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Comparative Analysis of various Sensory systems for Road Surface Unevenness Detection & Slope Detection on Curves

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Abstract– *Transportation agencies are in urgent need for low-cost, reliable alternatives to improve their data collection practices. Various manual methods for collecting data of cross-slope, road cross-section etc. are extremely accurate but time consuming. As time required for data collection through manual methods is more and interruption to traffic also takes place thus, this methods are infeasible for large-scale project database. Survey techniques using Total Station and Hand held GPS equipment can provide accurate results, but have disadvantage similar to those of the manual method. Now-a-days various researchers have developed such as Road-Surface Profiler (RSP), Road surface sensor, Low-cost mobile device to find out various parameters of road cross-section.. Also, Road Surface Profiler (RSP) device was used to measure super-elevation at a curve. Proposed paper focuses on introducing an innovation way to measure existing pavement geometric parameters, especially cross-slope, Super-elevation, Unevenness, etc.*

Key Words - ***cross-slope, survey techniques, total station, GPS, Road-Surface Profiler (RSP), unevenness, Low-cost mobile device, Super-elevation, pavement, geometrical parameters, etc***

I. INTRODUCTION

Providing comfort and safety are important parameters in horizontal and vertical curves. The balance of vehicle while passing through a curve is secured by super-elevation for horizontal curve and by Gradients for vertical curves. Lack of attention to road construction or inappropriate implementation of asphalt overlay during the maintenance period results in reduced comfort and safety of the curves. There are several methods for collecting cross slope data, but surveying techniques to collect data, accuracy, cost, speed of collection, and safety considerations are varied. Conventional survey techniques use manual methods to collect co-ordinate points. Surveyors use levels, rods and electronic devices for site measurement. The point and elevation data are extremely accurate; however, the time required for data collection coupled with reduced safety and restricted traffic operations makes this approach infeasible for large-scale project database. Survey techniques with hand –held GPS equipment can provide accurate results, but have disadvantages similar to those of the manual method. Locating survey equipment in a static vehicle permits data collection with improved safety. The vehicle is typically positioned on the shoulder of roadway, and with the aid of an electronic data collector,

Inclinometer, disto-meter, notebook computer and GPS unit, accurate results can be obtained for the pavement cross-section. This paper again describes the affecting parameters of Curves such as super-elevation, cross-slope, unevenness, gradients, etc.

II.COMPARATIVE STUDY

A. Evaluation of Horizontal Curve Super-elevation using Road Surface Profiler (RSP):-

Mojtaba Abbasghorbani; Armin Bamdad Ziksari; Ebrahim Shoormeij; Sina Brazvan describes the Road Surface Profiler (RSP) device which was used to measure super-elevation at a curve in a newly constructed Shahroud-Miami roadway.

In this research the Road Surface Profiler (RSP) device was used to measure super-elevation at a curve in a newly constructed Shahroud-Miami roadway. It was chosen because of the availability of curve parameters such as start/end points, Radius, super-elevation, and design parameters. A good agreement was found between super-elevation measured by RSP and that of the curve design. Also, it was found that rate of turn (RT) profile is a suitable tool to determine the start/end points of curves, which is a basic step in assessing curve super-elevation. Three horizontal curves of Andimeshk ring were then tested by RSP device and analyzed based on finding from the curve in Shahroud-Miami. Results show that all three curves have a super-elevation shortage of approximately 3%. In these cases, the temporary solution is to install a new "Posted-Speed" sign based on existing curve super-elevation.

RSP Introduction:-

RSP is used to determine the roughness and geometric properties of road and airport pavements. The device is capable of collecting pavement surface profiles up to 110km/h without any traffic disruption, hence, it is considered as one of the fast non-destructive equipment types for pavement evaluation. RSP enjoys seven lasers and two accelerometer in a box located in front of the vehicle, which are used to measure pavement profile along the wheel path. Also, geometric properties of the road including longitudinal slope, transverse slope (cross-slope), and rate of turn (RT) are measured using Inertial Motion Sensor (IMS). The RSP is equipped with an accurate Distance Measuring Instrument system (DMI), Global Positioning System (GPS), and a camera by which images of the road can be stored. The IMS and RSP is used to collect and derive geometric data of pavement including grade (pitch), cross slope (roll), and turn rate (yaw rate). The IMS type used in the RSP device is Watson AHRS-E304. It is a three-axis solid-state gyroscope with a three-axis accelerometer and a magnetometer to provide earth references. The IMS communicates with the RSP via an RS-232 serial port.

