PREDICTING ROAD CRASHES WITH MOBILE DEVICES USING THE LINE INTERSECTION TECHNIQUE

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ABSTRACT

Worldwide more than 1.24 million people die each year because of road crashes. In 2008 980,000 crashes were reported in South Africa alone. In 2004 the financial impact of these deadly events was estimated at $518 billion. Current integrated technologies in Smartphones and Tablets enable us to do something that has never been done before, that is to predict road crashes in real time. Mobile devices can access information such as traveling direction and speed from their Global Position System (GPS). Given these parameters, it is now possible to predict where the current mobile device will be in future. Information is easily shared with Wireless Technology (WIFI) between the devices. Searching for collisions is not always an easy task. This paper proposes a trajectory prediction formula where acceleration and Direction Change Rate (DCR) is considered as well as a search algorithm for optimal crash search detection. The results prove that the Line Intersection Technique (LIT) is a better algorithm to use when searching for collisions between different road using objects.

KEY WORDS

Trajectory prediction, trajectory estimation, collision detection, crash detection, real time trajectory prediction, collision detection method, Line Intersection Technique.

1. Introduction

The need to reduce road crash fatalities needs no justification. The facts and figures speak for themselves. Africa is hit hardest [1] by these fatalities. When considering that more than 91% of all worldwide crash fatalities occur in low to middle income countries [1] one must argue that something needs to be done to reduce these figures.

One method to achieve some sort of reduction in these numbers is to predict road crashes in real time and warn road users about these potential fatal incidents. This can be achieved using current mobile technology. The latest Smartphones and Tablets all have GPS, WIFI capabilities and high-end processing power that make this concept a possible solution. The mobile device that is traditionally blamed for causing road crashes can now be transformed to something that can prevent them.

In section 2 we will briefly explain the concept as well as GPS information and WIFI. In section 3 we will explore previous works and methods for trajectory prediction as well as present our improved method to predict trajectory of a moving object. Section 4 will explore previous collision detection methods and again introduce our improved method to search for collisions. In section 5 we will present our simulated results and in section 6 we will give general conclusion.

2. Real time collision detection

Figure 1 demonstrates the basic concept of trajectory prediction using GPS information. With information such as speed and driving direction it is possible to make a very accurate prediction where one would be in the very near future. Accuracy decreases as the time to predict into the future increases.
Several parameters can be received from the GPS instrument of a Smartphone. The only information related to our trajectory prediction however is current location, the speed and traveling direction. Information such as acceleration and DCR needs to be calculated. The following formulas are used to achieve this:

\begin{align*}
\alpha &= \frac{\Delta v}{\Delta t} \\
\gamma_r &= \frac{\Delta \alpha}{\Delta t}
\end{align*}

Equation (1) explains the simple principle of acceleration. It states that a acceleration is equal to the change in speed v divided by the change in time t. Acceleration indicates whether an object is increasing or decreasing its speed. DCR is calculated in more or less the same manner. DCR \( \gamma_r \) is equal to the change in driving direction \( \alpha \) divided by the change in time t.

One obstacle when working with mathematic coordinate systems and GPS coordinate systems is that the coordinate systems are not the same and not directly compatible. Figure 2 demonstrates the main differences between the mathematics/physics coordinate system vs. GPS coordinate system. On the left hand side of Figure 2 is a mathematical coordinate system whilst the system on the right hand side is for GPS.

These differences create an obstacle when calculating trajectory and positions. The two systems can’t be used together and angles need to be converted. Because mathematics is the base component to these calculations, the GPS coordinate system is converted.

\begin{align*}
da &= 90^\circ - \alpha_t \\
if \ da < 0: da &= da + 360^\circ
\end{align*}

Alpha \( \alpha \) is the actual driving angle. The driving angled \( \alpha \) is measured by the Smartphone’s GPS instrument. Conversion is done by equations (3) and (4). Drive angle \( da \) is equal to 90° minus the actual driving angle. If this equates to a positive number the drive angle has been successfully converted by (3). If the calculated value equates to a negative value an additional calculation is required (4). The value 360° is added to \( da \) to ensure that it will be become positive and indicates the correct direction on a mathematics vector coordinate system.

The communication strategy is not discussed in this paper. What can briefly be mentioned is that WIFI was selected because its physical communication range is adequate and also because it is a free independent system. Third party data service providers are eliminated as well as the cost that goes with this type of communication.

3. Trajectory prediction

Trajectory prediction is the process whereby the future position of an object is estimated or predicted. There has been in-depth research about this topic, and several methods are recommended to achieve this objective. Possible methods to predict trajectory falls basically into two categories. These categories are physics and visual observation systems.

There is several trajectory prediction methods proposed in previous research. In [4] it is proposed to use cameras that are mounted on the front of a vehicle to monitor the wheels. The wheel angle is used to calculate what that actual vehicle is doing in terms of steering. Although it might be possible to determine vehicle direction with some degree of accuracy, it will still not be possible to determine speed, a key parameter required for trajectory prediction. The methods proposed in [4] can only give some indication where the vehicle might end up, but not when the vehicle will end up in this position. Another key problem is the feasibility and practicality of installing such equipment on vehicles. Having cameras installed
with additional brackets on the front of your vehicle might be a big problem to most car drivers.

