Imaginary Wall Model for Efficient Animation of Wheeled Vehicles in Racing Games

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Abstract

Racing game requires plausible physics model that can be simulated in realtime. We propose an efficient and effective "imaginary wall" model for racing games. The method can be easily implemented because of the simplicity of the physical model used, and the result of the simulation is realistic enough for the racing games.

Keywords: racing game, physically-based modelling, realtime animation, impulse model

1 Introduction

Hung and Orin (2001); Shiang-Lung Koo and Tomizuka (2007) proposed dynamic models for wheeled vehicles in robotics and automation literature. de Wit and Horowitz (1999); Claeys et al. (2001) also proposed sophisticated models for simulating the tire/road friction. However, those methods are too complex to be easily implemented in game applications. The tire simulation in realtime is considered a difficult problem so that semi-empirical models are usually employed as in Deák (1999). However, the parameters for the industry standard models such as *Model of Pacejka* are unfortunately too complex to be modified intuitively. To avoid the expensive cost, a simple method that computes the angular velocity of a wheeled vehicle has been widely used as in Monster (1993). Let l be the distance between the front and the rear wheels. The angle between the direction of the front wheel and that of the vehicle is δ. The vehicle rotates about a single pivot point $\mathbf{c}$. Let C and r be respectively the circumference and the radius of the circular path of the front wheel. It is obvious that C is $2\pi r$ where r is $l/\sin\delta$. The time required for a vehicle with velocity $\mathbf{v}$ to complete the rotation is $2\pi r/|\mathbf{v}|$. Therefore, the angular velocity ω can be computed as $|\mathbf{v}|/r$. However, it is not actually easy to compute the radius because it can be extremely large when δ is very small. In other words, it will be the most difficult for the simple method to deal with the most usual case where the vehicle is moving *almost* straight.

2 Simulating Tire Friction with Impulse-based Contact Force

We propose an impulse-based method that introduces *imaginary wall model*. In our model, the wheels contact with ground and imaginary walls, and low friction is applied to the wheel direction so that the vehicle can be easily accelerated or decelerated along the driving path. When a wheel is, however, sliding aside from the driving path, strong frictional force should be produced to immediately hold the wheels. This kind of strong forces can be considered impulses from the imaginary walls. Let the masses of the object a and b be m_a and m_b respectively. The objects are colliding at $\mathbf{p}_c$, and $\mathbf{x}_a$ and $\mathbf{x}_b$ denote the mass centers. The vector from $\mathbf{x}_a$ to the collision point is denoted as $\mathbf{r}_a$, and $\mathbf{r}_b$ is also defined similarly. $\hat{\mathbf{n}}$ is the collision normal. The velocities of the objects at the collision point are denoted as $\mathbf{v}_a^{\mathbf{p}_c}$ and $\mathbf{v}_b^{\mathbf{p}_c}$. Baraff (1994) and Mirtich and Canny (1995) proposed methods for efficient and effective computation of impulses between non-penetrating rigid bodies. Let $\mathbf{K}_a$ denote $\mathbf{E}/m_a + \mathbf{r}_a^{*T}\mathbf{I}_a^{-1}\mathbf{r}_a^*$ where $\mathbf{E}$ is an identity matrix, $\mathbf{I}_a$ is the inertia tensor of object a, and $\mathbf{r}^*$ denotes the cross product matrix of the

