LaRa-OHVD: An Innovative Over-Height Vehicle Detection System to Protect our Bridges to Prosperity

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A student essay submitted for ITS- NY 2015 Best Student Essay Competition at 2015 Intelligent Transportation Society of New York 22nd Annual Meeting
Saratoga Springs, NY
LaRa-OHVDS: AN INNOVATIVE LASER RANGING OVER-HEIGHT VEHICLE DETECTION SYSTEM TO PREVENT BRIDGE STRIKES

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1. RESEARCH OBJECTIVES

PROBLEM STATEMENT

- Over-height vehicle bridge strikes a major problem all over the world.
- More than 200 bridge hits annually in the USA.
- Current Over-Height Vehicle Detection Systems (OHVDSs) are installed across the road width at mid-level or on the bridge.
- System & installation costs of OHVDS are high (up to $200,000 in some cases).
- Installation limited to very few temporary.
- No innovation in OHVDS technology since 1998.

RESEARCH OBJECTIVES

- To develop a new over height vehicle detection system that can be installed on the face of the bridge/overhead gantry/existing roadside infrastructure.
- Can detect incoming over-height vehicle at safe stopping distance.
- Most bridges already have electricity (street lights), telephone connections.
- Low cost device based on mature Ladar (Laser Detection and Ranging) technology, special optics and existing traffic engineering guidelines.
- Mass deployment because of low cost.
- Better performance features than existing OHVDS systems.

2. BRIDGE HIT PROBLEM

- $5,000 over-height vehicle bridge hits/year in U.S. in over $100 million worth of damage to public & personal property.
- Over-height bridge truck hits resulted in ~20 fatalities (1993-2013) and 75 injuries (2010-2013) per year respectively.
- Over-height truck hits have resulted in 33,108 structural damage bridge hitsiness (2010-2013).
- Societal cost of a major over height-vehicle bridge hit estimated to be $504,000 based on FHWA figures.
- 14 European Union Member States, Ireland (~180 hits/year), United Kingdom (~1,000 hits/year, Australia (352 hits between 2005-2013) consider bridge hits as a significant safety risk.
- 68% State DOTs consider bridge hits to be a significant problem.
- New York State had 1,600 hits since 1993. Many bridges have been repeatedly hit.
- Tractor trailers, large trucks constitute majority (98%) of hits.
- Bridges over Parkways, State Highways, Interstates most affected.

3. CURRENT MITIGATION METHODS

- Driver education on bridge hits: Using CMV license and experience, vehicle height signs in cabin (costly and awareness required).
- Bridge height signs on the bridge face next to the detector.
- Costly to implement. Vehicle/cargo damage or driver injury may result in liability issues.

4. STATE OF PRACTICE OHVDSs

- Introduced in 1965, proven effective in reducing hits, used by 15 State DOTs (2011).
- Consists of pair of aligned optical transmitter-receiver (A), Alarm bell (B) and VMS sign (C)
- Improvements to basic setup have been limited to:
  - Modifications in the light source (visible/infraed/laser)
  - Light modulation (visible), Operation Mode: diffuse, reflective or opposed infrared
  - Using a single, dual beam or 2-beam systems

LIMITATIONS

- Systems installed at greater distance before the bridge, up to a quarter mile
- Power & communication lines may have to be brought up to the installation site.
- Systems require a communication cable between the transmitter and receiver units. Requires digging a trench across the road width. Results in additional roadway closures & traffic delays.
- Structural & installation costs usually much higher than system costs
  - ITS grade installation $50,000-$100,000 per approach
- Stand alone detector-price cost is also expensive
  - $500,000-$1,000,000 each system

5. LaRa-OHVDSs

LaRa-OHVDS: Laser Ranging Over-Height Vehicle Detector

- Uniqueness in Operation
  - First OHVDS which can be mounted on the bridge being protected (or overhead gantry/roadside infrastructure).
  - Long range detection (<1000 feet). Detect incoming over height vehicle at safe stopping distance (570 feet @ 60 mph, Level Grade AASHO).
  - Broad detection zones instead of single optical beam for more comprehensive detection.
  - Eye safe, infrared laser rangefinder based device.
  - Uses a standard flowcard with warning signs with flashing yellow beacons, board operated variable messages.
  - Meet or exceed current OHVDS performance specifications

- Vehicle detection algorithms: minimum false detections
- Minimal System Cost including Detector, Warning Sign, Signals & Installation
- Line of Sight Warning Sign and Traffic Signal design
  - Driver control approach the warning signs
  - No need for expensive VMS/Matrix signs
  - Provide Over-Height measurement
  - Useful statistic for crash/damage assessment
  - Collision Prediction by Speed Measurement
  - Pre-emptive Emergency Response Recovery
  - Controlled Damage due to driver response

