Human Error in Evaluation of Angle of Inclination of Vehicles

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Error in evaluation of the angle of inclination
Force
Space disorientation
The vehicle

1. Problem

In the process of investigation of traffic accidents of vehicles, it has been concluded that the primary cause of these accidents is the human factor or “man-driver”, followed by the vehicle, and in third place, the “environment - roadway” equipped by signalization devices, Damiano and Rabitt [1]. According to Milosevic [2] man is definitely the primary cause of vehicle accidents in 64.3 %, and probably the primary cause in 90.3% of situations.

The errors made by drivers are influenced, besides systemic errors, by illusions, which are the result of the driver’s perception distorted and appear after appropriate external stimulation. Illusions as well can be classified in the following way Damiano and Rabitt [1]:

- vestibular structure in the ears
- visual organs
- kinesthetic organs.

The most difficult conditions for driving a motor vehicle are in the spiral curves of the road, when the driver is unable to evaluate the angles of the curve, due to which his use of the steering controls is erroneous, causing the car to overturn, Klarin and Cvijanovic [3].

The subject of this paper is to analyze the influence of external stimulation (night, fog, pollution etc.) at sensibility threshold influenced by angular acceleration and illusions that man feels and makes mistakes in commands usage in eight different conditions of driving (both sides rotation, uphill and downwards movement, with or without visual control instrument).
Symbols/Oznake

- $a$ - acceleration, m·s$^{-2}$
- $a_{\lambda, \mu, \nu}$ - coriolis acceleration components, m·s$^{-2}$
- $a_c$ - coriolis acceleration, m·s$^{-2}$
- $a_n$ - normal acceleration, m·s$^{-2}$
- $G$ - weight, N
- $\bar{G}$ - resultant force, N
- $F_{\text{m}}$ - normal force, N
- $F_{\text{in}}$ - inertial force, N
- $R, K_1, K_2$ - axial distances, m
- $SD_\tau$ - standard deviation of angle $\tau$, °
- $v$ - velocity, m·s$^{-1}$
- $\phi, \xi, \zeta$ - inertia axis
- $\dot{\phi}, \dot{\theta}, \dot{\psi}$ - velocity at axes $\phi, \xi, \zeta$, m·s$^{-2}$
- $\ddot{\phi}, \ddot{\theta}, \ddot{\psi}$ - acceleration at axes $\phi, \xi, \zeta$, m·s$^{-2}$
- $\tau$ - angle between weight and resultant force, rad, °
- $\bar{\tau}$ - estimation error of angle of inclination, rad, °
- $\omega$ - angular velocity, rad·s$^{-1}$, °·s$^{-1}$
- $\mu$ - normal force, N

2. Method

2.1. Theoretical Assumptions

The main theoretical assumptions are on the kinematics calculations shown in Figure 1. The center of gravity of the driver M has shifted from the geometrical center of the cabin $O'$, which is at a distance of 2 m from the central rotation axis $\tau$. Point M has the distance of $K_1$ along the axis $\eta$ in the plane of axises $\phi, \xi$ and $K_2$ on the axis $\zeta$. On the axis $\zeta, K_1=0$.

$$\vec{\lambda} (1), \vec{\mu} (2), \vec{\nu} (3),$$
$$\vec{\rho} = \vec{O}M = \vec{\xi} + \eta \vec{\mu} + \zeta \vec{\nu},$$
$$\vec{v}_M = \vec{v}_o + \vec{\omega} \times \vec{\rho}, \vec{v}_o = \omega \vec{\phi},$$
$$\vec{a}_M = \vec{\rho} + \epsilon \times \vec{\rho} + \vec{\omega} \times (\vec{\omega} \times \vec{\rho}),$$
$$\vec{a}_c = -\psi (\vec{\lambda} + \phi \vec{\mu} + \lambda (\psi K_2 - \phi K_1) - \mu \vec{\theta} K_1 + \vec{\nu} \vec{K}_1 +$$
$$+ \vec{\lambda} (\psi \vec{K}_1 + \phi \vec{\theta} K_1) + \mu (\psi \vec{K}_2 - \phi \vec{\theta} K_1 - \psi \vec{\phi} K_1 +$$
$$+ \vec{\nu} \vec{K}_1 - \lambda^{2} K_2 + \psi \vec{K}_2 + \psi \vec{\phi} K_1).$$

The vector calculation for the given conditions are obtained by the known functions and parameters.

