Bicycle Traction Detection System

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A riderless bicycle was modeled in SimMechanics. Three events were simulated: first the bike rolling on the ground, second the bike sliding on ice with the back wheel locked, and third, the bike sliding on ice with both wheels locked. Data such as the translational velocity and position of the bike, as well as the rotational velocity of the wheels was collected. The data is used to know if the bike has lost traction control, and is in a dangerous situation. A link to a video of the simulation can be found here: `https://youtu.be/H8sBELcTSS4`

1 Introduction

In the automotive industry, safety is a pressing concern. Today, many automobiles feature innovative safety systems such as collision detection, the check engine light, and traction control. In many cases, this information can be sent to companies who provide quick response to these emergency situations. These technologies of course can be incorporated into other vehicles. This article examines an emergency event where a bicycle loses traction, and suggests inexpensive and effective ways to detect this emergency event.

2 Methods

The bicycle was modeled using *SimMechanics*. For these simulations we assumed a riderless bicycles consisting of four rigid bodies: the rear wheel, the front wheel, the frame, and the handlebars.

Wheels Both wheels (seen as gray in Fig. 1.) were modeled with a density of 46.77 kg/m^3, a radius of 0.33 m, and a thickness of 0.025 m. Red massless markers were used to visualize the rotation of the wheels.

Frame The frame (green) was modeled using two cylinders with a density of 46.77 kg/m^3. Both cylinders had a diameter of 0.025 m. The first cylinder is 1.0 m long, and the other cylinder (the seat) is 0.375 m long.

Handlebar The handlebar was also modeled as two cylinders of equal density, 46.77 kg/m^3, and equal diameters of 0.025 m. The handles (red) themselves have a length of 0.45 m, while the turning shaft (blue) had a length of 0.75 m.

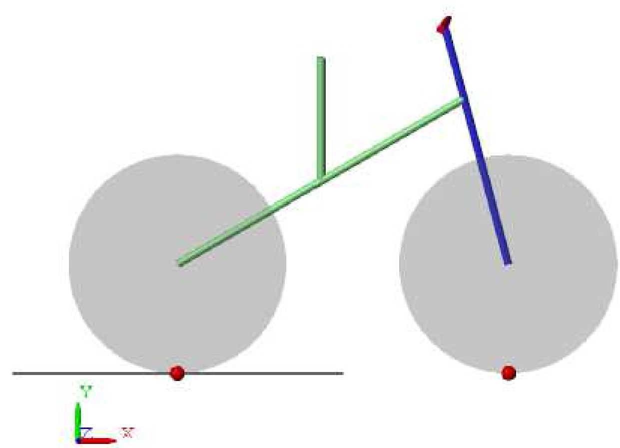

Fig. 1. The bicycle model consisting of four rigid bodies

First, the bicycle was simulated rolling on a surface. The bicycle started with a 3° tilt and with its handlebars turned 3°. The rear tire started with a rotational velocity of 810 deg/sec, and was used to drive the bicycle. It's trajectory was simulated for 2 seconds.

A second simulation was created to model the bicycle locking up its rear wheel and slipping on ice. The end conditions of the rolling simulation were used as the initial conditions of the bike in the second model with the exception of θ_y, the yaw of the bike. In this model, a planar joint was used between the world frame and the bicycle. This allowed the

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bike to translate without rolling, as well as rotate around it's central axis. A weak spring was used to damp the rotation of the front wheel. The simulation was run until the rear wheel rested flat upon the ground. Sensors were used to collect information about the positions and velocities of the bicycle components.

Finally, the third simulation modeled the bicycle locking both wheels and slipping on ice. Again, the end conditions of the rolling simulation were used as the initial conditions of this final simulation. Again, a planar joint was used between the world and the bicycle to allow for translation and rotation. The simulation was run until the rear wheel rested flat upon the ground. Sensors were used to collect information about the positions and velocities of the bicycle components.

2.1 Sensors

The notification and accident identification system on the bicycle would require certain components. The sensor system would need to differentiate between accident situations and normal use cases, in order to limit the number of false positives.

