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THE DESIGN AND SIMULATION OF AN INTERSECTION CONTROL SYSTEM

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Abstract: The object of this paper is to analyze and to suggest improvements on intersection management systems using existing equipment currently available in street intersections. In order to do this, we designed an intersection management system capable of detecting traffic violations as well as vehicle collisions using high-speed cameras. We propose to implement the above mentioned system through design and simulation in the LabVIEW programming environment. LabVIEW offers all the instrumentation necessary to accurately simulate the phenomena that occur in modern-day intersections, making it possible to further develop the existing intersection technology. It also makes it possible to determine the requirements and limitations of the existing equipment and to find the best solutions for every scenario.
Keywords: LabVIEW, traffic, intersection, red-light running, collision detection

1. INTRODUCTION

Intersections are among the most perilous places on the roads: 3.2 million crashes in the USA in the year 2002, hence 50% of all reported crashes, were intersection-related; 9,612 deaths, this meaning 22% of the total fatalities on the road, 1.5 million injuries and 3 million collisions took place at intersections. In Japan, more than half of all traffic collisions happened at intersections. The fatality rate of intersection accidents has changed little in than past two decades, regardless of vehicles innovation, improvements in intersection design, etc. [2].

Therefore, software and hardware that detects traffic violations, car crashes as well as the possibility of an accidents occurring, meaning accident prevention, is becoming a necessity.

There have been several attempts at designing intersection collision warning systems and/or avoidance systems, but no existing intersection collision warning and avoidance system can handle all the problems that can arise in intersections [2].

2. PROBLEM FORMULATION

Accidents happen on a daily basis, traffic accidents being one of the leading causes of casualties. But this isn’t how things should be like. Considering the technical advances that take place in our age and time, the dangerousness of driving a car is unjustifiable. So any system that can help reduce the number of accidents or increase the post-accident survival rates is not only understandable, it is welcomed [1].

In this paper, we plan to explore a few automobile safety options existing in literature while presenting our own collision avoidance system. We will start by analyzing how exactly cars can be made safer. One possibility is to detect when an accident is about to happen.

The systems that do this are called collision avoidance systems or pre-crash systems. They use radar and, sometimes, laser and camera sensors to detect an imminent crash. Once a possible collision is detection, these systems either provide a warning to the driver or take action themselves without any driver input (by braking or steering or both) [4]. The first system can be useful in warning the driver but it all depends on how soon the warning mechanism can be triggered. If it's triggered too soon, it gives the driver more time to react but it can be less accurate. If it is triggered too late, the driver cannot do anything about it. There's also a question of who to warn: the driver, who might not be in a position to do anything, or the authorities, making a false alarm a waste of very precious time.

The second system can prove to be a life saver or a threat to one's life because by taking control from the driver it takes the responsibility of the lives of the passengers inside the vehicle, being obliged to react very quickly to a very dynamic and insecure environment. It all depends on the adaptability and versatility of the vehicle.

Another possibility is to detect when an accident has just happened. An automatic alarm device for car accidents is a system which can detect accidents and send the basic information to a first aid center within a few seconds. This information should contain the geographical coordinates and the time and angle at which the vehicle accident had occurred [11]. Such a system can be made using accelerometers and a GPS navigational system. The accelerometers are used to automatically detect traffic accidents and the GPS is used in order to provide the GPS coordinates to the central emergency dispatch server after an accident. This can provide early response and rescue of accident victims. Therefore, these systems can actually save people's lives by reducing the time between the car crash and the arrival of the ambulance and/or fire truck. However, these in-vehicle systems are not available in all cars and are unaffordable or cannot be retrofitted into older vehicles [1].

Our solution to these problems is an intersection collision detection system. Vehicle-based collision warning systems work well enough for a single vehicle. However, in an intersection, more than one vehicle can be affected by a potential source of danger. Therefore, a cooperative system is preferred.

Existing intersection collision warning or avoidance systems are mostly built to suit a particular intersection. There are studies in literature suggesting intersection collision detection systems that adapt to different types of intersections by acquiring the collision patterns of the intersection through data mining. But the process of learning patterns of collisions is mainly done manually and repeated for each intersection. Therefore, system maintenance does represent a problem [2].

2.1. Red-light Running

Red light cameras are used in red-light running systems. They are typically installed in intersections based on the frequency of crashes and/or red-light-running violations. Red light camera systems utilize two inductive loops embedded in the pavement in order to measure the speed of vehicles. The loops are situated closely spaced just before the limit line. Using the measured speed, the system predicts if a particular vehicle will be able to stop before entering the intersection, and, if it cannot, takes two photographs or a video of the event. In the case of the photographs, the first photo shows the vehicle just before it enters the intersection, with the light showing red. The second photo is taken a second or two later, showing the vehicle when it is in the intersection.