For the value of $M$, which is the center of inertia (center of gravity) the coordinates are $\zeta=0, \eta=K_1, \xi=K_2$, so there follows:

$$\eta_c = 0; \xi_c = K_1; \zeta_c = K_2$$

$$F_{\text{in}} = -m \vec{a}_c,$$

which are also relevant for the example shown in Figure 2.

That is shown on the following example.
\[
\begin{align*}
\dot{\phi} &= \text{const} \quad \Rightarrow \quad \ddot{\phi} = 0 \\
\dot{\phi} &= \frac{\pi}{3} \text{ s}^{-1}, \quad a = R = 2 \text{ m} \\
\dot{\theta} &= \text{const} \quad \Rightarrow \quad \ddot{\theta} = 0 \\
\dot{\theta} &= \frac{\pi}{9} \text{ s}^{-1}, \\
\dot{\psi} &= \text{const} \quad \Rightarrow \quad \ddot{\psi} = 0 \quad K_1 = 0.2 \text{ m} \\
\dot{\psi} &= \frac{\pi}{10} \text{ s}^{-1} \quad K_2 = 0.3 \text{ m} \\
\ddot{a}_c &= \ddot{\lambda} K_1 (a \phi^2 + \psi K_2 - \phi' K_1 + \psi' K_1 + \phi' \psi K_2) + \\
&+ \ddot{\mu} (a \phi - \phi' K_1 + \phi' K_2 - \phi' K_1 - \phi' K_2) + \\
&+ \ddot{\nu} (\psi K_1 - \phi' K_2 - \phi' K_2 + \phi' K_1), \\
\ddot{a}_c &= \ddot{\lambda} K_1 (a \phi^2 + 3 \psi K_2 - \phi' K_1 + \phi' K_2 + \phi' K_1) + \\
&+ \ddot{\mu} (3 \phi' K_2 - \phi' K_1 + \phi' K_2 + \phi' K_1), \\
\ddot{a}_c &= -2.19 + 0.02 + 0.11 = -2.06 \text{ m/s}^2, \\
a_c &= -0.1 - 0.22 - 0.02 = -0.14 \text{ m/s}^2, \\
a_c &= -0.03 - 0.03 + 0.06 = 0, \\
\dot{G} &= m \sqrt{a_c^2 + a_c^2 + a_c^2 + g^2} = \\
&= m \sqrt{2.06^2 + 0.14^2 + 0^2 + 9.81^2} \\
\dot{G} &= 10.02 \cdot m \ [N].
\end{align*}
\]

Just how big the errors of the driver are in determination of the direction of the gravitation force, i.e., the horizontal plane in conditions of driving the vehicle, is possible to determine by simulations Klarin and Cvijanovic [4].

With that aim in mind, in our experiment a device has been used which has been specially constructed for the purpose of research in the field of aviation. It satisfies all the requirements with regard to simulation of driving a vehicle in curves in the road. Its sketch, which has been presented in Figure 3, shows that the driver has a cabin with instruments which have the option of rotary motion in all three planes of the coordinates system.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure3.png}
\caption{Device for pilot accommodation to space disorientation}
\end{figure}

Slika 3. Simulator prostorne dezorientacije ispitanika

\subsection*{2.3. Experimental Research Description and Results}

On the basis of these calculations, it can be concluded that for an assumed simple case with constant angle velocity of rotation along the axes, the result in point M, the center of gravity of the human body, is the centrifugal acceleration which diverts force \(G=mg\) from the vertical plane and also gives the resultant \(\dot{G}\). Since more complex motions and accelerations, which unavoidably occur, have an impact on the vestibular structure of the natural person, which is located in the middle ear of the person, this is a more complex question than the team of researchers had anticipated, and the experiment was conducted in the manner in which the system was given only the constant angular movement around the axis \(\phi\) of \(\omega=40\%\), with a constant inclination of the cabin in the direction of movement of the vehicle of \(+/-\ 10^\circ\) as shown in Figure 4.
In this case, the angle \( \tau \) between forces \( G \) and \( \vec{G} \) is the result of the calculations using formulas (equations 7,8,9):

\[
v = \omega \cdot R, \quad (7)
\]

\[
tg \tau = \frac{F_m}{G} = \frac{m \cdot a}{m \cdot g} = \frac{\omega^2 R}{g}, \quad (8)
\]

\[
a_n = \frac{v^2}{R} = \frac{\omega^2 R^2}{R} = \omega^2 R, \quad (9)
\]

\[
tg \tau = -\frac{\omega^2 R}{g} = \frac{\left(\frac{2\pi}{360} \cdot 40\right)^2 \cdot 2}{9.81} = 0.099,
\]

\[
\tau = \text{arctg}0.099 = 5.6746 = 5.7^0,
\]

\[
\tau \equiv 5.7^0.
\]

Since the \( \tau \) is the side angle, the driver will make efforts to “straighten” the direction of the vehicle in regard to the angle of inclination using the steering wheel by turning the vehicle contrary to the direction of the curve, which frequently leads to the vehicle going off the road, and to accidents.

