Optics and Photonics Used in Road Transportation

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ABSTRACT

Photonics is ideal for precise, remote and contactless measurements in harsh conditions. Thanks to major breakthroughs in the technologies involved, optical sensing is becoming more compact, robust and affordable. The purpose of this paper is to provide an overview on the capabilities of photonics applied to road transportation problems. In particular we will consider four types of situations: 1) measurements for traffic analysis and surveillance, 2) measurements for road infrastructures diagnosis and quality assessment, 3) photonics in smart driving and intelligent vehicles and 4) measurements for other purposes (safety, inventories, tolls etc.). These topics will be discussed and illustrated by using the results of different projects that have been carried out at INO over the last few years. We will look at different challenges we had to face such as performing sensitive optical measurements in various outdoor illumination conditions and performing fast and accurate measurements without interfering with normal road traffic flow.

Keywords: optical and photonic sensing, transportation, road measurement systems, laser triangulation, 3D vision, video traffic monitoring, video image processing.

1. INTRODUCTION

Road transportation technologies have changed dramatically over the last 20 or 30 years. Traffic flow in and around urban areas is increasing steadily, thus asking for more demanding solutions in terms of infrastructure inspection and maintenance, traffic flow monitoring, safety, and smart driving. We tend to consider that the benefits of automobile, in terms of increased independence and mobility, outweigh the drawbacks in terms of increased stress, environmental pollution, noise and the increased risk of accidents. But these problems are real and with the steadily growth of the number of vehicles on the road, these issues are harder to live with. For these reasons, it is becoming more and more important to benefit from the potential of available technologies such as optics and photonics to minimize these problems by insuring an optimized utilization of the transportation resources and infrastructures. The purpose of this paper is to provide an overview on the capabilities of photonics applied to these road transportation problems. In particular we will consider four types of situations: 1) measurements for traffic analysis and surveillance, 2) measurements for road infrastructures diagnosis and quality assessment, 3) photonics in smart driving and intelligent vehicles and 4) measurements for other purposes (safety, inventories, tolls etc.). Each of these topics will be discussed and illustrated by using the results of different projects that have been carried out at INO over the last few years. We will look at different challenges we had to face such as performing sensitive optical measurements in various outdoor illumination conditions and performing fast and accurate measurements without interfering with normal road traffic flow.

2. PHOTONICS FOR TRAFFIC FLOW MONITORING

So far, the most popular sensor technology used to analyze traffic conditions is the magnetic inductive loop. The latter makes it possible to count vehicles and measure their speed. However the area covered by this type of sensor is limited to one vehicle and one lane at a time. Furthermore, installing them requires burying them beneath the road surface, thus making them cumbersome to modify, replace or maintain. Traffic monitoring implies the estimation of microscopic as well as macroscopic parameters of the traffic flow. Microscopic monitoring deals with the counting and classification of individual vehicles in each lane. Different properties for each vehicle can also be monitored such as their speed and length. Macroscopic monitoring deals with the measurement of statistical properties of the traffic such as the traffic mean velocity, the traffic vehicle density and traffic flow. Photronics can be useful for traffic monitoring at both levels.

For measuring microscopic parameters such as vehicles velocity and class, INO has developed two types of optical sensors that can used for remote contactless monitoring. The first one is a correlation-based velocimeter which can measure speed
accurately from a point of view perpendicular to traffic flow. The system can be installed up to 300 meters away from the road. The system can measure from 0 to 300 km/hr with an accuracy in the range of fraction of a kilometer/hr. The sensor involves two laser sources at two different wavelengths. Two detectors displaced by a known distance are used to measure and separate the two reflected signals which are time lagged. Estimating the time delay between the 2 signals provides the velocity of the target vehicle. The second system, which is simpler and less expensive is based on laser point triangulation principle, thus measuring the longitudinal 3D profile of the vehicle passing beneath the sensor when attached to the roof of an overpass or a bridge. It implies one single sensor for counting and classification of vehicles. A pair of such sensors are required for velocity measurement with an accuracy better than 5%.

