MODELLING OF THE UGV'S TERRAIN STABILITY

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Abstract
This paper describes a mathematical modelling of stability of a Unmanned Ground Vehicle (UGV) that accounts for the tendency to slide, tipover, or lose contact with the ground considering both static equilibrium and dynamic effects. The mathematical modeling of stability is computed by solving for the range of acceptable angles that satisfy a set of dynamic constraints.

Keywords: UGV, stability, terrain, model, simulation, driveability

1 Introduction

The characteristics of Unmanned Ground Vehicle (UGV) designed for driveability, procure a high mobility for the driver but leads to an important rollover risk in counterpart. As a consequence, the increase of sells is accompanied by an augmentation of the number of accidents, especially lateral overturning. However the development of active devices requires a relevant knowledge of UGV lateral dynamic behavior and of parameters impacting the rollover. This paper proposes a study of the influence of several parameters on the rollover risk, through multibody model simulation. According to both a simplified tire/ground contact modeling and a multibody model, the influence of mechanical components (suspension mechanisms, anti-roll bars, transmission) and parameters variations (sliding, pilot inclination) has not been examined. A lateral stability criterion based on the lateral load transfer of the vehicle allows the rollover risk comparison.

2 Lateral and longitudinal stability of the UGV

The objective of this part is to study the dynamic longitudinal and lateral stability of UGV in function of several phenomena and parameters. For each analysis, the different surfaces represent the steady state value of the longitudinal and lateral loads.

2.1 Lateral stability of the UGV on a rigid surface (road)

Figure 1 and 2 depicts the effect of a bank angle on the load distribution of a vehicle. A bank causes the load on the lower tires to increase, and the load on the upper tires to decrease. The tire reaction forces are:

$$F_{RL} = \frac{1}{2}.\frac{m.g}{B}.[B_2\cos(\emptyset) - h.sin(\emptyset)] \tag{1}$$

$$F_{RR} = \frac{1}{2}.\frac{m.g}{B}.[B_1\cos(\emptyset) + h.sin(\emptyset)] \tag{2}$$

$$B = B_1 + B_2 \tag{3}$$

$$\sum F_x = 0 \tag{4}$$

$$\sum F_y = 0 \tag{5}$$

$$\sum M_z = 0 \tag{6}$$

After modification:

$$2.F_{latL} + 2.F_{latR} - m.g.\sin(\emptyset) = 0 \tag{7}$$

$$2.F_{RL} + 2.F_{RR} - m.g.\sin(\emptyset) = 0 \tag{8}$$

$$2.F_{RL}.B_1 + 2.F_{RR}.B_2 + (2.F_{latR} + 2.F_{latL}).h = 0 \tag{9}$$

It assumed the force under the lower tires, front and rear, are equal, and also the forces under the upper tires, front and rear are equal. To calculate the reaction forces under each tire, we may assume the overall lateral force F_{y1}+F_{y2} as an unknown. The solutions of those equations provide the lateral and reaction forces under the upper and lower tires.

$$F_{RL} = \frac{1}{2}.m.g\,.\frac{B_2}{B}\cos() - \frac{1}{2}.m.g.\frac{h}{B}.\sin(\emptyset) \tag{10}$$

$$F_{RR} = \frac{1}{2}.m.g\,.\frac{B_2}{B}\cos(\emptyset) + \frac{1}{2}.m.g.\frac{h}{B}.\sin(\emptyset) \tag{11}$$

$$F_{latR} + F_{latL} = \frac{1}{2}.m.g\,.\sin(\emptyset) \tag{12}$$

At the ultimate angle $\phi = \phi_M$, all wheels will begin to slide simultaneously and therefore,

