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Vision Based Tangent Point Detection Algorithm, Evaluation and Validation

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Abstract

In this article, we show how to find the Tangent Point (TP) and compute the Tangent Point Angle in real-time imaging with a monocular in-vehicle camera. To achieve this goal, we first need a ground truth to which compare our algorithms used to find the TP in real-time road imaging. We propose a method to compute this ground truth based on localization informations obtained through the use of a RTK[1] *GPS and a precise map of the road track. Then we present our vision based algortihm that depends on a lane markings detection system. We detail the needs and requirements of our vision based method, compare it with respect to the ground truth and give our conclusions on reliability and performance.*

1 Introduction

The Tangent Point (TP) is the rightmost point visible on the inside of a left turn and the leftmost point on visible the inside of a right turn (see Fig. 2).

Free locomotion and locomotion using vehicles are essentially different. In the first case one may move freely his body, moving different parts (legs, chest, head) independently whereas in the second case, the body is in a mobile and is mainly still while only the head can move. According to Land and Lee [4] [5], the drivers use the TP as a fixation point in order to adapt the steering to the curvature of the road. Salvucci and Gray [7] have proposed a trajectory control model based on the use of specific reference points like the TP, also maintaining for the fixation points theory. Though Land [6] and Fajen and Warren [1] argue on the necessity of optical flow, raw optical flow or fixation points ; they consider that instantaneous heading of the driver (heading of his chest) is a major information in locomotor tasks and is identical to the yaw angle of the vehicle (as the driver's chest is always stuck to the seat). This information is different than the direction of the head or of the gaze but seems to be useful in locomotor tasks and especially in driving situations. In this framework, identifying precisely the Tangent Point Angle (TPA) in regard to instantaneous heading of the driver and the vehicle may help in the comprehension of the impact of this position on trajectory management.

We have developed two different approaches. The first one is based on the use of our RTK GPS and a precise map of the road. This method is a post processing of the data and has been developed in order to dispose of a ground truth to which compare the second method, a real-time imaging method that can easily be embedded on a car.

Our goal is essentially to find the position of the TP in the image but also to determine the angle between yaw and TP that we call Tangent Point Angle (TPA). We'll see in section 2 the requirements in order to compute a ground truth. Then we will see in sections 3 and 4 the tools and algorithm we used to compute the TP and TPA in real-time road imaging.

2 Calculation of the ground truth

2.1 Equipments

The TP strongly depends on the viewing point (*i.e.* on the path), our ground truth must be computed on the same path corresponding to the images. First, we designed an algorithm that works offline and computes a ground truth TPA for a given path. We dispose of a map of the markings that we gathered using a RTK GPS. The track is sampled with a point every 10cm. The track on which we conducted the experiments is 3.5km long, it is outdoor so vehicles driving on are under natural conditions (atmospheric conditions, lighting conditions).

During the experimentations, the vehicle was equipped with RTK GPS giving its precise location with a sample frequency of 20Hz. The quality of positioning has been validated in [2]. Using the centimetric map of the track and a centimetric positioning of the car we will expose how to calculate the ground truth TPA that would subsequently be compared with the vision algorithm.

2.2 Denoising yaw estimation

TPA is an angle measured relatively to yaw. An error on yaw estimation directly leads to a biased estimation of the TPA. In order to precisely compute the TPA with positioning informations, we need only three informations : the position of the car on the track, the yaw of the vehicle and a map of the track. We will first compute the yaw angle. In order to do so, we will use the successive positions given by the GPS. Though the GPS accuracy is centimeter like, it is not exempt of noise, and computing the yaw (*i.e.* the derivative

[1]Real Time Kinematic

of the position, see Eq. (1)) provided noisy data will result in even more noisy yaw angle estimations.

