HANSE - Autonomous Underwater Vehicle for the SAUC-E Competition 2010

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Abstract

HANSE (**H**anseatic **A**utonomous **N**autic-Bot for **S**AUC-**E**) is the advancement of our autonomous underwater vehicle (AUV) built by students from the University of Luebeck for the 'Student Autonomous Underwater Challenge - Europe (SAUC-E) 2009'. It is 65 cm long, 75 cm wide, 40 cm deep and weights approximately 20 kg in air. The vehicle is composed of a waterproof case that is mounted on a 'sledge'. The AUV is powered by four thrusters. With its three cameras, an active scanning sonar, a pressure sensor, a compass and an inertial measurement unit, this vehicle is able to perform all tasks in this competition. As the innovation of this AUV, we use two webcams to generate a map and to localize the AUV by the information of the stereo image.

Short Overview

Dimension (LxWxH)	65x75x40 cm
Weight	approx. 20 Kg
Max Depth	6 m
Thrusters	4 (SeaBotix)
Camera	3x Philips SPC1030
Sonar	1x Imagenex Typ 852 scanning sonar
Computing power	Notebook with Intel®Core^{TM}2 Duo Processor ($1,2\,GHz$)

1 Introduction

After participating the SAUC-E competition in 2009 and winning the innovation prize for the low-cost design and the hand-made thrusters the whole team was quite motivated to improve the AUV and the software to fare better the this year's competition. Several enhancements like new thrusters, more computation power and a scanning sonar were made and new highly motivated students joined the team. This paper is organized as follows. In section 2 the organisation of the team is presented. Section 3 describes the mechanical design of HANSE while sector 4 introduces the electronic system overview. The software design is presented in section 5. A Conclusion is given in section 6 and the financial summary and the risk assessment are shown in the appenix A and B.

2 Team Organisation

For formal reaons a team leader was annouced and the team is partitioned in different groups, but all decisions are made collectively. Because, nevertheless, the fields of application often overlap, many problems are also solved across teams.

The team-members of this project and their functions in this team are:

- **Team Leader**: Christoph Osterloh
- **Mechanical & Electrical Engineering Team**: Benjamin Meyer, Christoph Osterloh, Thomas Tosik
- **Image Processing Team**: Jan Hartmann, Helge Kluessendorff
- **Navigation**: Dariush Forouher
- **Software Engineering Team**: Dariush Forouher, Marek Litza, Jan Hartmann, Christoph Osterloh
- **General Support**: Christoph Osterloh, Marek Litza

3 Mechanical Design

3.1 Frame and Hull

The base frame of our AUVs owns the form of a sledge (s. Fig 1). This form was chosen, because the thrusters can be attached at any position on the sides of the scaffolding. Thus the positions of each thruster can be evaluated during the test runs, and can be mounted to its optimal fixing point. Another advantage of this form is that the AUV can be carried convenient by two people.

The base frame of the AUV is made out of $50\,mm$ Polypropylen (PP) tubes. We have chosen this material, because of its light weight, and the possibility of weld single parts together easily. To increase the solidity of the frame, it was strengthened by a glass fibre sheathing.

Additional holes which are drilled in the frame in a distance of $10\,cm$ accelerates the submerging.

Figure 1: AUV *HANSE*

On the base frame a waterproof case of the company *Peli* is fixed. With its inside measurements of $30x22.5x13.2cm$ it offers enough place for all electronic parts.

3.2 Thrusters

The setup of the thrusters differs from the last year setup in quantity and position. This year we use four SeaBotix BTD150 thrusters in contrast to eight hand-made thrusters last year since the thrust of the commercial thrusters is considerably more than the thrust of the hand-made thrusters. Each thruster can reach a Bollard thrust of 2.21kg at a weight of 700g in air and 350g in water. Two of the four thrusters are mounted horizontal for speed and rotating while the other two thrusters are mounted vertical for diving and stabilization of the AUV.

3.3 Connectors

Since we had no problem with the connectors last year, we use again this year. We just had to change the inner part of the connectors for the thrusters which have two wires instead of four wires last year.

3.4 Camera Housing

As camera housing for our webcams we use a lamp housing that is usually used for illuminating garden ponds. These cases have a $5\,mm$ glass panel, and are waterproof up to $10\,m$.