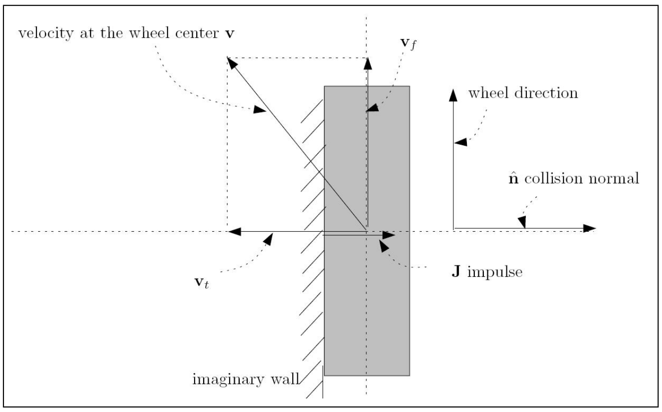


Figure 1: Impulse model with an imaginary wall

vector $\mathbf{r}$. $\mathbf{K}_b$ is defined similarly. The impulse $\mathbf{J}_b$ applied to object b can then be computed as $\mathbf{J}_b = \{-(1+\epsilon)(\mathbf{v}_b^{\mathbf{p}_c} - \mathbf{v}_a^{\mathbf{p}_c}) \cdot \hat{\mathbf{n}}/(\hat{\mathbf{n}}^T(\mathbf{K}_a + \mathbf{K}_b)\hat{\mathbf{n}})\}\hat{\mathbf{n}}$ where ϵ is the coefficient of restitution. Fig.1 shows the visual concept of imaginary wall model. The wheel moves forward and backward along the imaginary wall, and the imaginary wall continuously change its direction according to the wheel direction. The only role of the imaginary wall is to produce impulses that prevent a wheel from penetrating the wall. The velocity at the wheel center $\mathbf{v}$ can be decomposed into two parts: the velocity along the wheel direction $\mathbf{v}_f$ and the perpendicular part $\mathbf{v}_t$. The relative velocity between the contacting wall and the wheel is simply $\mathbf{v}_t$. Therefore, the direction of the impulse from the wall is $-\mathbf{v}_t/|\mathbf{v}_t|$. Because the wheel should not rebound from the wall and the imaginary wall is a static object, the restitution coefficient ϵ and the $\mathbf{K}$ matrix of the wall should be 0 and *zero* matrix respectively. Therefore, the impulse $\mathbf{J}$ from the imaginary wall can be computed as follows:

$$\mathbf{J} = \left(\frac{|\mathbf{v}_t|}{\hat{\mathbf{n}}^{\mathbf{T}}\mathbf{K}_w\hat{\mathbf{n}}}\right)\hat{\mathbf{n}} = \left(\frac{-\mathbf{v}\cdot\hat{\mathbf{n}}}{(\mathbf{K}_w\hat{\mathbf{n}})\cdot\hat{\mathbf{n}}}\right)\hat{\mathbf{n}} \tag{1}$$

where $\mathbf{K}_w$ is the $\mathbf{K}$ matrix at the center of the wheel.

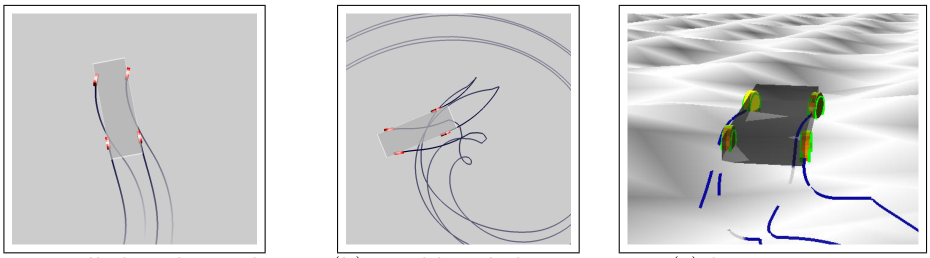
By employing the imaginary walls, the driving path can be perfectly and physically controlled as shown in Fig.2 (a). Only the wheels placed on the ground are affected by the imaginary walls so that our method is expressive enough to reproduce the realistic animation of a vehicle that trembles and tumbles as shown in Fig.2 (b), and moves on a bumpy terrain as shown in Fig.2 (c).

3 Shock-absorbing Imaginary Wall Model for Side Slip Simulation

It is often the case that a high-speed vehicle slips aside toward the outward direction of the turning circle. The side-slip is essential not only for the reality of racing simulation but also for the amusement of the game. The actual side-slip occurs when the frictional forces between tires and wheels are not strong enough. However, the proposed method does not use frictional model for the wheel dynamics. To enable the side-slip, the imaginary walls should allow wheels to penetrate them. The soft wall model can be modeled with a negative restitution coefficient. In order for a intuitive modeling, we employed a side-slip control parameter μ which ranges from 0 to 1. If the parameter μ is 0, the wheels can freely penetrate imaginary walls. The imaginary wall model with penetration can be formulated as follows:

$$\mathbf{J} = \left(\frac{-(1+\epsilon)\mathbf{v}\cdot\hat{\mathbf{n}}}{(\mathbf{K}_w\hat{\mathbf{n}})\cdot\hat{\mathbf{n}}}\right)\hat{\mathbf{n}} = \left(\frac{-\mu\mathbf{v}\cdot\hat{\mathbf{n}}}{(\mathbf{K}_w\hat{\mathbf{n}})\cdot\hat{\mathbf{n}}}\right)\hat{\mathbf{n}} \tag{2}$$

μ was defined to be $\max\{\mu_{max}\left(1 - |\mathbf{v}|/v_\theta\right), 0\}$ where μ_{max} is the maximum value for the parameter μ, and v_θ is a specifiable threshold speed where μ parameter becomes zero. If the speed of the vehicle exceeds the limit, μ is enforced to be zero. When we need a vehicle that drifts more easily, we have only to decrease the parameter v_θ.



