Vision-based Automated Flagging System in Construction*

Wei Han and Zhenhua Zhu

Abstract— **Flaggers are a high-risk profession. They are always required to work closely with the open traffic lanes. Any distracted, speeding or intoxicated drivers might hit them, leading to their injuries and fatalities. From 1980 to 1992, a total of 54 fatalities involving flaggers in the construction industry have been reported. To protect flaggers and reduce their exposure to potential vehicular traffic, previous studies proposed and implemented the Automated Flagger Assistance Devices (AFADs). However, the AFADs have not been widely used in practice due to their costs. In addition to hiring a flagger to remotely operate an AFAD, the cost of an AFAD system alone ranges from $25,000 to $30,000 without the consideration of device maintenance. Instead of creating an assistance device, this paper proposed an automated flagging system (AFS) that can guide the traffic without the need for a flagger available on the site. The proposed system is composed of two modules: information capturing and decision-making. The information module is to monitor traffic conditions and retrieves useful information for the decision-making module to decide which sign (STOP or SLOW) to display in the LED panel. So far, a prototype was developed and tested in a laboratory environment. A vehicle detector was trained and integrated into the prototype. The laboratory test results indicated that the prototype could correctly show the STOP or SLOW sign based on the detection of simulated traffics.**

I. Introduction

The United States roadway system contains around four million miles of roads [1]. The system is important in economics for communication and transportation. To keep the roads in a functional condition, the roads cannot be entirely closed for construction activities in most cases [2]. Thus, the workers in the work zones are in high-risk situations. From 2011 to 2015, a total of 279 fatalities related to vehicles were reported by the U.S. Bureau of Labor Statistics [3].

The use of flaggers on multi-lane highway work zones is a requirement of standard specifications for road construction in many State Departments of Transportation (DOTs) [4]. This makes flaggers becomes one of the most dangerous professions. They are required to work closely with the open traffic lanes, where physical barrier protections are not set up in most cases. They might be hit by any distracted, speeding, or intoxicated motorist, leading to injuries and fatalities. From 1980 to 1992, 54 fatalities involving flaggers were reported; and they were hit by vehicles on the construction sites [5].

As a result, the concept of automated flagger assistance devices (AFAD) has been proposed to protect the safety of the flaggers. An AFAD aims to be operated remotely by a flagger positioned outside the traffic lanes. This way, it could reduce the exposure of the flagger to vehicular traffic. The AFADs developed in the early time were remotely controlled to switch between the stop and slow signs or between red and yellow lenses to alternate the right-of-way [6]. Recently, the AFAD developed by the Missouri Department of Transportation combined signs and lenses; and the device could be further mounted on a truck to increase its mobility [7].

Although the concept of AFADs has been proposed and developed for a while, they have not been widely adopted in practice. One possible reason behind this is that the device is not cost-effective at the moment. Although a flagger does not have to stay close to the traffic lane to guide the traffic with an AFAD, he or she is still required and gets paid to operate the device remotely. On the other hand, the price for purchasing or renting an AFAD did not drop significantly in the market. It was noted that the cost of a single AFAD system could range from around $25,000 to $30,000 or $3,000 to $3,200 per month [8]. As a result, construction contractors or project managers prefer flaggers rather than the use of AFADs.

Compared with AFADs, this paper proposed the concept of creating an AFS that can guide the traffic without the need or aid of a flagger. The system is composed of two modules, i.e., the information capturing module and the decision-making module. First, the information capturing module is responsible to monitor the traffic through visual object detection, tracking, and distance estimation. Based on the traffic information captured, the decision-making module determines which sign (STOP or SLOW) should be shown on an LED panel for the traffic guidance.

So far, the main hardware of the proposed system has been assembled into a prototype. A vehicle detector was trained and integrated into the prototype. The prototype was tested in a laboratory environment. The test results showed that the vehicle detector could detect 7 classes of vehicles commonly seen on road, such as trucks, dump trucks, motorcycles, and buses. Also, the prototype could determine which sign (STOP or SLOW) to show based on the detection of simulated traffics.

II. Automated Flagger Assistant Devices

There are several AFAD products available in the market. They can be remotely operated by flaggers, keeping them away from the traffic lanes and reducing their possibility of being struck by vehicles. Virginia, Missouri,

*Research supported by Wisconsin Alumni Research Foundation.

Wei Han is with the Department of Civil and Environmental Engineering, University of Wisconsin – Madison, Madison, WI 53706 USA (e-mail: whan59@wisc.edu).

