Analysis of Compass Sensor Accuracy on Several Mobile Devices in an Industrial Environment

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Abstract. The digital compass on mobile devices plays an important role in the mobile computing domains where applications have to rely on the accuracy of this sensor. In this paper we investigate the difficulties that occur with a digital compass in an industrial environment especially concerning indoor localization systems using the digital compass in mobile devices. We focus on two dependencies of the accuracy of this sensor type: device and location.

1 Introduction

Many applications on mobile devices make usage of the digital compass. In domains like localization, navigation or gaming, the accuracy of this hardware sensor plays an important role in the usability of such systems. An analysis of several hardware sensors in [3] demonstrated the difficulty in relying on the values for outdoor *Augmented Reality*. However, in that paper it is shown that the achieved accuracy is sufficient for the proposed application but interferences of objects in the surrounding environment are a major concern.

In indoor applications, like localization systems the accuracy of the digital compass plays an important role for the applicability. Example systems such as revealed in [5, 6], combine hardware sensor outputs to increase the precision of the determined position. One such positioning system is *Dead Reckoning (DR)*, where positions are calculated based on a known location, speed and heading. This type of system is also used in our proposed concept of an indoor localization system in an industrial environment in this paper. We base our approach upon the work in [1, 6] where DR is combined with another positioning system. However, on mobile devices this means the usage of accelerometer and compass sensor values. In a common indoor environment, this concept already includes an uncertainty of interferences at different locations. Magnetic fields, produced by electronic devices, manipulate the results of the electronic compass. In this paper we investigate such influences in an industrial environment. In a field study within a 570 square metre large industry hall, we collected interference data on different mobile devices.

The result values are used to analyse the usability of indoor positioning systems in the given terrain. Another topic of this work is to find a coherent divergence of the compass values between several devices in the environment. Such coherency could be used for an adjustment to the raw compass output values. The contributions of the analysis in this paper are:

- Analysis of the influence of an harsh environment to the mobile devices digital compass.
- Analysis of the influence of different hardware to the sensors accuracy in an industrial environment.
- Discussion of the difficulties for indoor localization systems with inaccurate sensor data.

2 Analysing Sensor Data

The compass accuracy is critical for the applicability of many systems. In this paper we analyse if the digital compass on mobile devices have sufficient accuracy for indoor localization systems in harsh environments. We established this analysis based on two hypothesis for mobile phones in an industrial environment. To derive statements from those assumptions we made measurements in a test environment.

2.1 Analysing Dependencies

These are the mentioned hypothesises for a location and device dependency which we investigate in this paper:

- **Device dependency:** Because each mobile phone has different sensor hardware, we assume that the accuracy of the compass differs for the different device types. In the analysis of the device dependency we investigate differences of the sensor data for several mobile phone types and also differences between different devices of the same type.
- **Location dependency:** Especially for localization systems we have the need for an accurate sensing system in the whole environment. Because of different magnetic fields at different positions, the sensors accuracy will vary. Our assumption for this analysis therefore is, that in specific areas the errors are too high for a localization system like DR.

2.2 Test Environment

To make a specific and feasible statement about the digital compass in an industrial environment, we measured the raw values of the sensor in a test setting. We performed those tests in a 570 square metre large industry hall with seven different mobile devices of different model types (2x Galaxy Nexus, 2x HTC Desire, Galaxy Tab, Samsung Galaxy S2, Samsung Galaxy S3) and a common magnetic compass. The selection of the model type was done considering the current market share of Android handsets in mid 2012[1]. The industry hall is used

[1] http://www.appbrain.com/stats/top-android-phones

to compress/store natural gas and consists of two turbines and many metallic pipes. During the measurements on 39 equally distributed positions, the hall was in normal operation (no machine was turned off for the tests). At each point the mobile phone was held in one direction and we recorded the divergence of the resulting compass value to the correct heading (known from the construction plan).

2.3 Influences on localization system

As we point out in introduction section, the digital compass is often used in combination with indoor localization systems. In a practical attempt for the analysis of the sensors inaccuracy we want to have a special focus on the influence of compass errors to such a systems. The concept which we use for this purpose is a combination of DR with Map Matching (MM). DR is the technique for positioning and MM is responsible for matching locations to a known track. This combination is often used to have a more robust tracking of mobile devices [10, 4] in indoor and outdoor systems. Figure 1 illustrates the error calculation from compass inaccuracy in a DR system. This error is calculated with the formula:

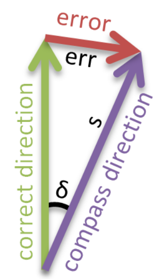


Fig. 1. Error calculation for DR.

