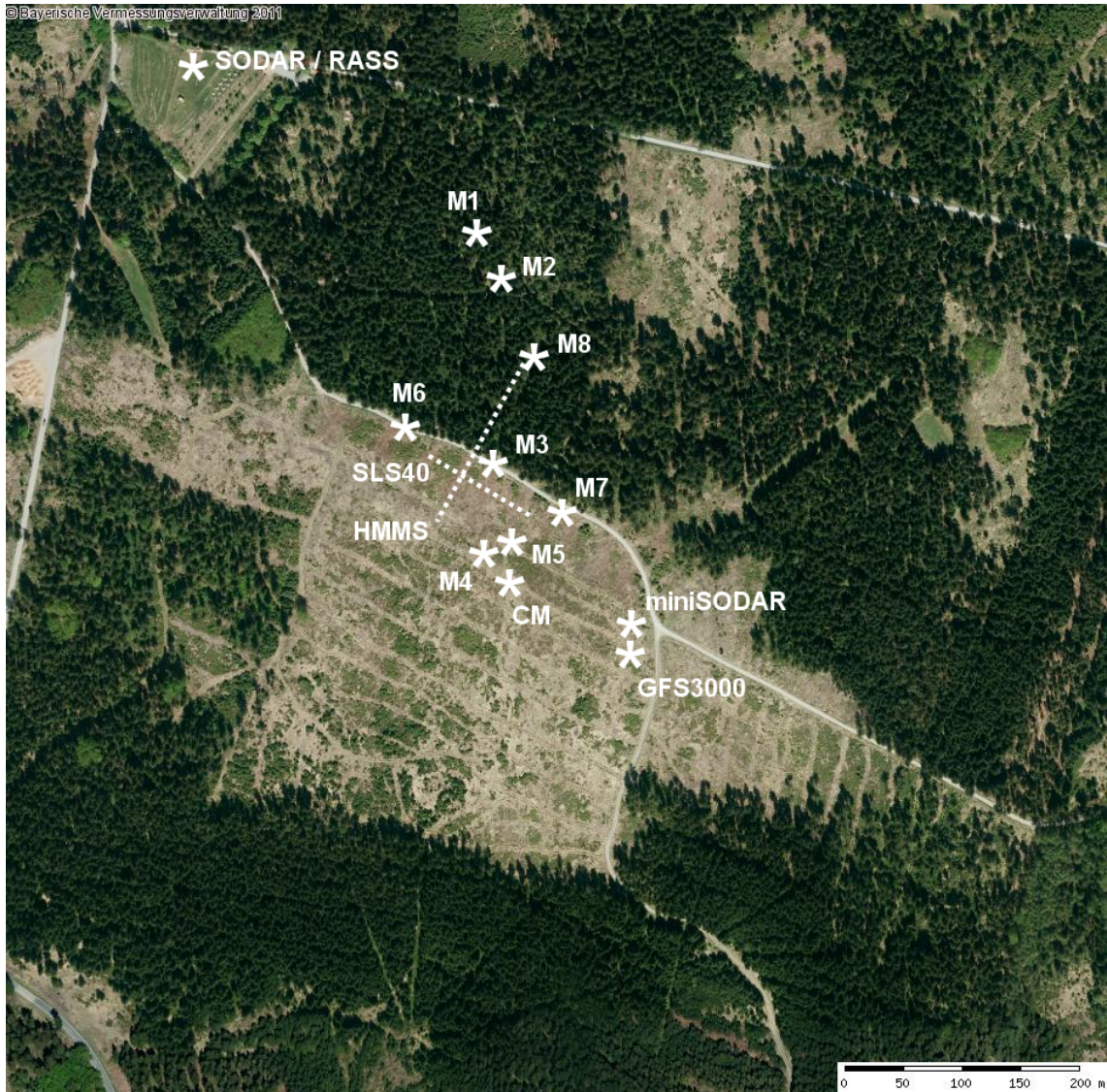
Figure 5.1: Top view on the Waldstein investigation site with all measuring points and exact positions of the main tower M1, the turbulence tower M2, the forest egde tower (Bio tower) M3, the turbulence mast M4, the mast for the Modified Bowen-Ratio Method M4, the turbulence masts M6-M8, the mast for chemical measurements CM, the Laser-Scintillometer SLS-40, the Horizontal Mobile Measuring System HMMS, SODAR/RASS, miniSODAR, and the GFS3000 (leaf gas exchange measurements). For detailed informations look in Serafimovich et al. (2011).

