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Application note

Compact_Eddy: A compact, low consumption remotely controlled eddy covariance logging system

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ABSTRACT

Compact_Eddy is a handheld computer-based logging system developed for eddy covariance installations. It is flexible to support different types of sonic anemometers, it has storing capability on internal memory, and data processing capability. The software is written in the Visual Basic .NET platform, entirely based on standard Windows operating systems thus allowing easy installation and configuration for a wide range of handheld PCs. The software computes half hourly statistics and fluxes with a simplified procedure, stores binary data with efficient memory usage and can be configured to send periodically, to a remote control station, system status information and basic computations using a GSM modem. The use of a handheld computer resulted in an average real conditions power consumption of 2.9 W, very low if compared with other standard logging devices, allowing important savings especially when systems are powered with solar panels in remote areas. Compact_Eddy has been installed and tested in three locations, with very different environmental conditions ranging from eastern European mountain forests to African semi-desertic areas. The field results demonstrated that the system operated reliably, resulting to be a good low-cost alternative to laptop computers and dataloggers.

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1. Introduction

In the recent years, eddy covariance has emerged as an important and powerful methodology to measure and assess surface exchange of energy, mass and momentum. In the frame of biogeosciences, such a technique is today widely applied to assess ecosystem carbon and energy exchange (Balocchi, 2003), in different ecosystem types, environmental and climatic conditions. A world-wide network of measurement sites, called FluxNet (http://daac.ornl.gov/FLUXNET/) has been established and is continuously growing in size. Effort has been put since the early 1990s to produce a common design for an eddy covariance system (Moncreiff et al., 1997). In brief, such a flux system is composed of a sonic anemometer to measure 3D wind components at high frequency, an infrared gas analyzer (IRGA) to measure carbon dioxide and water vapour concentrations, and a device for real time data acquisition and processing. Important issues in eddy covariance installations are low power requirement, low system failures, and a reliable and flexible data logging and processing system. Typically, the data logging and processing system is a laptop computer (Moncreiff et al., 1997; University of Edimburgh, 2005) or a datalogger (Campbell Scientific, 2004). The first has usually a higher power consumption (Van der Molen, 2006),

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while the second has much higher costs. To solve these disadvantages, we have developed a new eddy covariance logging system device named Compact_Eddy based on a handheld, serial communication interfaces, wireless Bluetooth and GSM devices, interfaceable to a wide range of sonic anemometers. The usage of handheld PCs for eddy covariance installations has been recently proposed also by Van der Molen et al. (2006), who developed a custom Linux-based software for specific handheld PCs. Our system is instead entirely based on standard and commercial operating systems (Microsoft Windows CE and Windows Mobile series) allowing an easy installation and configuration for the end user, as well as the flexibility to use the totality of handheld PCs with basic capabilities, which are almost entirely based on such Windows OS. Moreover, Compact_Eddy has the capability for the user to remotely control the status of the installation and receive some basic processed data through SMS transmission. The objective of this paper is to describe the system and its performance and limitations in different environmental conditions, and to highlight the installation setups that mostly could benefit from this type of architecture.

2. Technical details

2.1. *The palm hardware*

The systems described in this paper and tested in the field are based on a handheld PC with double slot for CompactFlash card (CF) and SecureDigital card (SD), and Bluetooth connectivity capability. The system (Fig. 1) was developed using Hewlett-Packard iPAQ hx2100 series unit. A Quatech serial Compact Flash adapter (mod SSCF-100 or DSCF-100), or alternatively a Socket Serial I/O Compact Flash Card (mod. SL2700-096) were used to implement a physical serial port on the palm unit, to be connected to the anemometer serial port. A second serial port was made available trough a Socket Bluetooth RS-232 adaptor, to be connected to a GSM modem (Audiotel, mod GPRS Base), that is used to send periodic SMS. The handheld system and the GSM modem are powered at 12VDC. Logged data are stored in real time on the palm internal 64 MB memory, while every half hour they are transferred and stored on the SDcard that can be easily removed to download data without system interruptions. A complete list of all the system hardware components is reported in Table 1.

