

Real-Time Assessment of Secondary Task Intrusiveness upon Real-World Driver Steering Performance using a Fiber-Optic Gyroscope

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Lateral steering stability is a critical parameter of driving performance from both a theoretical as well as applied perspective. The measurement of lateral steering stability in a driving simulation environment is both straightforward and ubiquitous. However, the ability to measure this performance parameter in real-time during real-world driving has typically been fraught with technical challenges. The recent introduction of low cost fiber-optic gyroscope devices appears to have addressed many of the traditional difficulties associated with the real-time measurement of steering performance. State-of-the-art fiber-optic gyroscopes are capable of providing continuous data representing the rate of change in heading angle with a precision of 0.001 deg/sec. The current study evaluated the reliability and potential usefulness of real-time angular heading rate data collected from a instrumented research vehicle fitted with a KVH AutoGyro (fiber-optic laser gyroscope). Data from the fiber-optic gyroscope was collected and logged (at 10 Hz) via digital computer while volunteer participants performed a number of standard driving maneuvers and in-vehicle tasks involving interactions with instrument panel interfaces and controls.

Introduction

A common outcome of the application of intelligent transportation systems (ITS) technology has been an ever increasing complexity of the person-vehicle instrument panel interface. A significant amount of research has been dedicated toward the development of techniques to measure and optimize the visual workload demands of such complex interfaces. Sensitive and diagnostic tools for measuring mental workload in the automotive context have been demonstrated (see Noy, 1997 for several state-of-the-art examples). Yet, the techniques available for measuring the “intrusiveness” of secondary tasks related to driving have remained somewhat crude and unreliable. Hence, it is possible that we often fail to detect small but meaningful interference effects upon the primary task of driving because our measures of intrusiveness have not kept up with advances in sensor technology.

Typical measures of secondary task intrusiveness upon driving (from operations such as using a cellular phone or following an in-vehicle navigation system) have included analyses of vehicular speed, speed variance, longitudinal following distance, etc. However, the most sensitive measures have tended to involve indices related to lateral lane deviations or short-term steering instability. Global positioning system (GPS) and electronic compass readings lack both the accuracy and precision needed to measure momentary variations in vehicle heading that are indicative of steering instability trends. As a consequence, the most commonly used measures of steering instability have involved video-based techniques for determining a vehicle’s moment-by-moment lateral deviation from the edge (or center) of the roadway (e.g., DASCAR). However, video-based systems for measuring lateral steering behavior are

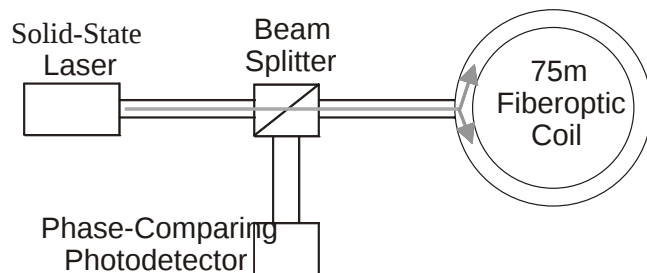
dependent upon the availability of continuous, high-contrast roadway delineation (such as a painted edge or center line). Yet, such markings are not available in many critical situations such as while turning or passing through an intersection or while driving on low speed/low volume roads in residential neighborhoods (where lane markings are the exception).

During the Spring of 1999 we began developing a new approach to measuring the momentary increases in steering instability that can sometimes result from driver interaction with instrument panel interface technology. Our goals were to develop a system that was: (1) highly sensitive and (2) not dependent upon the availability of a well-maintained roadway delineation infrastructure. This new system is based upon the use of a commercially available fiber-optic gyroscope that senses extremely small variations in the rate of change in vehicle heading. The theory of operation of this sensor and its application for driving research are discussed in the remainder of this report.