5.2 HMMS during EGER

5.2.1 Layout of the HMMS line

The line of the HMMS passed from the dense spruce forest to the open clearing. For the line a wooden base frame was build. First of all, piles made of oak with length of 1.2 m and 1.5 m were driven into the ground. The choice of the length depends on the character of the ground. In a second step, spruce planks were screwed lateral on both sites of the piles. With the planks an averaged height of 1 m above ground was achieved, plus an alignment with a water spirit level. On the planks 12 mm thick film mounted plywood plates were mounted. On the plywood plates the rails were mounted centric. The total length of the line is 160 m with 5 m currentless rails on both ends. The measuring length is 150 m with the starting point in the forest and the end point on the clearing. To guarantee a break free supply of current, cable were mounted, which fed the rails every 25 m with 24 V DC. At the starting point the bar code "0001" was installed on the left plank. Every meter one bar code was installed till the end point "0150" on the clearing. See Figure 5.2 for the illustration of the layout of the HMMS line.

Figure 5.2: The HMMS on his line during EGER IOP3 in summer 2011. For the declaration of the wooden base frame read the text above.

5.2.2 Adjustments in HMMS software

The possibility of a speed profile between every bar code was not used. All other adjustments are given in Table 5.1.

Table 5.1: Specification of the adjustments in the HMMS software during EGER IOP3.

Specifications	Details
Temperature	
Calibration	100 K/V
Offset	40 K
rel. Humidity	
Calibration	100 %/V
CMP3 topside	
Sensitivity	16.92 µV/W/m^2
Factor of amplification	50-fold
CMP3 bottomside	
Sensitivity	13.70 µV/W/m^2
Factor of amplification	100-fold
CGR3 topside	
Sensitivity	9.25 µV/W/m^2
Factor of amplification	500-fold
CGR3 bottomside	
Sensitivity	11.09 µV/W/m^2
Factor of amplification	500-fold
Bar code scanner	
RS-232 COM	COM1
CO$_2$ sensor	
RS-232 COM	COM2
Ozone detector	
RS-232 COM	COM5
Positions	
Distance between two bar codes	1 m
Bar code starting point	0001
Bar code end point	0150
Numbers of runs[1]	-
Stop at bar code[1]	-
Other settings	
Sampling rate	1 Hz

[1]Possibility of "Stop at bar code" is deactivated.

5.2.3 Operating time of HMMS

In Figure 5.3 the operating time of the HMMS during the EGER IOP3 is shown. In June 2011 the project starts and for the first measurement days the HMMS has no ozone detector (blue lines in Figure 5.3a). At June 24, 2011 the ozone detector was installed on the HMMS. First measurements with the ozone detector were conducted on June 25, 2011 (red lines).
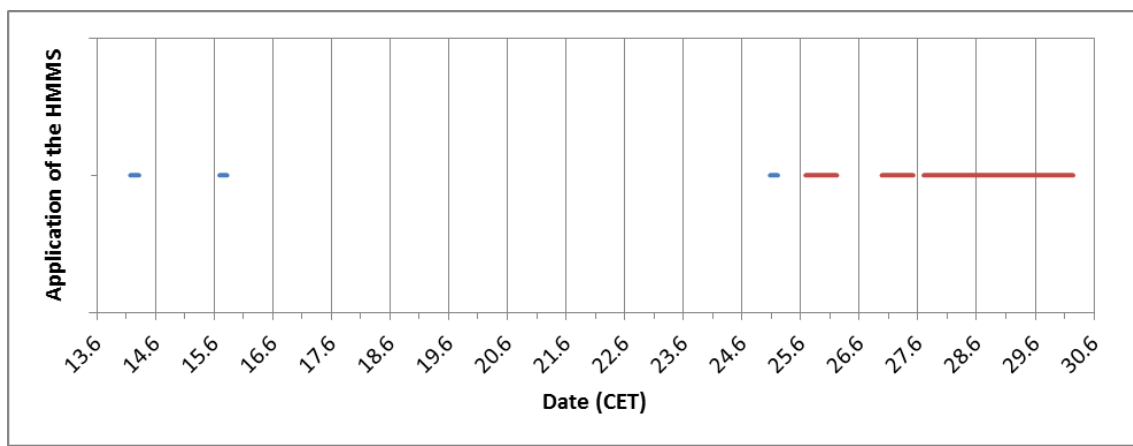
(a) Operating time of the HMMS in June.
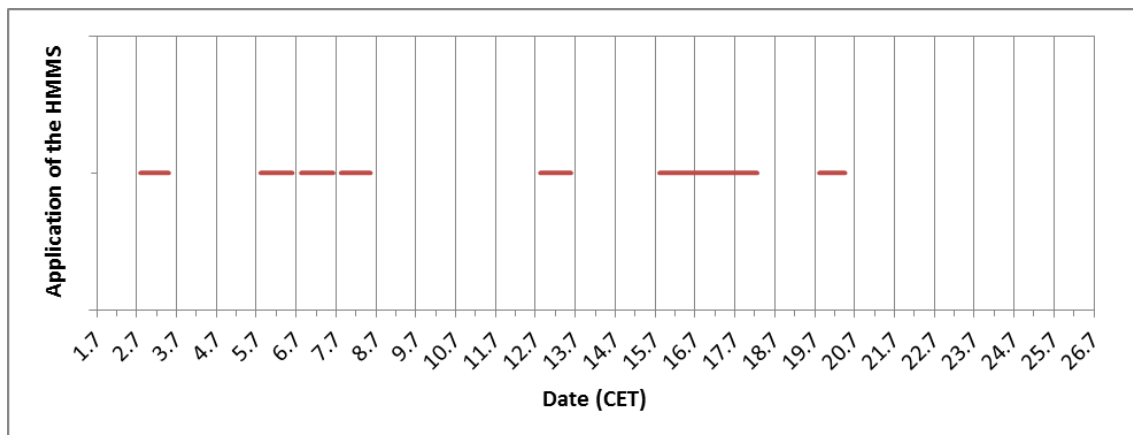
(b) Operating time of the HMMS in July.

