Navigation system with STV driver assistance function

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Abstract. The article deals with the problems of application of modern driver assistance systems on single-track vehicles (STV). The design features of the STV that prevent the installation of such systems are presented. Variants of a motorcycle entering a turn are considered, with concerning the gyroscopic moment of the STV wheels and the causes of situations in the turn. A new navigation system with a driver assistance function with an analysis of its operation and advantages is proposed.

1. Introduction
The number of single-track vehicles (STV) is increasing every year. This trend is easy to explain. Overcrowded roads with cars in cities make people think about an alternative form of transport. The benefits of motorcycles (STV) to cars are obvious: mobility in traffic jams, ease of finding a parking space, economic efficiency, environmental friendliness.

However, the single-track vehicles have several disadvantages. The most significant of them is still its low safety. The challenge of enhancing safety in this type of means of transport will be an acute problem that will stand in the way of manufacturers for a long time.

Despite the general decrease in road accidents, the problem of road safety is urgent, since they remain the most dangerous means of transport in the world, STV drivers die 4-6 times more than car drivers if we compare the number of deaths per unit of vehicles. Low level of passive and active safety of STV, and the lack of widely used advanced driver assistance systems (ADAS), in particular those that are triggered when driving in a curve.

2. Main part
Active safety systems play an important role in the prevention of accidents and include: anti-lock braking system (ABS), vehicle stability control (ESC / ESP) and other driver assistance systems.

In recent years, the concept of driver assistance systems ADAS (Advanced Driver Assistance Systems) or in Russian Language – ISPV (intelligent driver assistance systems) has emerged and the number of electronic assistants has increased that support drivers in specific situations through information warning and/or intervention (if necessary) in driving control [1, 2, 3].

Initially, the vast majority of safety systems were designed for their implementation in road transport. For example, adaptive cruise control (ACC), autonomous emergency braking systems (AEBS) and others.

Due to the design features of the STV, practically none of the above systems can be applied on them without prior adaptation, and some systems are not used at all on the STV until now.

The main design features of the STV include:
• the position of the motorcyclist (to control the motorcycle it is necessary to move the body, which affects the driver's fatigue);
  • lack of a stable position when parking;
  • due to the lack of a vehicle body in the motorcycle, the driver is exposed to negative external factors: wind, rain, dust, snow, foreign objects on the road, etc.
  • mandatory requirement for the use of a protective helmet, as well as other elements of motorcycle equipment at the request of the driver;
  • physical features of STV control when cornering;
  • the specifics of the location of the controls.

Ultimately, the use of electronic systems is limited by the fact that the design and dimensions of the STV do not allow to accommodate all the necessary elements of these systems. In other cases, the use of systems is impossible due to the specific features of the controls.

The list of systems that are still not commercially available on production of STV:
• "dead zones" warning system;
• parking assistance systems (PTS, AVM, TPMS);
• autonomous - robotic (partial or complete driver replacement) - adaptive cruise control (ACC), lane keeping system (LKSS), robot driver, etc.;
• assistance systems after an accident: eCall (emergency alert system launched), seatbelt (safety belt), active head restraints (AHR), airbags;
• active steering systems: direct adaptive steering (DAS), active front steering (AFS) [4];
• interior comfort systems (rain sensor, climate control, etc.) [5].

The analysis of the STV market shows that the following electronic safety systems, adapted for use on the STV, are now being installed on motor vehicles produced by popular and large motorcycle manufacturers (Yamaha, BMW, Kawasaki, etc.):
• anti-lock braking system (ABS);
• dynamic stability control systems (DSC);
• traction control system (TCS): Kawasaki traction control (KTRC);
• Hill-start Assist Control (HAC, HSA, HHC);
• front wheel detachment control system: Kawasaki launch control mode (KLCM);
• rear wheel slip level control system;
• cornering control system: cornering brake control (CBC);
• start control system.

It is important to mention that most of these systems are still found only on the most powerful and expensive modern motorcycles.

