# APPLICATION OF MULTI-SENSOR ROAD FEATURE DETECTION AND MAPPING IN KAZAKHSTAN AND DEVELOPMENT OF POLE DETECTION AND ANALYSIS PROCEDURE

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## ABSTRACT

A mobile multi-sensor monitoring system has been actively used in Kazakhstan for monitoring the road infrastructure. The main goal is to justify repair measures and to eliminate technological errors in the construction of new and reconstruction of existing roads, as well as to create an extensive database on the transport and operational condition of roads and road structures. This paper provides a short discussion of the currently adopted procedures to implement this approach. Although almost all data collection is automated, the detection of poles near the roads is still conducted manually. This paper is focused on the automation of pole detection and its detailed analysis to obtain the characteristics vital for its structural health monitoring. It is based on an analysis of point clouds collected by a laser scanner usually installed on top of the mobile monitoring system. A framework for pole detection and its assessment is presented.

Keywords: monitoring, point cloud, digital twin, structural health monitoring, traffic pole, sign pole, automotive roads, automated detection and analysis.

## INTRODUCTION

Kazakhstan is a landlocked country in Central Asia, and as such, its economy heavily relies on automotive and railroad transportation infrastructure. Kazakhstan is located in a region with wide temperature variations, which can be complicated by significant snowfall and freezing conditions on the roads [1]. In addition, it has the lowest population densities in the world, which calls for the necessity to automate monitoring of the condition of the roads in the country. JSC "Kazakhstan Highway Research Institute" (Astana, Kazakhstan) is leading this effort in digitizing the road infrastructure and developing maintenance strategies. The main goal is to justify repair measures and to eliminate technological errors in the construction of new and reconstruction of existing roads, as well as to create an extensive database on the transport and operational condition of roads and road structures. This paper provides a short discussion of the currently adopted procedures to implement this approach. Although almost all data collection is automated, the detection of poles near the roads is still conducted by a human. Hence this paper is focused on the automatization of pole detection.

## REVIEW OF CURRENTLY EMPLOYED PROCEDURES EQUIPMENT

The composition of the equipment used in the multifunctional diagnostic mobile laboratory system of the Dynatest series [2] includes a vehicle equipped with a set of control and measuring sensors (see Fig.1 and Fig. 2) and is divided into the following major modules: (1) positioning system; (2) a set of measuring equipment, and (3) data collection module.

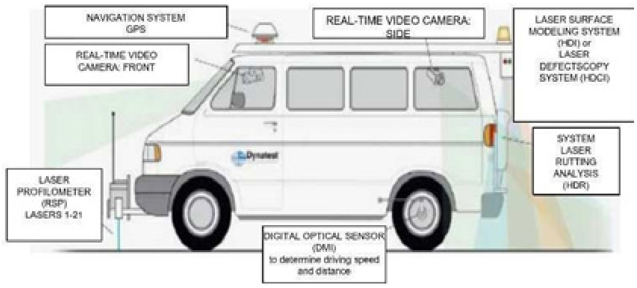


*Fig. 1. Road monitoring and data collection system (side view).*

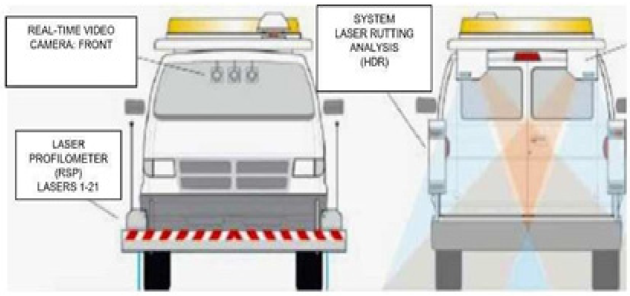


*Fig. 2. Road monitoring and data collection system (front and rear views).*

Module 1, the positioning system, is designed to track complex movements of equipment that occur during the movement of the base vehicle, which must be considered to obtain reliable measurement results. The positioning system consists of several functionally independent but time- synchronized devices, the collected data from which is sufficient to accurately determine the position of the base vehicle at any time and in any coordinates. At the same time, the synchronized operation of several devices allows for obtaining results that accurately correlate data collected from the devices to the vehicle's position.