Zhenhua Zhu is with the Department of Civil and Environmental Engineering, University of Wisconsin – Madison, Madison, WI 53706 USA (corresponding author, phone: 608-265-3228; fax: 608-262-5199; e-mail: zzhu286@wisc.edu).

and Maine DOTs started to evaluate and deploy them to the field [9 - 11]. AFADs were added in the 2009 edition of the Manual on Uniform Traffic Control Devices (MUTCD) for the use of controlling traffic in temporary traffic control zones [12]. The standards of AFAD applications have been listed in the MUTCD Section 6E.04. For example, if the AFAD is operated at nighttime, it should be illuminated. Additionally, different states may adopt more strict AFAD application policies or standards. For instance, MUTCD does not have any limitation in average daily traffic (ADT) in general; however, Virginia Department of Transportation only allows AFADs to be applied when ADT is below 12,000 vehicles [8].

In MUTCD, AFADs have been divided into two types. The device in the first type only contains a remotely controlled STOP/SLOW sign. The STOP sign is designed to inform drivers to stop in front of the sign and wait for the next instruction. The SLOW sign means that drivers can pass through with caution. It was pointed out that approximately 25 percent of the drivers might misunderstand the meaning of STOP signs, and they just stop their vehicles for a moment and then proceed [13]. Therefore, it was recommended to put on additional explanations, such as “wait on stop” and “go on slow”, to help the drivers understand the actual meaning of the signs [13].

The device in the second type is equipped with a Red/Yellow light remotely controlled and a gated arm. When the light turns red, the gated arm would be lowered to stop the traffic. When the light turns yellow, the gated arm would rise to let vehicles pass. Existing studies [13,14] showed that most of the drivers could understand the operation of the AFAD with the gated arm.

In addition to these two types of AFAD devices, the Missouri DOT proposed the AFADs that could be truck-mounted on trucks. The AFADs are equipped with STOP/SLOW signs, Red/Yellow lights, and a changeable message sign (CMS) [9]. The lights and CMS could make the drivers spot the AFAD far away and facilitate their understanding so that they could slow their vehicles earlier.

III. Proposed System

A. System Overview

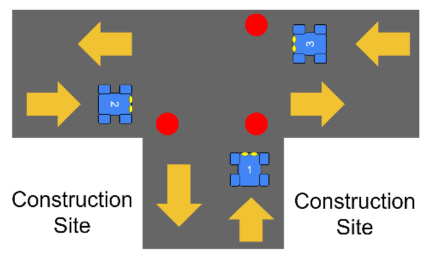
The proposed system is composed of two modules, i.e., the information capturing module and the decision-making module. To monitor the traffic conditions, the information capturing module collects and processes the video streams into objects with information on categories and actions. The action information of the objects is presented as approaching or leaving. Once the object information is obtained, the module leverages object tracking and action detection. Then, the object category and action information are fed to the decision-making module. The module gives a SLOW or STOP signal to the sign controlling module to show “STOP” or “SLOW” in the sign display panel.

B. Information Capturing

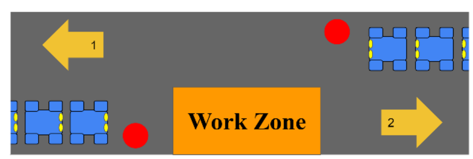
The information capturing module is to monitor traffic conditions on lanes and retrieves useful information as inputs to the decision-making module. Here, the traffic information of interest includes vehicle categories, quantities, and actions. The vehicle categories and quantities are retrieved through the detection and tracking of construction and non-construction vehicles, such as dump trucks, motorcycles, and buses. This way, the proposed system could know how many and what kinds of vehicles tend to go through. The vehicle actions include approaching, leaving, and idling, where the approaching is further identified as to whether the vehicle intends to enter the construction site.

C. Decision Making

The decision-making module determines which sign (STOP or SLOW) to show in the sign panel to guide and control traffic. Here, two scenarios are defined. The first scenario is referred to as the non-shared lane (NSL) scenario. It means that the vehicles in different directions do not need to share the same lane, as shown in Figure 1(a). The second scenario is the shared lane (SL) scenario. It indicates that a lane is temporarily closed and the vehicles in different directions need to share one lane, as shown in Figure 1(b).



(a) NSL Scenarios



(b) SL Scenarios

Figure 1. Examples of NSL and SL Scenarios

To guide the construction vehicles (e.g., trucks, excavators, backhoes, and loaders) that tend to enter or leave the construction site, three conditions in the NSL scenario are analyzed in general. When there are no vehicles in all the directions, all the devices show SLOW. When construction vehicles are coming from one direction, the device responsible for monitoring that direction shows SLOW, and others show STOP. When construction vehicles come from multiple directions, it is necessary to prioritize them and determine which one goes first. Here, the vehicle leaving the construction site is always given the highest priority. As for the vehicles in other directions, the vehicle turning left should always yield the right of way. Take Figure 1(a) for an example. Vehicle 1 that is leaving the construction site owns the highest priority; thus, it goes first. Then, vehicle 3 waits for vehicle 2 to go, because vehicle 2 turns right to enter the construction site. After vehicles 1 and 2, vehicle 3 can enter the construction site.