The value of the angle \( \tau \) does not depend on the mass of the driver and the cabin, but exclusively on the angular velocity \( \omega \). In Table 2 and Figure 5, the values of angle \( \tau \) in the function of angular velocity are presented.

Nine drivers took part in the experiment, of which three were 20 years old, five were 21 years old, and one was 50 years old, with average weight of 79kg and average height of 180cm, all in good physical shape, which corresponds to the average values of anthropomasures of this stratum of Yugoslav citizens, which makes our sample of applicants representative. They were all subjected to movements in the cabin with a constant angular velocity of \( \omega = 40^0/s \) in the horizontal plane. This velocity corresponds to the angle between the vertical plane and direction of intensity of force, which amounts \( \tau = 5.6746^0 \) (Table 1).

\[
\begin{array}{|c|c|c|c|}
\hline
\omega & \tau (\text{rad}) & \omega & \tau (\text{rad}) \\
\hline
0 & 0,0 & 0,0 & 50 & 0,1540 & 8,8252 \\
1 & 0,0001 & 0,0036 & 51 & 0,1601 & 9,1758 \\
2 & 0,0002 & 0,0142 & 52 & 0,1664 & 9,5326 \\
3 & 0,0006 & 0,0320 & 53 & 0,1727 & 9,8956 \\
4 & 0,0010 & 0,0569 & 54 & 0,1792 & 10,2646 \\
5 & 0,0016 & 0,0890 & 55 & 0,1857 & 10,6397 \\
6 & 0,0022 & 0,1281 & 56 & 0,1923 & 11,0208 \\
7 & 0,0030 & 0,1794 & 57 & 0,1991 & 11,4076 \\
8 & 0,0040 & 0,2277 & 58 & 0,2060 & 11,8003 \\
9 & 0,0050 & 0,2882 & 59 & 0,2129 & 12,1986 \\
10 & 0,0062 & 0,3558 & 60 & 0,2200 & 12,6245 \\
15 & 0,0140 & 0,8006 & 65 & 0,2566 & 14,7022 \\
20 & 0,0248 & 1,4230 & 70 & 0,2954 & 16,9254 \\
25 & 0,0388 & 2,2228 & 75 & 0,3361 & 19,2559 \\
30 & 0,0558 & 3,1991 & 80 & 0,3795 & 21,6759 \\
35 & 0,0759 & 4,3505 & 85 & 0,4218 & 24,1656 \\
40 & 0,0990 & 5,6746 & 90 & 0,4661 & 26,7041 \\
45 & 0,1251 & 7,1679 & & & \\
\hline
\end{array}
\]

Since the \( \tau \) is the side angle, the driver will make efforts to “straighten” the direction of the vehicle in regard to the angle of inclination using the steering wheel by turning the vehicle contrary to the direction of the curve, which frequently leads to the vehicle going off the road, and to accidents.
Eight conditions of driving have been simulated. First of all, rotation was performed in the direction of the hand of the clock, simulating the right curve, and then in the opposite direction, i.e., simulation of movement in the left curve.

In the case of both directions, an uphill movement with a 10° gradient was firstly simulated in such a way that the cabin of the simulator was inclined with its front end for 10° upward. With the opposite inclination of the cabin the downward movement - downhill at 10° was simulated.

In all the previous four variations of simulation of driving, driving with visual control instruments and also without them was simulated.

The volunteer was requested to begin his experiment from the moment with the constant angular velocity of $\omega = 40 \,^\circ/s$ and when this was achieved, he was given the sound signal to begin the operation of “straightening” the cabin of the vehicle. From the closed cabin he was not able to see the surrounding area, and he only had sound signal communication with the control room of the simulator. Then the volunteer moved the cabin into a horizontal position. After achieving the inclination of the cabin of 5.6746 degrees, which was monitored on the instrument (Figure 6.), the volunteer was asked to return to the horizontal position by use of the controls, which was being recorded by a sensitive instrument with a monitor. The period of time from the moment the volunteer gripped the controls and began operation to the moment of giving a sound signal that he has brought the cabin into a horizontal position was measured by a stopwatch, which was sufficiently accurate having in mind that the average time for this operation was 10.6sec., but this also depends on the inertia of the system.

