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Are You a Safe Driver

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***Abstract*—As the world continues to enhance and strengthen its emergency services, mobile phones may be used to aid in safe driving practices and detection of emergencies. To our knowledge, no work has been reported in understanding vehicle motion using accelerometers/compass in cell phones. In this paper, we used the multiple sensors in a Google phone to classify safe versus unsafe driving. In particular, we used breaking distance, acceleration, and deceleration for detecting safe verses unsafe braking. Next, we calculated the displacement in the axis perpendicular to the trajectory of vehicle and used it to classify safe and unsafe lane changes. The direction of the phone with respect to the motion of the vehicle is important during calibration of the above measurements, so we used 2D and 3D rotation matrices for transforming device orientation. Future work includes calibration of braking distance, lane changes, and reliable transformation of phone orientation with respect to trajectory of the vehicle.**

Keywords-testbed; accelerometer; Android; mobile phone; driving; safe; unsafe; orientation; emergency

I. Introduction

Mobile phones which have embedded accelerometers may be used for risk level detection while riding in a vehicle. Accelerometers have been gaining in popularity lately, mostly because of advances in gaming technology. They are typically used as 2-dimensional sensors for consumer electronics, such as cameras, to determine orientation, but may be used to enhance safety. Programming with accelerometers on the Android platform is straightforward and supports three axes. A triple-axis accelerometer is important for this study because phones may be carried in any orientation, as opposed to the device being carried in a known orientation in other studies [1-5].

Coupled with GPS capabilities, a microphone, and a digital compass, T-Mobile's G1 phone running the Android platform may provide an ideal test bed for mobile risk level detection [3]. Using accelerometer measurements, it should be possible to classify driving habits as safe or unsafe. In this paper, we look at the two horizontal axes to determine the safety level of the driver.

II. Triaxial Considerations

As Table I shows, the two horizontal axes are x and y. These axes were chosen for experiments because the driver has direct control over them in the way he steers, accelerates, and/or breaks. While abnormalities in the z axis may look different for safe and unsafe driving, these are more typically caused by road conditions than by driving habits.

TABLE I. SIGNIFICANCE OF TRIAXIAL MEASUREMENTS

Axis	Measurements Obtained	
	Direction	***Typical Driving***
x	Left/right	Change in direction (Steering)
y	Front/rear	Accelerator and brake pedals; friction
z	Up/down	Bumps in the road

The normal phone orientation used for all the measurements has the phone situated with its x axis parallel to the direction of travel, the y axis horizontally perpendicular, and the z axis vertical. In this context, our desired orientation is a quantifiable placement of the phone relative to the direction of travel. The T-Mobile G1 does have an orientation sensor, reporting values of "azimuth", "pitch", and "roll". The phone also has a GPS sensor that will give the direction of travel. Using these values, we should be able to adjust accelerometer measurements to a known orientation.

Disorientation is almost guaranteed to occur during field tests and when the program is in use because flat surfaces are hard to find in a car. Placing a phone in such a location may result in sliding. Phones may be kept in such non-ideal places as the driver's pocket, on the dashboard, or in a compartment within the car.

It is far more beneficial from a modeling and processing perspective to fit the data we have to a known model. If we leave the model open to all possibilities, complexity rises so it is more difficult to understand. Also, if our intentions are to model the car's behavior, adjusting data to the car's orientation should provide more meaningful results.

III. Braking

A. Safe Versus Unsafe Braking

When the phone is in its normal position, a change in the vehicle's speed is measured along the x axis. The term "acceleration" in this case is used to mean an increase

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in speed and "deceleration" to mean a decrease in speed, without regard to the acceleration vector's angle.

See Figure 1 for an example of safe acceleration and deceleration. Of course "safe" is a relative term so this paper only assumes that "safe" driving and "unsafe" driving have measureable differences in acceleration.

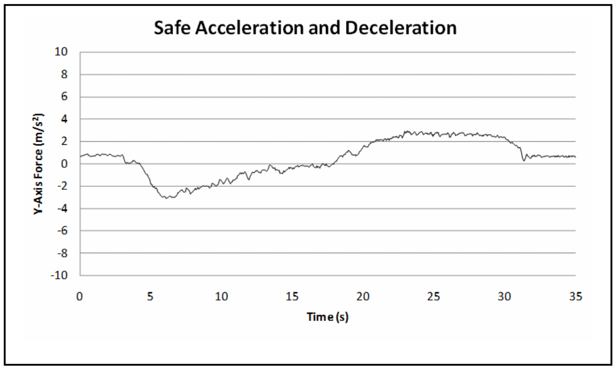

Figure 1. Safe Acceleration and Deceleration

What we see here is the phone at rest for the first few seconds on an incline, then a mountain-shaped acceleration in the negative y direction for about twelve seconds. The mountain-shaped region represents vehicle acceleration. After that, there is a plateau-shaped acceleration in the positive y direction followed by another period of rest. The plateau-shaped acceleration represents vehicle deceleration.