3.5 Cutter

In order to cut the fishing line we mounted a V-sharped mechanism at the front of the AUV. Four razor blades are mounted at the peak of the V in order to cut the line while driving forward. Since they are fixed and only one mm is apparent the risk of injury is is kept by a minimum.

4 Electronic System Overview

4.1 Power Management

The main power for the thrusters and the sonar devices come from two three-cell high performance lithium-ion-accumulator providing $10\,Ah$ at $11.1\,V$ that are series-connected. Fully charged the batteries achieve a voltage of about $24\,V$ overall. Of course the batteries are secured individual by fuses.

A kill switch is located on the top of the case. If this switch is pressed, the electricity supply of the engines is interrupted presently, and the AUV will emerge.

4.2 Onboard Computer

Similar to the last year we use a Notebook as onboard computer but with more computation power: an ACER 'Aspire Timeline 1810T Special Edition' with an Intel®Core^{TM}2 Duo Processor SU7300 $(1,2\,GHz)$, and $500\,GB$ harddisk. With a width of $285\,mm$ we have around 5mm space between the notebook and the case at the left and right side so we had to build or own USB-connectors for every device to fit in this small space. The runtime of the batteries is given as eight hours but not tested yet.

4.3 Navigation

The navigation sensors includes an inertial measurement unit, a compass and a pressure sensors. Because of the electrical and magnetic influence by other components, we fixed the compass and IMU-unit at the top of the case and shielded it with aluminum foil.

4.3.1 Compass

Solid-state (and many classic water based) compasses fail badly when not held flat. That's why we use the tilt compensated 'HMC6343' from *Honey-*

well. This is a fully integrated compass module that includes firmware for heading computation and calibration for magnetic distortions. The module combines 3-axis magneto-resistive sensors and 3-axis MEMS accelerometers, analog and digital support circuits, microprocessor and algorithms required for heading computation. It has a heading accuracy of typical 2° and a pitch and roll accuracy of 1°.

4.3.2 Inertial Measurement Unit

For our INS-System, we use a 'ADIS16354' high precision tri-axis inertial sensor from *Analog Devices.* This sensor combines the Analog Devices *iMEMS*®and mixed signal processing technology to produce a highly integrated solution, providing calibrated, digital inertial sensing. A SPI interface and simple output register structure allow for easy access to data and configuration controls.

4.3.3 Pressure Sensor

To measure the actual depth, we use a 'MS5541-CM' pressure sensors from *Intersema.* It has an absolute pressure range from 0 to 14 bar put out as 16 Bit value and achieves an accuracy of 2 cm.

Since we had some problems with the SPI-Interface last year, we built a SPI-to-I2C translator that is located in the housing of the pressure sensor. This translator additionally computes the temperature compensated pressure data as described in the datasheet of the sensor and gives the result to the I2C-Master.

4.3.4 Sonar

Instead of the active sonar device 'Model 852 ultra-miniature echo sounder' we use the 'Model 852 ultra-miniature scanning sonar' from *Imagenex.* This sonar has a beam width of $2.5° x 22°$ and a range resolution. Adjusting the gain, ranges from 150 mm up to 50 m are reachable. This sonar can be operated either in sector mode with a sector size of 18° or in polar mode that means 360° continuous. Additional it has to step sizes: normal (3°) and fast (6°). With a maximum range of 50 m one rotation requires 16 seconds in case of the normal mode and eight seconds in case of the fast mode.

4.4 Cameras

We use three USB webcams 'SPC1030' from *Philips.* Two of these cameras are facing forward for our stereo camera system and one camera is mounted facing downward. The cameras grab $640x480$ pixel images with a frame rate of 5 Hz. The 'SPC1030' webcam has a lens view angle of 80° that is decreased by the water to 60°.

4.5 Pinger detection

In order to detect the pinger at the middle point of the competition area, three hand-made hydrophones are mounted at the 'sledge'. A simple adjustable amplifier is located in the case to adept the required amplification to identify the pinger. The processing and orientation computing is done by an ATmega microcontroller that estimates the direction by analyzing the different times of arrival (TOA) of the three hydrophones.