In the SL scenario, four conditions are analyzed in general to guide the vehicles in both directions to pass by the work zone safely. When no vehicles are coming from both directions, two devices show STOP. When vehicles are coming from one direction, the device responsible for monitoring that direction shows SLOW, and the other shows STOP. When vehicles come from both directions, it is necessary to prioritize them and determine which one goes first. Here, the vehicles that are not on the same side of the work zone are given higher priority. To prevent the vehicles with a lower priority from infinite waiting, the priorities between two directions will be swapped after a predefined duration (e.g., 40 seconds). Take Figure 1(b) for an example. The vehicles in direction 1 get the higher priority because they are on the opposite side of the work zone. Thus, they go first. After a predefined duration, if those vehicles are not yet finished passing, the priorities of directions 1 and 2 will be exchanged. Then, direction 2 now owns the higher priority. Thus, vehicles in direction 1 stop for letting vehicles in direction 2 pass. The priorities keep exchanging until all the vehicles pass by the work zone.

IV. Implementation and Preliminary Results

A. Prototype Development

A prototype was assembled as shown in Figure 2. The prototype includes four cameras, a computer, a led panel, and a battery. They are mounted on a cart so that the prototype is movable, self-powered, and without the need for an internet connection. The cameras on the stand can be rotated horizontally according to the needs of monitoring traffic conditions. The led panel is controlled by a Raspberry pi which connects to the computer with an ethernet cable. The IDs of cameras are set up manually and shown on the number tags near the cameras. The prototype requires approximately 300 watts of power supply to operate for one hour without charge. The device will be further improved for energy efficiency. For example, the computer will be replaced with more energy efficient computing device. Also, low-power self-organizing network will be added to the system to reduce the energy consumption of communications between devices.

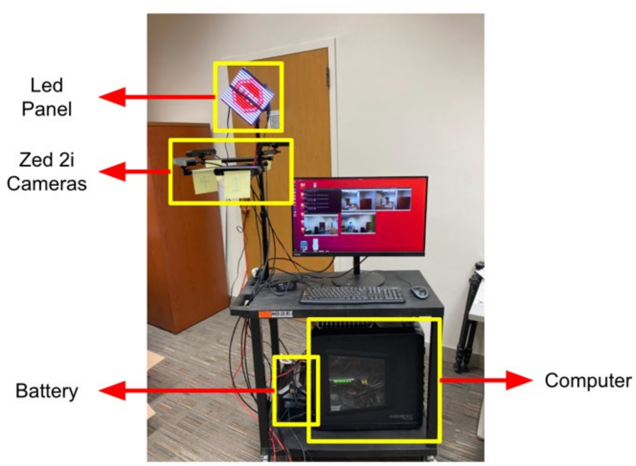


Figure 2. Prototype Development

B. Preliminary Results

So far, a vehicle detector has been trained and integrated into the prototype. To support real-time detection, the detector relies on YOLOv5, one of the fastest and most accurate object detection models [15]. It was trained to detect 7 vehicle classes, i.e., bicycle, car, motorcycle, dump truck, bus, cement truck, and truck. The dataset for training and validating the detector contains a total of 9,962 images with 32,060 labels, where 8,515 images with 28,030 labels were used for training and 1,447 images with 4030 labels were used for validation. The critical training settings were shown in Table 1. Figure 3 shows that 100 epochs are enough for model training, because the precision curve and loss curve begin to be steady after 160 steps (80 epochs). The detector was evaluated in terms of precision, recall, and mAP_{50} shown in Table 2.

Table 1. Detector Training Settings

Setting	Value	Setting	Value
epochs	100	Optimizer	SGD
Batch Size	2	Momentum	0.937
Image Size	640x640	Learning Rate	0.01

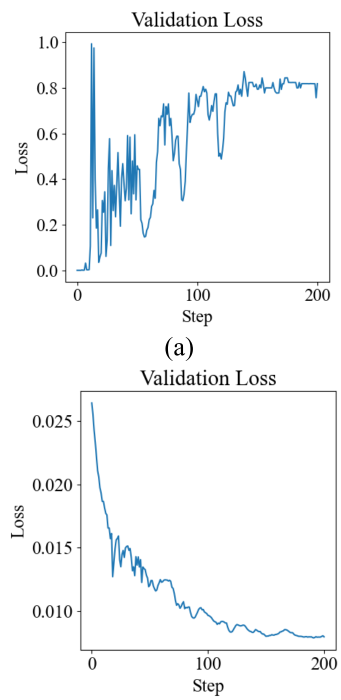


Figure 3. (a) Precision curve and (b) loss curve of training process.