6. TESTING & RESULTS

- Optical Testing to validate Laser Beam Shape
  - Triangular laser sheet. 7.2 cm wide @ 8 ft. (left edge, center, right edge) 2 cm thick
  - Beam Resolution
    - 0.029 ft (0.35 mm): 2.36 inch x 2.5 Ft wide
    - 0.020 ft (0.25 mm): 1.65 inch x 4.5 Ft wide
  - Finer focusing of optics can correct beam shape at field distances.
  - Range limitations due to APD receiver design
- Height Sensing Algorithm
  - Vehicle / False Detection Algorithms
  - Currently Under Development

7. LaRa-OHVDS PROTOTYPE

- An eye-safe (Class 1) infrared laser based prototype developed <USD $4,000
  - Size of a typical shoe box (LxWxH = 12” x 6” x 6”)
  - Weight < 3 lbs.
  - Actual product design can further reduce size & weight considerably
  - Custom laser rangefinder design uses special optics to transform the elliptical laser beam into a thin sheet of laser light (fan shape)
  - Field interface to Traffic Management Center can be integrated.
  - All weather performance needed is tested.
  - Mounted on a traditional camera enclosure bracket- simple installation
  - Maximum allowable traffic signal for higher visibility - Flash rate set as per MUTCD
- Operational parameters configured through a PC – Serial interface
- Requires one time on-site calibration
- Single lane design, Meets “Performance features” of existing OHVDSs
- “Direction discerning” feature of existing OHVDSs can be implemented

8. CONCLUSIONS

- By combining a mature vehicle detection technology (Ladar), special optics and existing traffic engineering guidelines, a cost effective Laser Ranging Over-Height Vehicle Detector is developed.
- Represents a new sensor innovation in over-height detection in decades.
- Current OHVDSs lack market competition, with archaic operation resulting in very high sensor and deployment cost. Find limited use at most problematic locations.
- Thousands of low clearance bridges & overpasses still vulnerable to over-height vehicle hits.
- LaRa-OHVDS is envisioned to detect over-height tractor trailers and large trucks which cause the maximum number of bridge hits (98%) in New York State.
- With respect to New York State, majority (78%) of bridge hits have been found to occur on Parkways, State Highways and Interstates; where the LaRa detector can be utilized.
- Actual field testing is required to validate the system utility and note performance limitations.
- The low cost design, minimal installation, features like broad vehicle detection zone algorithms to minimize false detections, line of sight warning sign, collision prediction & over-height measurement; makes the LaRa-OHVDS an innovative concept in over-height detection.
- LaRa-OHVDS has the potential to prevent thousands of bridge strikes; saves life, prevents congestion, save tax payer’s dollars and contribute to the vital infrastructure preservation goals in the United States.

ACKNOWLEDGMENTS

This research is supported by the University Transportation Research Center, Region 2
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Abstract

Collisions between over-height vehicles and bridges are a serious problem across the world. Over Height Vehicle Detection Systems (OHVDs) have been routinely utilized by transportation agencies to protect their bridges and overpasses. However, high system costs have limited their deployment making thousands of low clearance structures vulnerable to collisions. A new over-height vehicle detector based on existing laser ranging technology (LADAR) is developed to overcome the cost barrier while providing enhanced capabilities as compared to the state of practice OHVDs. Currently under development, the LaRa OHVD has immense potential to reduce the over-height bridge hits and protect the integrity of our transportation infrastructure.

Introduction

New York City is an excellent example of how bridges transform a city by providing vital links in its transportation network. The ~ 600,000 bridges across the United States (including the 17,000 highway bridges in New York State) shape the backbone of the American transportation infrastructure enabling connectivity, commerce and economic competitiveness. However, latest data from the National Bridge Inventory indicates that close to 145,800 bridges (~ 24%) are structurally deficient or functionally obsolete [1]. With aging infrastructure and increasing gaps in transportation funding, the bridge agencies
now require innovative and cost effective measures to protect and extend the service life of existing and newly constructed bridges and overpasses.

Over-height vehicle impacts to low clearance bridges, tunnels and overpasses cause significant damages to transportation infrastructure, create safety risks for the driver of the vehicle and other motorists on the roadways and often result in closure of the bridges for lengthy periods with costly repairs [2]. Most importantly, severe or repeated hits may result in reduced design life of bridge structure resulting in untimely and extremely high replacement cost.

Currently, many State DOTs/bridge agencies utilize Over-Height Vehicle Detector systems (OHVDs) over roadways to detect the erring vehicles en-route to low clearance structures. This technology while proven in field for many years; is outdated and has many noted limitations as reported by State DOTs. Current OHVDs lack market competition, with archaic operation resulting in very high sensor and deployment cost. Due to this, these systems are only used at most problematic locations leaving thousands of other bridges & overpasses vulnerable to over-height crashes.