$$F_{latR} = \mu\,.F_{RR} \tag{13}$$

$$F_{latL} = \mu\,.F_{RL} \tag{14}$$

The equilibrium equations show that

$$2\,.\mu\,.F_{RL} + 2\,.\mu\,.F_{RR} - m.g\,.\sin(\emptyset) = 0 \tag{15}$$

$$2\,.F_{RL} + 2\,.F_{RR} - m.g\,.\cos(\emptyset) = 0 \tag{16}$$

$$2\,.F_{RL}.\,B_1 + 2\,.F_{RR}.\,B_2 + 2.\mu.h.(F_{RL} + F_{RR}) = 0 \tag{17}$$

will provide

$$F_{RL} = \frac{1}{2}.m.g\,.\frac{B_2}{B}\cos(\emptyset_M) - \frac{1}{2}.m.g.\frac{h}{B}.sin(\emptyset_M) \tag{18}$$

$$F_{RR} = \frac{1}{2}.m.g\,.\frac{B_2}{B}\cos(\emptyset_M) + \frac{1}{2}.m.g.\frac{h}{B}.sin(\emptyset_M) \tag{19}$$

$$\tan(\emptyset_M) = \mu \tag{20}$$

These calculations are correct as long as:

$$\tan(\emptyset_M) \le \frac{B_2}{h} \tag{21}$$

$$\mu \le \frac{B_2}{h} \tag{22}$$

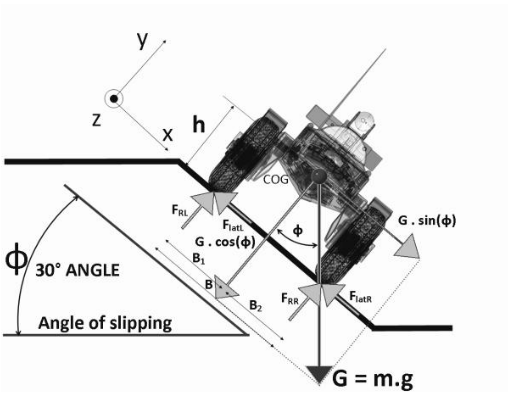

Fig. 1 *Normal force under the uphill and downhill of a vehicle, parked on rigid surface (banked road)*

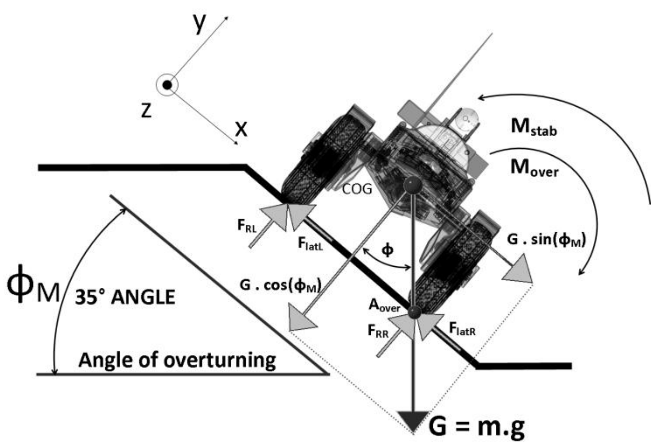

Fig. 2 *Normal force and moment under the uphill and downhill of a vehicle, parked on rigid surface (banked road)*

If the lateral friction μ_y is higher than B_2 / h, then the car will rolling downhill. To increase the capability of a car moving on a banked road, the car should be as wide as possible with a mass center as low as possible.

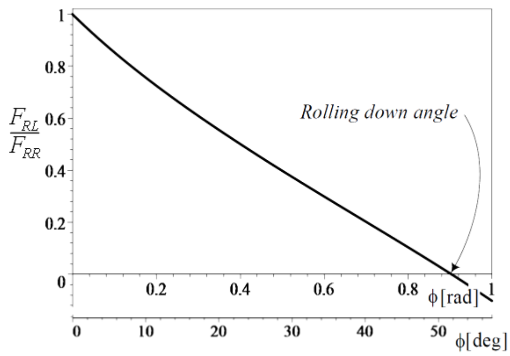

Fig. 3 *The force ratio F_{RL} /F_{RR} as a function of road bank angle ϕ*

2.2 Longitudinal stability of the UGV on a rigid surface (road)

Figure 4 and 5 depicts the effect of a bank angle on the load distribution of a vehicle. A bank causes the load on the lower tires to increase, and the load on the upper tires to decrease. The tire reaction forces are:

