Communication Architecture for Autonomous Sailboats

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Abstract—Although an autonomous sailboat can operate without human intervention a data link between boat and shore is necessary. During development a reliable connection for monitoring, debugging, and remote control in case of emergency is essential. When used for long-term observation tasks the operator on shore is keen to receive real-time measurement data.

A three-stage communication system for autonomous sailboats has been designed, implemented and tested successfully. It combines wireless LAN, GPRS/UMTS and satellite communication for a reliable data link between shore and sailboat.

I. INTRODUCTION

The vision of machines which relieve more and more tasks of humans induced many scientific initiatives in mobile robotics. Research in fully autonomous sailing boats was recently stimulated by the Microtransat idea of Yves Briere [1]. The Microtransat Challenge is a transatlantic race of fully autonomous sailing boats. The race aims to stimulate the development of autonomous sailing boats through friendly competition. The Transatlantic race is currently planned for late 2009.

An increasing number of research teams around the world try to teach their boats the complex task of sailing [2], [3]. The best routing decision, perfect handling of ever changing wind conditions and perfect timing during tack and jibe are some of the skills an autonomous sailing vessel has to master.

A robotic sailboat is able to autonomously navigate towards any given target without human control or intervention. The optimal route is calculated dependent on strategic goals and weather parameters. Rudder and sails are autonomously controlled in order to keep course and to execute manoeuvres like tack and jibe. As sailboats operate in a highly dynamic environment an autonomous sailboat has to respond quickly to ever-changing environmental conditions. Incoming data from sensors (GPS, compass, anemometer, etc.) have to be analysed permanently by intelligent control mechanisms.

During the research process of an autonomous sailing boat it is very important to have a permanent data link to the vessel. On the one hand to take over control manually for safety reasons if the artificial sailor on board does not work as expected or an obstacle crosses the boat’s trajectory. On the other hand it is quite convenient to have an opportunity for real-time monitoring from shore in order to identify room for improvement in the control algorithms of the boat.

Not only for research, but also for many possible applications of autonomous sailboats [4], [5], a reliable communication system between shore and boat is essential. Some of these applications are the following:

- Intelligent Sensor Buoy: An autonomous sailing boat can be completely energy autarkic and can therefore collect unlimited measured data from world’s lakes and seas. In other words this application would make possible, that surveying and mapping as well as water ecological studies or recording of fishing resources would be rather cost-effective.
- \( \text{CO}_2 \)-neutral in Transportation of the Goods: The fuel price is expected to grow dramatically in the next decades and complying with Kyoto standards is getting more difficult. Therefore better alternatives for the transportation of the goods need to be sought. Traditional sailing boats are environment-friendly but they require a rather high number of human resource. An autonomous sailing boat with its attributes from calculating the optimal itinerary to independently executing the right manoeuvres can be a serious option.
- Reconnaissance and Surveillance: An autonomous sailing boat can be sent out to far reaches or dangerous regions. Due to its silent, pilotless and energy self-sufficient attributes it is a safe alternative for surveillance of smuggler-boats.
- Supply Vessel: Secluded regions with lower number of inhabitants for instance researching base camps on islands can be cost-effectively supplied by the autonomous sailing boats with equipment, medicine, food or correspondence.

At least geographic coordinates of the boat or of the next target need to be transmitted for the applications mentioned above.

The next chapters gives an overview of the communication partners involved and a detailed description of a multi-stage
communication architecture. Finally, some experiments carried out in the Irish Sea are analysed and conclusions are made.

II. COMMUNICATION PARTNERS

Three entities are involved in the communication process: sailboat, visualisation software (Fig. 1), and remote controller.

During normal operation the sailboat transmits sensor values to the visualisation. The visualisation is a software program which runs on a computer on shore and represents the transmitted data like position or information about the boat’s strategy clearly. If required it is also possible to send important instructions or data, such as new target coordinates, obstacle information, or a new desired course from the visualisation to the sailboat.

In case of emergency, especially during test runs, an ergonomically designed remote control device can be used to overrule the autonomous onboard control of the sailboat. Therefore the desired actuator values, including position of rudder and sails are transmitted to the boat in real time.

III. MULTI-STAGE COMMUNICATION ARCHITECTURE

The System consists of three alternative communication channels between boat and shore. Each of them features specific advantages and disadvantages. Therefore it has to be ensured, that the system switches dynamically between the available communication channels in order to use the most appropriate way at any time.