The authors in [5] capture some elements that are also required in the concept of this paper. The key differentiation is in hardware requirements. The authors in [5] use a GPS connected to a laptop, with a WIFI access point that communicates with a hardware server next to the road. The equations and methods used in their work are over complex. The biggest concern of all is that the system focuses only on vehicle to vehicle crashes. Almost all research ignores pedestrians, cyclists and motorcyclists. This should be a major concern and focus point for research as almost more than 50% of all crash fatalities fall in this category [1].

In [3] it is proposed to use Differential GPS (DGPS) to calculate trajectory. The concept again in this paper is very good but a large focus is place on GPS measuring error correction. It is acknowledge and noted that it is very important to have some sort of error correction method for GPS measurements. This however is not the main focus of this paper and error correction is ignored so that the concept can be thoroughly tested. Error correction is however incorporated in the simulations as a parameter to compensate for measuring and prediction errors.

The work that is most relevant for the proposed concept was the research completed by the authors of [2]. The significance of object shape and size is emphasized in this paper. It demonstrates as illustrated in Figure 3 the important relevance of shape and size when predicting trajectory and detecting collisions.

The circle model is the easiest way to detect collisions. It uses a virtual line from the centre of and object to the furthest corner. It then takes this value as r the radius of a circle and plots a virtual circle around that object. Collision detection is then done by comparing the distance of the two objects centre points from each other. If the vehicles are closer than their combined radiuses it means that a collision will occur. The problem with this approach however is that there will be a rather large portion of the circle's area that will give you a false collision warning simply because the objects do not overlap, only their virtual collision circles does.

The last model proposed by [2] is the rectangular model. This model is best suited for our application. A rectangle can accurately represent several road using objects. This includes pedestrians, cyclist, cars and even large transportation trucks. Trajectory prediction and collision detection is made more difficult because of the complex shape of the rectangle, but the reward if doing it correctly is also so much greater.

Trajectory prediction is done by basic physics. The research completed by [2] leaves an opportunity for improvement. In the calculations proposed by these authors two very important variables are neglected. They are acceleration and DCR. This paper included these two parameters which allow for more accurate trajectory prediction.

\begin{align*}
    x(t+1) &= x(t) + (v(t) + a_x) \cdot \cos(\alpha + y_{rt}) + err \\
    y(t+1) &= y(t) + (v(t) + a_y) \cdot \sin(\alpha + y_{rt}) + err
\end{align*}

Equation (4) and (5) are the modified equations from [2]. Equation (4) predicts the next x coordinate of an object. The variables acceleration \(a_x\) and DCR \(y_{rt}\) are the ignored variables from previous research. Equation (5) predicts the next y coordinate of an object. The variable \(err\) is the error that is received from predictions and measuring.

Figure 4 illustrates the effects of DCR and acceleration when considering these parameters as part of the trajectory prediction algorithm.
4. Collision detection

Collision detection is the process where the trajectories of two or more objects are compared with each other. A collision will occur when the compared trajectories indicate that the objects will be at the same place at the same time.

Collision detection based on actual trajectories is not a topic that is researched in depth. Only a couple of papers touch on this topic. There is however one paper that separates itself from others [2]. As illustrated in Figure 5, the four corners of a reference object (Object 1) is tested to see if it exists inside the area of the collision object (Object 2), and vice versa. If one of the four corners exists at the same place and time inside the area of the other object, a collision is registered. This method is an almost solid approach to search for collisions but it delivers a fundamental flaw. What if the two objects exist exactly on top of each other at a perpendicular angle? Figure 5 illustrates this flaw. It is visually observed that a collision will occur but it is not detected by the search algorithm. This condition occurs because the four corners are never inside that area of the other object. This flaw brings an opportunity for improvement.

This paper proposes a new method to search for collisions. The method is called the Line Intersection Technique (LIT). The LIT concept is basic. Compare each of the four lines of the reference object (Object 1) with each of the four lines of the collision object (Object 2). If any two relevant line sections intersect it means a collision is detected. Figure 6 illustrates several scenarios where LIT detect collisions successfully.

