Research Solar Power Boat – Data Management and Online Visualization

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***Abstract*—The solar power boat of the Faculty of Electrical Engineering and Information Technology, HTWG-Konstanz, University of Applied Sciences, Konstanz, Germany is driven by an electrical motor whose energy is solely provided by photovoltaic cells. Since long-time performance of photovoltaic cells and batteries in a marine application is unknown, an Information-Management-System (IMS) was developed to collect all relevant data from cells, batteries, motor and environment. Periodically the data is sent via internet to the main data store at the institute where it is processed and made available in a web page. Thus real-time data can be observed online as well as graphically displayed as a function of time. Communication on board is done via CAN-Bus. For the skipper, real-time data is also displayed in numeric and graphical form.**

***Index Terms*—data management, LabVIEW, online visualization, photovoltaic cell, solar boat**

I. Introduction

The research solar power boat "Korona" , Fig. 1, is driven by a three-phase asynchronous electrical motor whose energy is solely provided by 9 m^2 of photovoltaic cells with ten car-batteries as storage medium. Hull and propeller are especially designed to combine optimum driving characteristics with efficient use of energy [1].

Fig. 1: Solar boat "Korona"

Manuscript received March 1, 2007.

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Following research goals were defined:

1) Analysis of long-time behavior of photo voltaic cells and batteries in marine application. The main question to be answered is: will photovoltaic cells be a viable option as energy source in recreational boating.

2) Comparison of energy demand versus energy supply profile. Energy profiles for most areas in the world are available; however, energy demand profiles for recreational boating are unknown. Here the question of the required amount of photovoltaic cells and batteries has to be answered.

3) Confirmation of existing models of energy chain components. The faculty is traditionally involved in research activities concerning regenerative energy. Extensive work has been done on Matlab/Simulink [2] simulation models of complete energy chains for various applications [3], [4]. Component models are first created according to theory and then have to be confirmed by experimental data.

4) Development and implementation of an intelligent energy management system. Energy is provided by the current energy content of the batteries and the irradiance of the photovoltaic cells. Energy demand is defined by the current to the motor which itself is dependent on the speed of the boat; the energy demand increases approximately with the third order of the speed. A situation can arise, where a destination can not be arrived at because of lack of energy (batteries empty). Based on current position given by GPS and the calculated distance to destination, the intelligent energy management provides the skipper with the information of the likelihood of arriving at the destination; it makes proposals for the optimum speed.

In order to achieve the above stated goals, the following requirements for an Information-Management-System (IMS) were established: (1) availability of all measured and calculated data for on-board staff, (2) availability of all measured and calculated data online for off-board staff, (3) storage of data in a main store for a period of 10 years and (4) provision of a tool for online graphical analysis of stored data.

II. On-Board Sensors

In Fig. 2 all sensor connections to the on-board IMS are shown in simplified view. The lower part represents the energy chain, starting from the left with the photovoltaic cells (PV-Generator) as energy source. A DC-DC-Converter adjusts the voltage of the cells, about 450 V, to the voltage of the battery pack, consisting of ten conventional car batteries. The batteries function as energy storage medium. A special photovoltaic cell gives reference values for irradiation and cell temperature. Energy user is the asynchronous 3-phase motor with attached propeller. A DC-AC-Converter provides the necessary adaptation of the battery voltage to the motor electronics.

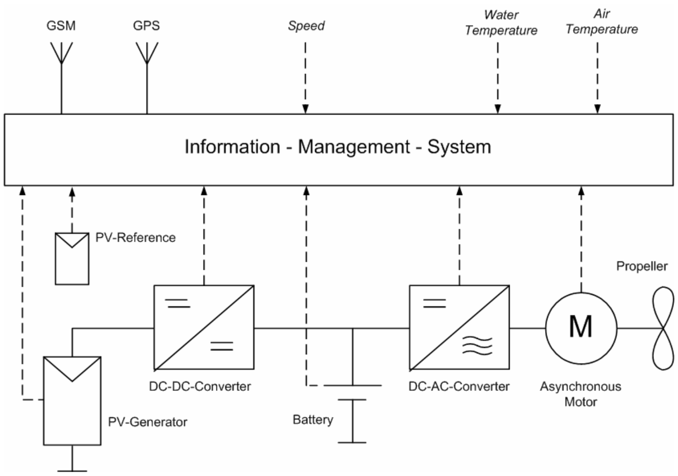

Fig. 2: Block diagram of energy chain and additional Inputs to the IMS

The upper part of Fig. 2 shows from the left the GSM antenna which provides connection to the server at the institute via internet. To prevent misuse by cell phones, only data transmission is allowed. GPS provides time and date as well as the location of the boat, from which speed above ground, course and distance to destination is extracted. Since the speed above ground is not very meaningful for moving water like e.g. a river or in a condition of wind drift, speed above water is given by a sumlog, a speedometer typical in marine application. Water- and air-temperature sensors complete the upper part.