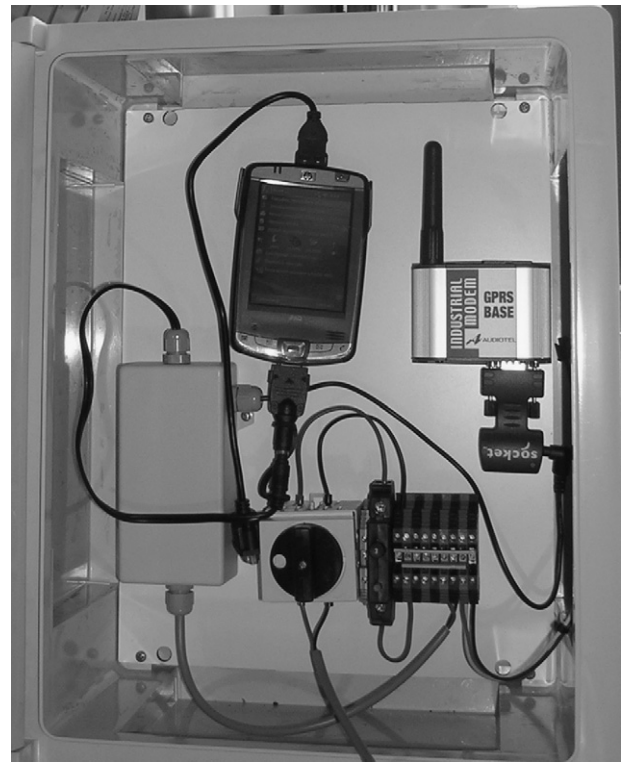

Fig. 1 – The hardware of the system.

2.2. *The eddy covariance installation and processing scheme*

Typically eddy covariance installations are based on a sonic anemometer that has a built in analog to digital converter, thus analog signals coming from IRGAs are digitally converted and synchronized with the 3D wind data. This capability is present in all the supported anemometers and is a prerequisite for our system. Supported anemometers are Young 81000V, Metek USA-1, Gill WindMaster Pro and Gill Solent R3. Infrared gas analyzers for CO_2 and H_2O flux measurements can be either closed or open path systems, with the latter becoming more widely used because of their simplicity, low power demand, and limited maintenance, despite of a lower absolute accuracy. Since Compact_Eddy has been especially designed for remote installations that require solar panels to power the devices, the real time processing software supports exclusively open path IRGAs. Nevertheless, the system

Table 1 – Logging system components and power requirement

Component	Brand and model	Description	Power consumption (W)
Handheld computer	HP iPAQ series hx2100	24 MB internal memory, touchscreen	2.5
Serial card	Quatech (mod SSCF-100 or DESF-100) or Socket (mod SL2700-096) serial adapter	Add one serial port	
Secure digital card	SanDisk	1 GB	
Bluetooth device	Socket Bluetooth RS-232 adaptor	Add one serial port	0.05
Modem GSM	Audiotel modem GSM GPRS base	GPRS	0.36

is flexible to store any type of analog signal taken from the anemometer, thus its usage with closed path systems as logging device is possible. The post-processing of eddy covariance data is a difficult and complex task, that takes into account many factors, some of which are site-dependent, and is continuously evolving (Massman and Lee, 2002). It is beyond the scope of this system to provide a full post-processing environment for such measurements, while a simplified processing scheme has been implemented to derive real time flux data and basic statistics. Such processing routines are based on the so-called Euroflux methodology (Aubinet et al., 2000), with the addition of Webb Pearman Leuning correction for open path IRGAs (Webb et al., 1980), and without any flux loss spectral correction applied.