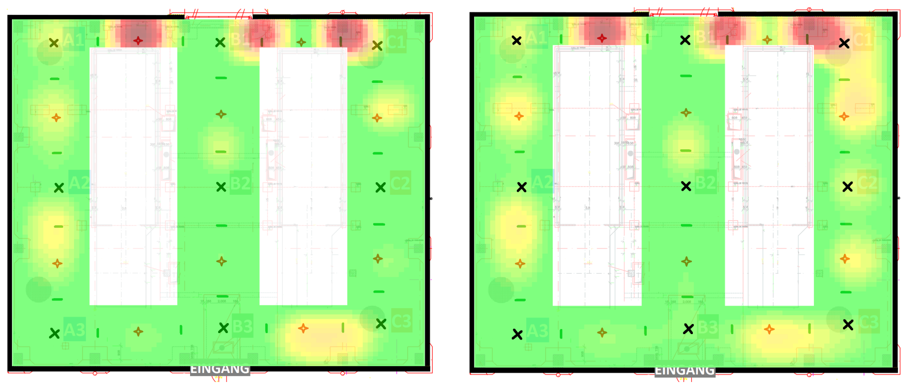
$$err = \sin(\frac{\delta}{2}) * s * 2 \quad (1)$$

Where δ is the compass error and s the travelled distance. This means that after a distance of 10 metre and an error of 10°, the calculated error is 1.74 metres. At 30°the error is at 5.17 metre and so on. For a DR positioning algorithm this error is already quiet high, especially because the computation of new positions is based on those wrong calculations and the error will increase over time. However, if we have a look on the combination of DR with Map Matching, we will discover that this calculation is more robust. With the underlying map information, we only need to determine the moving direction on the current track. On a straight line, where we only have two moving directions, a compass error below 90° is sufficient to calculate correct new positions. At a crossing of two lines we will need an accuracy of below 45° is needed for correct calculation of the walking direction.

3 Results

3.1 Location Dependencies

One major part in the analysis of the compass sensor accuracy played the evaluation of location dependencies. Goal of this appraisal was to find interrelated compass errors in specific environment areas. Such a relationship can be used to improve the sensor accuracy by adjusting raw values with measured differences. The results are illustrated in the heat maps of figure 2(a) and 2(b), where we used median and mean values of all devices for each measurement point.



(a) Heat map of the median values on all reference positions.

(b) Heat map of compass error mean values.

(c) Colour map for the graphs

Fig. 2. Results of the compass accuracy tests in an industrial environment. Figure (a) shows the fluctuations of error values between different reference positions as median values. Figure (b) shows the mean of the measured values.

The white rectangle in the middle of the image illustrates two manufacturing devices which are covered with metal and range from the floor to the ceiling. Green coloured areas illustrate low error values in that field (<5 degrees). Yellow is defined as the median and mean error value of $22°$ and red illustrates deviations of $60°$ or higher (see image 2(c) for the detailed color map). The resulting images show that the most problematic areas are located around the same area (at the top and the right side of the image). A probable reason for the disturbances is because of the manufacturing device in the middle and many metallic objects which surround this region. In these areas we have median and mean errors of up to $116°$ and $123°$. The other areas show lower deviations (green or yellow). The values in numbers:

- Median error values range from $2°$ up to $116°$.
- Mean error values range from $1.5°$ up to $123°$.

3.2 Device Dependencies

In the second analysis of the field study we evaluate the device dependencies of digital compass accuracy. We investigate the differences of the compass error values on multiple mobile phones and an analogue compass to determine influences of multiple hardware to the raw sensor values.