(a) controlled path on plane (b) tumbling behavior (c) bumpy terrain

Figure 2: The control and expressiveness of the proposed method: (a) a vehicle with moderate speed, (b) a high-speed vehicle with sharp turn, (c) a vehicle on a bumpy terrain

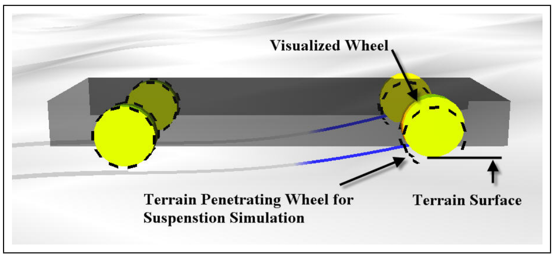


Figure 3: Suspension Simulation: the dashed black circles represent the actual dynamic wheels allowed to penetrate the terrain. Users can observe only the solid wheels lifted on the surface to show the suspension effect.

4 Impulse-based Suspension Simulation

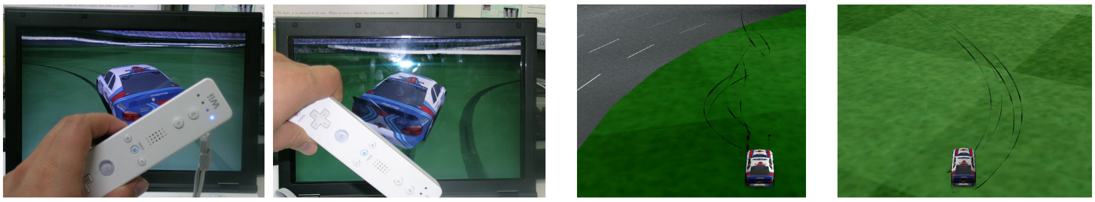
Although the imaginary wall model can be successfully employed for lightweight dynamics for steering a wheeled vehicle, the model does not simulate the suspension mechanism. Because the suspension is one of the most important mechanisms of usual vehicles, plausible racing game requires proper suspension model. The suspension is actually implemented with shock-absorbing stiff springs. However, the stiff spring model often causes stability problem. For the suspension simulation, we also used an impulse model. The suspension should be considered only when a wheel collides with ground. While the usual impulse model prevents wheels from penetrating the terrain, our impulse-based suspension model allows the wheels to penetrate the terrain surface. Let $\mathbf{p}_w$ be the contact position of a wheel that touches the ground, and $\mathbf{p}_g$ be the contact position of the ground. $\wp_\tau$ and $\wp_p$ denote the maximum penetration allowed and the actual penetration(i.e. $|\mathbf{p}_g - \mathbf{p}_w|$ respectively. The penetration ratio $\wp$ can be calculated as $\wp_p/\wp_\tau$. Let $\mathbf{J}_g$ be the impulse from the ground to wheel. We scale the impulse according to the magnitude of the impulse $|\mathbf{J}_g|$ and the penetration ratio $\wp$, and the scaled impulse is applied to the wheels. The scaled impulse $\mathbf{J}_s$ is computed as follows:

$$\mathbf{J}_s = \frac{1}{2}(e^{-\xi|\mathbf{J}_g|} + \wp)\mathbf{J}_g \tag{3}$$

Fig.3 shows the suspension effect of our model. The dashed black circle shows the actual wheel that penetrates the ground surface while the yellow solid wheel is lifted on the ground to provide plausible visualization to users.

5 Experimental Results

The proposed method produced physically plausible animation of wheeled vehicles in interactive applications such as game. Fig.4 (a) demonstrates realtime performance of the proposed method. The driving path was plausibly controlled in an experimental game applications. Since the impulse model makes it possible for the wheels to be independently simulated, trembling or tumbling



(a) Realtime Performance (b) Tumbling (c) Side slip

Figure 4: The effective path control of the proposed method: (a) realtime control (b) tumbling vehicle(c) side-slip of high speed vehicle

motions of vehicles can also be easily expressed as shown in Fig.4 (b), which cannot be simulated with kinematic approaches. The shock absorbing imaginary wall model for side-slip simulation described in Eq.2 was also tested, and the model produced realistic motion of high-speed vehicles as shown in Fig.4 (c).

6 Conclusion

A realtime approach to the vehicle wheel simulation was proposed. The method is plausible enough for racing game application because the behavior of each wheel is physically simulated with impulse. Moreover, the simplicity of the proposed method enables experienced game developers to easily implement a racing game in a short time. Because the proposed method efficiently generates plausible results, the method can be successfully employed for developing high quality racing game running on CPU-limited computing environments.

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