Accelerometer The accelerometer is to determine the relative speed of the bicycle and to limit the number of false positives. If the accelerometer senses a slow change in velocity, even if the wheels slip, this is likely to be a safe situation, such as the cyclist stopping the bike and storing it. If, however, the change in velocity is sudden, above a certain threshold, it is much more likely that this is an accident situation.

Gyro Sensors There are gyroscopic sensors attached to each wheel and to the bicycle frame itself. The wheel sensors monitor the angular velocity of the wheel and can detect slipping conditions if the wheels are not turning at the same rate. The frame-mounted sensor would monitor the general upright stability of the bicycle, comparing to the accelerometer data to determine if a change is due to accident conditions or normal use.

Bluetooth A Bluetooth sensor and communication protocol would be included in this sensor package. The device would connect to the cyclist's cell phone in order to use geolocation data and network connection to send notification of an accident to emergency response contacts.

A false-positive reading is the most likely failure mode of this sensor system. Therefore, implementing a state machine that enters the accident state when the values from all the sensors meet the correct condition is the best way to mitigate this possibility. The accident state would require the threshold surpassed for all three gyroscopic sensors as well as the accelerometer. Prior to the accident state, whenever one of the sensors reaches that threshold value, it would enter a state that would present a warning to the cyclist that they are within possible conditions for an accident. For example, if the wheel gyroscopic sensors detect a wheel slipping, the a light near the handlebars would illuminate that would signal this condition.

The limitations of these sensors in a package are that they would require power and added weight to the bicycle itself. The battery would ideally be rechargeable and the entire system low-power to maximize the time between charges, on the order of days or weeks. Bluetooth, rather than cellular or WiFi, has low enough power requirements that meet this specification [**?**]. The other sensors would have to be chosen accordingly, using MEMS devices and possibly inertial measurement unit (IMU) packaging.

The weight constraint is critical, as the sensor package must be mounted in a way that is unobtrusive to the cyclist and does not add much additional weight to the bicycle. Small-footprint sensors exist, and these can be mounted to the frame. The frame is the most mechanically stable part of the bicycle and provides the best mounting point in the center bar, where it can be unobtrusive and least likely to alter the overall center-of-mass. The wheel gyros need to be mounted just off the axis of rotation, near the pin and in a place where wiring is possible.

2.2 Cost

The sensor package ideally uses off-the-shelf parts for both usability and cost purposes. The following table pulls example models of each sensor from well-known component sellers.

Sensor Type	Model	Cost
Accelerometer / Frame Gyro	MMA7660FCR1	$1.36 [1]
	KXTE9-1050	$2.95 [2]
Gyro Sensor, wheels	MPU-6050	$8.25 [3]
	ITG-3200	$16.43 [1]
Processor	Bluz DK	$19.00 [4]
Total, low		$28.61
Total, high		$38.38

The components selected would also have to have impact resistances that would survive an actual accident. Maintenance would ideally be simply keeping the battery charged or replacing it.

3 Results

3.1 Rolling on ground

During normal operation on stable ground, the bicycle will self-stabilize when the initial handlebar tilt angle δ is zero. The simulation monitors the yaw, θ_x, and tilt, θ_y, angles and velocity, v, of the bicycle; the angular velocity, Ω_Z, of the wheels was also simulated. For this simulation, the initial values for the turn (δ) and tilt (θ_x) were set to 3 in and the yaw (θ_y) was set to 0 order to simulate a shallow turn.

[1] Newark element14
[2] Mouser Electronics
[3] DigiKey
[4] Bluz

Figure **??** shows the yaw, tilt, and handlebar angles over time while on stable ground. The δ value has the greatest change as it forces the overall turn of the bicycle.