The camera system can record such data as: the date and time when the event occurred, the location, the vehicle speed, and the amount of time elapsed since the light turned red and the vehicle passed into the intersection. The images, be they digital or developed from film, are sent along with the data to the police. The police determine weather a violation occurred or not. If it did, a citation is sent to the vehicle owner. These cameras are used worldwide. The statistics regarding the efficiency of red light cameras have been inconclusive. While these cameras have been known to decrease the number of right-angle crashes, there is evidence to suggest that they increase the number rear-end collisions due to the higher probability of sudden stops. Since studies show mixed results as to the utility of the red light camera, we do not suggest that they be used by themselves in an intersection, but as a part of a more complex accident detection system, in order to provide data as to the traffic violation that caused a detected collision [5].

2.2. Traffic Signal Timing

The importance of traffic signal timing is due to its direct influence over the quality of the transportation system, affecting the time we spend traveling, the quality of the air we breathe, the safety of roadway travel, the costs of our trips, and many other aspects of our daily lives. The main goal of traffic signal timing is to provide safe and efficient intersection management. There are a number of factors that influence the traffic signal timing, including the intersection design, the traffic control device layout, the overall geometry of the intersection, the capacity of the intersection, etc. Thus, a good signal timing plan is one with time interval adjusted according to the particularities of the intersection while keeping cycle lengths to a minimum, reducing the number of stops and minimizing delays.

Furthermore, travel demand patterns are not permanent, they change over time; making it necessary for the signal timing plan to be updated periodically in order to maintain intersection safety and efficiency.

In some cases, changes to the intersection design or the traffic control device layout may also be required [10]. Therefore it is in our best interest to design an adaptable intersection that can be controlled externally. The benefits of such a system include the possibility of monitoring the intersection and even of controlling the traffic lights in the case of extraordinary events such as vehicle collisions in order to prevent chain reaction collisions.

3. PROBLEM SOLUTION

Traffic simulation is useful in analyzing complex traffic processes and situations that occur between the main components of the traffic systems (roadways, traffic controls, drivers, vehicles). Such a situation can be a car crash or any other vehicle accident. Traditional analytical models can hardly described such processes. This is mostly because they often involve disrespecting traffic regulations and, therefore, do not constitute normal traffic events. Hence, the behavior of each of the system's entities and the huge amount of interactions between the entities cannot be accurately described mathematically through traditional analytical models. Thus, computer simulation becomes more suitable for the study of road traffic.

Traffic simulation models are flexible and present feasibility in testing. They could also be used for experimenting with different technologies without modifying or interrupting the system's activity, which may be very costly and unsafe [3].

Therefore we chose to simulate our intersection control system using the LabVIEW programming environment. The intersection we designed for testing the system is a two-lane intersection skew at 90 degrees, the lanes being of equal capacity and priority. The traffic was simulated using 3 different colored cars whose position and orientation can be modified according to the driving behavior we wish to simulate (Fig. 1).