III. IMS Mobile Station

Fig. 3 shows the block diagram of the on-board IMS. It consists of:

1) Sensor interface modules (SIF), converting the sensor information into CAN protocol [5]
2) Black box, storing the actual data till it is sent to the main store
3) Auto pilot, providing the connection to the internet respectively to the main server at the institute
4) On-board computer which processes the data and provides visual information via display
5) CAN-Bus as communication medium within the IMS, with a protocol adapted to the specific needs.

All SIFs consist of three functions: (1) adjusting the voltage of the sensors to the input range of the analog-to-digital converter (ADC) of the microcontroller, (2) converting the analog sensor signal into digital form and (3) sending the data to the CAN-Bus with the appropriate protocol. The SIFs differ only in function (1). It would theoretically be possible to use only one SIF for all sensors, however in order to prevent excess electro magnetic interference, short cable connections to the analog sensors were necessary, leading to distributed SIFs in the boat.

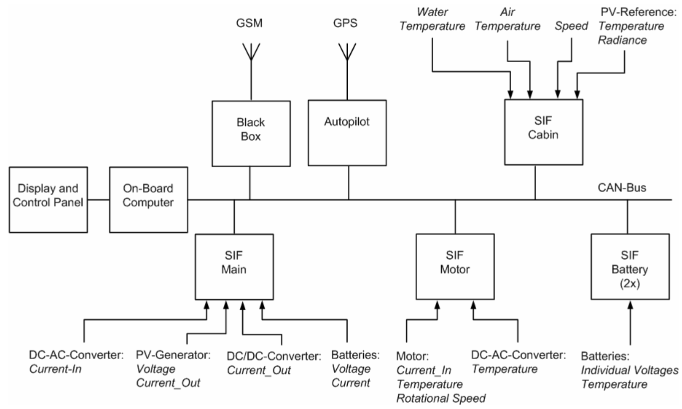

Fig. 3: Block diagram of on-board IMS

Following a description of the sensor interface modules.

A. *SIF Main*

SIF Main measures the photovoltaic generator voltage and output current, battery over-all voltage and current, DC/AC- and DC/DC-Converter current. The currents from photovoltaic generator, batteries and motor form a current node, from which the status of the batteries can be determined: are they being drained or charged and by which amount. Drainage and charging of a battery has to comply with a defined procedure; otherwise damage of the cell can occur.

B. *SIF Battery*

Two SIF Batteries exist, one for each side of the boat with two stacks of five batteries each. The voltage of each of the ten batteries is measured and displayed in numerical and graphical form, giving information about the quality of each battery with a quick glance. Deviation of one of the batteries can immediately be detected, Fig. 4. Furthermore the temperature inside the battery compartment is measured. From voltage and temperature, the stored energy can be derived.

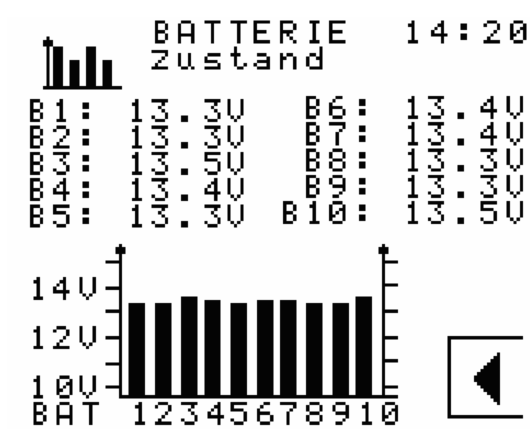

Fig. 4: Battery voltage display

C. *SIF Motor*

SIF Motor measures the DC/AC-Converter temperature, motor temperature, motor rotational speed and motor current.

D. SIF Cabin

SIF Cabin measures the speed above water as well as water- and air-temperature. From the photovoltaic reference cell, temperature and irradiance is extracted and used to calculate the total available energy from the cells.

E. Black Box

The Black Box is the center of communication within the boat as well as between boat and base station. The microcontroller of the Black Box gathers the measured information from all CAN nodes and stores it in its 64 Kbytes of energy independent static memory, Fig. 5. To limit the amount of transmitted data, data collection depends on the operational mode of the boat: during on-time, collection is every two minutes, during downtime every hour. If the memory reaches a preprogrammed level, the microcontroller switches on the GSM module, dials the phone number of the internet provider, establishes a connection with the main store at the institute and transmits the data from its memory. A timestamp is added to each measurement to guarantee chronological order in the main store. If the data was sent successfully, the memory is cleared for next use. If not, the microcontroller retries to send the data after a given time. Since each message being sent consists of approximately 450 Bytes of measured data, an estimated 62 MB have to be stored per year or 620 MB for the required 10 years of operation. To provide for changes in the main store, mainly IP-Address, Port-Number and Password, communication to the Black Box from the institute is also possible.