4.6 Bus Network & Univeral Interface Device

The communication interface between the sensors and actors and the notebook is done by our self-built 'Universial Interface Device' (UID). As hardware platform we use a small ATmega168-Board from *chip*45, but the UID architecture is not determined to this board, it can be used for almost any type of Atmel 8-bit processors. The UID is connected by USB and is addressed by a serial interface with a configurable speed from 2400 *bps* up to 2 $Mbps$. The standard communication speed is set to 256 *kbps* in order to allow the using of a normal terminal program to communicate with the UID. To buffer the incoming and outgoing serial data, an 256 *Byte* ring buffer both for the receive and the transmit unit is implemented.

Beside the I2C and SPI communication, additional features like GPIOs, 8 ADC channels, a small servo-controller for up to three servo motors as well as RS485 Transceiver are implemented. Figure 2 shows how the single components are connected to the Notebook.

5 Software Design

The software is programmed in C++/Qt and divided into a four level control architecture: the behaviour level, the middle layer, the drivers and the hardware interface (s. Fig 3).

5.1 Control Strategy

For our control we use a classic Proportional/Integral/Derivative (PID) controller. This controller is responsible for keeping the given depth, orientation and speed.

5.2 Image Processing

We use images from our forward-facing and downward-facing webcams in order to recognize objects. While the forward-facing camera captures the images for the gates and the mid-water target, the downward-facing camera captures the images for the bottom of the gates to know when passed them as well as the pipeline for the detections.

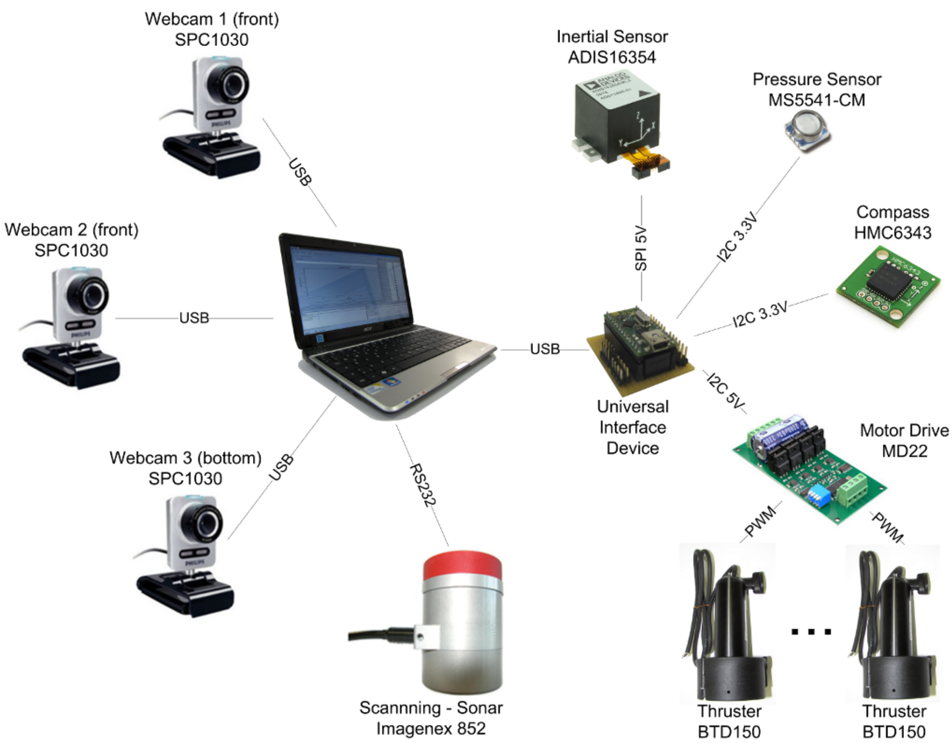

Figure 2: Bus network of the AUV

We use the computer vision library OpenCV for analyzing the images ans classical approaches like hough-transformation for detecting and following the pipeline or blob-tracking to find the mid-water target. Beside that we are using a Support Vector Machine (SVM) to detect objects e.g for finding the gates. We had good results with this techniques so we decided to adapt for the this year's tasks.

Beside the 'normal' image recognition, we use a second forward-facing camera to use the 3D informations to create a map and to localize the AUV in this map. The position of the landmarks is calculated by determining the 3D informations of the two cameras. Since the position and orientation from one camera to the other camera is known, the 3D position of two corresponding pixels can be estimated (see fig. 4.