Table 2. Detector Performance

Class	Precision	Recall	mAP_{50}
Bicycle	0.50	0.45	0.50
Car	0.64	0.61	0.65
Motorcycle	0.65	0.61	0.66
Dump Truck	0.84	0.82	0.53
Bus	0.72	0.71	0.78
Cement Truck	0.92	0.91	0.90
Truck	0.41	0.43	0.47
Overall	0.67	0.65	0.64

Figure 4 showed the STOP or SLOW sign on the prototype's LED panel. Here, the LED panel was set to be associated with the camera on the right side (Camera A). Camera A was manually assigned with the highest priority. The STOP sign was shown when traffics were detected in any other camera views and meanwhile, no traffics were detected in the view of Camera A. No matter whether traffics were detected in the views of other cameras, the SLOW sign was shown as long as there were traffics detected in the view of Camera A.

(a) STOP sign display

(b) SLOW sign display

Figure 4. Signs on the LED panel

V. CONCLUSION AND FUTURE WORK

This paper proposed a vision-based flagging system to automatically guide the traffic near a construction site. The system consists of two modules: information capturing and decision making. A prototype built upon the concept of the system was assembled. The prototype is equipped with four cameras, a computer, a led panel, and a battery, all of which were mounted on a chart for mobility. So far, a vehicle detector has been trained and integrated into the prototype. A laboratory test was conducted to illustrate the feasibility of the prototype to show STOP or SLOW signs depending on the detection and tracking results. Future work will focus on implementing the remaining parts of the system and testing it on real construction sites to evaluate the performance of decision-making algorithms.

REFERENCES

[1] "Highway Finance Data Collection," *U.S. Department of Transportation/Federal Highway Administration*, 7 Nov. 2014, https://www.fhwa.dot.gov/policyinformation/pubs/hf/pl11028/chapter1.cfm.

[2] Bushe, B., Feraco, T., Forbes, E., Stilwell, I., & Vanscoy, J. (2020). "A Study of a Traffic Controlling Robot for Safer Work Zones."

[3] "Fatal Injuries at Road Work Zones," *U.S. Bureau of Labor Statistics*, 5 Apr. 2017, https://www.bls.gov/opub/ted/2017/fatal-injuries-at-road-work-zones.htm.

[4] Ahmed, A., & Liang, L. (2017, January). Impact of flaggers on safety and mobility of highway work zones. In *Canadian Society for Civil Engineering Annual Conference and General Meeting 2017: Leadership in Sustainable Infrastructure* (pp. 264-271). Canadian Society for Civil Engineering.

[5] Ore, T., & Fosbroke, D. E. (1997). Motor vehicle fatalities in the United States construction industry. *Accident Analysis & Prevention*, 29(5), 613-626.

[6] Nada D Trout, Melisa D Finley, and Brooke R Ullman. Motorists' understanding of automated flagger assistance devices in work zones. *Transportation research record*, 2337(1):42–49, 2013.

[7] Zhu Qing, Siyang Zhang, Henry Brown, and Carlos Sun. "Evaluation of truck-mounted automated flagger assistance devices in Missouri: Case study," *Journal of Transportation Engineering, Part A: Systems*, 145(12):05019006, 2019.

[8] "Guidance on the use of Automated Flagger Assistance Devices," *American Traffic Safety Services Association*, (2012), https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/training/fhwa_wz_grant/atssa_afad.pdf .

[9] Qing, Zhu, et al. "Evaluation of truck-mounted automated flagger assistance devices in Missouri: Case study," *Journal of Transportation Engineering, Part A: Systems* 145.12 (2019): 05019006.

[10] Cottrell, Benjamin H. "Evaluation of the Autoflagger in Virginia," No. FHWA/VTRC 07-R12. *Virginia Transportation Research Council*, 2006.

[11] Thompson, Bill. "Field evaluation of automated flagger assistance devices (AFADS)," No. 42959. *Maine. Dept. of Transportation*, 2008.

[12] FHWA, USDOT. "Manual on uniform traffic control devices (2009)." *Baton Rouge: Claitor' s Law Books and Publishing* (2010): 137-179.

[13] Trout, Nada D., Melisa D. Finley, and Brooke R. Ullman. "Motorists' understanding of automated flagger assistance devices in work zones," *Transportation research record* 2337.1 (2013): 42-49.

[14] Finley, Melisa D. "Field evaluation of automated flagger assistance devices in work zones on two-lane roads," *Transportation research record* 2337.1 (2013): 1-8.

[15] Nepal, Upesh, and Hossein Eslamiat. "Comparing YOLOv3, YOLOv4 and YOLOv5 for Autonomous Landing Spot Detection in Faulty UAVs," *Sensors* 22.2 (2022): 464.