$$F_{ZL1} = \frac{1}{2} . \frac{m.g}{L} . [L_1 \cos(\emptyset) - h. \sin(\emptyset)] \tag{23}$$

$$F_{ZL2} = \frac{1}{3} . G . \cos(\emptyset) - h . \sin(\emptyset) \tag{24}$$

$$F_{ZL3} = \frac{1}{2} . \frac{m.g}{L} . [L_2 \cos(\emptyset) + h. \sin(\emptyset)] \tag{25}$$

$$L = L_1 + L_2 \tag{26}$$

$$L_1 = L_2 \tag{27}$$

$$\sum F_x = 0 \tag{28}$$

$$\sum F_y = 0 \tag{29}$$

$$\sum M_z = 0 \tag{30}$$

At the ultimate angle $\phi = \phi_M$, all wheels will begin to slide simultaneously and therefore,

$$F_{long1} = \mu . F_{ZL1} \tag{31}$$

$$F_{long2} = \mu \,.\, F_{ZL2} \tag{32}$$

$$F_{long3} = \mu \,.\, F_{ZL3} \tag{33}$$

By the solving of the equations (23) – (33):

$$G \;.sin\,\phi \;\leq\; F_{long} \tag{34}$$

$$G\,.\;sin\,\phi \leq \mu\,.\;G\,.\;cos\,\phi \tag{35}$$

$$sin\,\phi \leq \mu\,.\;cos\,\phi \tag{36}$$

$$\sum_{i=3} F_{long\;i} = F_{long} \tag{37}$$

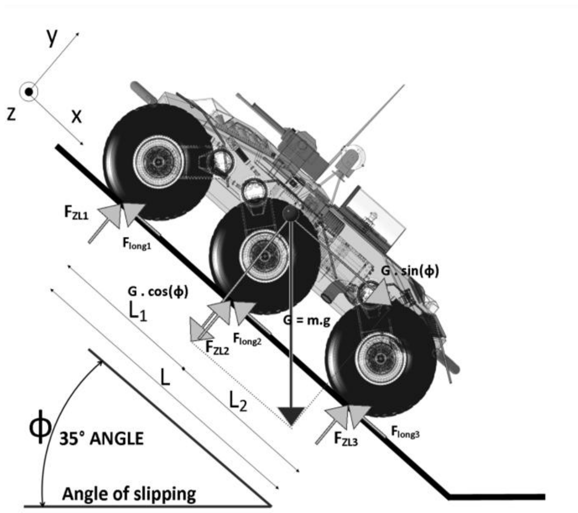

Fig. 4 *Normal force under the uphill and downhill of a vehicle, parked on rigid surface (banked road)*

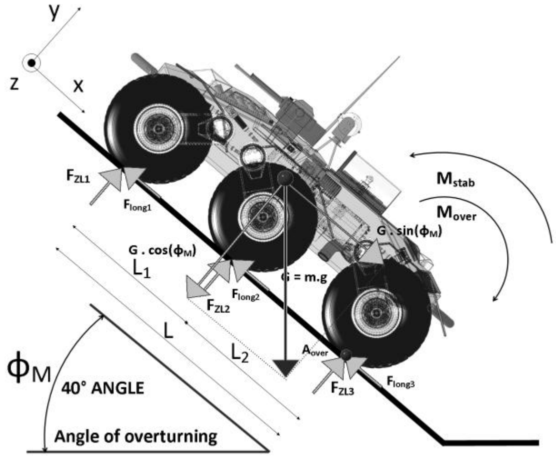

Fig. 5 *Normal force and moment under the uphill and downhill of a vehicle, parked on rigid surface (banked road)*