Looking at the periods of rest, it is obvious that the car is on somewhat of an incline. We can also see that the beginning incline is roughly the same as the incline at the end. Vehicle acceleration is measured in the negative y direction and deceleration in the positive y direction. As we see in this chart, safe acceleration and deceleration never reaches more than 0.3 g in either the positive or negative direction.

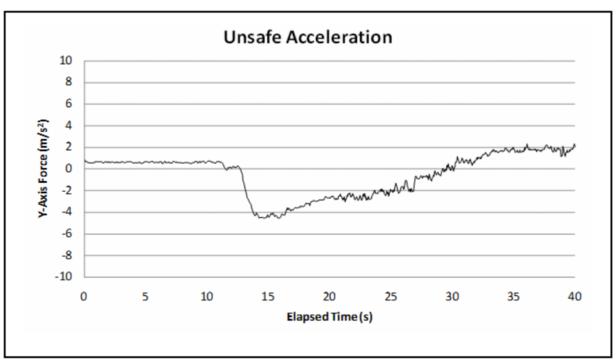

Figure 2. Unsafe Acceleration

The unsafe acceleration depicted in Figure 2 shows the same overall shape of safe acceleration but a slightly higher G-force of 0.43 g on this incline. Apparently the car used (2007 Pontiac G6 Sport) does not have enough power to significantly amplify the acceleration chart.

Unsafe deceleration, however, does show a significant difference. One such example is in Figure 3. The deceleration looks similar to the one in Figure 1, except that the vehicle did not sustain a high acceleration plateau. In this experiment, the G-force reached as high as 0.66 g at its peak. Looking at the chart, the sudden drop off in acceleration corresponds to the brakes locking onto the wheel's rotor. After locking, there is a period of oscillation for a few seconds as the car rocks back and forth.

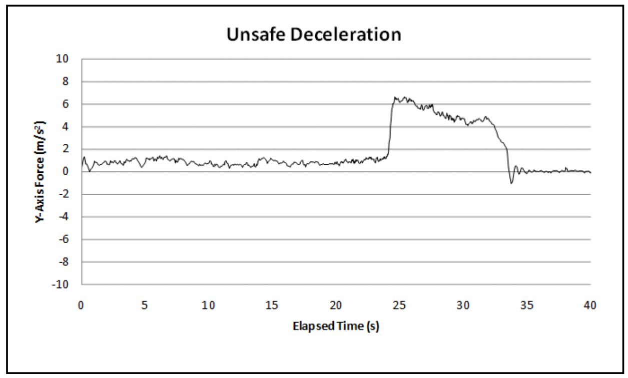

Figure 3. Unsafe Deceleration

Using this data it is easy to see the difference between safe and unsafe deceleration, yet the distinction is not so clear for accelerations.

B. *Braking Distance*

As acceleration is the double-derivative of distance, it is possible to perform a double integration to recover distance used in stopping a vehicle. Begin with a known estimate of speed from the GPS sensor and knowledge of when braking occurs. From Figure 1 and Figure 3 the point at which the driver begins to decelerate is apparent, as is the point at which the driver comes to a complete stop. Performing the first integration on the data determines speed measured by the accelerometer. Since the GPS speed sensor is assumed to be more accurate for this calculation, the first integration is linearly adjusted to fit within a proper window.

The second integration yields a rough estimate of distance used for stopping. In the trials, distance acquired from calibrated data had a high correction. We can use this distance to aid in determining safety.

IV. Changing Lanes

A. Safe Versus Unsafe Lane Changes

When the phone is in its normal position, a lane changes are measured mostly along the x axis. It should be possible to measure curve safety with the x axis. The physics vector definition of acceleration in the x axis is not used here because the x axis is always relative to the vehicle.

Figure 4 shows two safe lane changes which are safe and firm enough to register on the accelerometer by visual inspection. Note that there is an incline in this data as well.

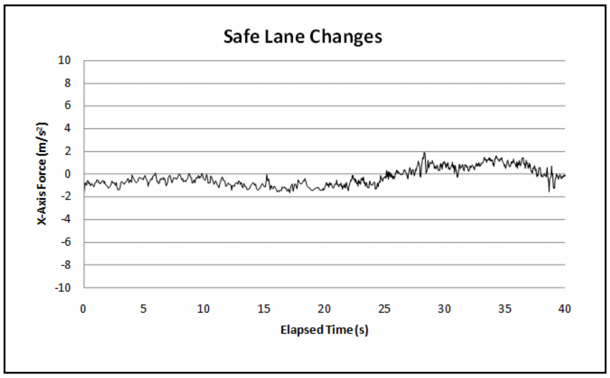

Figure 4. A Series of Safe Lane Changes

In Figure 4, there is first acceleration in the positive x direction, which means that the vehicle is making a lane change to the left. After that we see acceleration in the negative x direction as the vehicle completes its lane change and starts another one in the opposite direction. The next lane change to the right has noticeably more acceleration than the first.

