Cornering Law: The Need for Further Research and Development

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1. Introduction

Many current uninhabited ground vehicles (UGVs) require remote piloting by people (Jones, Johnson, & Schmidlin, 2011; Moravec, 2000). A concern with UGV operations is either damaging or getting the UGV stuck during a cornering movement. In a recent study Helton and colleagues (2014) employed the cornering law (Pastel et al., 2007) to investigate the time needed to corner an unmanned ground vehicle (UGV). The cornering law was developed by Pastel and colleagues as an extension of Fitts' law (Fitts, 1954; Mackenzie, 1992) and Drury's law (1971; the steering law, see Accot & Zhai, 1997). Fitts' law expresses the relationship between the time to select a target, movement time (MT), and the objective difficulty of the targeting task based on the properties of how far the person has to move to reach the target, amplitude (A), and the actual width of the target being selected, width (W). Fitts' law can be extended to model a person attempting to stay centred along a path, Drury's law (Hoffman, 2009). Pastel and colleagues developed the cornering law which was deduced by considering limiting cases, for example, when the vehicle is the same size as the corner width the task is impossible. Therefore Pastel et al. proposed the index of cornering difficulty as the width of the vehicle (P) divided by the tolerance (W-P), thus the index of difficulty of cornering (IDC) in information theoretic terms is \[ IDC = \log_2 \left[ \frac{W}{W-P} \right] \]. This formulation is similar to a previous model developed by Hoffman (1997) for a pin-to-hole transfer task. In simplistic terms, the cornering task according to Pastel et al.'s cornering law is an attempt by the UGV pilot to pin-a-hole or thread-a-needle.

The cornering law model may, however, in some cases be too simplistic and other properties of the cornering task are likely relevant to successful cornering (Hoffman, personal communication). Examples of other factors which may be relevant are path length, the kinematics of the vehicle (for example, can the vehicle completely yawl like a tank), the shape of the corner, and the shape of the vehicle. In regards to path length (amplitude), the assumption the pilot will attempt to stay centred regardless of the width of the path is unrealistic. An efficient pilot will likely attempt to hug the inside corner as much as possible. This may also be complicated by the angles involved in the corner. Once the corner itself is negotiated, then Drury's law may be used to model the movement of the UGV along the path length. If the vehicle kinematics enable complete yawl (for example, tank treads) then an additional limit on cornering is likely to be the vehicle's widest point during the rotation in the corner. Thus, the shape of both the vehicle and the corner may be critical and these factors may need further consideration.

Helton and colleagues (2014) study differed from Pastel and colleagues (2007) study, for example, in the nature of the corner itself. In Pastel's and colleagues' study the corner was enclosed, whereas, in Helton's and colleagues' study the corner was open (not enclosed). Helton et al. assumed the open corner would not alter the fundamental need for the pilot to pin-a-hole. While the open corner in theory placed no physical constraint on the pilot's movements during the cornering task (the pilot could have, for example, wandered off), Helton et al. assumed the requirement to move as efficiently as possible would have lead the pilot to constrain their own movements, in order to re-enter the constrained path. A closed corner may, however, place additional constraints on the pilot's movements. Indeed, for a vehicle that can completely yawl, a tight closed corner (high index of difficulty) should place additional constraints on the pilot and this may mean the simple pin-a-hole model of the cornering law is incomplete under those conditions.

The present study was designed to test the issue of whether the nature of the corner itself (open or enclosed) affects cornering time and thus, the cornering law. In the present study participants navigated six different corner widths with a virtual tank. The participants either performed the task with an open or an enclosed corner. If the cornering law is incomplete we would expect a difference for open and enclosed cornering times, especially when the index of difficulty was high (greater than 1).
2. Method

2.1 Participants

Sixteen participants (5 men and 11 women) completed the experiment for course credit. They ranged in ages between 20 and 50 years, (M = 23.7 years, SD = 7.2). They had normal or corrected to normal vision.

