AR Binocular:
Augmented Reality System for nautical navigation

Kristine Haase and Reinhard Koch
Computer Science Department
Christian-Albrecht-University of Kiel, Germany
haase,rk@mip.informatik.uni-kiel.de

Abstract: A realtime Augmented Reality binocular for the assistance of nautical staff is presented. AR systems combine the real environment with additional information. Nautical sea chart data is used to superimpose information into views with a magnification factor of 7 which cause a big effect on directional errors in the augmentation. We discuss the system requirements and present an analysis of the hardware components. The detection of the actual position is done without a magnetometer but using a gravity sensor in combination with an image-based marker tracking approach. It will be shown, that very high accuracies are achievable for the localization of real objects.

1 Introduction

We present a new application dealing with the Augmented Reality (AR) assistance - the embedding of additional information into images of a real scene - for ship navigation. An electronic binocular, equipped with sensors to capture its 3D world position, is used to provide combined information displayed in realtime at very high precision into the real environment and allows the user to directly detect navigational objects in the whole field of view. Even in complete darkness the user can call up instantaneous the information in free hand mode.

The challenge is to deal with the requirement of high accuracy, even increased by a magnifying augmentation view. Applications of AR range from superposition of virtual objects in TV and film productions [CTS07] to online support for industrial service maintenance [KSea07]. Caarls, Jonker and Persa [CJP03] proposed a sensor fusion approach for outdoor AR systems. They combine inertia sensors with a compass, a GPS unit and a marker tracking approach. They reached high accuracy only in the near environment. A similar proposal was puplished by You, Neumann and Azuma [YNA99]. They presented a hybrid approach to integrate inertial and vision-based data for outdoor tracking. At the time of publishing they did not reach realtime, but the accuracies were sufficient. A marker tracking with high accuracy is shown in [MWP06] and another interesting proposal is given by Roberts, Evans et al [RED02]. The paper explains the augmentation of subsurface features. They used magnetometers to estimate the orientation which is not applicable for usage on a ship. For the assistance of nautical navigation, very special requirements have to be met to fulfill the task. We will now discuss the required accuracy while in section 3 we present our approach to reach the goals set, and in section 4 we provide experiments.

Figure 1: Hardware overview of the ARBinocular. Left: Device with augmentation camera (right), fisheye heading sensor (top), accelerometer (bottom) and binocular display (left). Right: Image of AR Device, the original with overlays of nautical data as seen by the user.

2 Requirements and System Description

2.1 Basic demands

The nautical staff on the ships bridge will use a magnifying binocular in free hands mode to observe navigational beacons at a distance between 100m up to 10km. Typically, a magnification factor of a binocular of 7-6 and a field of view of 7x10 degree is used. We use a camera (PointGrey FireFlyMV) with a 25mm objective which magnifies 7 times. Therefore, directional errors have a big effect on the augmentation. Using a resolution of 640x480 pixel produces a mapping of 60 pixel per degree of the environment.
To reach a precise superposition up to pixel accuracy in the augmentation, the accuracy of the rotation angles has to be better than 0.016 degree. The observed beacons are known with absolut position in world coordinates from the sea charts database. The ship position is known with high accuracy from available GPS and compass sensors on the ship. Since the relative distance between ship and object is large, the positional error due to position uncertainty of the binocular w.r.t. the ships position can be neglected. Indeed, the viewing direction is needed with great accuracy. The free hands operation causes fast local rotations independently from the ships movements. After the outlining of the basic requirements, we will now discuss the conditions for the position estimation.

2.2 Estimation of local orientation

The position data of the sea charts is encoded in spherical GPS-coordinates. We can map the coordinates onto a local Carthesian plane and restrict the local environment to 15 kilometers, which is sufficient to avoid measurement errors caused by the neglected curvature of the earth surface [Fel07]. The local approximating plane is oriented tangential to the earth surface with its surface normal pointing towards the earth center of gravity. The plane also defines the horizon plane with good approximation. While the estimation of the orientation by a 6 DOF marker approach is not precise enough, deduced from the correlations between translation and rotation, the surface normal of the horizon plane can be estimated conveniently and with great precision using an accelerometer sensor that provides the gravity g. It is now easy to attach an accelerometer onto the AR Binocular to measure the local tilt and roll of the AR device. Thus, the sensor delivers two of the three rotation angles of the device. The rotation is defined by the rotation axis d' and the rotation angle α by:

$$\alpha = arccos(g_c^T \cdot a_{up}) \;\; and \;\; d' = g_c \times a_{up} \; , \; d = \frac{d'}{|d'|} \tag{1}$$

with g_c as surface normal in the Camera Coordinate System and a_{up} as corresponding up axis. The heading direction cannot be recovered from sensor data since it defines a rotation around the surface normal axis. Traditionally, heading information is provided by compass data on the ship, but a magnetic compass attached to the binocular will not work with high precision due to the metal construction of the ship. We will therefore use an image-based approach with a 1-dimensional marker. To deal with user movements and light changes, we use the combination of an infrared LED array and an omnidirectional camera.