$$Yaw(t) = Position(t) - Position(t-1) \qquad (1)$$

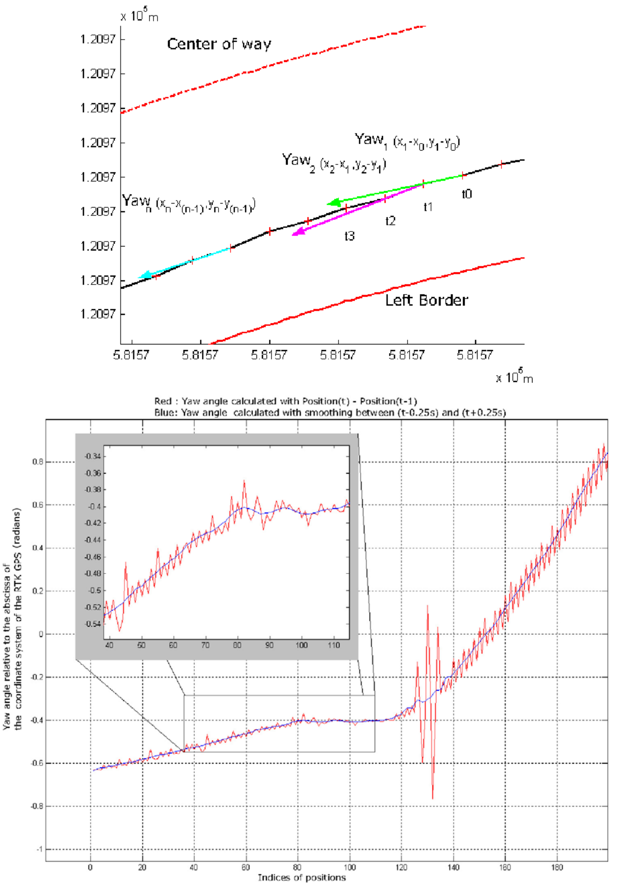

Figure 1: Noise on position / noise on yaw and denoised yaw estimation

Fig. 1 shows that instantaneous yaw calculation is very noisy. We chose to deal with yaw noise by smoothing the trajectory of the vehicle. We decided to do a polynomial regression of the 2^{nd} order around each position, using informations on the path between $t-0.25s$ and $t+0.25s$. The yaw is obtained by taking the tangent to the polynomial at the position at time t. This polynomial fitting can only be done offline or with delay but is only needed in the validation process when computing the ground truth. This process doesn't eliminate all noises, it eliminates much of the noise on yaw angle, not the positioning error.

2.3 Finding the Tangent Point

In order to build the ground truth that will be compared with our camera algorithms, we must take into account the real position of the camera inside the vehicle relatively to GPS RTK exact position. The lateral position of the camera in the vehicle impacts on the estimation of the TPA by creating an offset.

Using our yaw signal, the position of the car, the position of the camera inside the car and the precise location of the markings we can look for the TP on the map and compute the reference TPA for a given path on the map. The map of the road, though obtained through the use of a RTK GPS, is also noisy. As exposed in Fig. 2, we compute the angle between yaw and the side points of the road. Given two functions, '*angle to right side,* α_{R_i}', and '*angle to left side,* α_{L_i}', if a TP is present, one of those functions will present a maximum or minimum at this location. The side containing the TP and the TP itself can be retrieved as the first zero crossing of the derivative of α_{R_i} and α_{L_i} (see Fig. 2). The positioning of the side points being noisy, we may find erroneous TP by simply derivating the angles to sides (particularly if one specific point of the track is badly located).

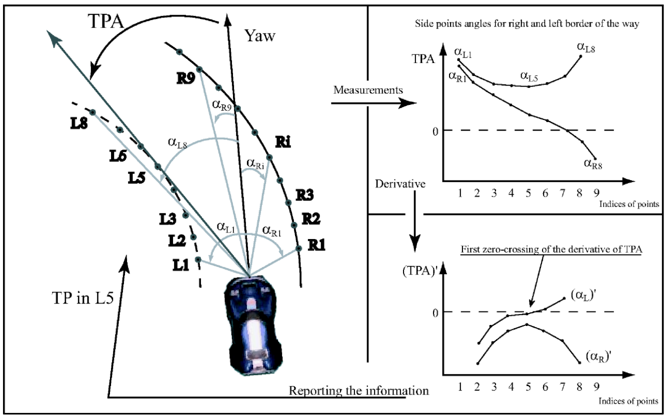

Figure 2: Methodology used to find the TP : the first zero-crossing of the derivative of side points angles belongs to the left border and occurs between points L5 and L6. The real TP is between points L5 and L6 ($\| L_iL_{i+1} \| \simeq$10cm). Finally, the TP is set to L5