RSP measures the road cross profile by means of lasers and IMS. The slope of the transducer beam and linear regression of laser points are measured to calculate pavement cross-slope, and this is called super-elevation in the area of Horizontal curve.

Table I. Output and Different Parts of the RSP

Parameters	**Hardware**
International Roughness Index (Iri)	Lasers And Accelerometers
Ride Number (Rn)	Laser And Accelerometers
Rutting	Lasers
Macro Texture	High Frequency Laser
Radius Of Curve	Inertial Motion Sensor (IMS)
Grade	Inertial Motion Sensor (IMS)
Cross-Slope	IMS And Laser
Positioning	GPS-DMI
Image Storing At User Specified Interval	Camera

. Road Surface Sensor:-

Keiji Fujimura; Takashi Sakamoto propose a road surface sensor using a near-infrared beam as another useful sensor for vehicle control. The principle is based on the reflection flux polarization when a light source and a detector are set at Brewster's angle. This means that the light flux reflects from a completely wet surface, e.g. specular surface, is horizontally polarized whereas the light principle is based on the reflection flux reflected from a completely dry surface e.g. diffusing surface, and is almost un-polarized.
After testing a developed model under several typical road surface conditions, they are confident that dry, wet, frozen, and snow-covered surfaces can be classified with better than 90% accuracy.

They believe that this sensor will be applicable for a brake control system, driver's safety information system, and so on in the near future. Sensor features the ability to detect both parallel and vertical polarization components simultaneously for onboard detection of various status changes on road surfaces. Therefore, it is necessary to make the detection characteristics of the two systems as equal as possible to ensure accuracy of detection.

Variation in detection characteristics are mainly caused by-
1 .Light detector sensitivity
2. Image formation balance (determined by prism precision and spherical aberration in the image-dividing lens system)
3. Electrical circuit characteristics.

Table II. Road surface sensor application

Applied systems	**Features**
Anti-skid control system	Permits braking control corresponding to the road surface coefficient of friction, resulting in improved safety.
Anti-collision system	Allows braking control to be conducted flexibly depending on the state of road surfaces while detecting by radar the distance and relative speed between a car and the one in front.
Road information system	Provides drivers with real- time announcements of the state of road surfaces in front and gives alarm as necessary, with displays installed beside the highway.
Road maintenance and control system	Diagnoses the state of road surface deterioration by measuring polarization characteristics of the same road surface periodically.

C. Identification, Calculation and warning of Horizontal Curves for low-volume Two-lane Roadways Using Smartphone Sensors:-

Shaohu Zhang's Analysis proposes two smartphone applications C-Finder and C-Alert, to collect two-lane road horizontal curves data (including radius, super-elevation, length etc.), collect this data for transportation agencies (providing a low-cost alternative to mobile asset data collection vehicles), and for warning drivers of sharp horizontal curves, respectively. C-Finder is capable of accurately detecting horizontal curves by exploiting an unsupervised K-means machine learning technique. Butterworth low pass filtering was applied to reduce sensor noise. Extended kalman filtering was adopted to improve GPS accuracy. Chord method-based radius computation and super-elevation estimation were introduce to achieve accurate and robust results despite of the low-frequency GPS and noisy sensor signals obtained from the smartphone. C-Alert applies BLE technology and a head-up display (HUD) to track driver speed and compare vehicle position with curve locations in a real-time fashion. Messages can be wirelessly communicated from the smartphone to a receiving unit through BLE technology, and then displayed by HUD on the vehicle's front windshield. The field test demonstrated that C-Finder achieves high curve identification accuracy, reasonable accuracy for calculating curve radius and super-elevation compared to the previous road survey studies, and C-alert indicates relatively high accuracy for speeding warning when approaching sharp curves.

This research again includes the design, implementation and evaluation of the mobile system for low-cost real time horizontal curve inventory and warning of horizontal curves. Two Smartphone applications, C-Finder and C-Alert, were developed and evaluated.