This paper presents a new ITS roadway sensor (currently under development) by our research group to detect over-height vehicles. The Laser Ranging Over Height Vehicle Detector (LaRa-OHVD) or simply “LaRa” is a new detection concept in over-height sensing which uses LADAR technology to infer a vehicle’s height. This mature technology finds many applications in transportation namely, in LADAR speed guns, vehicle profiling and automotive sensors (e.g. adaptive cruise control). LaRa meets the operating requirements of current OHVDs while providing marked improvement in detector capabilities with a very low system cost.

The paper starts with a background review defining the problem scope. State of practice OHVDs are then presented with their operation and noted limitations. This is followed by a description of the proposed solution, the sensing methodology and the advantages of the proposed detector. The paper concludes by summarizing key findings and directions for future research.

**Background Literature**

*The Over-Height Vehicle Bridge Hit Problem*

Collisions between over-height vehicles and low-clearance bridges & overpasses (hereby referred as “over-height bridge hits”) are a major problem in USA and the world. It is estimated that in U.S., there are ~5,000 low clearance bridge hits per year which cause over 100 million dollars’ worth of damage to public & personal property [3]. Crash data for large trucks indicates that, over-height bridge hits alone have resulted in approx. 20 fatalities (2003-2013) and 75 injuries (2010-2013) per year respectively. Over height trucks have resulted in ~13,108 structural damage bridge hits in last four years (2010-2013) [4]. Since there is no national database on over-height crashes including all vehicle types, these numbers paint a very conservative picture of the magnitude of the problem. More conclusively, a 2011 survey of State Department of Transportation (DOTs) in U.S. revealed that 68% (30 out of 44 State DOTs) consider bridge hits to be a significant problem. New York State alone has reported ~200 bridge hits /year with many bridges being repeatedly hit in last few years [5]. Internationally, Ireland (>180 hits/year), United Kingdom (>2,000 hits/year) and 14 European Union Member states including Western Australia and East Japan Railway consider bridge hits to be significant safety risk [6].

Factors contributing to bridge hits include; wide disparities in penalties for over height violations [7], variance in standard bridge clearances between National and off-National Network, different over-height permit requirements between States, anecdotal reporting of bridge clearances (actual/under-
reporting), driver ignorance regarding vehicle/cargo height, lack of route planning by haulers, use of consumer grade GPS [5], drivers not following authorized routes [8] and inadequate low clearance warning signs [9]. In U.S., State DOTs have identified “over-height trucks” as prime cause of bridge hits. Once an over-height vehicle is en-route towards a low clearance bridge, OHVDs are usually the last line of defense to prevent the bridge hit from occurring.

**State of Practice OHVDs**

The typical set up for current OHVDs (Figure 2) consist of an aligned optical transmitter and a receiver unit mounted on poles (A) on opposite sides of the road at the required detection height. The transmitter emits a light beam across the road width which is continuously detected by the receiver. As an over-height vehicle passes through, it obstructs the light beam, which triggers the receiver to activate the warning sign/VMS (B) and alarm bell (C) to alert the driver. Once an over-height vehicle is detected, the driver can be instructed (using VMS) to stop or take an exit before the structure. The warning sign/VMS, alarm bells are typically placed 100-150 feet after the detectors (A). The system is designed to work at highway speeds (75mph) and is installed much before the structure (up to a quarter mile) to accommodate approach to suitable exits or to allow a safe stopping distance to the structure.

A review of 16 OHVDs systems from 11 different companies (across U.S., U.K, Canada, Germany, Australia) revealed that this operational set up is used across the world which is exactly similar to the first reported OHVDs in 1965 [11]. Improvements to the basic set up have been limited to (i) modifications in the light source (visible red/Infrared/laser), (ii) light modulation (visible), diffuse, reflective or opposed mode operation (infrared), (iii) using single, dual beam or Z-beam systems [12].

![Figure 2. Detection concept of State of Practice OHVDs [10]](image)

**Limitations of State of Practice OHVDs**

Since these systems are installed up to a quarter mile before the bridge, many times power & communication lines have to be brought up to the installation site. A communication cable between the transmitter and receiver units requires digging a trench across the road leading to roadway closures & traffic delays [13]. Associated structural & electrical installation costs are usually much higher than detector costs. ITS grade installation has been reported to cost between $50,000 -$100,000 per approach. The stand alone cost of detector–pair (A) itself is very high ($9,000-$25,000 per approach). Because of such high system costs, installations are limited to critical locations. State DOTs have reported these OHVDs to suffer from alignment issues due to ground heave and false detections due to vehicle antennas,
flying debris, birds and snow deposits on vehicle. Rain, snow and sunlight during certain hours of the day have also been reported to cause false positives [5]. Most times, the drivers miss the only warning sign (C) while some do not hear the alarm bell (B) (while listening to radios, etc.). There is no further line of sight signage to stop them from hitting the bridge. Also, utilizing expensive VMS/matrix signs ($20,000-$70,000) for regulatory messages adds heavily to the system cost.