2.2 Procedure

In the task, participants drove a square tank (block) through six hallway widths with a left sided turn (see Figure 1). They were randomly assigned to either an open or enclosed corner condition. In the open condition the corner was open and consisted of two halls that met at an open intersection. In the enclosed condition the corner was walled. The participants used standard computer game controls to control the tank: keyboard keys W and S for controlling horizontal acceleration. The computer mouse controlled the viewing perspective and yawing of the tank simultaneously. The tank could stay in one position and completely yaw as would be possible with tank treads or yaw while moving forward. The hallway widths relative to the width of the tank was used to calculate the index of difficulty using the cornering law or pinning the needle information processing law (log₂ [W/(W-P)]) (Pastel et al.2007; Hoffman et al. 1997). Participants viewed the hallways and front end of the tank in first person perspective on 1280x1024 flat screen monitors. The tank would explode if it touched any wall and the participant would have to repeat that width (respawn). The ordering of the six widths was randomized for each run. Participants performed four runs but the first three runs were regarded as practice runs and were discarded. Only the last run of the sixth indices of difficulty (width) were analysed. Cornering time was measured from when the front-end of the UGV crossed a line in front of the corner till the front-end of the UGV exited the corner.

Figure 1. Third-person trailing view of the cornering task course; on the left side is the open corner and on the right side is the enclosed corner.
3. Results

The movement times were analysed with a 2 (corner open vs. no corner enclosed) by 6 (index of difficulty) mixed analysis of variance. Mauchly’s test for sphericity was statistically significant ($p < .05$), therefore the degrees of freedom were Hunyh-Feldt corrected. There was a significant main effect for index of difficulty, $F(3.3,46.4) = 8.23$, $p < .001$, $\eta_p^2 = .37$, and a significant index of difficulty by corner type interaction, $F(3.3,46.4) = 2.72$, $p = .05$, $\eta_p^2 = .16$. The main effect for corner type was not statistically significant, $F(1,14) = 2.53$, $p = .13$, $\eta_p^2 = .15$. The interaction is displayed in Figure 2. There was only a significant difference between the corner open and enclosed conditions for the highest index of difficulty, $t(14) = 2.91$, $p = .01$, $M_{\text{difference}} = 3.54$ sec, 95%CI [0.92; 6.14]. The overall fit of the relationship between index of difficulty and mean movement for open corner was $r = .85$ and for enclosed corner was $r = .81$.

![Figure 2. Mean cornering times for each block of the 6 indices of difficulty for both the enclosed and open corners. Error bars are standard errors of the mean.](image)

4. Discussion

The cornering law or pin-a-hole version of the information theoretic approach to negotiating a corner produced a reasonable fit for both open and enclosed conditions. Indeed, the fit was slightly better for the open corner situation. In regards to movement times, the open and enclosed conditions only differed for the most difficult index of difficulty (the narrowest hall). Indeed, when the index of difficulty is less than 1, there appears to be little influence on movement times. This may be due to the cornering law’s simplistic model which underestimates the difficulty of cornering an enclosed hall or corner, where hitting the wall is disallowed, for a narrow or challenging hall width (high index of difficulty). In the present example, the actual turning manoeuvre requires rotation of the tank and for an enclosed corner this places an increased constraint on the cornering task; when the corner is open this constraint is removed.

The present results, therefore, indicate that a more complete model for cornering a UGV is necessary. For applications, when the cornering task is more difficult and enclosed the simple pin-a-hole model of Pastel et al.’s cornering law can likely be improved by taking into consideration additional variables, like corner shape, vehicle shape, and the kinematics of the vehicle itself. If these characteristics can be incorporated adequately then an improved cornering model may be developed. This improved model could then be used in the testing and evaluation of UGV control interfaces, UGV vehicle kinematics, and UGV shapes. Until the new model is developed the current cornering law model when combined with Drury’s or the steering law may still provide a reasonable model useful for testing and training.
Acknowledgements

We wish to thank Errol Hoffman for his keen insights and comments regarding this paper, although we exonerate him of all responsibility for any resulting content.

References