Figure 5.3: Operating time of the HMMS during EGER IOP3. Blue lines indicate measurements of the HMMS without the ozone detector from enviscope GmbH and red lines with the ozone detector.

5.2.4 Preliminary results of HMMS measurements

In Figure 5.4 preliminary results for one measurement day (June 26, 2011) with the HMMS are shown. There are eight subplots with daily cycles for each measured quantity. The red line in the subplots indicate the forest-edge in the middle of the HMMS line. Problems with the RS-232 communication between the sensor and the software leads to identical measurement values in the subplots for CO_2 (g) and ozone (h) in the early morning-hours and before lunch time. After a restart of the HMMS software everything works fine. The HMMS software version 1.10 (see chapter 3.3) has an improved stability with the RS-232 connection.

In (a) the daily cycle for the temperature is shown. The plot shows that the lowest temperatures occur during nightime and the highest during daytime on the clearing. The increase of temperature starts on the clearing significantly earlier than in the forest. The rel. Humidity (b) is at nighttime higher on the clearing, than in the forest, at daytime it is reversed.

The short-wave radiation components ((c) and (d)) are very low in the forest, but sunny spots can be seen at different locations and time. In the morning the shadow of the forest edge can be seen in the first 20 m on the clearing. Also the HMMS itself has an influence on the measurements in the morning hours, because of the sensor location on the sun-shaded side. Later in the day, this effect has been disappeared. The long-wave downwelling radiation (e) in the forest is similar to the long-wave upwelling radiation (f) on the clearing, a result of similar temperatures of the surface of the clearing and the top of the forest.

The carbon dioxide concentration (g) has its maximum in the early morning and early evening under very stable situations and the minimum at noon due to assimilation. In both cases the highest and lowest values are on the clearing.