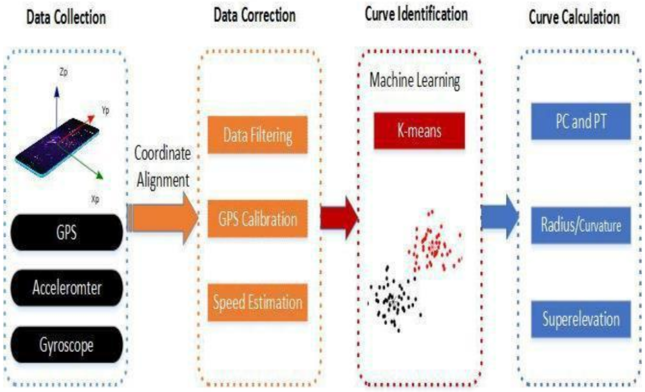


Fig I. System Architecture of C-Finder

III. PROCESS WORK

It involves inter-connection and interface of Accelerometer sensor, rotation sensor, GPS, GPRS (GSM), Arduino Mega UNO, Graphic display, battery, etc. with some fixture and fastening.

In this system, Accelerometer sensors are used to determine level difference between levels of front wheel of car. To know radius of curve, rotation sensor are used which are mounted on axel of front wheel.

Rotation sensor will give rotation angle depending upon which radius of curve will be found out. To determine the speed with which vehicle is negotiating the particular section of road, speedometer is used. All instruments used in this research are compatible with Arduino which is essential condition for interfacing all instruments with each other.

Super-elevation-

The inward transverse inclination provided to the cross-section of the carriageway at the horizontal curved portion of a road is called super-elevation. Thus, providing a transverse slope to counter-act the effect of centrifugal force and to reduce the tendency of vehicle to overturn and to skid laterally outwards super-elevation is provided.

It is expressed as the ratio of elevation of outer edge above inner edge to the horizontal width of the carriageway or as the tangent of the angle of slope of the road surface. Ti is generally denoted by 'e' or 'S.E'.

Super-elevation, $e = BC/AC = \tan\alpha$

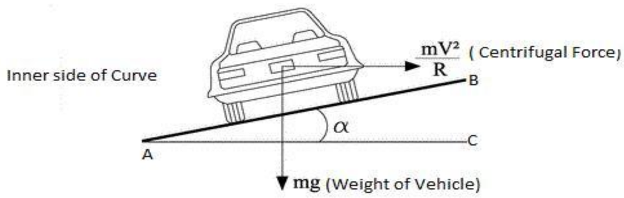


Fig II. Super-elevation on curved portion of road

Now,

Weight of Vehicle (W) = mg

Centrifugal force (P) = mV^2/R

So, $P/W = \dfrac{mV^2/R}{mg}$

I.e. $P/W = \dfrac{V^2}{gR}$

If the Speed of the vehicle is in kmph

Then, $e = \dfrac{(0.278V)^2}{9.81*R} = \dfrac{V^2}{127R}$

Indian Road Congress (IRC) has recommended the following formula for calculating the design value of super-elevation required on horizontal curve in India-

$$S.E = (0.75)\,V^2/127R$$

$S.E = V^2/225R$

This is assumes that centrifugal force corresponding to three-fourth the design speed is balanced by super-elevation and rest counteracted by side friction.Super-elevation obtained from the above formula should however be kept limited to the following values-

1. In plain and Rolling area-7%
2. In snow bound areas-7%
3. In hilly area not bound by snow-10%

When the design value of super-elevation is less than the road camber, the normal cambered section should be continued on the curved portion without providing any super-elevation.

As per I.R.C recommendations, the radii of horizontal curves for different camber rates, beyond which super-elevation will not be required, are given below-

Table III. Radii beyond which no super-elevation is required

Design Speed km/ph	Radius in meters for camber of				
	4%	3%	2.5%	2%	1.7%
20	50	60	70	90	100
25	70	90	110	140	150
30	100	130	160	200	240
35	140	180	220	270	320
40	180	240	280	350	420
50	280	370	450	550	650
65	470	620	750	950	1100
80	700	950	1100	1400	1700
100	1100	1500	1800	2200	2600

Hardware Design-

The components of Hardware are shown below-

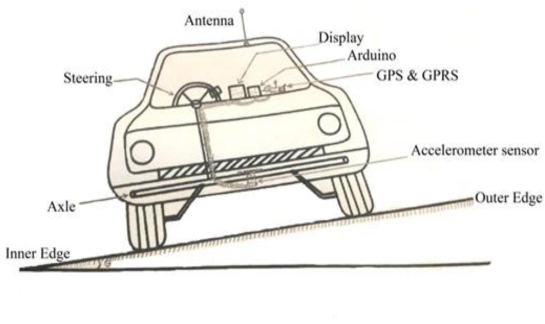


Fig III. Components Parts of Multi-sensory system.