Thus, the applied list of electronic safety systems used in commercial large-scale production is small, and their field of application is limited by the powerful and overweight motorcycle. Most of the electronic systems are used in sports motorcycles, whose operating environment is a race track.

However, there are such marketing leaders as Bajaj, Racer, Motoland, which are highly popular due to their low cost, but they do not have any security systems. For example, the Bajaj brand has only one model with an ABS system - the Bajaj Dominar 400.

3. Causes of emergencies situations in turning a corner.
In view of the design of the STV and the peculiarities of its control, a section of the road with a curved trajectory is the most dangerous and requires special attention when driving along it.

Accident statistics show that the share of accidents involving associated with a motorcycle flying off the road in a turn without the participation of another vehicle is 41% of all fatalities involving motorcyclists. The percentage of accidents when turning a corner is twice the number of accidents for other reasons.

Driving at a speed above the critical speed or choosing the wrong trajectory leads to the fact that the driver tries to correct the situation directly during the cornering. In fear, an inexperienced driver may apply the brake or open the throttle too sharply. Such situations, when the STV moves with a
certain roll angle, can negatively affect its stability, because at this moment, the mass of the motorcycle is redistributed and the area of the contact patch of the front or rear wheel with the road decreases. Loss of adhesion of one of the wheels to the surface leads either to the motorcycle skidding and falling in the turning direction, or the driver throws up and flies over the motorcycle. In this case, in addition to hitting the driver on the road surface, he also at risk of getting hit by the motorcycle itself which is moving behind him.

The reasons for this are:
1. Insufficient deceleration before entering a turn. High speed when entering a turn leads to the following consequences: driver fear and loss of control, attempts to reduce the speed by closing the gas and pressing the brake, an attempt to increase the roll angle by hanging the driver's body.
2. Errors in handling the motorcycle when exiting a corner. The transient process of movement, both entering and exiting a corner, is the most unstable and dangerous.
3. Incorrect reading of the traffic situation and the choice of the trajectory. A late reaction to a turn leads to the fact that the driver does not have time to select a safe driving mode, as well as to shift in the necessary direction within his lane, depending on the type of turn. Closed turns are especially dangerous and require an advance decision on safe traffic in this section (Fig. 1).
4. Changing the road surface. The presence of irregularities on the road, as well as oil, sand and other foreign objects leads to deterioration in handling, wheel traction and slipping.

Cornering has a phase character: approach, entrance, movement in an arc, exit. In the approach phase, the driver reduces the speed by one of the braking techniques: engine, front brake, rear brake. In the best case, the driver tries to perform a preliminary maneuver - "approach", which allows him to build a trajectory of the maximum radius, which is terminologically referred to as "Trajectory Smoothing". Entering a turn is a transition from straight ahead to arc of a given radius. This process is the most dangerous, occurs because the center of mass displacement, as well as a shift in the contact spot patch of the tire with the road.

Movement along the arc presupposes ideally construction of trajectory smoothing, although it does not exclude additional maneuvers with forced change of trajectory during the competitive struggle. When moving along an arc, the methods of balancing techniques of maintaining stability and controllability are particularly important. The balance of stability is achieved by changing the tilting of body forward, backward, to the sides. Particular attention is paid to the throttling technique, since the complete cessation of traction provokes the motorcycle to fall after skidding, lateral side-slip and rotation. Depending on the configuration of the turn, the coefficient of adhesion, the individual characteristics of the rider, there are constant, variable, alternating throttling, as well as smooth, forced and sharp.

![Dangerous trajectory in a closed corner](image)
The movement along the arc of the smoothing trajectory involves a "cut", which is marked in the "apex" zone (the steepest part of the arc). When entering a turn, a rational gear is selected, which can change in the exit phase, or when stability is lost on the arc.

The phase of exit from the turn is associated with a decrease in the motorcycle roll, an increase in the load on the rear wheel, an increase in the radius of movement.