The ozone concentration (h) increases in the afternoon. The increase is mainly a sun induced photochemical production.
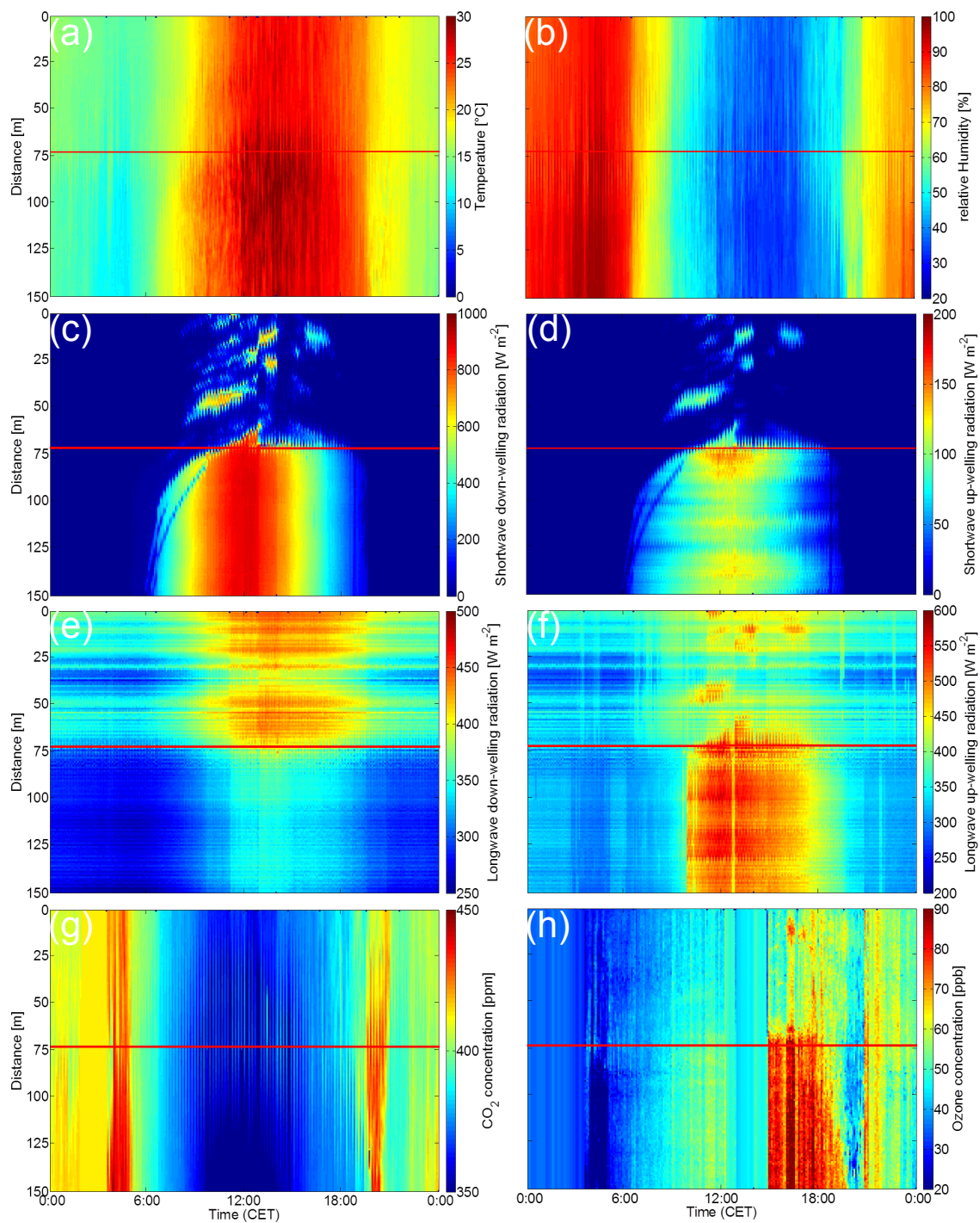
Figure 5.4: Subplots of daily cycles for each quantity at June 26th, 2011. With (a) as the daily cycle for temperature, (b) for rel. humidity, (c) for short-wave downwelling, (d) for short-wave upwelling, (e) for long-wave downwelling, (f) for long-wave upwelling radiation (g) CO_2, and (h) for ozone concentration. The red line indicates the forest-edge. Above the red line the measurements are located in the forest, below on the clear-cutting.

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Appendix

A Detailed specifications of HMMS parts

A.1 DCDC-USB (DC-to-DC-Converter)

Table A.1: Product specifications of DCDC-USB (CarTFT, 2011).

Specifications	Details
Minimum input operating voltage	6 V
Maximum input operating voltage	Electronic shut down at 34 V (clamping will occur at 34-36V)
Deep-Discharge shutdown threshold	11.2 V
Input current limit (fuse protected)	10 A (10 A mini-blade fuse)
Max Output Power	100 W (limited by 10 A input fuse)[1]
Regulation accuracy	2.5 %
Operating temperature/	-40 to +85 ℃
humidity	10 to 90%, non-condensing
Storage temperature/	-55 to +85 ℃
humidity	5 to 95%, non-condensing
MTBF	<100000 hrs @ 65 ℃ body temp
Efficiency (input 9-16 V)	<95% (output = 12 V, 2 A)
PCB dimensions	135 mm x 37mm (W x D)
Input, output connectors	Right angle, Mini-FIT JR 4 pin

[1]At output power greater than 40 W or if unit temperature exceeds 65 ℃, forced air ventilation will be required in order to prevent unit from excessive thermal stress for long period of times.

A.2 Quanmax Qbox-1010 (Micro PC)

Table A.2: Product specifications of Quanmax Qbox-1010 (Quanmax Inc, 2009). With additional specifications for the HMMS.