Figure **??** compares the Ω_Z values of the front and back wheels. The back wheel remains mostly stable, with only minor oscillations resulting in overall stability. The front wheel, as it is designed to turn, shows the most divergence over time. Using the Ω_Z value, it is possible to determine the speed, $|v|$, of the bicycle in this state because the wheels are rolling without slip.

$$\Omega_{Z,front}\left(\frac{\pi}{180}\right)(2\pi R_{wheel}) = |v_{wheel}|$$

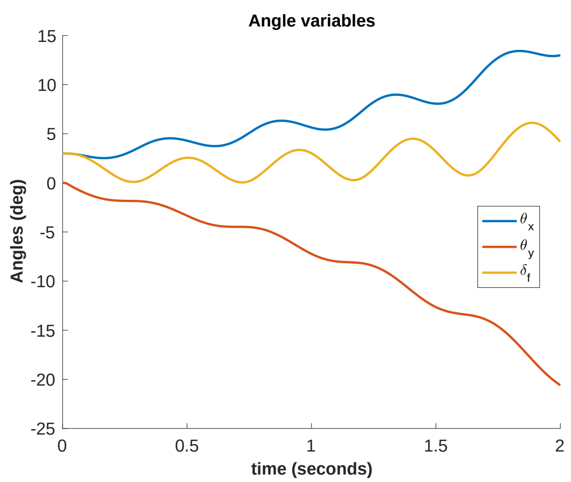

Fig. 2. The angles of the bicycle model rolling on ground

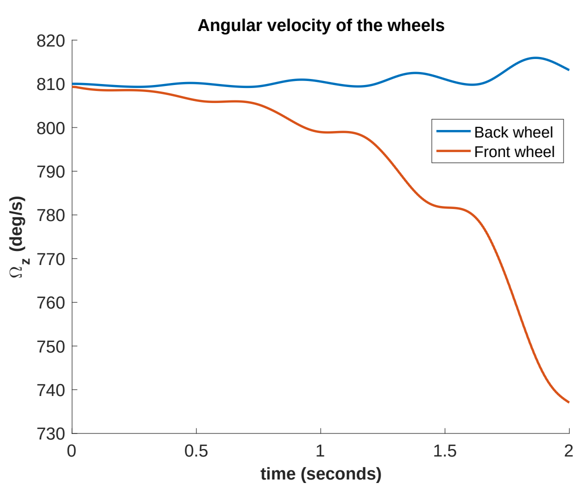

Fig. 3. The angular velocities of the bicycle model rolling on ground

3.2 Sliding on ice with back wheel locked

When the rider holds only the rear brake of the bicycle, the bicycle will slide on ice with back wheel locked. In this case, the bicycle's yaw angle, θ_x, the angular velocity of both wheels, Ω_Z, and the turn of the handlebar, δ, are initialized with the corresponding values at the end of the perfect ground simulation case. The bicycle behaviors were simulated on ice and all four aforementioned variables, plus the tilt angle of the bicycle, θ_y were measured.

As shown in Figure **??**, the angular velocity of the back wheel, $\Omega_{Z,back}$, stays around zero during the initial period of the simulation, which reveals that the back wheel is slipping on the ice. Following that, $\Omega_{Z,back}$ decreases dramatically because of the final crash of the bicycle.

