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Research on the Mechanism and Segmental Law of Vehicle Trajectory Systematic Deviation in Different Road Scenarios

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Abstract. Systematic offset of vehicle trajectory relative to road geometry and its segment law is key for road design and traffic safety. This paper use high-precision trajectory data from real vehicle test and drone aerial photography. It focus on mountain expressway and complex interweaving area in mountain city. It analyze trajectory offset in straight section, curve section, roadside structure area and overtaking condition. It reveal segment law and key influence factors of trajectory offset in different scene. Study show that vehicle usually left offset in straight section. In curve section, trajectory offset to inner side. Roadside structure and overtaking make obvious avoidance offset. Trajectory offset is strong affected by lane position and road geometry parameter. Based on vehicle size, trajectory offset and lateral safety margin, this paper give suggested width for small passenger lane. It provide theory support for road design.

Keywords: vehicle trajectory, systematic deviation, segmentation rule, road scene

1. Introduction

The key parameters of road design like lane width must base on real vehicle driving path. In ideal situation, vehicle should drive along the center line of lane. But by driving habit and road condition, actual path have systematic offset from road shape. This offset show different segment rule in different scene. It direct affect road traffic efficiency and safety. Highway or expressway have complex alignment. Urban interweaving area have many lanes and frequent lane change [1]. So vehicle path offset is more complex. Learn this offset rule can help optimize lane width, roadside structure and interweaving area design. It is very important to reduce accident and improve road use rate. Scholars at home and abroad already do many research. Some scholar get curve path of twolane highway from video. They find driver's familiar with road affect path offset. Some scholar use real vehicle test on mountain road. They find path shape and safety risk on sharp curve. On straight section, vehicle tend to left offset at high speed. On curve section, path offset to inner side. This is very obvious on highway. On interweaving area, scholar find frequent lane change make three-stage difference of path offset. It prove path offset depend on scene. But current research still have many shortage. Most research only study one road type [2]. They lack compare of offset rule in different scene. Describe of path segment feature is not enough. They not fully use road geometry parameter. Research on path offset mechanism in special scene is not deep. So this paper use multi-source data. It study systematic feature and segment rule of vehicle path offset in different scene.

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2. Data acquisition and index system construction

2.1. Data acquisition scheme

I choose 2 expressways and 2 fast roads (inner ring fast road) in City A as test scene. I use Mobileye 630 forward warning system, Speedbox sensor and driving recorder to collect data. The test vehicle is a 7-seat car. I recruit 85 drivers, 38 for expressway and 47 for fast road. The natural driving test is finish in good weather [3]. We collect data of straight section, curve section, roadside structure area and overtaking condition. The data output frequency is 10Hz.

Table 1. Basic information of real vehicle test personnel for expressway

sex	number	Age		Actual Driving Years	
		mean value	standard deviation	mean value	standard deviation
Man	35	36.37	7.18	12.00	4.53
Woman	12	40.41	4.01	9.92	3.80

Table 2. Basic information of highway real vehicle test personnel

sex	number	Age		Actual Driving Years	
		mean value	standard deviation	mean value	standard deviation
Man	22	40.64	6.74	13.50	5.29
Woman	16	39.62	6.81	11.13	5.31

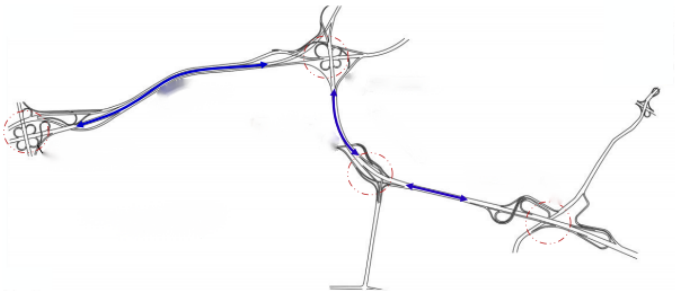

Figure 1. Schematic diagram of the test route and data sampling section for the expressway(The blue section is a highway)