2.3. *The Compact_Eddy software interface*

The logging and processing software is written in the Microsoft Visual Basic .NET programming language and operates on a number of operating systems, including Microsoft Windows Mobile 5.0 and all the older version of Microsoft Windows CE. Source code is available upon request. The software is designed to store the raw data received from the sonic anemometer without modification for further analysis and computation, as recommended because of continuously evolving post-processing procedures (Aubinet et al., 2000). Instantaneous measurements are logged from the anemometer serial port, typically at 10 or 20 Hz logging frequency. Half hourly means and flux computations are showed on the palm screen, allowing the user to check proper functioning of the system in the field. The software can be used with the following anemometer types: Metek, Young, Gill Windmaster Pro and Gill Solent R3. However, knowing the output string of the anemometer, the software can be easily updated and used with other anemometer type. Before starting the software for the first time, it is necessary to configure the system by editing an ASCII setting file on the internal palm memory. This file contains information on site name, measurement height, serial port settings, sampling rate, type of anemometer, the number of analog channels connected to the anemometer and their scaling, number of half hours to be sent by SMS and telephone number of the receiving station. After starting the software, the data are acquired and stored in hourly binary files on the SD card. Half hourly fluxes (Net Ecosystem Exchange, latent and sensible heat, momentum), air temperature and humidity, and wind speed and direction are computed, showed on the palm screen (Fig. 2) and sent as SMS to the specified telephone number to allow the user to check the eddy installation remotely. Furthermore, this elaborated data are stored in a daily text file on the memory card. Data retrieval is easily accomplished by removing the memory card and replacing it with a new one. A 1-GB SD card memory can hold about 40 days of data with a sampling rate of 20 Hz. The acquisition of additional LI-7500 parameters needed for raw data post-processing and flux corrections (i.e. AGC, pressure) is performed using a SDM connection to a Campbell Scientific Datalogger (CR-1000; see LI-7500 user manual for more information) which is used for the acquisition of slow sensors signals (i.e. radiation sensors). The acquisition frequency is at a frequency is 0.1 Hz and half-hourly average is then computed.

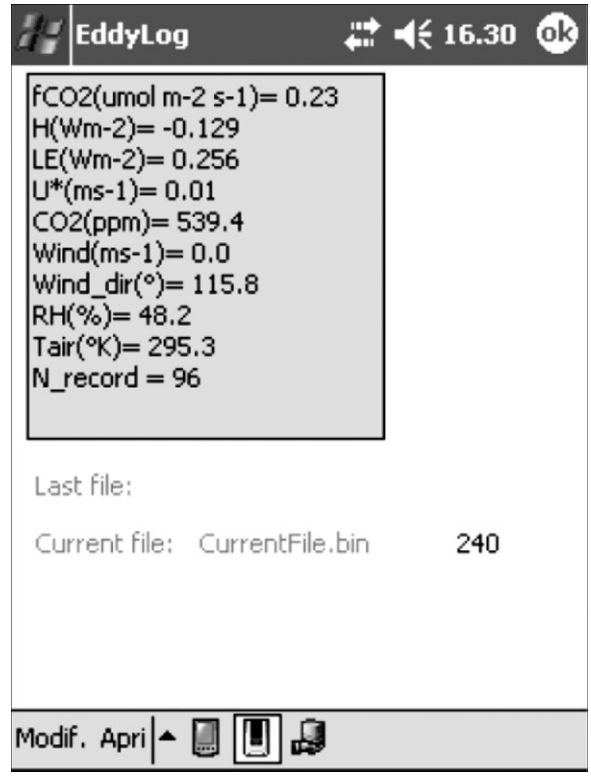

Fig. 2 – Screen half hourly output.

3. Test results

The Compact_Eddy device has been tested in three different locations and by different research groups. The first test site is located in Lecceto (Siena, Italy), in a mixed forest in the central part of Tuscany (Italy) at 300 s.l.m. (43°18′13.7″N, 11°16′13.7″E) with a Metek USA-1 anemometer and Licor LI-7500 IRGA, starting from August 2005, with a typical temperature range of −5 to +30 °C. The second site is located in the High Tatra Mountains (Slovakia Republic) at 1100 s.l.m. (49°09′37.3″N, 20°15′03.7″E) with a Metek USA-1 anemometer and Licor LI-7500 IRGA starting from September 2005, with temperatures in winter season lower than −20 °C. The third site is in Demokeya (Sudan) (13°28′29″N, 30°47′83″E) with a Gill Solent R3 anemometer and Licor LI-7500 IRGA starting from March 2007, with temperatures as high as +40 °C. These installations allowed the evaluation of system performance in a wide range of experimental conditions, especially in terms of extreme air temperatures. The results are focused on system real power consumption, system failures number, and simplified processing procedure reliability evaluation. Power consumption was monitored in the lab on all the installed devices, and resulted in an average consumption of the handheld with associated devices and accessories of 2.9 W. The overall stability and robustness of Compact_Eddy has been evaluated by the number of failures occurring to the logger device. The results are shown in Table 2, confirming an over-