If T, R is the translation resp. rotation of the right camera concerning the left camera the 3D Position regarding the left camera can be computed by:

$$P_l = \left(\left(a_0, q_l^i\right) + r\left(b_0, q_r^j\right)\right),$$

where

$$(a_0, b_0) = argmin_{(a,b)} \left\| l(a, q_l^i) - r(b, q_r^j) \right\|,$$

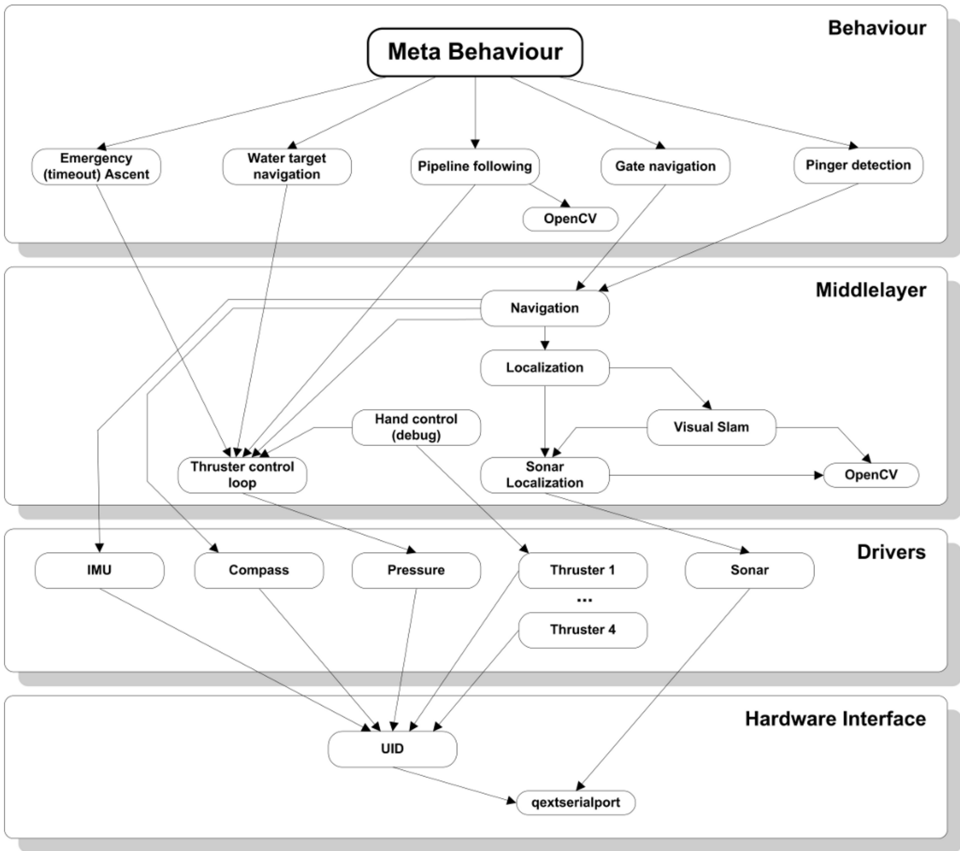

Figure 3: Software schematics of the AUV

and p_l^i is a left pixel corresponding to the right pixel p_r^j and $l(a, q_l) = aq_l$ and $r = (b, q_r) = T + bR^T q_r$ the lines through the origin and the pixel of the current camera.

To create the map, a visual Simultaneous Localization and Mapping (SLAM) is applied. The landmarks are mapped and based on these the location of the AUV can be estimated.

5.3 Navigation

Early during the design phase we concluded that many tasks can be performed much easier if the position of the robot inside the basin is be known. Besides visual orientation we thus use a scanning sonar (see chapter 4.3.4to archieve localization. Sonar localization has the advantage over visual image recognition to be potentially be more robust even in murky water.

A scanning sonar is an sonar echo sounder whose head rotates along an axis while performing continuous meassurements every couple of degrees.