Figure 1: a) optical vehicle counting and classification using laser triangulation sensor (left) 3D vehicle profiles measured with the sensor, (right) the installed sensor at the top of an overpass, b) laser Doppler velocimeter for perpendicular measurement of vehicle speed (left) schematic diagram illustrating the principle of operation, (right) field test using the sensor installed along a road in daylight conditions.

For measuring macroscopic parameters of the traffic conditions, network of video cameras provides useful information in particular on the traffic in urban highways. Up to now, this approach was used mainly for visualizing information monitored by operators in a control room. Automatic diagnosis based on these video image data was rarely attempted so far due to the lack of economical computing power, the algorithmic complexity of the problem and the continuous change of illumination and visibility conditions, thus making the image processing and analysis tasks difficult to tackle with. Thanks to low cost reliable solid state CCD and CMOS cameras and recent progress in computing technology, INO has been able to develop a real-time video-based automated traffic analysis system which can detect traffic incidents in a highway scene independently of the illumination conditions. The incidents detected by the system comprise slowdowns, traffic jams and stopped vehicle. The estimation of the macroscopic traffic parameters such as average speed and car density serve to assess the presence or absence of an incident. Motion detection is performed using a subtractive scheme involving an estimated background image and the current image of the video input stream. Tracking of moving objects is done with a Kalman filter.

Figure 2: traffic analysis system: a) background estimation and virtual detectors b) camera network and results displayed.
Each year substantial amount of money is being spent for the inspection of the road network showing the need for an automatic and objective assessment of road pavement conditions. Road surface inspection is a very demanding application involving a large and relatively flat surface. To inspect a road surface requires covering the full four meter width of a typical highway corridor with sub-millimeter vertical precision. In spite of technological progress, pavement rutting and crack detection are often still measured manually. In order to cope with this issue, INO has developed two technologies aimed at inspecting the road surface. The first one is a 3D laser-based triangulation system designed to detect and characterized pavement rutting. This low-cost measurement system is capable of acquiring 4 meter wide profiles of a highway lane at inspection speed of up to 100 km/hr. The system uses two custom made laser line projectors which are capable of projecting up to 4W of very short laser light pulses. Two standard CCD video cameras geared with special filters and optics are used to view the deformation of the laser lines as they contour the shape of the pavement surface. Because of the optimized optical design and the high power from the pulsed laser line sources, the system can operate in full daylight or night time conditions. The cameras are synchronized with the projectors and integration time is kept very short (100 microseconds) in order to minimize image blur while moving on the road. Safety mechanisms are included in order to protect the operators and surrounding from the laser sources when the vehicle is stopped or moving at low speed. The maximum line acquisition rate of the system corresponds to the standard video frame rate of 60 Hz. The system is coupled to GPS and odometers for geo-referencing and for keeping constant the longitudinal sampling in normal traffic conditions. Road profile data is collected, compressed, store on tape with a GPS time stamp and processed on-board in real-time. Processing tasks include calibration corrections due to the tilt and roll of the vehicle. A rut analysis software has been developed for automatic classification of short and wide radius ruts and for the measurement of the road’s rut depth. The system has been implemented on board a Transport Quebec vehicle and to date, over 30,000 km of roads have been surveyed with this system.

The second technology is a unique multi-function pavement distress characterization system based on custom high performance 3D laser scanners. The two scanners have been designed using the auto-synchronized laser scanning mechanism which was originally developed at NRC Canada. This system is capable of acquiring full 4 meter width topographic data of a typical highway lane surface at inspection speed of up to 100 km/hr with sub-millimeter precision in depth (350 microns). Each scanner is capable of acquiring up to 1024 3D points per scan line at a rate up to 300 scans/s for a total of 76000 3D data points per second. At such a velocity, a very short integration time (13 μs) is achieved to avoid image blur during acquisition. Thanks to its optical design and its optimized laser sources, the system can operate during both days and nights. Similar to the rut measurement system, this one is also equipped with odometers and GPS time stamps for geo-referencing and keeping constant the longitudinal sampling in normal traffic conditions. Pre-processing is also performed to compensate for the roll and tilt of the vehicle. The main asset of this technology is its versatility. With one single pair of sensors, one can basically measure all main types of road distress features and parameters such as ruts, IRI, crack patterns, holes, lane painting conditions, surface texture and roughness. The system has been field tested successfully over the last 3 years in collaboration with Transport Quebec.
Photonics can be used in the context of smart cars and intelligent vehicles in three application fields: in information systems, in distributed communications, and in instrumentation. For example, photonics can play a major role in storing and displaying information to the driver in a most convivial way. Fiber optics has several advantages such as compactness, high bandwidth, lightness and immunity to EM interferences, over conventional wires to distribute signals and information from different locations in the vehicle. Photonics is also very important to acquire information and monitor the status of the vehicle operation as well as monitoring the surrounding environment. For this purpose, we will give two examples. The first one implies a system that can be used for on-board driving assistance and navigation based on the automatic detection and the recognition of road signs. The second example illustrate the use of fiber optic strain gauges for monitoring on-board and in real-time the distribution of weight on each set of wheels of trucks and road trains.