Table 2 – Number of failures at the test sites

Site	Test period	Number of failures	Number of failures per month
High Tatra Mountains (Slovakia Republic)	19/07/2006–31/12/2006	3	0.54
Demokeya (Sudan)	07/07/2007–09/08/2007	0	0
Lecceto - Siena (Italy)	19/07/2006–31/12/2006	4	0.72

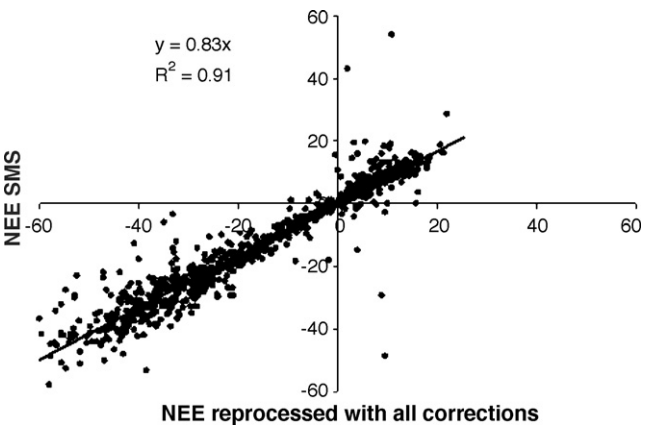

Fig. 3 – CO_2 fluxes (μmol m^{-2} s^{-1}) calculated with the Compact_Eddy simplified procedure compared with the same fluxes calculated according to state of the art methodology.

all good performance, also in critical conditions. The number of failures on the more extreme sites of Tatra and Sudan is even lower than what was observed in the Italian site. Average number of failures per month across the three sites has been 0.42. Almost all the failures were caused by voltage spikes on the power line which freezed the handheld and stopped data acquisition. The modem allowed the users to remotely control the status of the system and, because no SMS were received after system failure occurs, a field visit allowed to solve the failure by reset the handheld PC. Moreover, a comparison between fluxes computed by the Compact_Eddy software and fluxes calculated with all the necessary corrections has been performed to evaluate the overall reliability of the real time flux computations that are sent as SMS (Fig. 3). A flux underestimation was obtained with Compact_Eddy software (slope value of 0.83), that can be related to missing flux loss corrections, including sensor separation, instrument response time, and low frequency contribution (Aubinet et al., 2000).

4. Conclusions

Compact_Eddy is an eddy covariance logging system which has been shown to be reliable and low power consumption when compared to laptop computers. Real power consumptions were monitored and resulted in an average of 2.9 W, that is very low if we compare it with others logging systems like desktop PC or laptop PC, that have a power consumption of about 200 W, and about 30/60 W, respectively. Since those systems are usually installed in the field and supplied with solar power, the resulting savings in number of batteries and solar panels can be very relevant, both in terms of installation and maintenance costs. The system operated in different environmental conditions without major problems, working properly at a wide range of air temperature (−20 to +40 °C), with different anemometer types sampling at different rates, and left un-attended for several months. Overall, this system allows the installation of eddy covariance stations in remote locations with difficult environmental conditions. The flux processing simplified procedure that is included in the software permits to obtain an overall figure of the flux magnitudes at the site, as well as a functionality status of the remote station. Of course scientific and more detailed analysis cannot be based on such processed data, but raw data stored in the internal memory can be reprocessed according to state of the art methods.

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