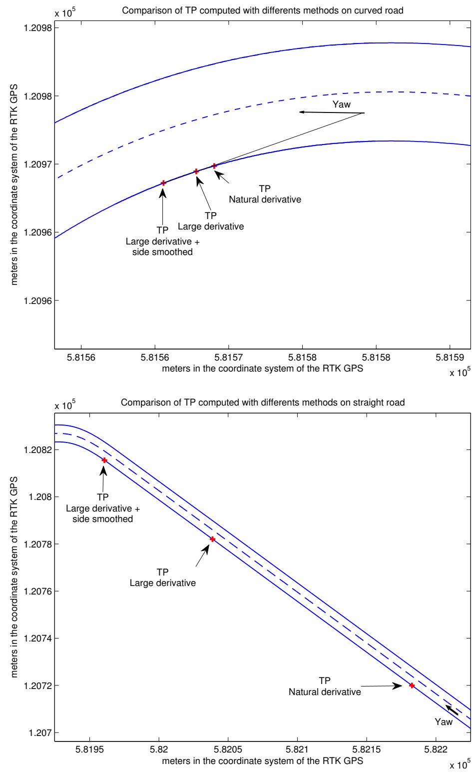

Figure 3: TP detection in curve and on straight line

We tried different ways of computing the TP using GPS informations, taking a simple derivative, taking a large derivative and finally we have tried to roughly estimate the position of the TP by a large derivative then approximating the side near this point with a 2^{nd} order polynomial and finally calculating the tangent to this polynomial passing through the camera optical center. As we can see on Fig. 3, the '*natural derivative*' is very sensible to noise, the '*large derivative*' and '*large derivative + side smoothing*' are almost equally efficient (considering the distance to the TP in Fig. 3, the TPA estimated with the last methods are almost equivalent).

On the digital map of the track we can look several kilometers ahead of the car if we need to, but obviously, a driver may never have such visibility. In order to be coherent with reality, we don't look for TP further than 50 meters for multiple reasons. Fixation points theories are mostly used when dealing with curved trajectories, this information on straight lines is of lesser use. Angles for points further than 50 meters on a road are very low ($\leq 0.1 rad$) and hardly differentiated by the camera because of CCD resolution or limited atmospheric visibility. Finally, the operational range of our road following algorithm is usually less than 50m.

We have computed this ground truth for comparison with TPA value estimated using the camera. The RTK GPS positions of the car that were logged at 20Hz were timestamped, as for the images taken by the camera that were timestamped when registered. We will compare the TPA estimation using the camera with the ground truth value of the TPA corresponding to the position closest in time with the image.

3 Tools

3.1 Lane markings detector

Labayrade and Douret lane detection system [3] has a few working steps. First, primitive features of lane markings are detected. Those primitives are detected using two different algorithms, one using a lateral consistent detection on the two sides of markings, and the other ones relies on longitudinal coherence along each side of the markings. Those detections are confirmed afterwards with a higher level process that combines the outputs of the low-level algorithms, confirm them and using a Kalman filter can predict the position of the lanes on the following image, thus accelerating and making the detections more robust.

Figure 4: Lane detection algorithm

Though robust, as this road following system is based on a frontal monocular camera, it has limitations. If the image is hardly exploitable due to hard lightning conditions or atmospheric disturbances or if the markings are unusable (quality, quantity, position particularly unfavourable) the lane markings following algorithm will provide wrong results. In those situations, the input of the TP detection algorithm is wrong, resulting in a false TP estimation.

3.2 Geometric calibration of the camera

Some informations like focal length and position of the optical center of the camera are necessary in order to compute precisely the TPA with geometric features extracted from the image. Given the lateral position of a marking in the image, as we're only interested in the angle between yaw and this marking (i.e. the lateral component of the 3D angle between optical axis and marking), we use the following equation :

$$TPA = \arctan(\frac{X_c - X_0}{\alpha}) \qquad (2)$$

with X_c, lateral position of the marking (column number), X_0 the lateral position of the optical center of the camera in pixels and α focal length in pixels. If the manufacturer's informations on focal length are false, we may find angle values dilated or compressed. But the position of the optical center of the camera is never given by the sellers and is as much important as the focal length. Any shift in its position leads to an offset on the estimation of any angle using pixel location informations. In our case, for a PAL image of 576x768px we estimated the position of the optical center using Jean-Yves Bouguet[2] Calibration Toolbox and found it to be 231x390px (as compared with a theoretic position of 288x384px).