Fiber-Optic Gyroscope: Theory of Operation

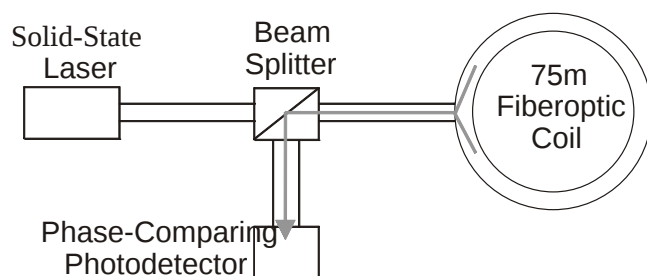
Our preliminary work to date has utilized the KVH Industries Model 222140 AutoGyro (which is based upon their E-Core line of fiber-optic gyroscopes). This device measures changes in angular heading rate (yaw angle) from 0.0 to plus/minus 100.0 degrees per second with an accuracy (repeatability) of 0.025 degrees per second (worst case scenario). This implementation of the fiber-optic gyroscope is based upon a device known as the *Sagnac effect interferometer* (Lefevre, 1993). A highly schematic representation of the device is shown in Figure 1.

As depicted in Figure 1A, specially polarized and temporally modulated light from a 820 nm compact disc laser is inserted into a 75 m long coil of fiber-optic material. The coil is tightly wound so that the entire device fits in a box approximately 115 x 90 x 41 mm in size. The laser light is equally split so that half of the light travels in a clockwise rotation about the coil while the remainder of the light races about in a counterclockwise path through the 75 m loop. Part B of Figure 1 shows how both of these streams of light are recombined (at the beam splitter) upon completing their journey through the coiled loop and are redirected toward a phase-comparing photodetector.



Part A.

Laser light is inserted into the a tightly wound coil of special fiber-optic material. Note that the light travels in both directions around the coil.



Part B.

Light exiting the coiled loop is combined and analyzed via a phase-comparing photodetection device.

Figure 1. Fiber-Optic Gyroscope

It is important to note that the coil, or loop, of fiber-optic material is placed in the same plane as the roadway surface upon which the test vehicle is traveling. As a result, any change in the heading of the vehicle will yield a small but measurable difference in the phase of the light traveling in opposite directions around the loop. This is the *Sagnac effect*. Phase differences in these streams of light on the order of one part in 10^{16} can be reliably recorded by the photodetector circuitry. When the rate of change in the angular heading of the vehicle containing the gyroscope is zero, there is no phase difference in the light emerging

from the clockwise versus counter clockwise streams -- resulting in a maximum intensity of the return light signal. However, as the rate of change in the heading angle increases so does the phase difference introduced between the clockwise and counterclockwise streams. When the phase-shifted streams of light are combined there is an interferometric reduction in the intensity of the resulting light signal which is proportional to the rate of change in angular heading. Hence, output of the photodetector decreases as angular rate increases (Bennett, Emge & Dyott, 1997).

Using the angular rate signal of the fiber-optic gyroscope together with distance traveled (wheel-based sensors) and a real-time clock, an in-vehicle computer can accurately calculate the path of travel of the test vehicle along with statistical estimates of short-term steering instability.

Case Study Evaluation

Video-taped records of driver behavior were collected simultaneously with computer-based calculations of lateral steering instability using the output of the fiber-optic gyroscope. Visual inspection of the records revealed that noticeable increases in lateral steering instability occurred when drivers engaged in secondary tasks such as tuning a radio or using a cellular phone (relative to baseline driving performance).

Select samples from these video tape case studies will be presented and discussed. Some quantitative analyses of the size and range of the steering instability measures will also be presented. In addition to being shown at the meeting, these video clips and analytical findings will be posted on the Internet at <http://www.usd.edu/~schieber/iea2000>.

Acknowledgement

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References

Bennett, S., Emge, S.R. & Dyott, R.B. (1997). *Fiber optic gyros for robotics*. Orland Park, IL: KVH Industries, Inc. (Available on-line at <http://www.kvh.com>)

Lefevre, H. (1993). *The fiber-optic gyroscope*. Boston: Artech House.

Noy, Y.I. (1997). *Ergonomics and safety of intelligent driver interfaces*. Mahwah, NJ: Lawrence Erlbaum Associates.

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