Specifications	Details
Construction	Aluminum extrusion
System Board	Proprietary motherboard, Intel® Atom N270 Processor , 945GSE / ICH7-M
Memory	DDR2 533 SO-DIMM up to 2 GB
	Front I/O panel
	1x Phone Jack for Line-Out
	1x Phone Jack for MIC-In
	1x Push button for power on/off
	1x Push button for reset
	1x POWER LED
	1x HDD LED
	2x USB2.0
I/O panel	1x eSATA connector
	Rear I/O panel
	1x DC JACK for 12 V DC input
	1x DVI-I connector for CRT & DVI output
	2x USB2.0
	1x RJ-45, GbE port
	2x DB9 male connectors for COMs
	(2x RS-232/422/485, 5 V/12 V voltage selected by BIOS setting)
	1x DB9 female connector for digital I/Os
Storage	1x 2.5" SATA HDD or 1x Internal Compact Flash Type II slot
Power Supply	Input: 100-240 V AC, 50-60 Hz
	Output: 30 W, 12 V DC , 2.5 A
Expansion Slot	None
Cooling	Fanless and Internal Heat Pipes
Temperature/	Operating: 0 ℃ to 35 ℃, 0 %-90 %, non-condensing
Humidity	Storage: -20 ℃ to 80 ℃, 0 %-90 %, non-condensing
Dimensions	130 x 40 x 110 mm (W x H x D)
Weight	750 g
Mounting	Desktop, VESA-mount, DIN-Rail mount
Certification	CE, FCC Class A
Additional detailed specifications HMMS:	
Operating system	Windows 7 Professional 32-bit

Specifications	Details
Storage	250 GB 2.5" SATA HDD
External Monitor	CTF400 - VGA 7" TFT
External Keyboard/ Mouse	CTFWIKE-2 Wireless RF-keyboard with Trackball (10m range) [DE-Layout]

A.3 National Instruments USB-6211 (i/o controller)

Table A.3: Product specifications of National Instruments (NI) USB-6211 (National Instruments Corporation, 2011).

Specifications	Details
General:	
Product Family	Multifunction Data Acquisition
Form Factor	USB
Operating System/Target	Linux , Mac OS , Windows
DAQ Product Family	M Series
Measurement Type	Voltage
RoHS Compliant	Yes
Analog Input:	
Channels	16 , 8
Single-Ended Channels	16
Differential Channels	8
Resolution	16 bits
Sample Rate	250 kS/s
Max Voltage	10 V
Maximum Voltage Range	-10 V, 10 V
Maximum Voltage Range Accuracy	2.69 mV
Maximum Voltage Range Sensitivity	91.6 µV
Minimum Voltage Range	-200 mV, 200 mV
Minimum Voltage Range Accuracy	0.088 mV
Minimum Voltage Range Sensitivity	4.8 µV
Number of Ranges	4
Simultaneous Sampling	No
On-Board Memory	4095 samples
Analog Output:	
Channels	2

Specifications	Details
Resolution	16 bits
Max Voltage	10 V
Maximum Voltage Range	-10 V, 10 V
Maximum Voltage Range Accuracy	3.512 mV
Minimum Voltage Range	-10 V, 10 V
Minimum Voltage Range Accuracy	3.512 mV
Update Rate	250 kS/s
Current Drive Single	2 mA
Current Drive All	4 mA
Digital I/O:	
Bidirectional Channels	0
Input-Only Channels	4
Output-Only Channels	4
Number of Channels	4, 0
Timing	Software
Logic Levels	TTL
Input Current Flow	Sinking
Output Current Flow	Sourcing
Programmable Input Filters	No
Supports Programmable Power-Up States?	Yes
Current Drive Single	16 mA
Current Drive All	50 mA
Watchdog Timer	No
Supports Handshaking I/O?	No
Supports Pattern I/O?	No
Maximum Input Range	0 V, 3.8 V
Maximum Output Range	0 V, 5.25 V
Counter/Timers:	
Counters	2
Buffered Operations	Yes
Debouncing/Glitch Removal	Yes
GPS Synchronization	No
Maximum Range	0 V, 5.25 V
Max Source Frequency	80 MHz
Pulse Generation	Yes
Resolution	32 bits
Timebase Stability	50 ppm
Logic Levels	TTL

Specifications	Details
Physical Specifications:	
Dimensions	169 x 31 x 94 mm (W x H x D)
I/O Connector	Screw terminals
Timing/Triggering/Synchronization:	
Triggering	Digital

A.4 Sick CLV412-1010 (bar code scanner)

Table A.4: Product specifications of bar code scanner Sick CLV412-1010 (SICK AG, 2006).

Specifications	Details
Type	Raster scanner CLV412-1010
Focus	Fixed focus
Reading window	Line/raster scanner: front
Laser diode (wavelength)	Red light ($\lambda = 670$ nm)
MTBF of laser diode	20,000 h
Laser class	Class 2 (pursuant to EN 60825-1)
Useful aperture angle	Max. $60°$ (front reading window)
Scanning/decoding frequency	200 to 800 Hz
Resolution	0.1 to 0.2 mm
Raster height	15 mm (8 lines) at a reading distance of 200 mm (front reading window)
Bar code print contrast (PCS)	$\geq 60\%$
Immunity to ambient light	2,000 lx (on bar code)
No. of bar codes per scan	1 to 3
No. of bar codes per reading interval	1 to 10
Bar code types	Code 39, Code 128, Code 93, Codabar, EAN, EAN 128, UPC, 2/5 Interleaved, Pharmacode
Bar code length	Max. 50 characters (max. 100 characters across all bar codes per reading interval)
Print ratio	2:1 to 3:1
No. of multiple reads	1 to 99
Optical indicators	4 x LEDs (status indicators)
Acoustic indicator	Beeper, can be deactivated and assigned to a function for result status indication
Reading pulse	Reflector Polling/"Sensor 1" switching input/free running/serial interface