Module 2, the set of measuring equipment, includes originally supplied equipment and additional measuring instruments (for simplicity, only a few are shown in Fig. 1 and Fig. 2): (a) a deflectometer designed to determine the elastic modulus of road structures, (b) a high-precision measuring sensor for determining the coefficient of adhesion between a wheel and the road surface, (c) a laser profilometer for measuring the surface profile of road surfaces, (d) a laser system for identifying pavement defects, measuring and analyzing cracks and other defects in road surface, (e) digital optical sensor, designed to determine movement speed and distance, (f) gyroscope - inertial motion sensor (IMS), measuring longitudinal slopes, (g) built-in GPS, which determines the geolocation and provides georeferencing, (i) ground penetrating georadar, (j) video cameras designed to record streaming video images of the road surface, construction elements, roadside strips, etc., and (k) laser scanner - a device for high-speed recording of the coordinates of many points around the vehicle. The latter is usually installed on top of the vehicle, and, for simplicity, it is not shown in Fig. 1 and Fig. 2.

## TYPICAL RESULTS

The road monitoring system described above produces two types of results: (a) the physical properties of the road's cover and (b) the geometry of the road in the global coordinate system. The latter is used for accurate mapping of the roads that include curb lines, the slope of the road, its width, and other road features. A typical process of acquisition of the road geometry is presented in Fig. 3.

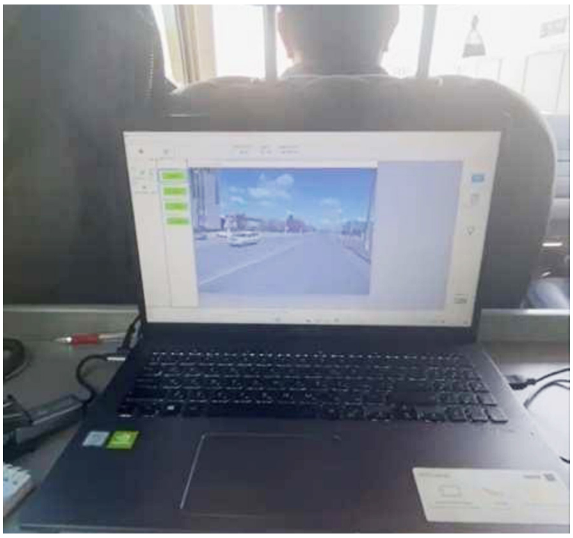

*Fig. 3. Acquisition of the road geometry in progress.*

A typical result of the latter process is presented in Fig. 4.

*Fig. 4. Typical result of the road geometry's acquisition.*

The geometry of the road has all the features, but as of today, it is missing the poles and signs near the road. This information is entered manually by investigating the recorded geo- referenced videos, as presented in Fig. 5.

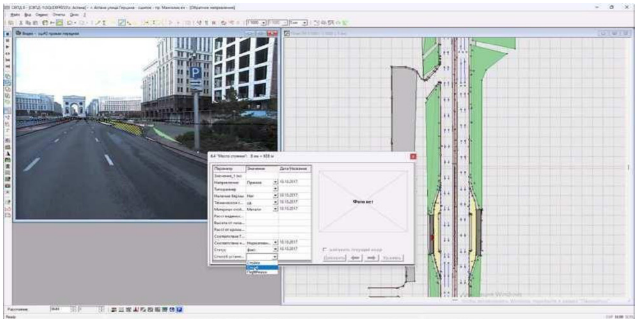

*Fig. 5. Manuel entering a pole's location.*

For obvious reasons, this procedure is prone to human errors, and the location of the pole cannot be measured precisely. In addition, it cannot be detected when lighting conditions are limited, during nighttime, for example.

This paper is focused on the development of an automated procedure for pole detection. In addition, it measures its cross- sectional size, inclination (if any), and accurate location in the global coordinate system.

## AUTOMATED ACQUISTION OF POLES

The automated procedure for pole acquisitions is based on the utilization of the point cloud generated by a laser scanner that is usually installed on the top of the vehicle. For the purpose of this paper is based on the point clouds collected by a terrestrial laser scanner in [3]. This paper was related to a problem of detection of the power lines in close vicinity of the roads. To simplify the discussion, it is limited to round poles.

## DETECTION OF POLES

A point cloud of a pole with traffic lights is shown in Fig. 6. As can be seen from the image, it consists of a light fixture on the very top, a traffic light fixture on a cantilevered portion, and a traffic light fixture at the pole's mid-elevation along for the sign controlling pedestrian crossing. This type of pole is common for the roads of the United States and Kazakhstan.

*Fig. 6. Point cloud of a pole at a road intersection.*

This point cloud was exported to be reduced in the Matlab [4] environment, as presented in Fig. 7.