The Cumulative Distribution Function (CDF) of the study results in figure 3 shows that the probability of having an error below $20°$ is around 85% for

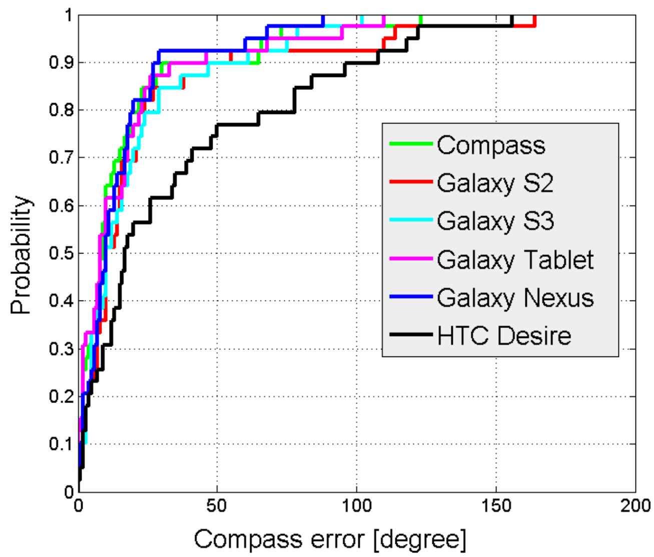


Fig. 3. Cumulative distribution function of the error values on several mobile devices.

most mobile devices. Only the HTC Desire (M[2]=29.00, SD[3]= 34.32) showed significant worse result than all others (M=19.24°, SD=28.18°); T-Test result: $t(114)=2.269$, $p = 0.025$. The probability of having a compass error below 20° at the HTC Desire is 55%.

Between the magnetic compass (M=16.95°, SD= 22.36°) and all other mobile devices (M=22.36, SD=30.99) we were not able to find a significant difference; T-Test result: $t(310)=1.051$, $p = 0.294$. Also the CDF in figure 3 suggests that there is no difference in the resulting error values. The maximum errors are similar high for all devices (above 100°). Table 1 lists values for the different devices in more detail.

	Magn. Comp.	**GS2**	**GS3**	**Galaxy Tab**	**Galaxy Nexus**	**HTC Desire**
min	0°	0	0°	0°	0°	0°
max	123°	164°	102°	110°	135°	156°
med	9°	10°	10°	8°	9°	20°
mean	16.74°	22.82°	19.41°	16.85°	15.21°	32.44°

Table 1. Digital compass error values on several mobile devices.

[2] Mean value
[3] Standard Deviation

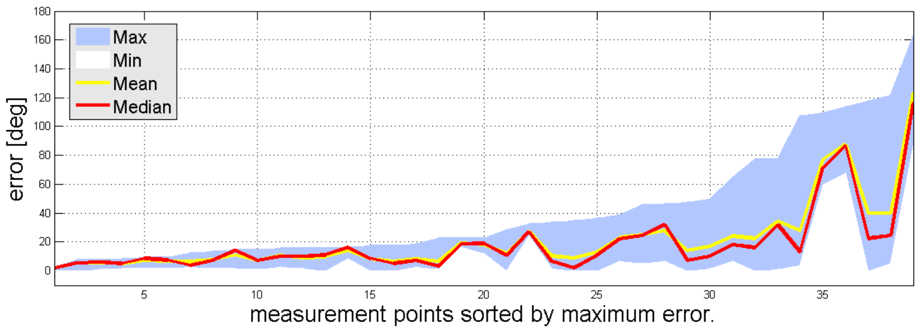


Fig. 4. Measured error values of all mobile devices at 39 reference points. The graph is ordered by the maxima that was captured for each position.

In figure 4 we illustrate the deviance of all mobile devices at the 39 reference points. It is ordered by the maximum error values that have been measured. For almost half of the reference points the maximum error is below 20° and the deviation is narrow. Above that point, the difference between maxima and minima is increasing. This means that the sensor quality on mobile phones is varying more on certain measurement points not in the whole environment. The mean and median values are also increasing at the same time. Only the last 5 values of figure 4 are passing the 45° mark which would cause bad positioning in a combined localization system of DR and MM.

Differences within model type In addition to the investigation of the compass accuracy in an industrial environment, we also wanted to find out if there is a difference of the sensors accuracy between different devices of the same model type. We made measurements with two Galaxy Nexus and two HTC Desire. Results are shown in table 2. The deviation in median and mean value for the Galaxy Nexus is around 1°. For the two HTC Desire it lies within 6° and 8°. Although the deviance is increasing with the HTC Desire, we cannot determine a significant difference. However, we are not able to make a specific and feasible statement at the moment. More test devices would be required.