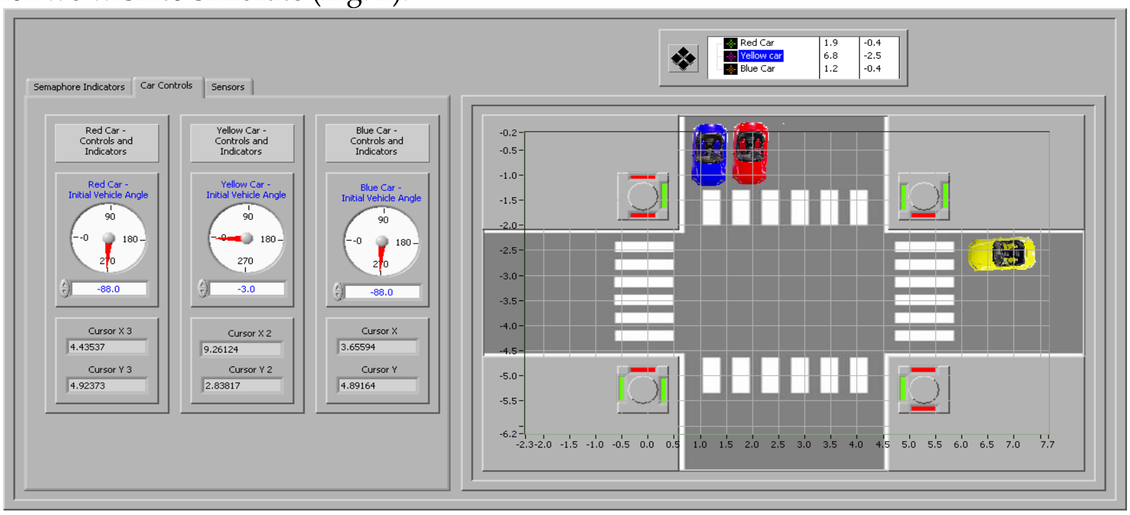
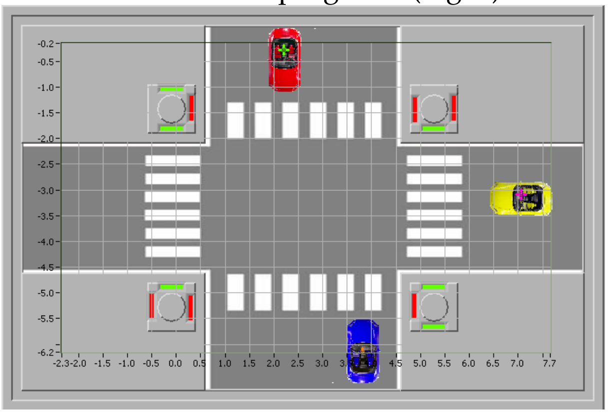
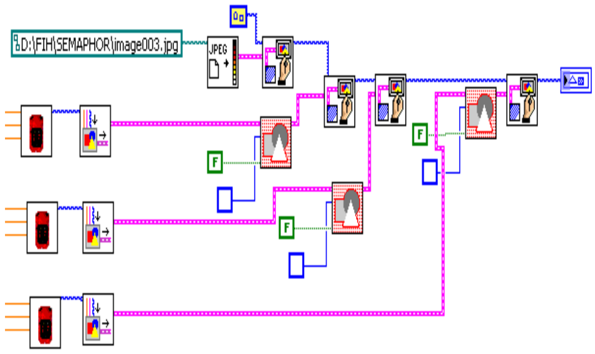


Figure 1. The intersection complete with cars whose position and angle can be modified

The cars can be made to move programmatically, but this involves following a pattern which is not recommendable when simulating accidents because accidents have a random character. They usually happen when traffic rules are not obeyed, this sort of behavior being simpler and more accurate to simulate through manual control of the animated cars then through programmatic behavior. The animated cars and the intersection are designed with image overlay techniques and existent LabVIEW subprograms (Fig. 2).



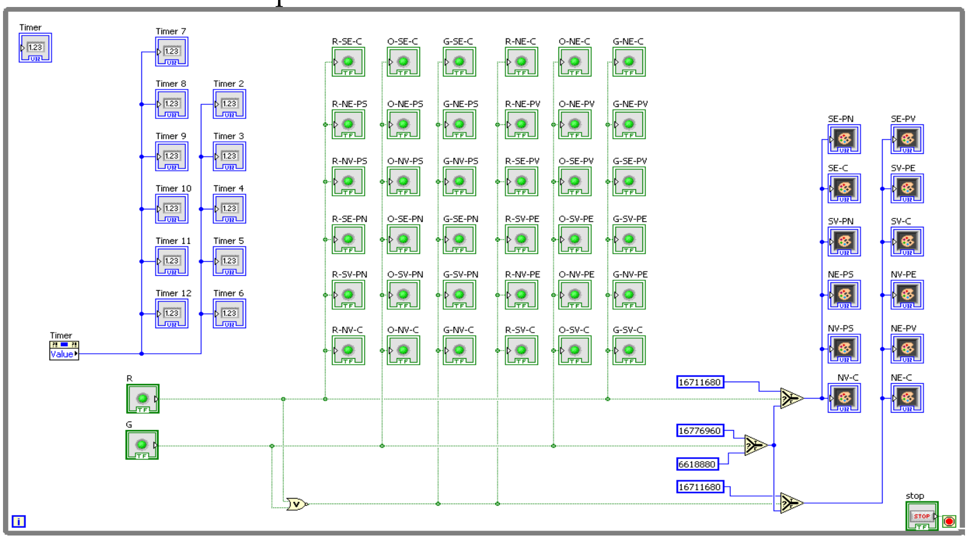
a) The outlay of the simulated intersection