The volunteers could not “return” to the horizontal position, but made errors in evaluation of the angle.

Errors in the evaluation of the angle in the absolute values (degrees) were considered, since the deviation from the direction of movement of the car to the left or the right with similar consequences and possibilities of causing accidents, and the researchers obtained an average error in the evaluation of angle, of 2.425° with the standard deviation of 1.88°. The average reaction time of the driver, i.e., the time of bringing the cabin into the horizontal position was 10.6sec. with standard error of 5.58sec.

The numerical results are shown in Table 1 with statistical function of distribution of errors for ranges from $\Delta \tau = 1^\circ$ in Table 2 and diagram in Figure 7.

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<td>21 17 10 10 7 3 3 1</td>
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</table>
3. Conclusion

Considering the results obtained by the volunteer, it may be concluded that all data have equal dispersion for error in evaluation of angle \( \tau \), and for its standard deviation SD, and the time necessary for bringing the cabin into the desired position ti, as well as for its standard deviation SD, all of that by the volunteer and for each of the different groups selected for investigation. This means that the sample used nevertheless is small it is representative.

The error of evaluation ranges from \( \tau_{5} = 1.19^\circ \) in the case of the fifth volunteer to \( \tau_{2} = 3.29^\circ \) in the case of the second volunteer, while in the case of the first experiment for all volunteers in conditions of movement to the right-uphill-“light”- from \( \tau_{rd} = 1.1^\circ \), to \( \tau_{rld} = 3.4^\circ \) in the experiment made in conditions of movement right-uphill-“dark”.

The results of these experiments further show that in simulating driving uphill or downhill in respect of error of angle, the least deviation from the average value for all volunteers \( \tau = 2.425^\circ \) ranges from \( \tau_{u} = 2.415^\circ \) for “uphill”, and \( \tau_{d} = 2.4325^\circ \) for “downhill”. There has always been an experiment with visual control of the experiment, and then without visual control, so that the volunteer in the first experiment could have certain sense of the how big the angle of inclination of the cabin was. The average value of the error made with visual control of instruments amounted to \( \tau_{vc} = 2.1575^\circ \), while without the visual control it amounted to \( \tau_{vwc} = 2.69^\circ \). There was slightly less difference in this error when driving in the left curve than in the right curve, and this figure for the left curve was \( \tau_{l} = 2.64^\circ \) and for the right curve \( \tau_{r} = 2.21^\circ \) but it must be stressed that this difference was least expected considering the equal conditions of simulation.

In case where the error of evaluation of the angle is considered by application of positive and negative values, the results obtained show a greater difference in the evaluation of angle (Table 2). In driving with “lighted” instruments, the average error of evaluation of angle in the right curve is \( \tau_{rl} = 0.38^\circ \), and in the left curve \( \tau_{rl} = -2.74^\circ \). There is much greater difference in average errors of evaluation of angle when driving with control instruments and without them (light - dark) in the right curve where the values are \( \tau_{rd} = 0.38^\circ \) and \( \tau_{rld} = -2.74^\circ \), while in the left curve these values are \( \tau_{ld} = -2.74^\circ \) and \( \tau_{ld} = -0.86^\circ \).

By application of this method of consideration of data, the results show that drivers in the left curve make errors in the sense that they do not put the vehicle in the horizontal position, but cross over by 2.74 \(^\circ\). The total average value of the evaluation of angle in respect of positive and negative values is \( \tau = -0.86^\circ \) with a standard deviation of SD = 2.944, while the function could be approximated by normal distribution. This really means that the drivers have, in the time period of approximately 10.6sec. lost, the sense for the horizontal plane, and that these drivers are still making erroneous evaluations.

The general conclusion of our research is that the error in the evaluation of angles should be considered in a system with absolute data values and also in a system with relative data values. It should also be concluded that accidents and overturning of vehicles in curves may often be caused by erroneous evaluation of the angle of inclination of the vehicle, and therefore, the wrong or erroneous reaction of the driver, who is not able to make this evaluation in a short period of time, so that is the direction of future research especially in the field of automotive industry.

**REFERENCES**


