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Automated detection of grade-crossing-trespassing near misses based on computer vision analysis of surveillance video data

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ABSTRACT

Grade-crossing trespasses are one of the greatest sources of injuries and fatalities on railways. While there is a wealth of data regarding grade-crossing accidents, near misses (or precursor events) associated with unsafe trespassing on railroad tracks are not reported, and therefore a comprehensive dataset is unavailable. This paper presents a Computer Vision (CV) algorithm to automatically detect trespassing near misses based on surveillance video footage of railway-road grade crossings. The CV algorithm is designed to be robust under changing lighting conditions over the course of the day-night cycle and works well under varying weather conditions. The algorithm is currently implemented based on data from one grade crossing in New Jersey. With minimal configuration changes, the algorithm can be adapted to various other grade crossings. Ultimately, the CV methodology can support data-driven grade-crossing near-miss risk analysis and contribute to proactive safety improvements at grade crossings.

1. Introduction

Highway-railroad grade crossings are intersections where a railroad line crosses a highway. According to US Federal Railroad Administration (FRA) in 2015, there were approximately 210,000 highway-rail grade crossings in the nation, of which 61% were publicly approachable (FRA, 2017a). Each highway-rail grade crossing presents a potential hazard to highway users and train crews. The possible dangers, such as collisions between highway vehicles and trains, can result in property damage, casualties, or even the release of hazardous materials (Chadwick et al., 2014). Collisions between highway vehicles or pedestrians and trains have been the greatest source of injuries and fatalities in the railroad industry since 1996 (FRA, 2017a). From 2006 to 2015, there were over 22,000 highway-rail grade-crossing incidents, resulting in 2717 highway-rail deaths and 9595 highway-rail injuries (FRA, 2017b). Therefore, there is a significant need for safety advancements of highway-rail grade crossing.

Considerable research has been conducted on highway-rail grade-crossings accidents, most of them aiming to reduce accident frequency and/or severity (e.g. number of fatalities and injuries). Observed accident data is useful for safety research; however, a far greater number of risk-prone events (near misses or precursors) occur in which there is no collision or loss of life but which might *possibly* have contributed to such accidents. These events did not result in fatalities, injuries, or property damage to either highway users or trains, but had the propensity to do so if they repeatedly occur. This paper focuses on the near misses due to trespassing at highway-rail grade crossings, which are defined as those incidents where roadway users are found to be in violation of existing laws related to grade crossings. Grade-crossing near misses may precede costly accidents but are not well documented because they did not result in immediate harm. The analysis of near misses can provide additional insight that may contribute to grade-crossing safety improvement. However, very little prior research has focused on near-miss-based grade-crossing data collection and corresponding safety analysis.

This knowledge gap motivates the development of this paper, which aims to develop an adaptable Artificial Intelligence (AI) framework for automatically collecting near-miss data based on surveillance video data. Surveillance cameras are currently deployed at many grade crossings in the United States. The existing video data can be used to track various objects such as pedestrians and wheelchairs that cannot be detected by conventional photoelectric, ultrasonic, and loop coil systems (Fakhfakh et al., 2010). In this study, closed-circuit television (CCTV) cameras are placed at railway grade crossings to monitor real-time activities. Due to limited storage capability, most railroads delete the raw video data every one or two months after relevant data has been collected. To preserve useful near-miss information from these unused big data sources, we collaborated with one rail agency in New

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Jersey to develop an AI-aided analytic platform for extracting near-miss information from video data. Ultimately, our aim is to build a unique, expanding near-miss database for proactive risk management at grade crossings in the future.

2. Literature review

This study examines the automated detection of near misses due to highway-rail grade-crossing trespassing using AI as a support technology. Three major fields of research are relevant to this project: grade-crossing safety, near misses, and artificial intelligence algorithms for video analytics. The following subsections review some of the most relevant prior studies in each field.

2.1. Grade crossing safety

Considerable efforts have been made to quantify the frequency and severity of highway-rail grade-crossing incidents. The U.S. Department of Transportation (USDOT) Accident Prediction Model is a commonly used model in the U.S. to predict the number of collisions occurring at grade crossings, given specific highway and railroad conditions (Faghri and Demetsky, 1986; FRA, 2007). Saccomanno et al. (2004) performed Poisson regression and Negative Binomial Regression to achieve higher prediction accuracy and found that train speed, exposure, surface width, and number of tracks were significant factors in collision prediction models. Statistical models were developed to analyze the impact of a grade crossing collision on highway traffic (FRA, 2007; Hu et al., 2010) as well as rail traffic (ADL, 2010; Hu et al., 2010; Chadwick et al., 2012). Furthermore, research has also been conducted to examine passenger train car crashworthiness (Simons and Kirkpatrick, 1999; Tyrell et al., 2006).