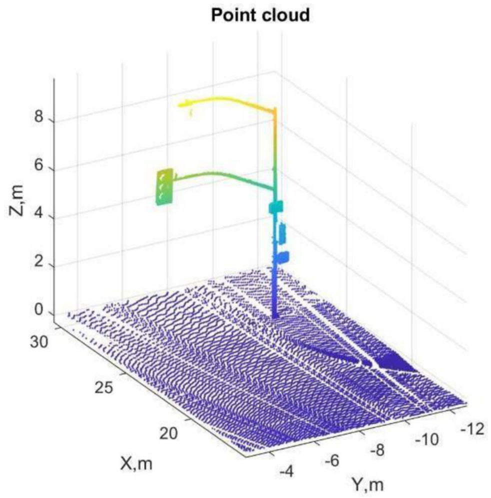


*Fig. 7. Point cloud with coloring that changes over elevation.*

A number of horizontal cross-sections of the pole were introduced, as presented in Fig. 8.

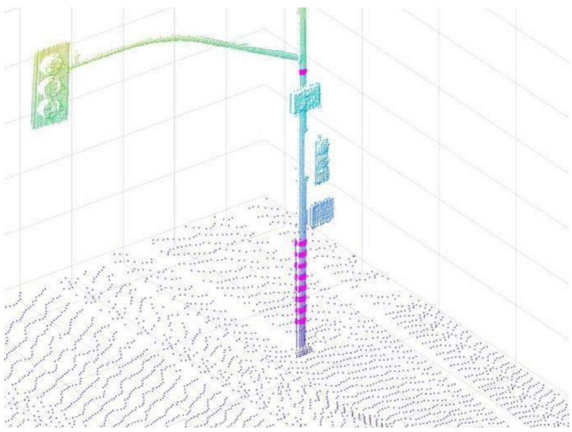

*Fig. 8. Horizontal cross sections of the pole (magenta).*

Each of these cross-sections was best fit to a circle by utilizing the least square approach. This procedure was used earlier to estimate the structural parameters of minarets, tall and slender objects [5]. A typical example is presented in Fig. 9. As a result, the following two major parameters of the pole can be computed: (1) the radius of the pole at this elevation (0.092 m) and (2) the location of the cross-section's center (26.375 m, - 10.309 m).

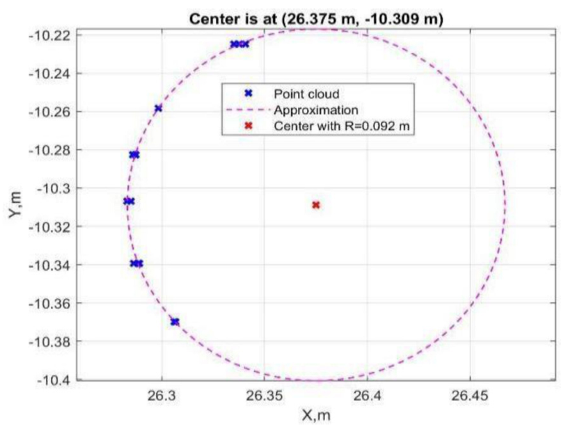


*Fig. 9. Result of best fitting of the point cloud's cross-section*

This best-fitting procedure can be repeated for other horizontal sections at higher elevations. This will produce a set of centers and radii at each elevation. The change of the center locations will produce an inclination or residual drift of the pole, as presented in Fig. 10. For this particular pole, the drift is estimated to be 0.74 degrees. The drift is an important measurement to monitor to make sure that it is not progressing over time.

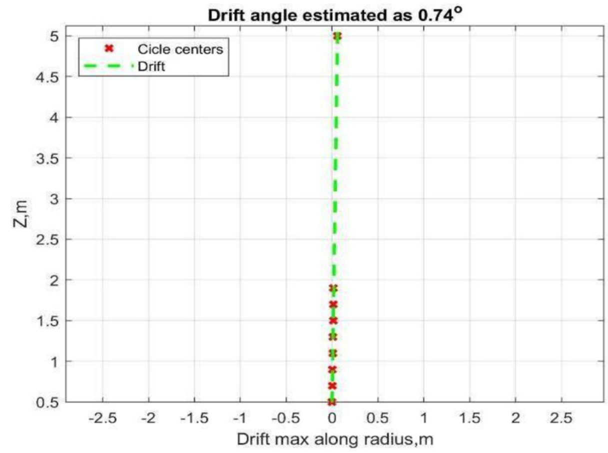


*Fig. 10. Esatimate of the residual drift.*

The change of the radii over the elevation will produce the taper of the pole (if any). The latter is very close to 0.33 degrees, as shown in Fig. 11.