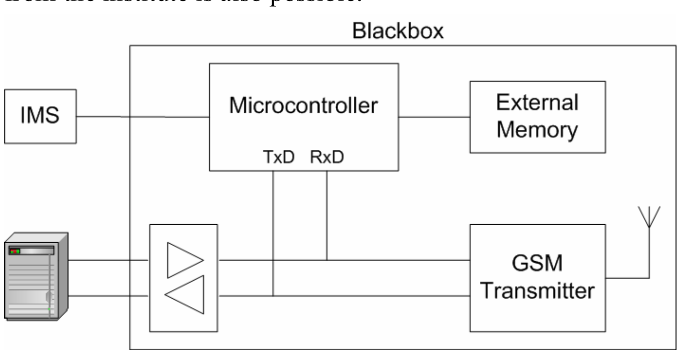

Fig. 5: Block diagram of Black Box

An RS-232 connection from a computer to the transmitter module in combination with standard Telnet software provides the capability to test the module without the microcontroller and to observe communication in normal operation.

Since all information of the IMS is concentrated in the Black Box, the algorithm for the intelligent energy management system is also included in its processor.

F. Autopilot

The autopilot receives GPS data and is responsible for the position information (latitude and longitude) of the boat. Based on consecutive measurements of time and position, the speed of the boat over ground is extracted and the difference to the speed over water calculated, resulting in a value for drift. Furthermore, the course of the boat is determined. The intelligent energy management system uses the actual position of the boat, destination and actual speed over ground to compare the required energy with the available energy, resulting in information for the skipper about the possibility of reaching the destination and under what condition.

G. On-Board Computer and Display

On-Board Computer and display provides the user-interface to the IMS. All information, measured and calculated, is displayed in real time; menus are selectable with soft-keys on both sides and bottom of the display, Fig. 6. The computer also allows for adjusting the IMS parameters IP-Address and Port of the main server. Furthermore, it executes an error handling engine, indicating the principle area of failure (top row).

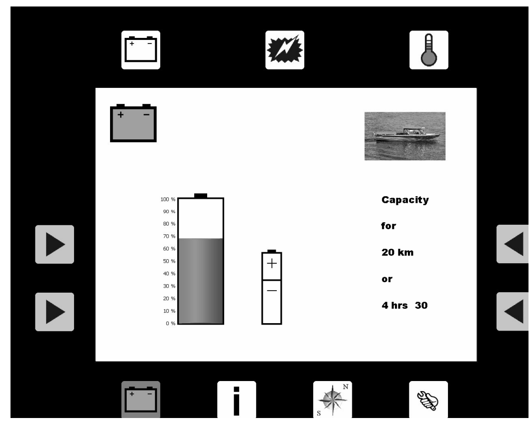

Fig. 6: Example of on-board computer display

H. CAN-Bus

The CAN bus was selected because of its high EMI tolerance in a hostile environment of the boat with its high switching frequencies and currents of DC/DC-Converter, AC/DC-Converter and motor. Furthermore due to the fact that the CAN-Bus is found in all modern cars, a multitude of inexpensive components are available. In addition, a network can be implemented with simple wiring and is easily expandable. Because of the diversity of the measurements, CAN-open [5] profiles seemed inappropriate which led to a simple protocol specifically adjusted to the needs of the IMS.

IV. IMS Base Station

The IMS base station at the institute provides the following services: (1) archiving of data from mobile station, (2) administration and visualization of stored data, (3) bidirectional communication for receiving data from and sending data to the mobile station and (4) online visualization and graphical analysis of stored data. All services were implemented using LabVIEW V8.2 [6]. Fig. 7 shows a block diagram of the system.

A TCP/IP communication protocol between mobile and base station was developed with two goals: (1) handshaking, to assure proper transfer of data, (2) security to prevent unauthorized access to the base station.

The mobile station starts periodically the communication with the base station, as previously described, by sending the IP-Address, Port-Number and password, which is checked by the block KoronaAdmin. For a false condition, e.g. wrong password, the connection is terminated, for a true condition, the next block KoronaConnect is activated. Here the security check is done by observing the specific connection procedure defined. If all checks perform positive, data from the mobile station is accepted in the block KoronaDataStore. For negative check, again the connection is terminated. Each transmitted set of data has a defined start-of-frame and end-of-frame ID which are continuously checked. Confirmation of the end-of-frame to the mobile station will start the next transmission. KoronaGetCommand checks for the correct handshaking control characters in the incoming TCP data stream, whereas KoronaSendCommand inserts the control characters into the outgoing TCP data stream.