A system for real-time automatic detection and recognition of road signs is currently being developed at INO. Images of traffic scenes are acquired by a color camera mounted on a vehicle. Two main stages are involved in the processing of these images: 1) detection of regions potentially containing road signs using chiefly color information and 2) recognition and classification using digital and optical template matching. The system features a tracking module capability in order to include temporal integration and reduce the amount of processing by following the already recognized road signs, thereby increasing both the speed and reliability of recognition. Because the system deals with outdoor scenes, it has been designed to be robust and adaptive to outdoor illumination changes. This features is embodied in proprietary algorithm used at the detection stage. Recognition and classification are carried out using template matching and rule-based techniques with a reference database of standard traffic road signs.
Figure 6: some results obtained with the road sign detection and recognition system (from left to right) first and third images represent cloudy and sunny outdoor scenes taken with the video camera, second and fourth images correspond to the road signs detected and extracted.

The second system illustrates the use of fiber optic strain gauges (FOSG) for weighting the distributed payload on trucks and road trains. The FOSG can be described as a miniature extrinsic Fabry-Perot interferometer. The FOSG originally developed at INO uses a true white light source which guarantees that absolute strain measurements and intrinsic linear response can be obtained while satisfying the high strain rate and precision required. These strain gauges have been installed on different locations of the trailer axles, one for each set of wheels. The overall system includes user interface software, a data processing unit as well as an optical communication network to gather the distributed data and bring it to the tracking vehicle. The system has been field tested on a Transport Quebec vehicle. Tests have shown that a precision up to 1% of the distributed weight on each axle can be achieved.

Figure 7: (left) FOSG attached to one of the axle, (center) schematic diagram showing the distribution of the sensors on the trailer, (right) diagram illustrating the position of each FOSG on the axle for each set of wheels.

5. OTHER USES OF PHOTONICS IN ROAD TRANSPORTATION

Photonics can play other roles in road transportation applications. For example, the real-time video system that is being developed at INO for road signs detection and recognition could also be applied for inventory purpose. Regular inspection of road signs infrastructure over the road network, in particular in large urban areas is very important for safety reasons. OCR (optical character recognition) is also an active area of R&D applied to the tolling problem for reading car plates on pay highways and bridges. Finally, other photonic technologies such as thin film coating, solid state LED light sources and flat panel display based on liquid crystal light modulators are being investigated for use in improving reflectance of panels as well as for enhancing contrast in programmable display panels and traffic lights.
6. CONCLUSIONS

We have presented few examples of optical and photonic systems that have been developed at INO for road transportation applications. All these examples indicate that photonics has an immense potential which is still largely unused for road transportation applications. Advances in precision, speed and repeatability are occurring rapidly in the photonics and imaging industry and this can be applied to good use for low cost efficient instrumentation applied to road transportation. Benefits include a better use of the transportation agencies' funds, immediate and more accurate assessment of the road network infrastructure and traffic conditions leading to better protection of the road networks, improved safety, faster response time in emergency conditions, improved flexibility in the use of the road networks and increased driving comfort. We believe that photonic technologies offers a distinct advantages for modern road network and infrastructure monitoring.

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REFERENCES