Specifications	Details
"Host" data interface	RS-232 and RS-422/485, variable data output format
Data transfer rate	300 to 57,600 Bd
Protocols	SICK Standard, SICK Network (RS-485)
Physical configurations	Stand-alone, SICK Network
Switching inputs	2 ("Sensor 1", "Sensor 2")
Switching outputs	3 ("Result 1", "Result 2", "Result 3")
Electrical connection	15-pin D Sub HD connector, cable length 0.9 m
Operating voltage/power consumption	5 to 30 V DC[1]/max. 3 W
Housing	Cast zinc die-cast, does not represent a problem in paint shops
Enclosure rating/protection class	IP 65 (to DIN 40 050)/Class 3 (to IEC 1010-1)
EMC/vibration/shock tested	To EN 61000-6-3, EN 61000-6-2/to IEC 68-2-6 Test FC/to IEC 68-2-27 Test EA
Weight	250 g with connecting cable (front reading window)
Operating/storage temperature	0 to +40 ℃/-20 to +70℃
Max. rel. humidity	90 %, non condensing
Colour	SICK blue (RAL 50129)

[1]UL certificated when a class 2 power supply according to UL 1310 is used.

B Detailed specifications of HMMS sensors

B.1 Vaisala HMP155

Configuration code of the HMP155

The configuration code for the HMP155 device on the HMMS is: "A2GB11A0A1A1A0A"

HMP155 Humidity and Temperature Probe   with voltage or RS485 output for temperature

				1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Vaisala HUMICAP® Humidity and Temperature Probe		HMP155	A 2 G B 1 1 A 0 A 1 A 1 A 0 A Price	
1. Probe type	2 x voltage output (RS485 for service use)		A	
	RS485 serial output		E	
2. Signal output selection	RS485 serial output (only for probe type E)		1	
	0...1 V output		2	
	0...5 V output		3	
	0...10 V output		4	
3. Analog output signal for CH1	None (RS485 output used)		A	
- Choose option A, if no T output	T (-40...+60 ℃)	(-40...+140 ℉)	G	
is desired, or output is RS485	T (-80...+60 ℃)	(-112...+140 ℉)	J	
4. Analog output signal for CH2	None (RS485 output used)		A	
	RH	(0... 100%RH)	B	
- Choose option A, if	Td (-60...60℃)	(-76...+140 ℉)	C	
output is RS485	Tdf (-60...60℃)	(-76...+140 ℉)	D	
	Tw (0...60℃)	(+32...+140 ℉)	E	
	x (0...200g/kg d.a)	(0...1400 gr/lb)	F	
5. Units	Metric		1	
	Non-metric		2	
6. Humidity sensor type	General purpose	HUMICAP180R	1	
	Composite sensor	HUMICAP180RC	2	
	General purpose	HUMICAP180	3	
	Composite sensor	HUMICAP180C	4	
7. Heating options	None		A	
- See note (*) below!	Warmed probe (only with composite sensor)	RH&T outputs only with Additional Temperature probe	B	
	Warmed probe with Xheat (only with composite sensor)	RH&T outputs only with Additional Temperature probe	C	
8. Chemical purge	None		0	
	Periodical (only with composite sensor)		1	
	Start-up (only with composite sensor)		2	
	Both periodical & start-up (only with composite sensor)		3	
9. Sensor protection	Sintered Teflon filter	item: 219452SP	A	
	Membrane filter	item: 230727SP	B	
0. Probe cable length	No cable (no counter connector)		0	
	3.5 m (with 8 pin M12 female connector)	item: 220496	1	
	10 m (with 8 pin M12 female connector)	item: 220497	2	
	30 m (with 8 pin M12 female connector)	item: 220498	3	
1. Additional Temperature probe	None		A	
	Additional T-probe with 2 m cable		B	
2. Calibration	At room temperature		1	
3. PC-Accessories	None		A	
	PC connection cable (USB)	Item: 221040	B	
	MI70 connection cable	Item: 221801	C	
	PC connection cable (USB) & MI70 connection cable		D	
4. Installation accessories	None		0	
	Installation kit to Stevenson screen	Item: 221321	1	
	Additional T-probe installation part to DTR502	Item: 221072	2	
	Additional T-probe installation part to DTR13	Item: 221069	3	
5. (For production use only)			A	

Figure B.1: Configuration code of the HMP155 with voltage or RS-485 output for temperature. Red circled numbers/letters fulfill our requirements.