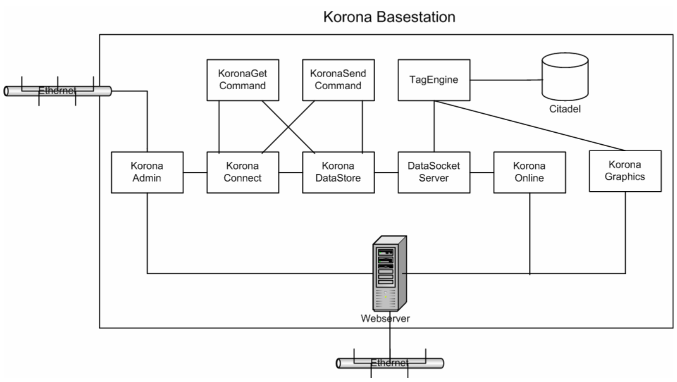

Fig. 7: LabVIEW realization of base station

The DataSocket Server governs the data in real time. The Tag-Engine adds a time-stamp to the data and stores it in the main store called Citadel. As can be seen from Fig. 7, two web applications are available [7]: KoronaOnline (Fig. 8), and KoronaGraphics (Fig. 9).

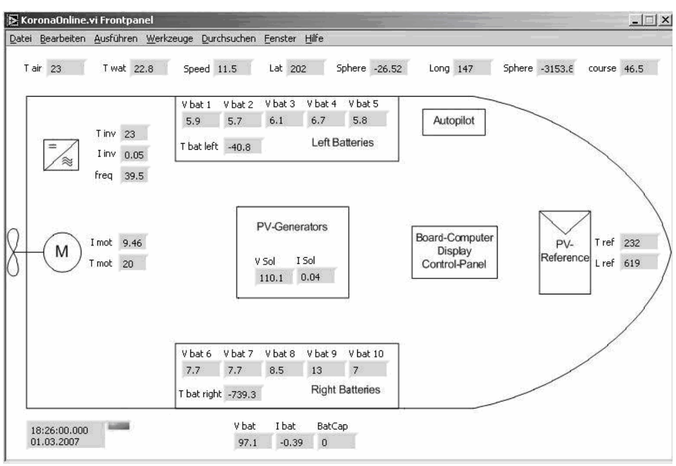

Fig. 8: KoronaOnline as seen with a browser

KoronaOnline displays the measured data from the solar boat in real-time. Fig. 8 shows the browser image with the outline of the boat and the approximate location of the sensors. In the lower left corner, a green LED indicates the connection of the base station to the mobile station; the values to the left of it display the last received data (the displayed data is not correct, since the boat was in storage when this picture was taken). KoronaGraphics allows the user to graphically display via internet all data from Citadel in a classical x-y-diagram as a function of time. As shown in Fig. 9, parameters can be selected from a list on the right hand side. With buttons on the upper left corner, the time period of interest can be adjusted.

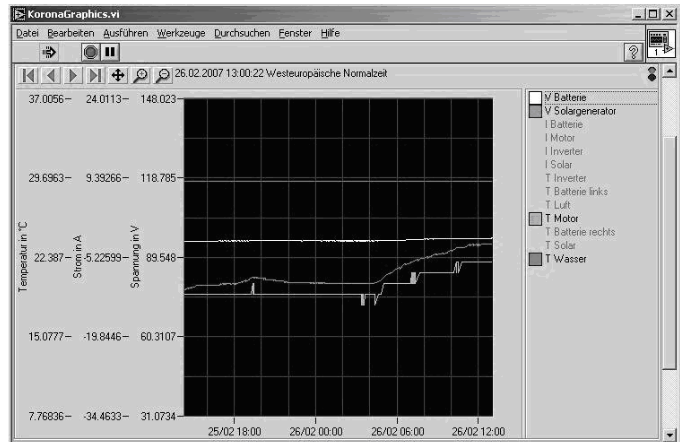

Fig. 9: KoronaGraphics as seen with a browser

V. Conclusion and Future Developments

The Information-Management-System is in operation for about a year now. It turned out to be an important means to analyze the performance of the components. Online visualization of real-time measurements and the capability to graphically display stored data via internet extremely simplifies the analysis of all measurements. In the first year, one immediate success was the detection of a degrading battery cell, which could be replaced in time. Currently, only a simple energy management algorithm is installed; the intelligent algorithm will be worked on in the next semester. With the IMS, a powerful tool is now in place to help reach the previously stated research goals.

A new boat is currently being designed using photovoltaic cells and fuel cells. The IMS of the new boat will be a modified version of the one described in this article.

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