3 Representation of the results obtained

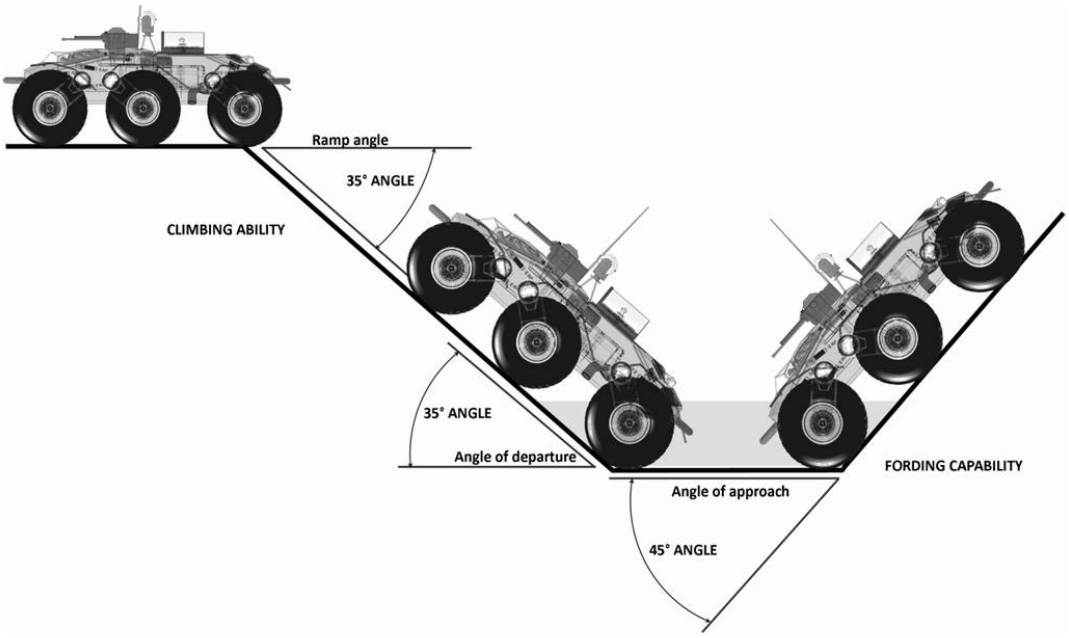

Fig. 6 *Simulation of the driveability (stability) under the uphill and downhill on rigid surface (banked road)*

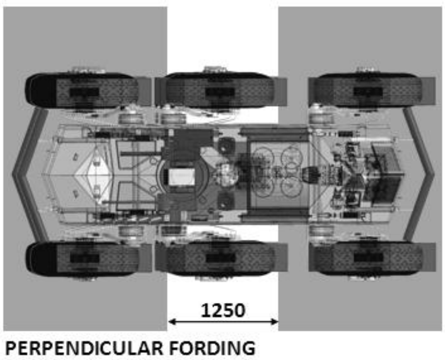

Fig. 7 *Simulation of the vehicle's motion during the perpendicular fording*

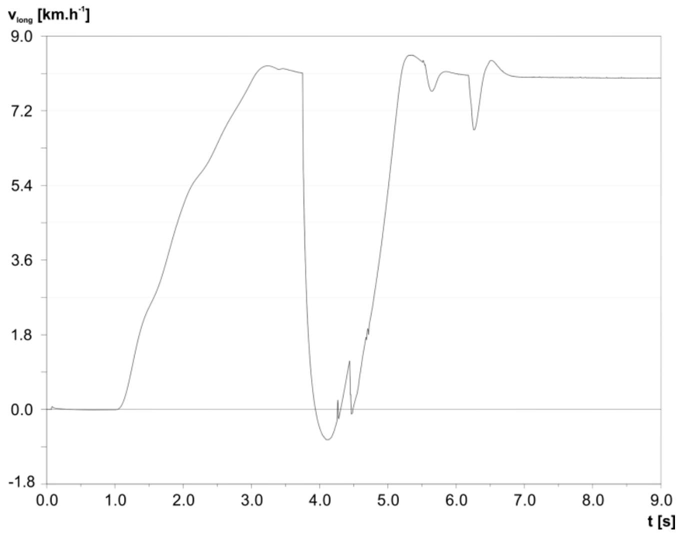

Fig. 8 *The result of the longitudinal velocity of the vehicle during perpendicular fording*

