Design and calibration of an inertial navigation sensor node for precise tracking

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Abstract

An inertial navigation system provides the required information by either sensing the relative movement of mobile vehicle, or by determining where a vehicle is with respect to a reference position. The inertial navigation system presented in this work consists of a magnetic compass and distance sensor. The compass sensor provides directional information by measuring the earth magnetic field based on the hall-effect principle. The used analog compass has a range of $\pm 0.6\,VDC$ and has been calibrated to have a resolution of $0.5°$/direction. The distance sensor is a combination of a hall-effect switch and a permanent magnet which gives the distance travelled referred to an initial position. The complete system is controlled by an Atmel ATmega169, 8-bit micro-controller, which provides the necessary computation resources and data display, 12 bit A/D converter, a well-regulated $\pm 5\,VDC$ power supply and LCD display. Errors caused by bias, scale factors and non-linearities in the sensor readings which cause accumulations in navigation errors with time are considered.

1 Introduction

Nowadays, and due to the complexity of vehicle systems and in particular those of the autonomous nature, navigation is encapsulated by the science and technology of being able to determine the position, velocity and orientation of a vehicle in real time with a greater demand on accuracy. This has been spurred on by the demand for higher productivity and lower costs, both of which are improved through automation [1]. A navigation system provides the required information by either sensing the relative movement of the vehicle, or by determining where the vehicle is with respect to external features, or both. This is accomplished through the implementation of either dead reckoning or absolute sensors. Dead reckoning sensors measure the relative movement of the vehicle with respect to a previously known state. Examples include inertial units, wheel encoders and air data systems. Absolute sensors observe the external environment and relate the vehicle's state to those observations. Examples include vision, radar and the Global Positioning System (GPS). Dead reckoning sensors usually output their data at high frequencies, however, due to their relative accumulation of data, errors also accumulate with time. The errors associated with absolute sensors on the other hand are fixed. However, the update rates are generally low [2].

An extensive body of research on inertial navigation systems and theirs applications have been reported in the literature. The work of Beauregard [4] describes an approach for using shoe mounted sensors and inertial mechanization equation to directly estimate the displacement of the feet between footfalls. A pedestrian tracking framework based on particle filters is proposed in [3]. This framework is supposed to extend the typical local positioning radar –based indoor positioning systems by integrating a low cost MEMS accelerometer and map information. Different of these research contributions our approach concentrates more on the practical design concepts and inertial measurements integration aspects in order to get optimal navigation accuracy.

The rest of this work is organised as follows; a brief description of the measurement system with the details on the employed sensor is given in the next section. Analysis of possible errors and disturbances which negatively affect the measurement with proposed solutions are presented. The last section introduces samples of the measured data and plots of the error distributions. Finally, we concluded this work and suggest some points for future extensions.

2 Measurement setup

2.1 Sensor Concept

The system presented in this work consists of a Hall-effect bipolar switch, a magnetic compass sensor, and a microcontroller unit. The hall-effect switch is installed on the front wheel of a mobile vehicle and used to generate two pulses on every revolution of the wheel, it triggers with a magnetic field produced by a permanent magnet attached to the rotating axis of the wheel. The hall-effect switch has a continuous-time operation, fast power-on time, low noise, stable operation over full operating temperature range, reverse battery protection, solid-state reliability, and regulator stability without a bypass capacitor. To be interfaced to the microcontroller it requires a 5 VDC power source and external pull up resistor as shown in Figure 1.

The installed switch provide highly sensitive switching for applications using magnetic fields of alternating polarities, such as ring magnets. There are three switching modes for bipolar devices, referred to as *latch*, *unipolar switch*, and *negative switch*. Mode is determined by the switch point characteristics of the individual device. In this context, a negative magnetic value indicates a north polarity field, and a positive magnetic value indicates a south polarity field. For a given value of magnetic strength, B_X, the values $-B_X$ and B_X indicate two fields of equal strength, but opposite polarity. B = 0 indicates the absence of a magnetic field.