2.3 Hardware Overview

The above discussion on the requirements of an AR device is used to define a practical AR binocular that can meet the defined criteria. An overview of the resulting system is shown in figure 1. We used a perspective camera for augmentation and a fisheye camera for the detection of the heading marker. Additionally, we equipped the system with an accelerometer sensor. The monocular images of the real environment and the augmented scene were represented in a binocular OLED display. The system performs with 25 frames per second on a standard PC and appears with dimensions of 100mm (w) x 200mm (l) x 120mm (h) and a weight of 600gr very similar to an analog binocular.

3 Component Analysis and Processing

3.1 Orientation sensor

An accelerometer component of an Inertial Sensor (XSens MT9) was used for gravity estimation. The gravity vector is given as direction vector in the local Sensor Coordinate System, measured as acceleration in m/s^2. The sensor delivers gravity measurements at 100 Hz, but the data is quite noisy and susceptible to vibrational errors. To characterize the sensor data we mounted the device on a calibrated pan-tilt unit (PTU) and performed controlled angular movements. We found that errors can reach up to 15 degree deviation in the beginning of controlled single step movements. Moreover, the noise of a sensor is a problem when aiming at high accuracy orientations. In this characterization the measured Root Mean Square error (RMS) of the sensor output is 0.1365 degree while the observed non-linearity of the sensor is very small. To further improve the data we filtered the raw data with respect to the delay between image processing and the sensors sample rate by an integration over time. Therefore we use a gaussian window which is centered at the date of the actual camera image. We observe a certain augmentation delay on the camera pitch, which causes a misalignment of about 1 degree during pitch rotation, however the misalignment vanishes fast when holding steady. Because the delay time is small, it does not affect the augmentation. The noise is now reduced to a RMS of 0.025 degree, which is sufficient to our application.

3.2 Heading estimation

While pitch and roll can be determined with sufficient accuracy, the heading is estimated using a marker-based image sensor with a fisheye camera with 190 degree opening angle. We used a greyscale camera with 640x480 pixel, which means that 3.18 pixel correspond to one degree of the environment. We therefore require a precision of the marker orientation of 0.016 degree to achieve pixel accuracy in the augmentation. This implies that the detection of the marker within the fisheye camera has to be with a precision of at least 0.053 pixel. Since only the heading angle is unknown, a 1-dimensional marker with infrared LEDs is used which is mounted on the ceiling of the ship bridge and can be seen from all positions by the fisheye camera. Because the heading is measured in the horizon plane of the local coordinate plane, pitch and roll of the AR device will cause perspective distortions that need to be compensated for. This can be achieved by realigning images with the horizon plane. The used marker consists of seven infrared LEDs, with wide opening angle (flat lenses), see figure 2 for an image example. The marker detection is then performed by a template matching approach to find the lights followed by an estimation

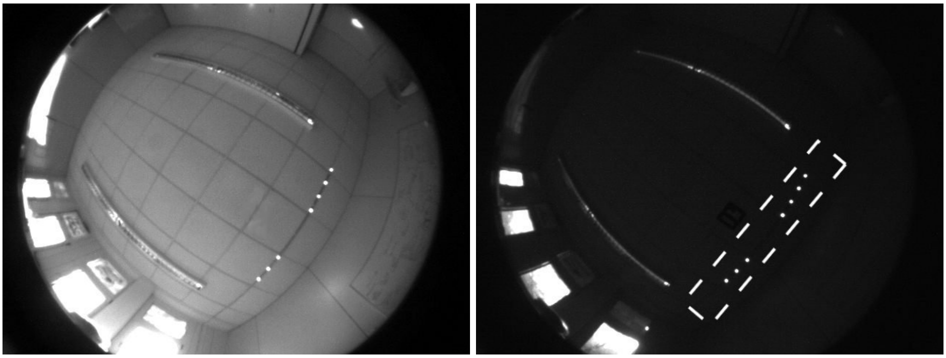

Figure 2: Left: original fisheye image; Right: fisheye image with near-infrared filter; the marker array is highlighted by the dashed line

of the real centers of the light sources [gau04]. To obtain a heading angle in global coordinates the marker line has to be calibrated with respect to the ship compass. The marker is addionally equipped with a similar sensor to provide the ship movements in the horizontal plane and the compass of the ship provides the heading of the ship. We analysed the accuracy of the heading using the PTU to make movements from -102.85 degree up to 102,85 degree around the vertical axis. The resulting RMS of the noise of the marker detection was 0.01 degree yielding an RMS of 0.03 degree for the rotation accuracy.