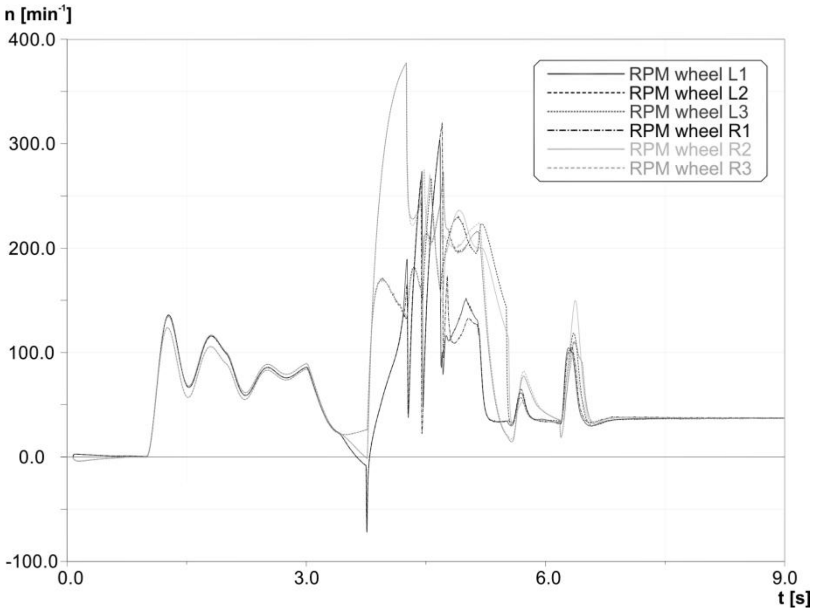

Fig. 9 *The result of the wheels RPMs during the perpendicular fording*

4 Conclusion

In this paper a basic mathematical model of stability for six wheeled vehicle created is. The results displayed on the Fig.6-9, is corresponding with derived mathematical model and with the simplified conditions of the solutions.

The Fig.6 is characterizing stability during the motion of the vehicle in longitudinal direction, the Fig. 8 is characterizing longitudinal velocity of the vehicle and Fig.9 is characterizing the wheels RPMs during the perpendicular fording.

From the obtained results leads to recommendations for further research, especially on issues:

- Mathematical modeling of the stability solving during the UGV's motion
- Mathematical modeling of the crossing of the other obstacles
- Influence of the flexible terrain for the UGV's stability

Presented solutions require a deeper analysis of the effects on wheeled UGV's stability and driveability.

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References

[1] D. CHUGO, K. KAWABATA, H. KAETSU, H. ASAMA, T. MISHIMA: *Step Climbing Omnidirectional Mobile Robot with Passive Linkages*, Optomechatronic system control, Vol. 6052, 2005.

[2] R. RAJAMANI: *Vehicle Dynamics and Control*, Springer, 2006, ISBN 978-0-387-26396-0.

[3] V. FERENCEY: *Development and Utilization of Unmanned Ground Vehicles.* In: Výzbroj a technika pozemných síl 2010: 16. medzinárodná vedecká konferencia. Liptovský Mikuláš, 10.-11.11.2010. Liptovský Mikuláš: Akadémia ozbrojených síl, 2010, p. 44-47. ISBN 978-80-8040-409-3.

[4] M. BUGÁR, V. STAŇÁK, V. FERENCEY: *Hybrid Powertrain Conceptual Design for Unmanned Ground Vehicle*. Science & Military Vol. 6, No. 1. p. 13--19. ISSN 1336-8885.

[5] Z. SONG, S. HUTANGKABODEE, Y.H. ZWEIRI, L.D. SENEVIRATNE, K. ALTHOEFER: *Identification of soil parameters for unmanned ground vehicles track– terrain interaction dynamics*. In: SICE Annual conference, Sapporo; 2004.

[6] STEEDS, W.: *Tracked vehicles (in three parts*). Automobile Engineer; 1950. p. 143–148, 187–190, 219 - 222.

[7] WONG, J.Y.: *Theory of ground vehicles*. 3rd ed. John Wiley & Sons; 2001.

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