A. First Stage: Wireless LAN

A radio mast, equipped with a directional wireless LAN antenna, is mounted on shore. On the mast top of the boat an omnidirectional antenna is mounted. The higher the antennas are mounted, the longer is the distance that can be covered by this technology. Experiments have shown a reliable 10 Mbit data link between boat and shore for up to 3 km distance. Both antennas have been mounted at a level of about 5 m.

Advantages of this technology are:

- No base fee and no connection fee
- High bandwidth which allows even real-time video transmission
- TCP-based communication; software maintenance can be carried out during runtime

Disadvantages are:

- Infrastructure (antenna, router) needs to be set up
- Limited operating distance

B. Second Stage: Data Service of Mobile Phone Provider

The boat as well as a server on shore is equipped with a data modem of a commercial mobile phone provider. This allows internet-based communication between these two stations. Common data modems provide UMTS (Universal Mobile Telecommunications System) and GPRS (General Packet Radio Service) and switch over automatically depending on the availability of the services.

Advantages of this technology are:

- Infrastructure is provided by the mobile phone service provider
- High bandwidth which allow even real-time video transmission, at least for UMTS
- TCP-based communication; software maintenance can be carried out during runtime

Disadvantages are:

- Base fee and connection fee, can be extremely high abroad (roaming)
- Operating distance is limited by the network coverage of the service provider

C. Third Stage: Satellite Communication

The sailboat is equipped with an Iridium satellite transceiver. The Iridium satellite constellation is a system of 66 active communication satellites with six spares in orbit and on the ground. It allows worldwide voice and data communications. The Iridium network is unique in that it covers the whole earth, including poles, oceans and airways.

Various Iridium based services are available. The most appropriate for communication to an autonomous sailing boat is the Iridium Short Burst Data (SBD) Service. Iridium SBD Service is designed to serve a range of applications that need to send data messages that on average are typically less than 300 bytes. The used Iridium 9601 SBD transceiver on the sailboat is controlled by AT commands over an RS232 serial port. An Iridium Gateway allows receiving data from respectively transmitting data to the sailboat via e-mail [6].

Advantages of this technology are:

- Covers the whole surface of the earth
- The Iridium SBD transceiver offers not just message transmission, but delivers rough geographic position information as well. This can be used as backup system if the GPS receiver on board fails.

Disadvantages are:

- Low data volume (max. about 2 kB pro message [6])
- High transmission latency (between 7 and 22 seconds modem processing time [7])
- Base fee and connection fee (USD 21.00 per month plus USD 1.30 per 1,000 Bytes at the provider used for this experiment)
IV. SELECTION OF THE APPROPRIATE COMMUNICATION STAGE

Not every communication technology is adequate for every combination of communicating devices. Any of the three stages can be used between sailboat and visualisation, even though with different scope of operation. A reasonable Communication between sailboat and remote control requires a line of sight to the boat and real time transmission of the instructions. Therefore, for this case only Wireless LAN and UMTS/GPRS are suitable. (Fig. 2)

The selection of the appropriate communication stage is mainly based on the availability of the data networks. Considering advantages and disadvantages of each technology the following strategy is implemented.

If a proper wireless LAN link to the boat is available, it will be used for visualisation and remote controller. If the link quality decreases below a certain threshold, the system automatically switches over to UMTS/GPRS if available. For both communication partners this happens transparently. If neither wireless LAN nor UMTS/GPRS is available, satellite communication via Iridium SBD will be activated. In this case direct manual control of rudder and sail position is not possible and not reasonable. This is because of the limited sight caused by long distance to the sailboat and the high latency of satellite communication.

The availability of all communication stages is verified periodically. If indicated, a switch over will be initiated. A hysteresis condition is implemented in order to avoid constantly switching between the communication stages.

When no communication stage is available, the boat keeps on sailing fully autonomously. The sailing functionality of the boat is completely independent from the communication system. A user on shore is not able to monitor the boat’s data or to influence its strategy in this situation.

V. FEATURES OF THE INDIVIDUAL COMMUNICATION STAGES

Wireless LAN and UMTS/GPRS enables the user to request all available data from the sailboat. There are two different modes:

- **Pull mode**: a request for a certain value is sent to the sailboat and immediately answered.
- **Push mode**: the client software can subscribe to a set of values. The sailboat delivers every update of the subscribed values automatically.

These communication stages also allow transmission of multimedia data, such as images, videos, or sound files. Furthermore it is possible to remotely log into the boat’s main computer. This can be used to check log files, update software, or to restart system services during runtime.

The third communication stage, satellite communication, has restrictions concerning bandwidth and latency. Therefore it focuses on transmission of short and concise data packages. By default only the location data (GPS coordinates) of the sailboat are transmitted regularly. Further values (wind speed, battery voltage, etc.) are transmitted if certain thresholds are reached. Moreover, any value can be requested on demand.