Consider the options for moving the STV in a turn, depending on the speed of movement. When cornering, it is important to take into consideration the gyroscopic moment of the STV wheels.

When driving at low speeds, for example, when maneuvering in a parking lot, the motorcycle turns in the usual way - turning the handlebar in the direction of movement (Fig. 2). The figure shows that the driver, moving around the site ground at low speed, turns the handlebar in the direction of the turn and goes in the direction in which the front wheel is moving.

**Figure: 2. Maneuvering at low speed**

Considering cornering at speeds where the gyroscopic moment has a large effect, the technique of entering the turn is fundamentally different. Since turning the handlebars at high speed towards the bend, contrary to the rider's expectations, his STV will tip over from the center of the turn, and not vice versa. Thus, in order to safely enter a corner at high speed, the driver must first shift the center of mass of the motorcycle by displacing the driver's body in order to tilt it, and only then turn the handlebars towards the turn (Fig. 3).

**Figure: 3. Entry into a turn by shifting the driver's body towards the turn**

There is a third special case of entering a turn when the driver turns the handlebar away from the turn. Before entering a turn, the driver deliberately turns the handlebar away from the center of the turn, knowing that the motorcycle will start to tip over to the same side which he turns, due to the gyroscopic moment on the wheels (Fig. 4).
This way of cornering is extremely dangerous. As a rule, this technique of handling is used by motorcyclists on the racetrack. This method allows them to enter and move in a corner as quickly as possible and with the smallest radius. Also, motor sportsmen use the counter-steering technique at stunt riding competitions when performing drift on a motorcycle.

Thus, there are three main ways to entering the corner on a motorcycle:

1. at low speed: the absence of gyroscopic moment allows the driver to turn the handlebar in the direction of movement;
2. at high speed (safe): due to the influence of the gyroscopic moment, the driver is forced to first shift the center of mass of the motorcycle with his body, then smoothly turn the handlebar in the direction of the turn;
3. at high speed (unsafe): due to the influence of the gyroscopic moment, the driver intentionally turns the handlebar away from the center of Turning.

In everyday life, excluding extreme driving, the driver avoids critical driving modes in every possible way. But, moving along a curved trajectory, often the wheels of the motorcycle begin to slip. Of course, this can be caused by unforeseen circumstances, such as oil or sand on the road, but the most important reason for slipping the wheels in a corner is improper motorcycle control due to movement at speeds above critical. Every driver needs to clearly understand what speed is safe before an approaching turn.

As an example, let's calculate the critical slip speed for a specific turn, the radius of which is \( R = 48 \) m, for dry and wet asphalt. The coefficient of adhesion of the wheel to the road surface \( \phi_f \) is 0.8 for dry asphalt and 0.3 for wet asphalt.

Let us calculate the critical slip speed in a turn using the following formula [6]:

\[
V_{css} = \sqrt{g \phi_f R}
\]

where \( g = 9.81 \) m/s\(^2\) is the acceleration of gravity, \( \phi_f \) is the coefficient of adhesion of the wheel to the road surface, \( R \) is the radius of curvature of the turn.

\[
V_{css} \text{ (dry asphalt)} = 69.87 \text{ km/h}
\]
\[
V_{css} \text{ (wet asphalt)} = 42.79 \text{ km/h}
\]

On the section for which the calculation was made, a speed limit sign of 50 km/h was installed. As it is observable, it is relevant for dry asphalt, because the design lateral slip speed exceeds the speed set by the SDA. However, if driving in the rain, following the 50 km/h limit may result in the rider falling. Therefore, speed limit signs can be objective for the safe movement of motorcyclists, moreover, one cannot be sure of the presence of such signs before each turn, since they may be insignificant for the motorist, while it will be useful for the motorcyclist to have information in advance that will allow him to enter safely into the turn.
4. Navigation system with STV driver assistance function

As previously mentioned, entering a corner incorrectly leads to a number of consequences that can be hardly dealt with either a very experienced driver or an intelligent driver assistance system (ISPV). However, these systems have a narrow application and are not yet available on most STV.