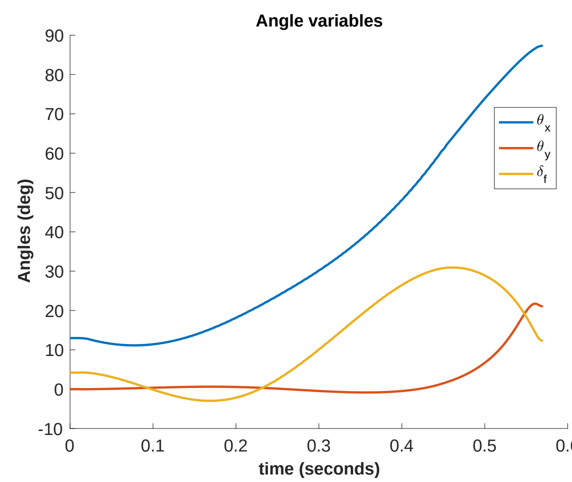

Fig. 4. The angular positions of the bicycle model with the rear wheel slipping

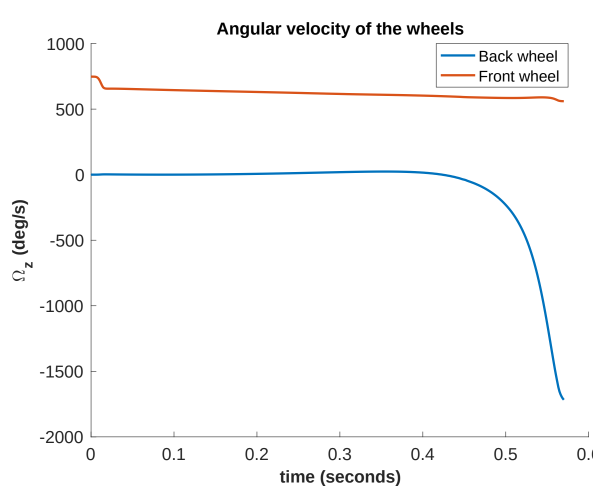

Fig. 5. The angular velocities of the bicycle model with the rear wheel slipping

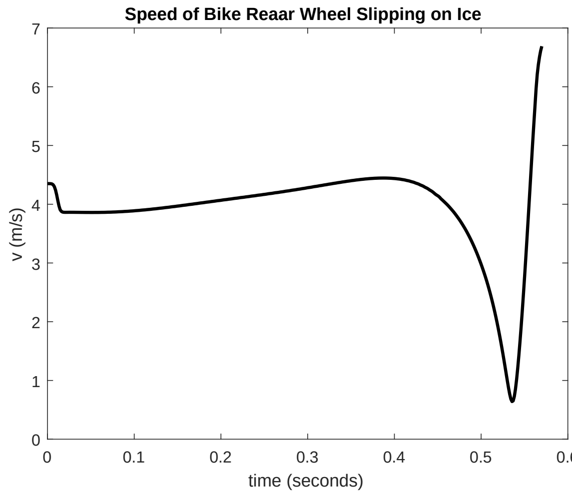

Fig. 6. The speed of the bicycle model with the rear wheel slipping

Comparing the angle measurements here with that in rolling on ground case, we can pick up the angular velocity of wheels Ω_Z as the indicating variables on whether the wheels of the bicycle are under slipping. Furthermore, the gyro sensor can be applied here to generate the needed measurements.

3.3 Sliding on ice with both wheels locked

Now both brakes are applied completely immediately upon the bikes contact with ice. In this situation, both the front and rear wheels stop rotating, and the bike slides along the ice. Again, the yaw angle, θ_x, and tilt angle, θ_y, of the bicycle, the angular velocity of wheels, Ω_Z, and the turn of the handlebar, δ were measured as figure