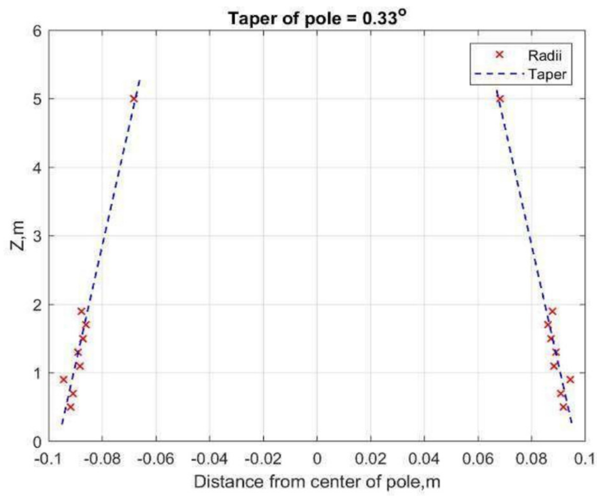


*Fig. 11. Estimate of the residual drift.*

## LOCATION OF THE POLE IN THE GLOBAL COORDINATE SYSTEM

Finally, the location of the pole can be placed into the database in addition to the data collected by the mobile multisensor system. It is presented in Fig 12. The axis of the pole is shown by a red dashed line. It is a vertical line that starts from the ground elevation, and X and Y coordinates coincide with the center of the bottom circle approximating the very first horizontal cross-section.

As an option, a residual drift of the pole can be introduced as a parameter in the database for monitoring purposes. It was used earlier for monitoring steel frame buildings [6].

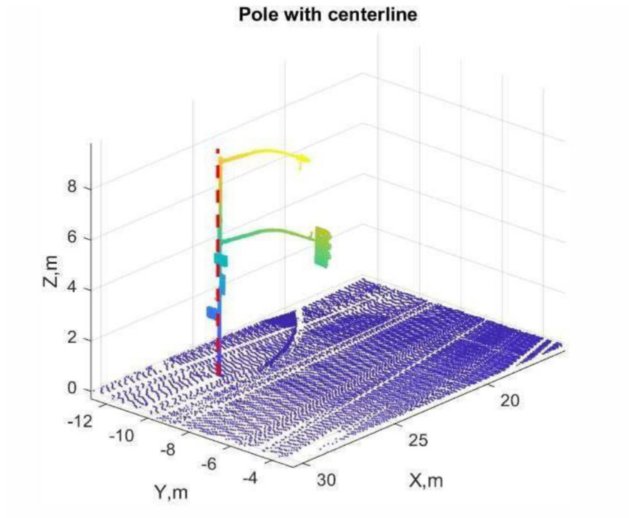


*Fig. 12. Pole with its access estimated from the point cloud.*

## ATTRIBUTES OF THE DATASET RELATED TO THE POLE DETECTION

It is worth noting that the reliability of pole detection will depend on many parameters, including the density of the point cloud. Therefore, the number of points in a horizontal cross- section, N, used for the pole detection is one of the main attributes of the dataset collected for the pole. In addition, a parameter providing information about the accuracy of the best fitting to a circle is needed. It can be an average of the normalized differences, $D^n_{aver}$, between the computed radius of the circle, *R*, and the distances of the point cloud's points, (*x, y*), from the circle's center, $(x_o, y_o)$:

$$D^n_{aver} = average((sqrt(x-x_o)^2+(y-y_o)^2)-R)/R \qquad (1)$$

In addition, the number of vertical sections is a vital attribute to add to the pole's dataset. Since all calculations of the taper and the residual drift are based on linear regression, the coefficient of determination or R2 for each of them needs to be added as a parameter to the dataset.

All the abovementioned attributes of the dataset are summarized in Table 1.

Table 1. PROPOSED ATTRIBUTES FOR POLE DETECTION AND CHARACTERIZATION

| The best fit to the bottom horizontal section | | | |
|---|---|---|---|
| *Number of points, N* | *Center's coordinates (x,y), m* | *Radius, R (m)* | $D^n_{aver}$ |
| 15 | (26.375, - 10.309) | 0.0919 | -4.6151e- 05 |
| **The best fit to compute taper** | | | |
| *Number of sections* | *Taper, degrees* | *R2* | |
| 9 | 0.33 | 0.9516 | |
| **The best fit to compute residual angle** | | | |
| *Number of sections* | *Taper, degrees* | *R2* | |
| 9 | 0.74 | 0.9926 | |

In the subsequent phases of this research, these attributes will be computed for a large number of poles to automate pole detection and assessment by utilizing the procedures related to artificial intelligence.


## ACKNOWLEDGMENT

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## CONCLUSIONS

The paper develops a framework for pole detection and its assessment. The paper shows that poles near roads can be investigated in great detail. It is based on the utilization of laser scanners usually installed on top of the mobile multi-sensor monitoring system. As presented in this paper, the exact location of the pole can be obtained. In addition, a taper of the pole, if any, can be computed. More importantly, a residual drift of inclination of the pole can be measured and monitored by multiple measurements separated in time. The pole detection procedure will be added to the multi-sensor monitoring system that is being used in Kazakhstan.

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