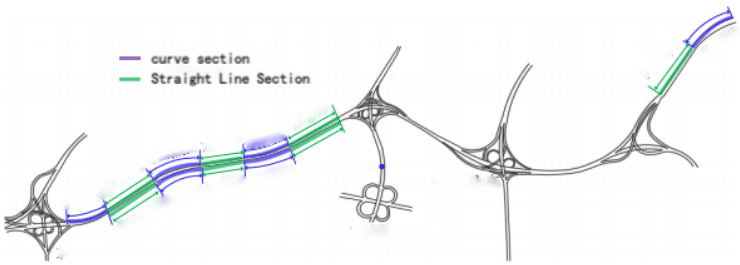

Figure 2. Schematic diagram of highway test route and data sampling section

We target Sigongli A-type weaving area in this city, it have 3.5m lane width, 70m weaving length and 200m influence area. We use drone shoot video in peak and off-peak period, and use multi-scale

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KCF optimize algorithm extract vehicle micro trajectory data [4]. Time accuracy is 0.1s, space accuracy is 0.1m, we get 2912 complete trajectory in total. We do filter and interpolation for collected data, remove abnormal value from construction section and blurry lane line. We use high-order polynomial fit road edge line and vehicle trajectory, fit goodness are higher than 98.5%, it ensure data precision.

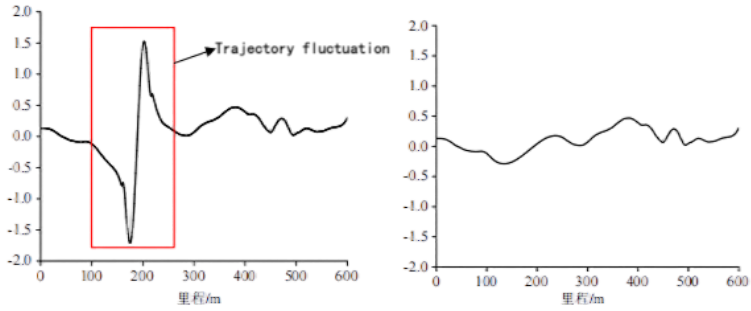

Figure 3. Comparison of test track data before and after processing

2.2. Core trajectory offset indicator

The average value of the lateral distance between the center line of the vehicle and the center line of the lane reflects the systematic characteristics of the track deviation.

$$y_e = \frac{y_{m1}+y_{m2}+\cdots y_{mn}}{n} \tag{1}$$

$y_m = -(y_l + y_r)/2$, y_l and y_r represent the distances from the vehicle's center point to the left and right lane markings, respectively. Ye<0 indicates leftward deviation, while ye>0 denotes rightward deviation. The lateral swing amplitude Y is defined as the difference between the maximum and minimum trajectory offsets within a single cycle, and the swing cycle distance D is the longitudinal distance between adjacent inflection points [5].

$$Y = y_{max} - y_{min} \tag{2}$$

$$D = |X(y_{max}) - X(y_{min})| \tag{3}$$

The lateral distance between the vehicle's contour line and the same-side lane line, including the left clearance (wl) and right clearance (wr) [6].

$$w_l = |y_l| - 0.5w_b \tag{4}$$

$$w_r = |y_r| - 0.5w_b \tag{5}$$

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3. Systematic offset and segmental regularity of trajectory in different scenarios

3.1. High/expressway trajectory deviation patterns

3.1.1. Straight line section

Vehicles on straight sections of highways and fast roads all show obvious left offset trend: the average lateral offset of expected trajectory on highways is -0.1388m, which concentrate in [-0.2m, 0.1m]; the average value on fast roads is -0.240m, concentrate in [-0.3m, 0.1m]. The offset show "stable-gradual change" segment feature: the offset in the first section (0-200m) is stable, and the left offset in the latter section (more than 200m) increase a little [7]. Lane position have obvious influence, the left offset of the outer lane is most obvious, and driving speed have no obvious influence on offset (the absolute value of Pearson correlation coefficient is < 0.3) [8].

3.1.2. Curve section

Trajectory show systematic offset to the inside of curve, and left turn and right turn have different offset rule. On expressway, left turn offset mainly between [-0.3m, 0.1m], average value is -0.0617m; right turn offset mainly between [-0.2m, 0.3m], average value is 0.079m [9]. Offset show three-stage pattern: before curve, middle curve, after curve. Offset become bigger at entry section (50m before curve start), reach maximum at middle section (±30m around center), move close to center line at exit section (50m after curve end). Smaller curve radius make larger offset. When radius < 500m, middle offset is over 60% bigger than radius > 1000m.