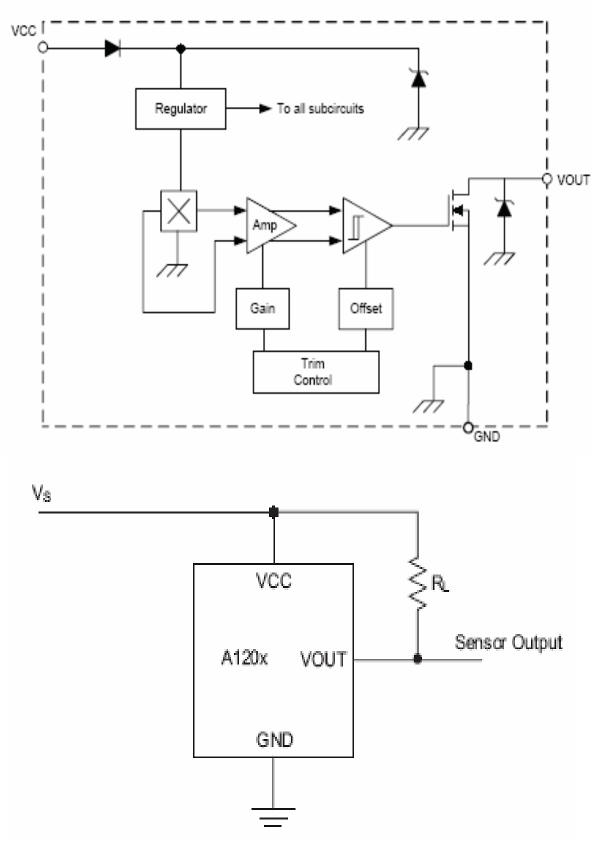

Fig.1. Internal construction and circuit diagram of the bipolar hall- effect distance sensor

Bipolar devices typically behave as latches. In this mode, magnetic fields of opposite polarity and equivalent strengths are needed to switch the output.

The analog compass sensor is designed to get the direction of the vehicle within a resolution of 1°. It provides two voltages that represent the orthogonal component of the direction vector within a quadrant. In other words, the direction is resolved in a sine and cosine functions as shown in Figure 2.

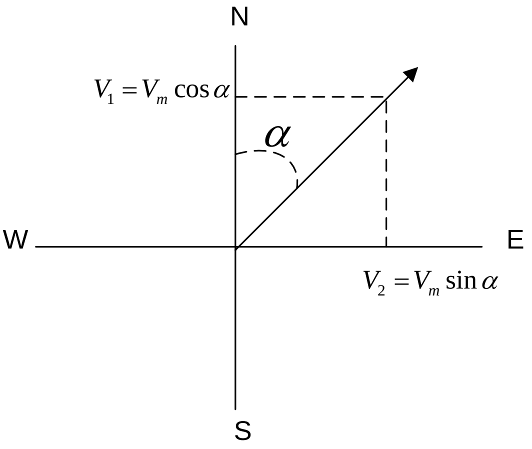

Fig.2. Direction resolution using analog sensor

The sine and cosine have the same value but in different positions 45° and 225°. These potentials determine the upper and the lower intersections, where the voltage between is taken as the zero point. The output voltage swings between 1.9 & 3.1 V as shown in Figure 3, so that the centre voltage is 2.5 V. The output range is $\pm 0.6\,VDC$ but the crossing voltage is $\pm 0.4\,VDC$ only. To evaluate the two output potentials the section of the curves between the two intersections is taken as linear. The voltage outside the range between the upper and the lower intersections determines the four quadrants [5].

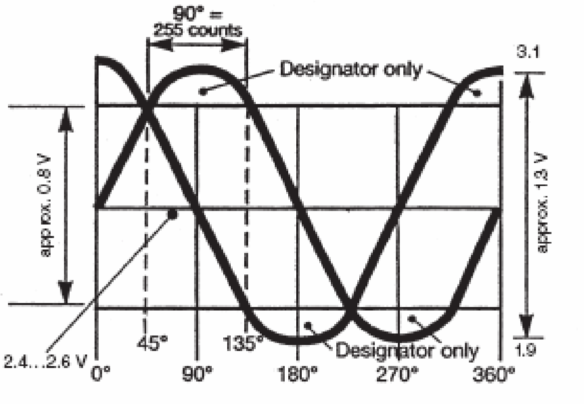

Fig.3. Sensor analog output voltage

2.2 Microcontroller Assembly

This work employs ATmega32 Microcontroller developed by Atmel. The ATmega32 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture with 32K Bytes in-System Programmable Flash . By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed. The AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers.