Unsafe lane changes can be seen in Figure 5. These lane changes take less time, so there are more of them performed in the same amount of time. Figure 5 shows a G-force of well over 0.5 g in the x direction.

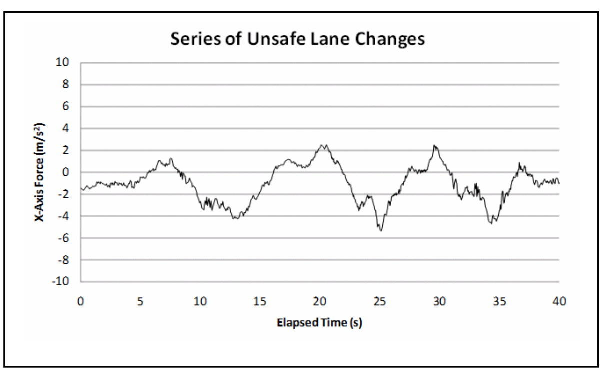

Figure 5. A Series of Unsafe Lane Changes

Using this data, not only is it possible to count lane changes and detect when they occur, it is possible to classify safe and unsafe lane changes. A person trying to weave in and out of traffic might very well perform several lane changes of this type over a short period of time.

B. Lane Change Width

When a lane change occurs, there should be a measureable displacement in the axis perpendicular to the vehicle's trajectory. The vehicle's relative x-axis changes directions relative to the lateral axis throughout the lane change. Figure 6 shows a curve which causes a displacement in the lateral axis. Input information includes time, speed (estimated by the GPS sensor), and relative x-axis measurements reported by the accelerometer.

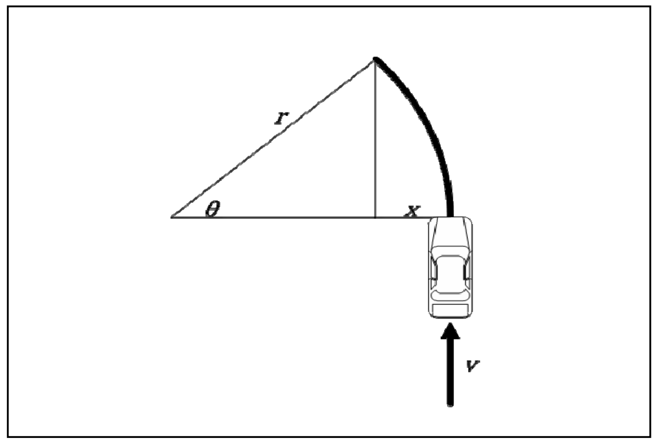

Figure 6. Rotation Displacement

First, we shall note the radius of a curve with respect to speed (*v*) and x-axis acceleration (a_x).

$$a_x = \frac{v^2}{r} \tag{1}$$

Therefore,

$$r = \frac{v^2}{a_x} \tag{2}$$

Next we find angular speed using acceleration, time (t), and radius.

$$v = \omega \cdot r \tag{3}$$

Therefore,

$$\omega = \frac{v}{r} \tag{4}$$

The angle (θ) of the curve can be found by simply integrating the angular speed over time, or in this case, summing instantaneous angles.

$$\theta = \omega t \quad (5)$$

From Figure 6, we can find a relationship between r, θ, and x.

$$\cos\theta = \frac{r - x}{r} \quad (6)$$

Finally, solving for x and plugging in values of r and θ from prior equations yields the required formula.

$$x = \frac{v^2}{a_x} \cdot \left[1 - \cos\left(\frac{a_x t}{v}\right)\right] \quad (7)$$

Given that the range of a cosine function will always be bound between -1 and 1, the bracketed portion of the previous equation can never be negative. The same is true for v^2, which leaves the sign of the acceleration to directly determine the sign of our resulting displacement, x. Also note that the cosine function is symmetrical about the y-axis so the formula will not be affected by the sign of θ.

For testing, speed should remain constant while input values of time and acceleration change. We will assume that the reported acceleration is a weighted average of acceleration over the *previous* time period. Applying the formula sequentially to individual accelerometer readings leads to poor results and experiments with time weighted averaging are underway.

It is important to note which derived values in the previous equations can be instantaneous (used only for one line of calculations) or cumulative. All input values are assumed to be instantaneous in order to perform the calculations except for elapsed time, which was already cumulative and must be made instantaneous. Radius (r) and angular speed (ω) are instantaneous. Angle (θ) and total lateral displacement (x) are integrated values and as such must be cumulative. This information is summarized in Table II.