Specifications of the HMP155

Table B.1: Product specifications of Vaisala HMP155 Humidity and Temperature Probe (Vaisala Oyj, 2008).

Specifications	Details
Performance	
RELATIVE HUMIDITY	
Measurement range	0 . . . 100 %RH
Accuracy (incl. non-linearity, hysteresis and repeatability) at:	
+15 . . . +25 ℃	±1 %RH (0 . . . 90 %RH)
	±1.7 %RH (90 . . . 100 %RH)
−20 . . . +40 ℃	±(1.0 + 0.008 · reading)%RH
−40 . . . −20 ℃	±(1.2 + 0.012 · reading)%RH
+-40 . . . +60 ℃	±(1.2 + 0.012 · reading)%RH
−60 . . . −40 ℃	±(1.4 + 0.032 · reading)%RH
Factory calibration uncertainty (+20 ℃):	±0.6 %RH (0 . . . 40 %RH)[1]
	±1.0 %RH (40 . . . 97 %RH)[1]
Recommended humidity sensor	HUMICAP® 180R(C)
Response time at +20 ℃in still air with a sintered PTFE filter [2]	
63 %	20 s
90 %	60 s
TEMPERATURE	
Measurement range	-80 . . . +60 ℃
Accuracy with voltage output at:	
−80 . . . +20 ℃	±(0.226 − 0.0028 · temperature) ℃
+20 . . . +60 ℃	±(0.055 + 0.0057 · temperature) ℃
Temperature sensor	Pt100 RTD 1/3 Class B IEC 751
Response time with additional temperature probe in 3 m/s air flow [2]	
63 %	< 20 s
90 %	< 35 s
General	
Operating temperature range	−80 . . . +60 ℃
Storage temperature range	−80 . . . +60 ℃
Connection	8-pin male M12 connector
Connection cables	3.5, 10, and 30 m
Cable material	PUR
Wire size	AWG26
Housing material	PC

Specifications	Details
Housing classification	IP66
Sensor protection	sintered PTFE
Weight (probe)	86 g
Inputs and Outputs	
Operating voltage	7 . . . 28 V DC
Note: minimum operating voltage 12 V with 0 ... 5 V output and 16 V with 0 ... 10 V output	
probe heating, chemical purge or XHEAT.	
Outputs	
voltage output	0 . . . 1 V
resistive Pt100 (4-wire connection)	
Average current consumption (+15 V DC, load 100 kOhm)	
0 . . . 1 V output	< 3 mA
Settling time at power-up	
voltage output	2 s

[1]Defined as ± 2 standard deviation limits. Small variations possible, see also calibration certificate.

[2]This response times differ from the individual repsonse times measured with the HMP155 on the HMMS. Compare with chapters 4.1.1 and 4.4.

B.2 Kipp & Zonen CGR3/CMP3

Table B.2: Product specifications of Kipp & Zonen short-wave/long-wave radiation sensors CMP3/CGR3. (Kipp & Zonen, 2011a,b).

Specifications	Details	
	CMP3	CGR3
Spectral range	300 . . . 2800 nm	4500 . . . 42000 nm
Response time @ 95%	< 18 s	< 18 s
Non-linearity	0 . . . 1000 W/m^2: < 1 %	$- 250 . . . 250$ W/m^2: < 1 %
Temperature dependency	$- 10$ ℃ . . . $+ 40$ ℃: < 5 %	$- 40$ ℃ . . . $+ 40$ ℃: < 5 %
		$+ 40$ ℃ . . . $+ 80$ ℃: < 10 %
Sensitivity	5 . . . 20 µm/W/m^2	5 . . . 15 µm/W/m^2
Operating temperature	$- 40$ ℃ . . . $+ 80$ ℃	$- 40$ ℃ . . . $+ 80$ ℃
Maximum solar irradiance	2000 W/m^2	
Field of view	180 °	150 °
Directional error	Up to 80 ° with 1000 W/m^2 beam:	
	< 20 W/m^2	
Tilt error	@ 1000 W/m^2: < 2 %	< 2 %

Specifications	Details	
	CMP3	CGR3
Zero offset	A: 200 W/m^2 FIR: $<$ 15 W/m^2	dt = 5 K/h: $<$ 5 W/m^2
	B: dt = 5 K/h: $<$ 5 W/m^2	
Non-stability (change/year)	$<$ 1 %	$<$ 1 %
Uncertainty in daily total	$<$ 10 %	
Window-heating offset		with 1000 W/m^2 global radiation:
		$<$ 15 W/m^2

The CGR3 is equipped with the optional PT100 temperature sensor.