Above Figure shows the Inter-connection and interface of various sensors and equipment's which are used for designing Sensory system. Accelerometer sensor are mounted on axle of front wheel base which gives the angle of inclination and the level difference between two wheel with reference to truly horizontal plane. Rotation Sensor and Speed Sensor are mounted on steering which will give the rotation angle and the real-time running speed of vehicle. On the basis of rotation angle and the turning radius of vehicle the radius of curve will be determined. Antenna mounted on top of roof panel programmed with GPS and GPRS (GSM). Antenna will give the current location of vehicle and will give signal to following vehicle on type and real time condition of road and its surrounding. If Vehicle is travelling on Horizontal curve then it will also inform following vehicle regarding maintaining safe speed on horizontal curve on the basis of super-elevation evaluation.

All the instruments are inter-connected to each other through controlling circuit with the help of Arduino UNO and the will give their output on graphic display. The values recorded by sensory system will be compared to standard values inputted in standard database. Result obtained by comparing standard values with actual obtained values will be studied and the remedied and precaution on speed will be stated by sensory system which will be displayed on display.

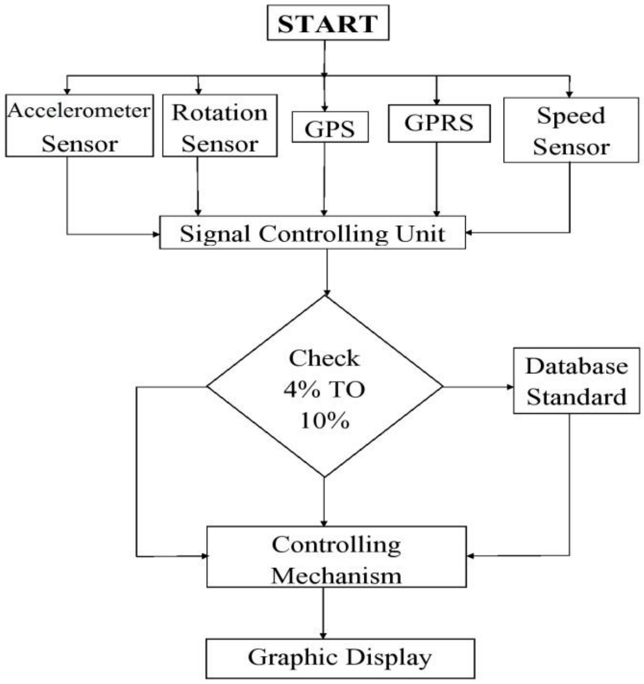
Software Design-

Following flow diagram shows the mechanics on which driven circuit will work.

IV. CONCLUSION

Based on the experimental studies following results are made:-

1. Construction or maintenance tasks could change the geometric properties of curves, especially super-elevation. Thus, curves need to be evaluated with efficient and appropriate devices. RSP is capable of measuring RT and cross-slope profiles quickly (up to 110km/h). Therefore, it is a suitable device to assess curve super-elevation quickly.



2. Road surface condition sensor are effective for judging if there is an appreciable unevenness on a road surface to provide desirable performance of brakes for a vehicle.

3. Although the GPS frequency from smartphone is only 1 Hz, the field test demonstrated the proposed approach can achieve desirable radius measurement accuracy for sharp curves. The average error is approximately 3%. Since, the highest accuracy of GPS is 2-5 meters; the adjusted lane width doesn't have a significant effect on the accuracy of radii estimation.

4. The accuracy of super-elevation relies on the accuracy of curve radius, vehicle speed and acceleration rate from smartphone. Improving their accuracy can achieve more accurate super-elevation measurement.

5. The design value of each curve factor and its range need to be decided with design context which include analysis of Sight Distance and Design speed.

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