TABLE II. PERSISTENCE OF LANE WIDTH VARIABLES

Value	*Symbol*	*Persistence*
Time	t	Instantaneous
X-Axis Accelration	a_x	Instantaneous
Speed	v	Instantaneous (constant)
Radius	r	Instantaneous
Angular Speed	ω	Instantaneous
Angle	θ	Cumulative
Total Lateral Displacement	x	Cumulative

V. TRANSFORMING DEVICE ORIENTATION

Sensor data collection with the mobile phone requires some extra considerations regarding device placement. We may not assume a given orientation of the mobile phone with respect to a vehicle's motion. Instead, orientation

The direction the phone is facing is called its "azimuth". This is a compass measurement which reports deflection from true North. In addition to accelerometer and GPS sensors, the G1 does come with a digital compass [3]. The direction of the phone's face will determine azimuth. For example, the LCD display has to be pointing North in order for the azimuth to read a value of "North". If a person is already facing North and looks at the phone, it will likely read "South". Use Table III as a reference for azimuth values. Note that when the phone is in a horizontal position, it will be nearly impossible to see an accurate azimuth value.

TABLE III. PERSISTENCE OF LANE WIDTH VARIABLES

Cardinal Direction	*Reported Azimuth Value*
North	0 or +360
East	+90
South	+180
West	+270

"Pitch" readings usually show a slant upward or downward from the direction of travel. An airplane's pitch would be positive on take-off because the nose is in the air. If the plane were to take a nose dive, its pitch would be negative. On G1 phones, we can consider the speaker end of the phone its nose. However, when the nose is down there will be a positive pitch, and when the nose is up we will see a negative pitch. The sign in this case correlates to shifts in the accelerometer's y-axis measurements. Values range from -180 to 180 degrees.

The last orientation value is "roll" which represents left and right banking of the device. Turning the device on its right or left long edge changes its roll value. Again, on the G1, reported readings are counterintuitive. A positive roll indicates a bank in which the right side of the phone (that is, the side with the "end" button) goes down. By contrast, when the phone banks to the left, we will see a positive roll. The sign in this case correlates to shifts in the accelerometer's x-axis measurements. Values range from -180 to 180 degrees.

The last reading of import is heading information from the GPS sensor. "Heading" is the direction of motion, or in our case, the direction of travel. The difference between heading and azimuth is that azimuth is the direction the phone is facing but heading is the direction of movement. We wish to reconcile the azimuth with heading in our rotations.

Understanding two-dimensional (2D) rotation is fundamental for understanding three-dimensional (3D) rotation. Once we have a formula, we can apply the transform to each coordinate pair to form a new set of points.

One important thing to realize here is that, since the rotation angle is the same for the roughly seven thousand points forming this image, neither the cosine nor sine of the angle changes. Processing will be faster to calculate all the sinusoid functions in advance of performing the batch calculation. Such optimizations are crucial to mobile development because of limits on processing power.

2D rotation matrices lead gracefully into a generalization for three dimensions. Euler proved that a single 3D rotation can be performed by applying 2D rotations in the proper sequence and with the proper angle.

It is theoretically possible to correct for pitch and roll at the same time, however, more study is required and until then we are currently limited to one degree of freedom.

For a roughly 45-degree pitch incline, orientation sensors read -41° pitch and -1° roll. Original accelerometer readings were {-0.11, -6.39, -7.37} for x, y, and z axes, respectively. After the coordinate transformation, output values were {0.02, 0.01, -9.75}, amounting to a 0.5% error in the z axis.

For a roughly 45-degree roll incline, orientation sensors read 0° pitch and -44° roll. Original accelerometer readings were {6.74, -0.01, -7.04} and output values were {-0.04, -0.01, -9.75} and hence a 0.5% error in the z axis.

For both of these experiments, expected output values are {0, 0, -9.8}. A device already in this orientation indicates that its orientation does not need an incline adjustment.

VI. CONCLUSIONS

T-Mobile's G1 phone may be used as a black box to determine varying levels of risk while riding in a vehicle. General classification is possible given its GPS speed sensor and triple-axis accelerometer, but the hardware may not be accurate enough to perform other measurements such as braking distance and lane change width reliably. In order to be useful as a measurement tool and phone, the coordinate space must be periodically measured and corresponding accelerometer measurements adjusted for.

VII. FUTURE WORK

With the latest platform release of Android, 1.5, developers now have access to raw microphone data. Prior to version 1.5 audio was compressed and recorded via an API, after which a developer could decompress and analyze it. For this project, the two computationally expensive steps of compression and decompression are not necessary for all audio. This project will expand to include limited audio processing for classification purposes.

Transforming data in three dimensions is a must. Android 1.5 comes with more functions to help with coordinate transformations on the phone but its function to calculate a rotation matrix depends on geomagnetic hardware which the G1 phone does not have.

ACKNOWLEDGEMENT

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