The microcontroller assembly with the magnetic compass design are shown in Figure 4. In order to test the performance of the developed sensor system we conduct several practical experiments, where we gather information about the displacement and direction using a sample mobile vehicle. The system is installed in a laboratory environment and connected on line to evaluation software written in Matlab.

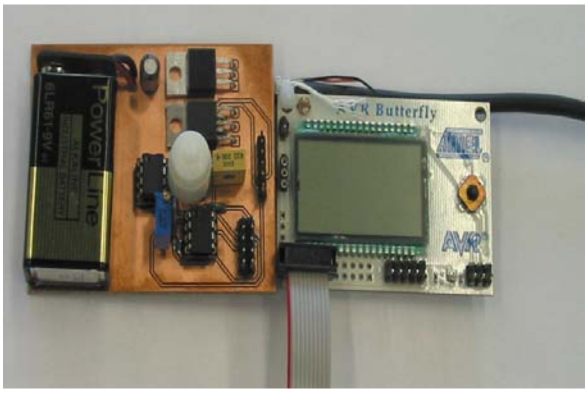

Fig.4. Prototype of the developed magnetic compass sensor system

3 Error analysis and discussion

3.1 Error analysis

It can be shown that there are two kinds of error types; the one that can be corrected by calibration and the ones that cannot. A large number of experiments within the last years show that it is usually possible to calibrate for the following types of errors: Linear bias, Scale factor, Non-linearity , and Signed symmetry.

Among these items, the non-linearity is special because often it must be piecewise approximated.

On the other side, the uncorrectable errors which have to be part of the measurement noise density assumptions are mainly: Dead zones, Quantisation, and Crossing distortions [6].

It is not possible to correct them in an analytical algorithm, instead only their influence can be mitigated by applying probabilistic filtering methods, i.e. minimising the overall estimation error of the entire tracking system.

Illustration of the Constant offset linear bias, as a typical example of correctable errors, is shown in Figure 5. Here, The reference value and the measured value are biased by a constant over the entire measurement range, the expectation value of the sensor output is biased by a constant value, $E[x_{out} - x_{in}] \neq 0$.

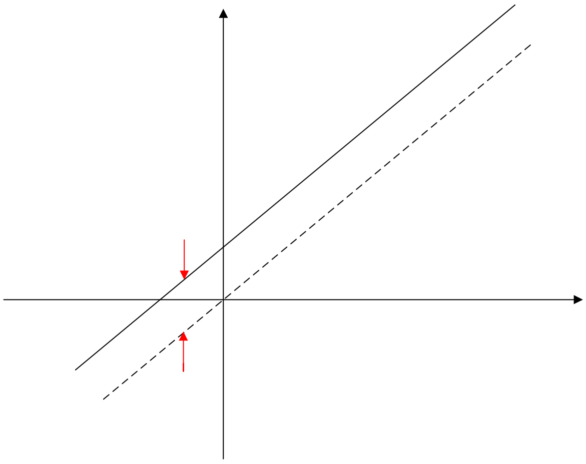

Fig.5. Constant offset linear bias error

This error exists almost in every device. Usually, correction is performed by acquiring a characteristic curve with reference measurement equipment and implementing a mechanism that applies the same constant with a different sign to the signal.

The error caused by analog to digital conversion is a common non-correctable error, the process of analog-to-digital convertion comes with an information loss because only discrete steps of signal value can be sampled at specific moments. A typical quantisation curve is presented in Figure 6. Measurements between these stairs are sampled as either higher or lower value. These dead zones can be unsymmetric to the reference curve, and is dependent on the kind of conversion process, for example successive approximation, parallel weighting or sigma-delta.

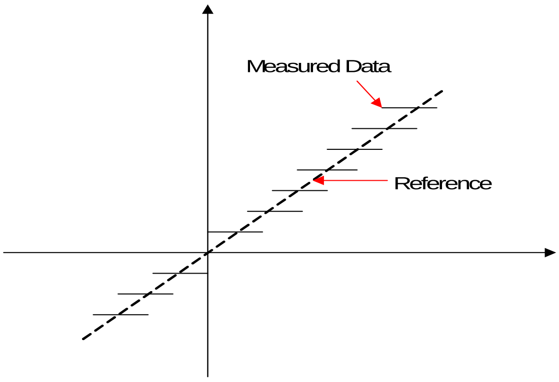

Fig.6. Quantization error due to A/D conversion

Today’s converters yield an uncertainty of about ±1/2 bit for the entire error caused by the conversion processor while informer times, up to 2 bit could be observed with some models.