The LIT uses several familiar linear algebra equations to calculate whether collision is detected or not.

\[ y = mx + c \]  

(4)

Equation (4) is the equation for a straight line. Each object in the simulation will have four linear equations representing the four outer lines of that object. Each line will have a start position and an end position; this means that lines will have two sets of xy coordinates that can be used for calculations. The point \( x_1 \) represents the start coordinate and \( x_2 \) represents the end coordinate.

\[ \text{min1} = \min(x_{1\text{line1}}, x_{2\text{line1}}) \]  

(5)

\[ \text{min2} = \min(x_{1\text{line2}}, x_{2\text{line2}}) \]  

(6)

\[ x_{\text{min range}} = \max(\text{min1}, \text{min2}) \]  

(7)

The purpose of equation (5) and (6) is to find the minimum x value of the line. Equation (5) is relevant to the reference object and equation (6) is relevant to the collision object. Equation (7) selects the biggest smallest value of the two lines. This value is the minimum point where a line is allowed to intersect. If the intersection...
point is smaller than this value it means that no intersection will occur.

$$\max_1 = \max(x_{\text{line1}}, x_{\text{line2}})$$  \hspace{1cm} (8)$$

$$\max_2 = \max(x_{\text{line2}}, x_{\text{line2}})$$  \hspace{1cm} (9)$$

$$x_{\max \_range} = \min(\max_1, \max_2)$$  \hspace{1cm} (10)$$

The purpose of equation (8) and (9) is to find the maximum x value of the line. Equation (8) is relevant to the reference object and equation (9) is relevant to the collision object. Equation (10) selects the smallest biggest value of the two lines. This value is the maximum point where a line is allowed to intersect. If the intersection point is bigger than this value it means that no intersection will occur.

$$x_{\text{intersect}} = \frac{(c_2 - c_1)}{(m_1 - m_2)}$$  \hspace{1cm} (11)$$

Equation (11) is the actual intersection point of the two lines that are being compared. The variables $c_1$ and $c_2$ are the y values where x is equal to zero and $m_1$ and $m_2$ are the slopes of the two lines. Any two lines will eventually intersect as long as their slopes m is not equal.

$$x_{\min \_range} \leq x_{\text{intersect}} \leq x_{\max \_range}$$  \hspace{1cm} (12)$$

Equation (12) is the final equation and is the main equation to check for intersection. It states that if the $x_{\text{intersect}}$ point is greater or equal to the $x_{\min \_range}$ and smaller or equal to the $x_{\max \_range}$ an intersection in the tested section of the line exist. This means that a collision is detected between the two different objects. This equation is executed sixteen times to cover all possible combinations of the eight lines of the two objects.

This paper also proposes two additional improvements to improve collision detection.

The first improvement is called Relative Device Location Position (RDLP). This technique creates additional parameters that allows for the mobile device to move around inside the object. This technique allows for a more realistic trajectory. Figure 7 illustrates the differences in techniques from [2] (A) and from this paper (B). It is assumed that the device is always located in the dead centre of an object. In a realistic environment the device are more likely to be located in the front of a car or truck.

The second improvement is to accommodate and search for collisions between more than two objects in the network. Although our model can theoretically accommodate for an infinite amount of objects, we have chosen to simulate with not more than six objects to keep the visual elements of the simulations understandable.

### 5. Simulations and results

Figure 8 illustrates a simulation that was done with 5 objects inside the network. Only one collision was detected. This is the collision between the blue reference object and the purple collision object. In the simulation from Figure 8 several other objects intersect but not at the same time interval. This indicates that they will be at the same place but not at the same time, meaning no collision will occur. Figure 9 and Figure 10 illustrates the details of the simulation results.

Figure 9 indicates that there will be a collision in 1.2 seconds between the reference blue object and the purple collision object. Figure 10 on the other hand show that there will be no collision between the blue reference object and the turquoise collision object.
6. Conclusion

Incorporating extra parameters such as DCR, acceleration and RDLP makes it possible to predict the trajectory of an object much more accurately. These three parameters play a crucial role to simulate actual road using objects. It is expected that objects are always exposed to acceleration or following natural road curvature. Device object offset is required if more accurate predictions are required.

The LIT method eliminates any possible false true conditions. Using this method it is now possible to check in much more detail where and how two objects will collide. Simulations provide exact information on when, where and from which direction a potential collision will occur.

The LIT method requires more processing power because of its increased accuracy. This however is not a problem when considering the processing capabilities of today’s Smartphones and Tablets. Calculations are done immediate and without any delay. The LIT method is extremely accurate and systematic.

The concept presented in this paper has got both advantages and disadvantages.

The main advantage of this concept is that it applies to the entire road using community. Everyone is covered, from pedestrians to the drivers of large transport trucks. Most proposed systems today focus only on vehicles and are sometimes only manufacturer specific. Smartphones and Tablets breaks this barrier and open the opportunity for everyone to be part of a system that is decentralised and serve the purpose to protect all.

What gives this concept another major advantage is the fact that it is based on current technologies, equipment and methods. It is assumed that technologies such as GPS accuracy, WIFI range and processing power of mobile devices will only improve over the next few years.

The main disadvantage of this system is that all road users need to be part of the system for it to be efficient. This means that the system is heavily depended on the actual road user community. This might be a problem for low to middle income countries where road crash fatalities are the biggest problem. Smartphones and Tablets are relatively inexpensive, but not for everyone using the roads, and as previously stated the success of this system is dependent on the amount of road users using it. A nother disadvantage is that the system is depended on GPS. If the GPS system is not functioning for some reason then the complete system will be down.

A working prototype App has been developed using Google’s Android platform. The initial results from this prototype are extremely positive. The complete system is performing exceptionally well and further testing is currently being performed.

References