Intelligent driver assistance systems, which are implemented in motorcycle transport, affect the parameters of the motorcycle's movement when there is an immediate risk of falling. However, there are no such systems that could recognize turns in advance, read the traffic situation and give recommendations to the driver about the safest driving mode.

Therefore, one of the ways to deal with accidents in a corner is to prevent cases that the driver cannot cope with on his own, that is, the task is to inform the driver in advance about a possible change in the traffic situation. In order to minimize accidents and develop driving skills, we will consider a navigation system with an STV driver assistance function.

The navigation system in its usual sense is designed to determine the position of the vehicle, select and follow the route. In other words, the driver gets a general idea of how far to travel to the desired turn or final stop.

Navigation with a driver assistance function, theoretically considered in solving the problem, assumes that the driver will not only receive a signal about the presence of a turn, but also recommendations about its passage based on the following data:

- distance to the nearest turn;
- radius of curvature of the turn;
- speed limit on this section of the road;
- weather;
- technical data of the motorcycle.

First, let's consider the navigation that is currently available using the example of the Yandex.Navigator application (Fig. 5a). When moving along the constructed route, the screen displays the following information:

- current speed of the vehicle;
- the speed set by the traffic rules for this section;
- distance to the nearest turn.

This navigation option does not take into consideration the peculiarities of traffic on the STV and the state of the road surface. But it is known that these factors are very important for safe movement and must be considered in navigation systems.

Also, the methods of entering the turn were considered depending on the gyroscopic moment on the wheels, which in turn depends on the speed of movement, mass and radius of the wheels. These factors should also be considered when adjusting the navigation and offering recommended technique for the driver the to enter the corner.

Figures 5 b, c show examples of updated navigation. Its peculiarity is that in addition to the information that is available in the first version, the driver sees the following information on the screen:

- the recommended speed before the nearest turn, which will be relevant for entering the turn on the STV;
- recommendations on the technique of entering into the corner turn.

Thus, the driver will be able to reduce the speed in advance, select the desired gear, take the required position in the lane in which he is moving, and be ready to move in a dangerous area.

It is also assumed that in addition to visual information, prompts will be duplicated through a Bluetooth headset (Fig. 6) in order to distract the driver from the road as little as possible.
Figure: 5. Variants of the navigation system: a - built route in Yandex.Navigator; b, c - proposed navigation options with the function of assistance to STV drivers

Figure: 6. Bluetooth headset

5. Algorithm of the modified navigation.
If the calculated critical speed is less than the one set by the traffic rules for this section of the road, then the program checks whether the driver exceeds the calculated critical speed. If the result is negative, then the driver receives only information about the cornering technique. If the result is positive, then in addition to the recommendation about the turning technique, the driver will be informed about the speed with which he needs to move before the next turn.

If the estimated critical speed is greater than or equal to that set by the traffic rules on this section of the road, then the program also checks whether the driver exceeds the traffic speed. Further, the information to the driver is received according to the principle of the first case: if the driver does not exceed the speed according to traffic rules, then information appears on the technique of cornering, if it does, then the motorcyclist is additionally informed that it is necessary to reduce the speed.
6. Conclusions

Features and benefits of improved navigation.

This function, of course, is not able to prevent an imminent fall, but it will help the driver to navigate and concentrate his attention, orientate himself more quickly in the road conditions and take the necessary actions for safe driving. The advantage of navigation with enhanced functionality is that it is accessible to any driver and will be especially useful for those drivers who are getting their first experience of driving a STV in an urban condition.

Moreover, standard navigation only informs the driver about those turns that have intersection of two or more roads. In other words, the turns formed by changing the direction of the road are not signaled in any way. This is of no importance to the motorist, but it is important for the STV driver to know in advance of any change in the direction of track motion.

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