3.2 Conclusion and Results

The results of calibrating this sensor for better accuracy are done on different location considering the variations of earth magnetic filed. These calibration results are shown in Figures 7 and 8. The plotted results show real measured voltage responses of the angle sensor recorded in clockwise and counter-clockwise directions against angle in degree. These calibration curves are used to calibrate the sensor for optimal directional accuracy with the help of the ideal working curve of this sensor shown in Figure 3 above.

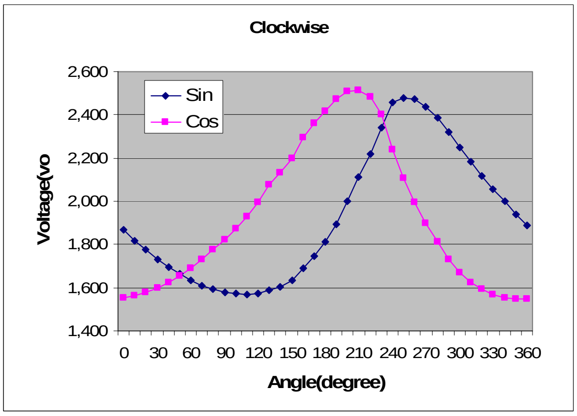

Fig.7. Sensor output (clockwise)

Small deviation are recorded when the position of the sensor is changed. This is due the variations in the earth magnetic field. A compensator for reducing these variations should be built in order to get better direction accuracy. To illustrate the variation of angle measurement due to changing the direction of rotation of the sensor, Figure 9 shows a plot of the sensor output with this deviation.

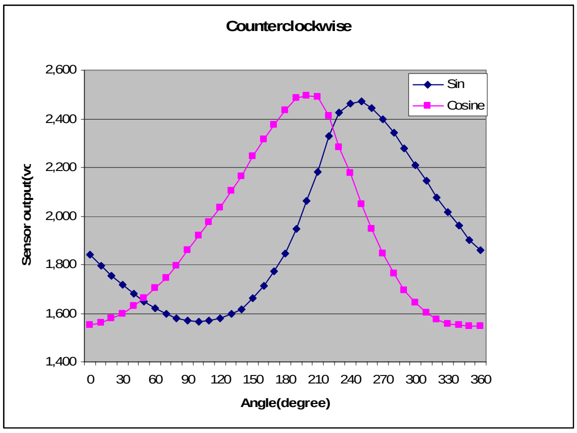

Fig.8. sensor output (counter-clockwise)

In General, the selection of an appropriate inertial measurement system depends heavily on the trade off between cost and performance requirements.

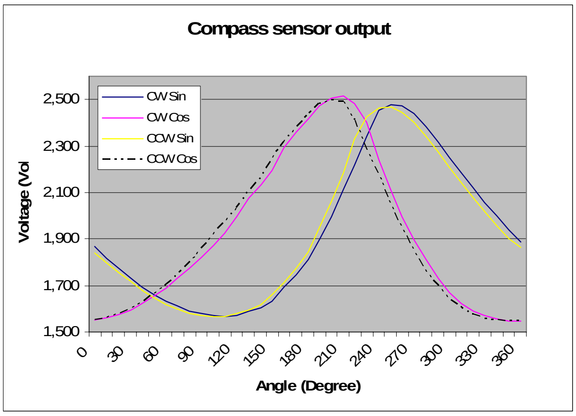

Fig.9. Compass sensor output

The Inertial navigation system described in this paper concentrates more on the accuracy aspects. The sensor is still sensitive to variation in the earth magnetic field; therefore more tuning is still required. A heading error up to 5 degrees is recorded. The main contribution in this work has been on the development of a accurate inertial navigation system based on thorough characterization of the errors which inversely affect the navigation accuracy. Our goal is to achieve a minimum error of position over a given travelled distance. A well designed recursive filter is still needed to minimize the continuously accumulated heading error.

4 Literatur

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