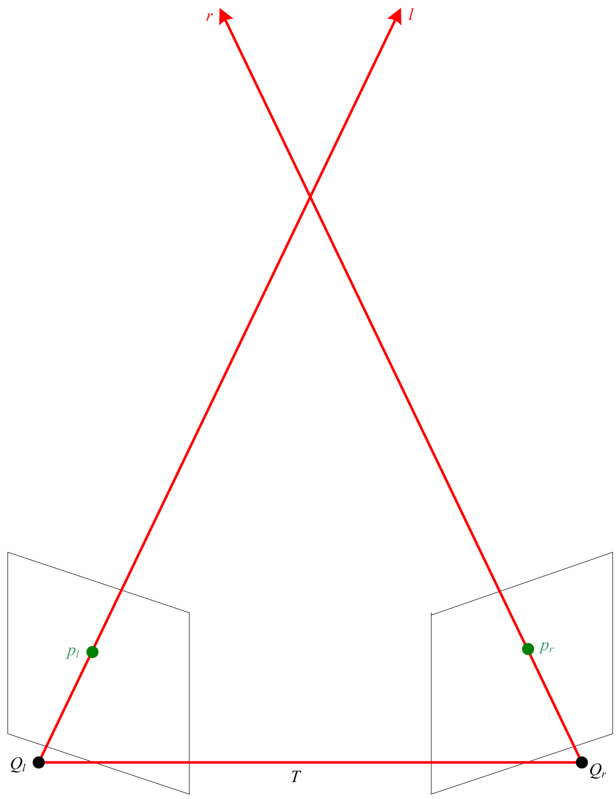

Figure 4: Triangulation of the 3D position from two corresponding pixels. The 3D position is the intersection point of the two lines respectively the spot where the two spots of the lines are located closest.

In theory combining the echo return data results in an image in which all (sound-reflecting) objects in the surroundings of the robot can be identified. The scanning sonar has a range of 50m, which should be sufficiently large to be usable in the competitions's water basin.

We perform sonar localization by extracting landmarks from the sonar data and then matching the observations to a known and fixed map using a particle filter[1]. As landmarks we are using walls, since they can be relatively easy extracted even from noisy meassurements. Wether the sonar head is observing a walll is decided by looking for a peak in the echo return data with a sufficiently high variance (the wall), and then checking if there is negeglible signal behind (after) this peak. Additionally we employ heuristics to weed out false-positives.

Once a number of (approximatly) consequtive wall points been identified,

[1]Thrun, S. and Burgard, W. and Fox, D.: Probabilistic Robotics (Intelligent Robotics and Autonomous Agents), The MIT Press, 2005

they are grouped together and fed into the particle filter. The particle filter maintains a number of position hypotheses, which together form a probability distribution of the position of the robot. When a new observation is available, the particles are updated with control information, i.e. they are moved based on the motion the robot was expected to make, as well a gaussian error, accounting for control noise. After that, each particle is matched against the map, resulting in different weights for good and bad particles. Finally a resampling process causes bad particles to be dropped.

A round trip of the sonar head takes 8-16 seconds using a range of 50 meters (depending on resolution used). An update of the particle filter needs about two seconds (using 1000 particles), which is thus suffiently fast to be used in realtime.

6 Conclusion

The AUV *HANSE* competition-designed, small, light, and highly mobile AUV test platform mainly based on commercially available low cost standard products developed to enter for the first time the SAUC-E competition by fulfilling its severe requirements.

Nearly all components are customary products which can be easily exchanged. The *HANSE* AUV is controlled by software designed specially tailored for the SAUC-E competition's demands and primarily developed task-oriented.

A Financial summary

Since we just modified the AUV from the last year, we did not have to buy all parts again. The remaining parts of the last year are marked by an (*).

Item	**Cost** (€)
Mechanical	
Framework$^{(*)}$	5.00
Case$^{(*)}$	100.00
Waterproof Connectors$^{(*)}$	250.00
Thrusters	
Motors	1280
Motor Controller	140.00
Electronical	
Fuses, switch, cabel,etc.$^{(*)}$	50.00
Battery System	
Lithium Polymer Cells$^{(*)}$	130.00
Computer	
Laptop	500.00
Sensors	
Compass$^{(*)}$	100.00
Inertial Sensor$^{(*)}$	250.00
Pressure sensor$^{(*)}$	14.00
Sonar	5000.00
Total (new investments	6920.00

B Risk Assessment

Risk	**Precaution**
Loss of control	Kill switch
Sharp edges	Sharp edges have been kept to a minimum. There are no sharp edges at the framework or case.
High Speed Propeller Rotation	Because of the brushless-motors it is possible to stop the propellers by hand.
No compressed air used	
Lifting injuries	• AUV designed to keep weight to a minimum. • The shape of the sledge allow easy lifting for two people.