B.3 Edinburgh Instruments Ltd. Gascard® NG CO$_2$ 1000 ppm

Table B.3: Product specifications of Edinburgh Instruments Ltd. Gascard® NG CO$_2$ 1000 pm (Edinburgh Instruments Ltd. 2011).

Specifications	Details
Range	0 . . . 1000 ppm CO$_2$[1]
Accuracy	$\pm$ 2 % of range $\pm$ $<$ 0.015 % of range per mbar[2]
Stability	$\pm$ 2 % of range (over 12 months)[2]
Response time	Bitswitch selectable T90 = 10 seconds or programmable RC
Operating temperature	0 . . . 45 ℃
Operating pressure	800 . . . 1050 mbar
Power requirements	24 V DC (7 . . . 30 V DC)
Warm-up time	1 minutes (initial) 30 minutes (full specification)
Humidity	Measurements are unaffected by 0 . . . 95 % relative humidity, non condensing
Output	Linear 4 . . . 20 mA, 0 . . . 20 mA (bit switch selectable) maximum load dependant on supply voltage

[1]Stability specification does not apply.

[2]Not including calibration gas tolerance.

B.4 Enviscope Fast Ozone Detector

Table B.4: Product specifications of enviscope GmbH fast ozone detector (enviscope GmbH, 2011).

Specifications	Details
Sample flow 1 ... 3 L/min	$\sim$ 0.5 %/Hz at 10 ppbv
	$\sim$ 0.25 %/Hz at 50 ppbv
	$\sim$ 0.1 %/Hz at 200 ppbv
Sample flow > 3.5 L/min	$\sim$ 0.5 %/Hz at 10 ppbv
	$\sim$ 0.4 %/Hz at 50 ppbv
	$\sim$ 0.35 %/Hz at 200 ppbv
Analog output signal	0 ... 2.5 V DC
Additional output signal	RS-232
Maximum measuring frequency	50 Hz
Power consumption	< 10 W at 9 ... 36 V DC
Flow[1]	Fan integrated
Tube fittings	3/8 inch PFA tubes
Operation temperature	<50 °C(reading of internal temperature)
Weight[1]	2.8 kg
Dimensions ozone detector[1]	133.4mm (3U) x 214 mm x 231 mm
(without optional housing)	

[1]Details are changed for the requirements of the HMMS. Please read chapter 4.1.4.

B.5 Logitech HD Webcam C310

Table B.5: System requirements to use the webcams Logitech HD Webcam C310.

Specifications	Details
OS	Windows® XP (SP2 or higher), Windows® Vista, Windows® 7 (32 or 64-bit)
Minimum requirements:	
Processor	1 GHz
RAM	512 MB RAM or more
HDD	200 MB hard drive space
Internet connection	yes
USB	USB 1.1 port (2.0 recommended)
For HD 720p video calling and recording:	
Processor	2.4 GHz Intel® Core™2 Duo

Specifications	Details
RAM	2 GB RAM
HDD	200 MB hard drive space
Internet connection	1 Mbps upload speed or higher
USB	USB 2.0 port
Screen resolution	1280 x 720 dpi

B.6 Devantach Ltd. SRF02 Ultrasonic Distance Sensor

Table B.6: Specifications of the SRF02 ultrasonic distance sensor from Devantech Ltd.

Specifications	Details
Voltage	5 V (stabilized)
Current	4 mA
Frequency	40 KHz
Range	15 cm . . . 6 m
Analogue Gain	Automatic 64 step gain control
Connection Modes	1 - Standard I2C Bus
	2 - Serial Bus - connects up to 16 devices to any uP or UART serial port
Full Automatic Tuning	No calibration, just power up and go
Timing	Fully timed echo, freeing host controller of task
Units	Range reported in uS, mm or inches
Light Weight	4.6 g
Small Size	24 mm x 20 mm x 17 mm

C Sample Data file of HMMS

C.1 Data file with raw voltages

Filename: 06_07_2011 03_02_00_inV.txt

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    PT100oben[K],PT100unten[K],CO2[ppm],CellTemp[°C],Pressure[mbar],O3[count],Ultraschall unten [m],v[m/s],Richtung,Barcode
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C.2 Data file with calculated values

Filename: 06_07_2011 03_02_00.txt

Time,T[°C],rF[%],GlbST[Wm-2],RflST[Wm-2],GegST[Wm-2],AusST[Wm-2],PT100oben[K],PT100unten[K],...
CO2[ppm],CellTemp[°C],Pressure[mbar],O3[count],Ultraschall unten [m],v[m/s],Richtung,Barcode
2011-07-06 03:02:00.000,11.4,99.9,-4.9,-20.5,336.7,333.3,287.2,287.6,461.5000,42.6,916.9,4117.0,-,0.0,-
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D Contact Software engineer - GAF

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