4 Discussion

4.1 Location

The results in section 3.1 show that in most areas the error is below 5°. These deviations can be ignored for most applications (for Dead Reckoning this would result in an error of 0.87 metre at a distance of 10 metres). The yellow areas in the heat maps visualize errors of around 22° which would mean a DR error of up to 3.82 metre. Such an error would already result into inaccurate positioning in a pure DR approach. In combination with MM, this error values can be ignored.

	HTC Desire (1)	**HTC Desire (2)**	**Galaxy Nexus (1)**	**Galaxy Nexus (2)**
min	0°	0°	0°	0°
max	125°	156°	135°	88°
med	23°	17°	9°	10°
mean	28.82°	36.05°	14.92°	15.48°

Table 2. Differences of the digital compass error values for devices of a single device type.

However, the red areas in the heat maps are illustrating mean and median values of above 45°. This inaccuracy would result into defective positioning for the combined approach as well.

These results suggest that there is no conclusive coherence in the total deviation in an industrial environment. Magnetic fields are present at very specific locations where a combined approach of Dead Reckoning and Map Matching (as proposed in section 3.1) would not work. Those magnetic fields where produced by manufacturing devices in that specific area. In all other regions the compass accuracy showed sufficient accuracy.

4.2 Device

The visualization of the device measurements in figure 4 show that one-half of the overall results are below 20 degrees. With a maximum error of 3.47 metre on a distance of 10 metre this would still allow acceptable positioning in indoor localization systems (in Dead Reckoning). The quarter above, with error values ranging up to 45°, will result into defective positioning for a pure DR system (error up to 7.65 metres). For the combined approach with MM, this inaccuracy is still sufficient for calculation of new locations. Only values higher than 45° do not allow reliable positioning at all.

The high variance between max and min values in the second half of the graph indicates the spreading between the electronic compasses in mobile devices. However, the CDF graph has shown that only one device showed significant worse results than all other mobile phones. The majority of test device had similar results as the analogue compass and small deviation to each other. We can therefore suggest that the device type has an impact on the compass accuracy but the digital compass in mobile phones has sufficient quality for Dead Reckoning with Map Matching in an industrial environment.

5 Related Work

Lenz and Edelstein [7] discusses the magnetic sensor and their applications in general. They analyse the different kinds of magnetic sensor and investigate the basic operation mode of those different types. One of those investigated application is the magnetic compass for *Medium-Sensitivity*. They present different categories of this sensor and suggest that high sensitive compasses can achieve an accuracy of $0.1°$. Especially interesting for our work is their analysis of error sources and improvements to the compass sensors accuracy by applying calibrations.

A detailed overview of different indoor localization approaches and techniques is given by Liu et al. [9]. In their survey they do not only compare the accuracy but also highlight the differences in precision, complexity, robustness, scalability and cost. The paper of Lewandowski and Wietfield [8] targets localization in harsh environments. They present a solution to enhance the fault-tolerance and position accuracy for ToA (Time of Arrival) based systems. In their work they mainly focus on developing a system for the industry and analyse the influences of the environment to the localization accuracy.

Another approach for positioning in an industrial environment was done by Duvallet and Tews [2]. They base their system on a localization technique that relies on WiFi signal strengths. Using Gaussian process regression they build WiFi maps for indoor and outdoor usage with existing infrastructure. The main advantages of this system is that it is cheap, effective, do not need modifications to the environment and, most important, does not need line of sight to the sensors. This makes it possible to use this system even in presence of obstacles.

6 Conclusion

The analysis of the compass sensor accuracy has shown that the error values in an industrial environment highly depend on the physical location. Most areas show sufficient accuracy for Dead Reckoning over short ranges, especially if it is combined with Map Matching. We suggest that the fault tolerance is increased to $45°$ for such a combined approach. Only very specific areas show higher error values, which would make positioning problematic only at those specific positions. In future work we will build the suggested approach and test our concept in an industrial environment.

The analysis also showed that the sensitivity of different hardware plays a further role in the compass accuracy. The results suggest that the device type has an impact on the overall accuracy. This excludes the possibility of an overall adjustment to the raw compass values in an industrial environment. However, the accuracy of the digital compass in mobile phone has shown to be sufficient for indoor localization systems.

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