In addition to the analysis of accident frequency and severity at highway-rail grade crossings, a clear understanding of driver behavior and the identification of the human factors can contribute to the development of better accident-prevention strategies. Caird (2002) summarized a taxonomy of accident contributors in six categories: unsafe actions, individual differences, train visibility, passive signs and markings, active warning systems, and physical constraints. Although each of these issues requires slightly different approaches to reduce undesirable occurrences, engineering, law enforcement, and the education of the public about the risks are three generally effective approaches to the improvement of grade-crossing safety. For more concrete details regarding human factor causes, Chadwick et al. (2014) provided a comprehensive overview of grade-crossing risk research in the United States. The frequency of grade-crossing accidents has declined 80% over the past 20 years, despite an increase of both train and highway traffic. Nevertheless, collisions between highway users and trains are still the greatest source of fatalities and injuries in the U.S. railroad industry (FRA, 2017a). Hence, it is crucial to better understand noncompliant behaviors at grade crossings, through both accident data and near-miss data.

2.2. Near-miss events in transportation safety research

Prior research has been conducted regarding near-miss identification in maritime and aviation sectors. For example, Zhang et al. (2015) proposed a method to identify potential ship-ship collisions using Automatic Identification System (AIS) data. High risk vessel encounters are evaluated by navigational experts to identify a potential near miss. In another study of bird collision hazard to aircraft, Klope et al. (2009) used digital avian tracking radars to automatically monitor and identify near-miss events. It shows that a combined dataset of actual bird-strike incidents and near-misses can provide risk managers with a more responsive metric in assessing the hazards over time than by using only the bird-strike dataset.

To date, almost all prior studies in the field of grade crossing safety have focused on using the reported highway-rail grade-crossing accidents in the available databases, such as the U.S. Federal Railroad Administration Rail Equipment Accident database or Grade Crossing Incident database. However, none of these databases contain near-miss events that did not cause actual damage. Several studies, however, indicated the importance of near-miss data for railroad safety and risk analysis. For example, Wright and Van der Schaaf (2004) stated that accidents are (fortunately) too few in number to support decision making about investing in safety improvements, while the use of near misses is able to dramatically increase the available data to counteract this problem. In addition, most accidents, such as grade-crossing collisions, were preceded by near-miss events and accident prevention should not wait until an accident actually occurs. Nevertheless, a large proportion of published studies have continued to focus on accidents only, while very few included near-miss data. The primary reason behind this deficiency may be the lack of sufficient, available near-miss data. San Kim and Yoon (2013) collected near-miss data from 80 rail accident investigation reports published by an independent accident investigation organization in the UK; however, it is time-consuming to manually judge the type of outcome (accident, incident, or near miss) derived from the title or summary of each report. A similar method was used by Le Coze (2013), in which near misses were identified from published studies or books. Given the limitations of these previous studies, an efficient near-miss collection method with high accuracy is essential to support the study of near misses.

Grade-crossing near-miss data is largely unavailable. Lobb (2006) pointed out that inadequate reporting has hindered the understanding of grade crossing collisions. Understanding and affecting driver behavior and human factors has contributed to about 70% of the decrease in the number of collisions and fatalities at grade crossings over the past 30 years (Mok and Savage, 2005). Behavioral models, such as Signal Detection Theory (SDT), have been used to model motorists' stopping behavior at grade crossings (Richards and Heathington, 1990; Yeh et al., 2009). A FRA report (Raslear, 2015) also discussed the application of SDT in motorist behavior at grade crossings, but also claimed that the models have only been tested against limited data and more field studies about motorist behavior and train arrival times are necessary. Thus, it is crucial to create an algorithm to detect and record grade-crossing near-miss data, so that it can provide sufficient data to test and refine the models within the framework of behavioral risk analysis.

2.3. Artificial Intelligence for video analytics

AI technologies, particularly computer vision, is used to train computer program to "understand" images and videos and identify useful features. AI techniques in computer vision include background subtraction (Shah et al., 2007; Sheikh et al., 2004; Ramesh, 2003; Elgammal et al., 2000; Fakhfakh et al., 2010; Zivkovic, 2004), image segmentation (Sheikh et al., 2004; Elgammal et al., 2000; Salmane, et al., 2015; Sen-Ching and Kamath, 2004), and trajectory prediction using Kalman Filtering (Salmane, et al., 2015; Sen-Ching and Kamath, 2004; Patel and Thakore, 2013). Patel and Thakore (2013) have reviewed the technique of foreground detection by learning the background template of the frame and then applying a background subtraction technique to identify moving objects. After that, objects are detected through segmentation of the isolated pixels, and their movement is tracked using Kalman Filtering. This has proven to be an effective technique for handling this task in computer vision. However, to implement this technique for the detection of highway-rail grade-crossing near-miss events, it is necessary to address several challenging problems in this real-world scenario, such as severe weather conditions and isolation of the train from the rest of the moving objects.

Very little prior work has used these techniques on grade-crossing safety analysis, except the following few studies. Shah et al. (2007) presented a background subtraction approach that detects moving