3.1.3. Special operating condition

Roadside structure area: gantry, overpass, bridge support cause avoid offset, show "approach–pass–leave" three-stage character. Bridge support area make outer lane have strong left offset (average -0.401m) [10]. Offset is biggest at pass section, and return normal at leave section. Overtake condition: when overtake big truck, left offset become more serious. Average lateral offset of expect path is -0.2074m, 74.28% path are left offset. It show "prepare–parallel–finish" three-stage rule: left offset increase at prepare stage, keep stable at parallel stage, return to center line at finish stage.

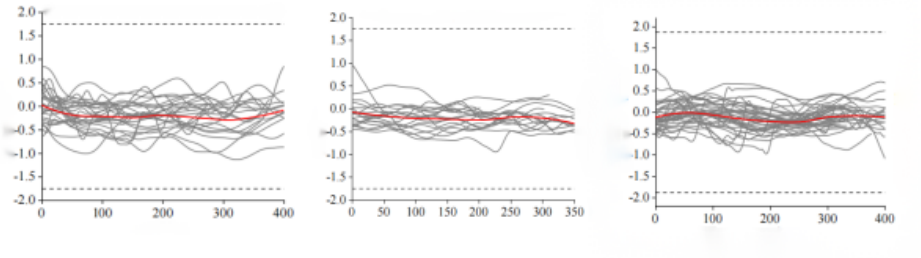

Figure 4. The trajectory diagrams of the three road sections are straight lines, curves, and special routes, respectively

3.2. Trajectory offset patterns in complex interwoven zones

Urban complex weaving area have many lanes (no less than 3 lanes one way) and short weaving length (less than 150m). Vehicles change lane very frequent. The rate of sharp accelerate and sharp

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slow reach 5%. Trajectory offset is very strong affect by lane change need. It show "upstream-main–weaving area–downstream-main" three-stage distribution [11]. In upstream main section (100m before weaving area), trajectory offset to left (average -0.12m), few lane change. In weaving area (70m weaving part plus 30m before and after), offset change very obvious. Vehicles from main road to ramp change lane mainly in middle and upstream. Vehicles from ramp to main road change lane mainly in middle and downstream. In downstream main section (next 100m), offset become stable slowly. Difference between different lane is very obvious. Inner lane have small offset (average -0.08m), lane change point near end of weaving area. Middle lane have biggest offset (average -0.15m), lane change very frequent. Outer lane have biggest offset change, rate of right offset reach 35%.

4. Influencing factors and design optimization suggestions

The wider the lane width, the bigger the offset range; the smaller the curve radius, the bigger the offset. When weaving length is less than 100m, offset fluctuation increase 40%. Outer lane have most obvious left offset. When drive at high speed (90-120km/h), driving path is more stable. The offset range of small passenger car is smaller than big truck. Roadside structure make offset increase 20%-50%. Without hard shoulder, avoid effect is more obvious. Male drivers have a little more left offset than female. Skilled drivers have smaller path swing.

Based on vehicle size (control value 1972mm), path swing (average 0.844m on high-speed straight section) and lateral safety margin, we put forward these suggestion: the lane width of small passenger car special expressway is 3.35m (suitable for 80-120km/h design speed); the width of small passenger car special lane is 3.6m (suitable for sections with high overtaking need). Structures like bridge support and gantry should keep enough distance with lane line. The minimum distance of two-way four-lane section is no less than 0.5m. Structures on curve section should be placed at inner side to reduce the risk of opposite lane being occupied. The length of complex weaving area is no less than 100m, and the number of lanes is controlled within 4. Middle lane can be widen 0.1-0.2m properly. At the same time, optimize signs and markings to guide vehicles change lane, reduce offset conflict.

5. Conclusion

Vehicle trajectory have obvious systematic offset in different scene. On straight section, trajectory usually offset to left, average value is -0.13 to -0.15m. On curve section, trajectory offset to inner side. Roadside structure and overtaking make offset change suddenly. Trajectory offset show clear segment rule. On curve section, it show "entry–middle–exit". In structure influence area, it show "approach–pass–leave". Overtaking follow "prepare–parallel–finish". Weaving area show "upstream–weaving zone–downstream". Lane position and road geometry parameter are main influence factor. Speed have no obvious influence. The suggested width of special lane for small car are 3.35m and 3.6m. It provide quantitative support for road design.

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