4 Evaluation

The system setup allows the multiple sensors to provide independent measurements. The GPS sensor of the ship delivers positions with high precision. Since the observed targets are far away from the ship, position uncertainties due to movement inside the ship's bridge and short term ship motion can be neglected. Orientation in world coordinates are estimated by the gravity sensor for the horizon plane, and an independent heading estimate from the ship's compass via the fisheye camera. The sensor delivers dritf-free data that is filtered to reduce noise. To estimate the preformace of the system, we took the bearing of three real objects for 10 times from a non-moving platform to analyse the repeatability, the noise and the resulting overall system accuracy. Table 1 shows the true heading estimated from the positions in the World Coordinate System. Furthermore, it shows the means of the 10 measurements together with the standard deviations to the true headings. With standard deviations between 0.021 and 0.014 degree, the results are quite sufficient for nautical applications and rely to an error of 4 pixels in the augmentation which allows an overlay with 3D symbols. In figure 1, a screenshot from the view through the augmentation camera with superimposed data is shown. The system can be used to mark certain objects and retrieve additional information from the sea chart database by pointing towards them. The similiarity to a standard analogue binocular secures an intuitive usage. The ARBinocular needs no interaction devices except of the device motion.

Table 1: Measurement results for 3 objects, repeated 10 times; all values in degree

Objects	True Heading	Means of 10 tests	Std. Dev.
1st	39.06	39.09	0.021
2nd	51.24	51.21	0.019
3rd	27.20	27.22	0.014

5 Conclusion and Outlook

We presented a novel AR application, with the challenge to build up a hand held system for the realtime overlay of nautical chart data. Concerning the magnification factor of 7, we have found that the angular accuracy has to be better than 0.016 deg. We propose a combination of a gravity sensor and an image-based marker detection system, and to faciliate a maximum of user movements we propose to use a fisheye camera for the task of heading estimation. We have shown that the system is able to reach the high accuracy demands of the hand held mode. In the near future we will perform thorough tests of the system on a ship's bridge.

So far we developed a robust and accurate orientation estimation. To guarantee an intuitive use of the ARBinocular we will define an interface for the representation and the selection of the data. This allows the user to predicate the display of the data on certain conditions.

6 Acknowledgements

This work was funded by the Innovation Foundation of the State of Schleswig-Holstein (ISH) in the program eRegion SH PLUS (EU). We acknowledge the project participant SevenCs GmbH for the support and the permission to use the sea chart database.

References

[CJP03] Jurjen Caarls, Pieter Jonker und Stelian Persa. Sensor Fusion for Augmented Reality. *EUSAI 2003*, Seiten 160–176, 2003. LNCS 2875.

[CTS07] Jigna Chandaria, Graham A. Thomas und Didier Stricker. The Matris Project: Real-time Markerless Camera Tracking for Augmented Reality *Journal of Real-time Image processing*, 2(2-3):69–79, 2007.

[Fel07] J. Feltens. Vector methods to compute azimute, elevation, ellipsoidal normal, and the Cartesian (X,Y,Z) to geodetic (ϕ,λ,h) transformation. *J. of Geod., Springer Verlag*, 2007.

[gau04] *Pattern Recognition, Lecture Notes in Computer Science*, Jgg. 3175/2004, Kapitel 3D Segmentation and Quantification of Human Vessels Based on a New 3D Parametric Intensity Model, Seiten 111–119. Springer Berlin / Heidelberg, 2004.

[KSea07] Reinhard Koch, Didier Stricker und et al. Architecture and Tracking Algorithms for a Distributed Mobile Industrial AR System. 2007. The 5th ICVS07 , Bielefeld.

[MWP06] Simon Meers, Koren Ward und Ian Piper. Simple, Robust and Accurate Head-Pose Tracking Using a Single Camera. 13^{th} *Conf. on Mech. and Ma. Vi. in Prac.*, 2006.

[RED02] G. W. Roberts, A. Evans und Prof. A. H. et al. Dodson. The Use of Augmented Reality, GPS and INS for subsurface data visualization. *FIG XXII Internat. Congress*, 2002.

[YNA99] Suya You, Ulrich Neumann und Ronald Azuma. Orientation Tracking for Outdoor Augmented Reality Registration. *J. IEEE Comp. Graph. and Appli.*, Vol. 19(Nr. 6), 1999.