4 Vision based TP detection

We have tested different methods to find the TP in images. All those methods had in input the positions coming from the lane marking detection algorithm. For example, we tried the same approach as in the ground truth computation (derivative of the positions of marking points), but it lacked efficiency due to the few number of marking points detected and their sampling compared with the number of GPS points of the track we dispose of. We now present the best method we have and that is based on prototypes of turns. This method allows us to calculate the TP only when approaching a turn or in a turn.

We proceed in two steps, finding the model of the road ahead (straight line or turn) using only the points detected and confirmed as markings, then, if we detect a turn, we look for the TP and compute the TPA on the right lane if we are in a right turn and on the left lane for a left turn..

In order to find the model of the road, we define prototypes of turns according to the beginning and the end of the markings detected.

Those prototypes are used to determine which side is susceptible of containing the TP. If the evolution of the beginnings and the ends of the markings is typical

[2]http://www.vision.caltech.edu/bouguetj/calib_doc/

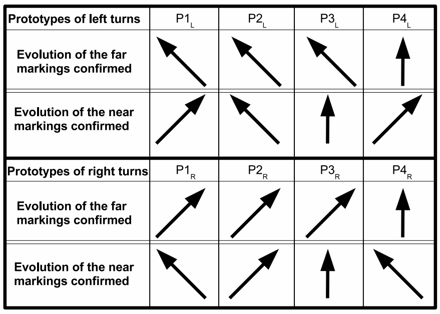

Figure 5: Prototypes of turn

of a straight path (*i.e.* if both sides tend to converge toward one point) we do not try to find a TP. Once the side containing the TP is known, we compute all possible angles between the yaw axis and the markings of this side and we keep the lowest one. The real radian value of this angle is obtained using Eq. (2) with the geometric parameters of the camera we got through a calibration process.

Figure 6: TP detection in curve

We present on Fig. 7 our results in the estimation of the TPA in a series of left turns. The error is inferior to 0.03 radians when both ground truth TPA and vision estimation TPA are defined. Zero values occur when no TP has been found, wether the prototype of the road ahead has been classified straight road (no seeking of the TP) or sometimes because the road following algorithm no longer provides markings confirmed.

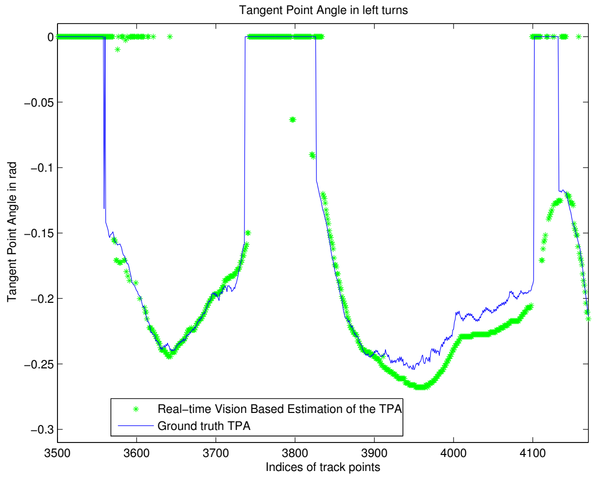

Figure 7: Comparison of ground truth TPA with vision based estimation of the TPA

5 Conclusion

In this work we have shown a method that allows to compute the Tangent Point Angle in real time with in-vehicle monocular camera. One difficult part we overcame was to build a ground truth algorithm that could perform an estimation of the TPA with a given run.

The results we get are very close to ground truth and false positive are low. With the road prototypes method, we have very few stops of the good working of the algorithm, we could filter them in real time by using 2 or 3 buffer images. That would introduce a little delay (40-80ms) but would make the output continuous in turns.

We have validated the monocamera algorithm, we have shown it can be used in any car provided that we calibrate the camera before, take its position in the car into account and that our road following algorithm provides us with positions of the markings.

We have already provided a version of this algorithm to psychology and cognition researchers that will use it in combination with an embedded oculometer in order to better comprehend what makes a secure trajectory.

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