**Proposed Solution: LaRa- OHVD**

The LaRa detector is designed to be installed on the face of the structure (e.g. bridge) being protected itself. The detector uses a standard freeway sized warning sign with flashing yellow beacons which are also installed on the bridge face next to the detector. Since most bridges already have power (street lights), this results in minimal installation cost. LaRa combines LADAR, optics and traffic engineering principles to detect an incoming over-height vehicle at safe stopping distance from the bridge. The infra-red laser based device is eye safe and low cost, satisfying the performance requirements of state of practice OHVDs.

**Detection Concept of LaRa- OHVD**

The LaRa detector is mounted in the center of the roadway, above the bridge clearance height; on the bridge face itself, pointing towards the oncoming traffic. The detector transmits a sheet of laser light covering the road width at a distance greater than the safe stopping distance to the structure. The top view of the installation is shown in Figure 3.

![Figure 3. LaRa –OHVD (Top view)](image)

Pre-defined vehicle detection zones are established before the safe stopping distance to the bridge and LaRa continuously checks for vehicle presence in these zones using LADAR technology. Once a vehicle is detected, La Ra measures height from top of vehicle to sensor as shown in Figure 4. If vehicle height is less than bridge clearance, then LaRa discards the measurement. If the vehicle height is more than the bridge clearance then the vehicle is detected in the large and over-height detection zones (Figure 4).
5). As “**Measured height**” decreases than “**Fixed install height**”, the over-height vehicle is confirmed. LaRa then activates the yellow traffic beacons installed next to the warning sign “OVER HEIGHT VEHICLE STOP WHEN LIGHTS FLASH” mounted on the bridge itself. As soon as over height vehicle is detected LaRa can communicate with transportation/emergency agencies through a suitable interface.

![Over Height Vehicle Image](image)

**Figure 5. LaRa over height detection and proposed driver warning system**

**Advantages of LaRa- OHVD**

LaRa is unique it is operation. It is first OHVDs in the world which is installed on the bridge being protected and features long range detection (> 1000 feet). It detects vehicles travelling at highway speeds and provides a broad detection zone instead of single optical beam. Existing OHVDs often utilize inductive road loops to confirm vehicle presence leading to higher installation/system costs. LaRa employs vehicle detection zones and algorithms to detect vehicles and minimize false alarms (due to flying debris, birds), a significant advantage over the beam-break approach used in conventional OHVDs. The total system cost (including detector, warning sign/beacon, installation) is minimal compared to conventional OHVDs enabling mass deployment. A unique advantage is the line of sight warning system. Since the warning sign and traffic beacons are installed on the face of the structure, drivers can always see them and they are hard to miss. This eliminates the need for expensive VMS/Matrix signs or alarm bells reducing cost and simplifying installation. LaRa can measure vehicle speed and predict if collision is imminent. This provides crucial seconds for agencies to plan pre-emptive emergency recovery and response. Also, LaRa continuously measures the vehicle height in detection zones and can provide a very useful collision statistic for the responding agencies to assess the legal vehicle over-height. LaRa can also reduce the level of structural damage for an over speeding driver as he responds to the warning sign and hits the structure at a reduced speed (while braking).

**LaRa –OHVD Prototype Construction**

Currently, the device is in its design stage and a prototype is being assembled for testing. Figure 8 shows the prototype and the typical test setup. For demonstration purposes, the warning sign is excluded and only a single traffic beacon is considered.
Figure 8. LaRa-OHVD prototype (Left) and test set-up (Right).

Conclusions

Existing OHVDs are limited in deployment and operational features. By combining a mature vehicle detection technology (LADAR), state of art optics and existing traffic engineering guidelines; a cost effective LaRa-OHVDs is proposed. LaRa is envisioned to detect over-height trailers, trucks and large sized loads which cause the maximum number of bridge hits (94 %) in New York State [5]. Expected limitation is the requirement of a straight approach road up till the safe stopping distance to the protected bridge. With respect to New York State, majority (78%) of bridge hits have been found to occur on State Highways, Parkways and Interstates which can provide such site characteristics [5]. With LaRa OHVD currently under development, actual field testing will be required to validate the system performance. However, the low cost design, minimal installation and features like broad vehicle detection zones, algorithms to minimize false detections, line of sight warning sign advantages, speed & over height measurement; makes the LaRa OHVDs an innovative concept in over height detection. By facilitating mass deployment, LaRa has the potential to protect thousands of our bridges to prosperity; save lives, save tax payer’s dollars and contribute to the vital infrastructure preservation goals in the United States.

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