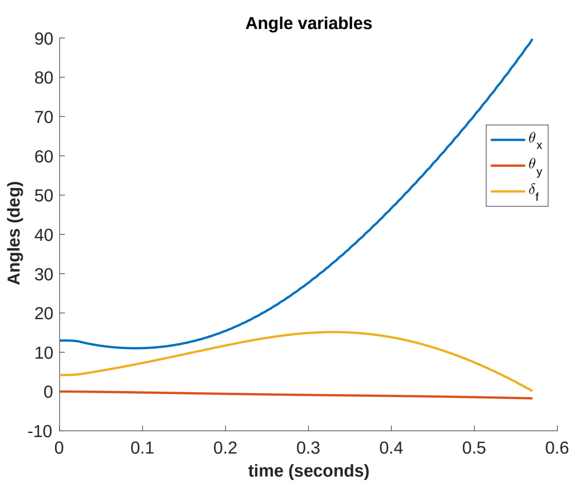

Fig. 7. The angular positions of the bicycle model with both wheels slipping

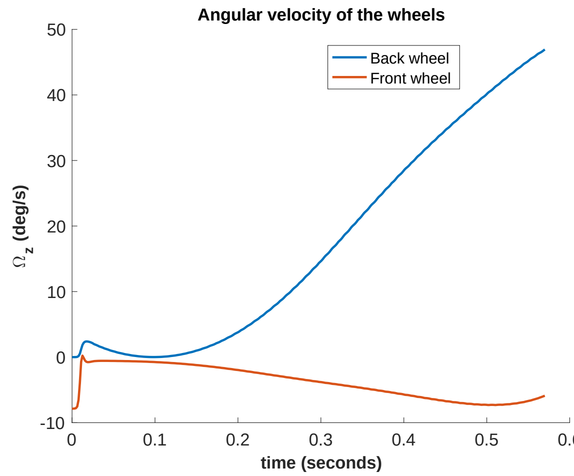

Fig. 8. The angular velocities of the bicycle model with both wheels slipping

As seen in figure **??**, when θ_x becomes 90° the simulation stops because the bicycle has fallen over. It is interesting to see that both the yaw (θ_y) and the turn of the handlebars (δ) stay relatively small during this simulation. Perhaps another iteration of this model could account for the user turning the handles during the slide. It is also interesting to see that although both wheels start at zero angular velocity, they spin as the simulation progresses. This is because the brakes are not applied throughout the entire duration of the slide, rather they are only applied upon immediately upon contact with the ice.

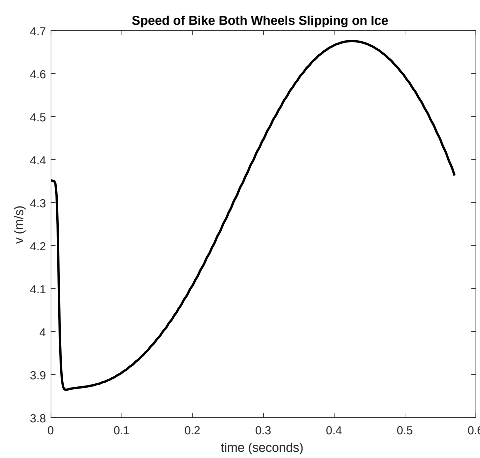

Fig. 9. The speed of the bicycle model with both wheels slipping

By comparing the angular velocities of the wheels and the position of the bike to the speed of the bike, one can determine if the bicycle is sliding. As seen in Figure **??**, the initial angular velocity of both wheels is very close to zero. Yet, Figure **??** shows that the bike is moving with a speed greater than 0 m/s. In a normal scenario, if the wheels are not spinning, the bicycle should not have any speed. So with these data, one can determine if the bicycle is sliding and falling on a surface, and is therefore in an emergency situation.

4 Discussions

This bicycle model is far from a perfect model. Several assumptions were made which would affect data collected from an *in vivo* experiment. The first assumption that could affect the results of the simulation is assuming a riderless bicycle. A human has a mass of roughly 70 kg, and would increase the weight of the bicycle. This would allow friction to apply a greater force on the bike while it is on the ice. Another assumption made was that all the bicycle components were constructed from the same material. An improvement would account for the properties of the frame differing from the properties of the handlebars and the wheels. Additionally, the bicycle model only consisted of four rigid bodies. Commercial bicycles consist of hundreds of components including cables, nuts and bolts, sprockets, chains, rivets, rims, pedals, etc. A more thorough model could account the the mechanical properties of these other components and gather information to determine whether a component is failing.

5 Conclusion

The bicycle model allowed for the collection of data useful for determining whether or not a bicycle is in a normal situation of safely rolling on the ground. By comparing the angular velocities of the wheels to the translation velocity of the bicycle, the bicycle method of movement can be determined.

A low cost system of sensors consisting of accelerometers, gyro sensors, and bluetooth can be developed for traction detection. This suggests that incorporating an accident detection system on a bicycle is feasible, efficient, and effective.

Acknowledgements

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References

[1] Paul Smith, 2011, "Comparing Low-Power Wireless Technologies" from `http://www.digikey.com/en/articles/techzone/2011/aug/comparing-low-power-wireless-technologies`