VI. EXPERIMENTS DURING MICROTRANSAT 2007

A. Microtransat 2007

Prior to the ultimate goal of the Microtransat Challenge, the fully autonomous crossing of the Atlantic Ocean, several smaller competitions have already taken place. These competitions allowed researchers to exchange ideas and test their boats in less harsh environments.

The second of these pre-races took place on the Irish Sea off the coast of Aberystwyth, Wales, UK in September 2007. It was the first competition on sea. Aside from ASV roboat from the Austrian Society for Innovative Computer Science (InnoC), which is the basis for the current work, three other teams (Aberystwyth University, ENSICA/JUT de Nantes, and Queens University) took part.

The InnoC team was announced the winners by the judges, who released the following statement:

“We are very pleased to announce that the overall winners of this event were the Roboot team from Austria. This team demonstrated true Autonomous sailing for the full 24 hour period of the challenge and a very robust control system. ...”

B. ASV Roboat

The ASV Roboat is an autonomous robotic sailboat, which is able to autonomously navigate towards any given target without human control or intervention. The optimal route is calculated by weighting drift coordinates against weather parameters. The rudder and sails as well as the tacks and jibes are autonomously controlled by incoming data from sensors (GPS, compass, anemometer, etc.) [8], [9], [10]. The Roboat won the international Microtransat event in Toulouse. In September 2007 the InnoC team won the Microtransat again on the Irish Sea in Aberystwyth, Wales. And in May 2008 the ASV roboat became first World Champion in robotic sailing. The World Robotic Sailing Championship was held on Lake Neusiedl in Austria.

The basis for the autonomous sailboat ASV roboat is a commercial sailboat designed by Jan Herman Linge, the boat type Laerling. The Laerling is a product from the same drawing board as the well-known Olympic class Soling and Yngling.
The boat was originally created for kids to learn sailing, and therefore safety and stability are the major characteristics of the boat. It comprises a 60kg keel-ballast, which will bring the boat upright even from the most severe heeling. A brief overview of the adaptations and the technical equipment on board can be found in Figure 3.

C. Communication Setup

The experimental setup provides all three communication stages. Figures 4 to 6 illustrate the interaction of the involved communication partners for each stage separately.

**First stage - Wireless LAN communication:** A laptop for visualisation and remote control is connected to a directional wireless LAN antenna, which is mounted on a 5 m mast on shore. This is used to establish a connection to an omnidirectional wireless LAN antenna on mast top of the boat. (Figure 4)

**Second stage - UMTS/GPRS communication:** Both communication partners are connected to the internet via a UMTS/GPRS modem. The communication partners are connected via a virtual private network (VPN). (Figure 5)

**Third stage - satellite communication:** The sailboat is equipped with an Iridium SBD modem, which transmits data via the Iridium satellite network. Data packages are forwarded to a mail server by the Iridium provider. The visualisation software is connected to the Internet via a UMTS/GPRS data link in order to fetch transmitted data from the mail server. (Figure 6)

D. Experimental Results

Figure 7 compares the network coverage of all three communication stages in Aberystwyth, where Microtransat 2007 took place. For runs near shore, wireless LAN coverage was sufficient and UMTS/GPRS served as backup system. Whenever the sailboat left the area covered by wireless LAN the system switched to UMTS/GPRS automatically without user intervention and vice versa.

As there was no race outside UMTS/GPRS coverage, the UMTS/GPRS modem was deactivated manually to test the switchover to satellite communication. As soon as the boat sailed out of the wireless LAN covered area it switched over directly to satellite communication, because UMTS/GPRS was not available. In this stage the system transmitted the boat’s GPS position every 5 minutes as configured. Remote control of the boat was not possible until the boat sailed back autonomously and received a wireless LAN signal again.
VII. CONCLUSIONS

Several test runs have shown that real-time communication for monitoring and remote control is of importance for safety especially in the field of vision close to shore. In case of emergency immediate manual control has to be possible.

On the other hand, for long-term missions over huge distances the main focus is on global network coverage and reliable transmission of a few essential values. Higher transmission latency can be accepted.

A three-stage communication system for autonomous sailboats has been designed, implemented and tested successfully. Advantages and disadvantages of the individual stages have been illuminated with regard to availability, costs, bandwidth, and real-time abilities. Requirements during development of autonomous sailboats as well as its applications have been considered separately.

Based on the experiments carried out, the presented concept turned out as appropriate. Long-term test runs have to be done in order to get more valuable results on longevity, maintenance effort, and robustness, especially in harsh environments.

REFERENCES