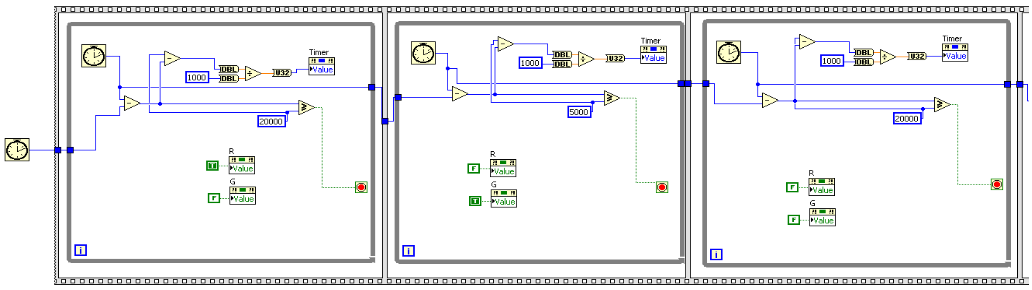
b) The image overlay code for obtaining the intersection complete with cars

Figure 2. Intersection design

The view of the intersection we simulated can be taken with traffic cameras positioned directly above the intersection. The latest technology in traffic camera software identifies moving vehicles through image processing, being also able to read their license plate number through character recognition. This being said, our particularized version that uses 3 known cars would have the software basis in real life to be implemented.



a) The While Loop used to create the actual traffic lights



b) The Sequence Structure used to create the traffic signal controller

Figure 3. The traffic signal controller

The traffic signal controller we produced is a very accurate and easily adaptable system. It was made using Sequence Structures and While Loops with Tick Count conditioning, as can be seen in fig. 3. The components used play an important part in designing the intersection because they determine the preciseness of the program. The use of other components, such as delay-type components, will unwillingly impact the timing plan. These components, although easy to use, will have a duration that depends on the time needed to perform the process, in this case the movement of the simulated cars. This is due to the fact that the LabVIEW compiler creates separate execution threads for parallel sections of code. [12] This results in a logical parallelism that will cause unwanted lagging in the execution of the traffic lights structure unless it has a universal stop time.

As mentioned before, in a real intersection, this timing plan has to be set according to the characteristics of the intersection and the needs of the drivers. We simulated an intersection of roads that have the same priority skewed at 90 degrees, each having two lanes of equal capacity with 4 traffic signals arranged as can be seen in figure 4. The signal timing settings we used, in this case, were as follows:

- ✓ Red: 20 seconds;
- ✓ Yellow: 5 seconds;
- ✓ Green: 20 seconds;
- ✓ Yellow: 5 seconds.

These settings were adapted to the needs of our LabVIEW intersection in order to facilitate the simulation of the driving patterns and the collision patterns we wanted to test. If different requirements were met, the timing setting would most certainly have different values. For example, if the roads had different priorities, the red and green intervals would be altered.

The purpose of the yellow interval is to facilitate safe transfer or right-of-way from one movement to another. The safety benefits of this interval are achieved when its duration is consistent with the needs of drivers approaching the intersection at the onset of the yellow indication. These may also include the decrease of intersection crashes; therefore, having an appropriately timed yellow interval could benefit our entire system [10].

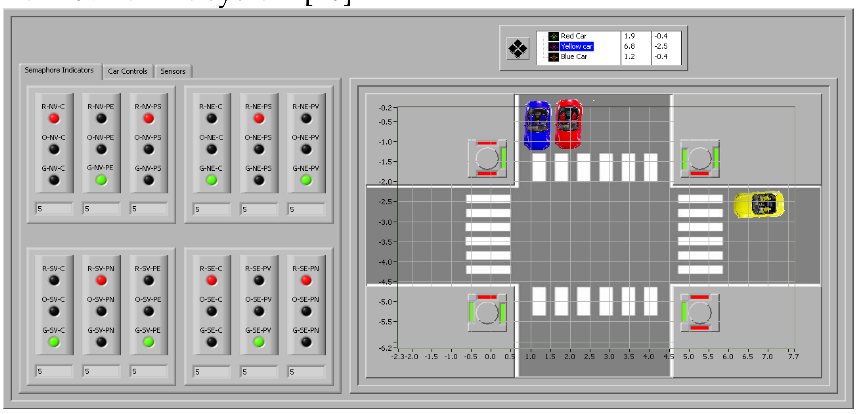
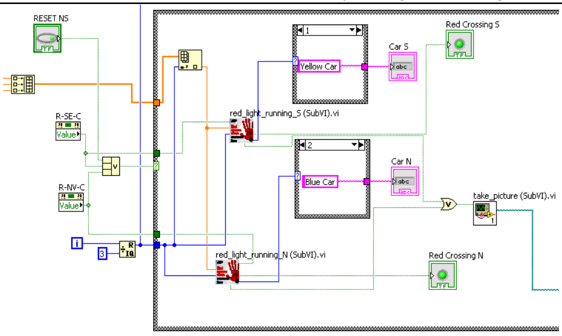
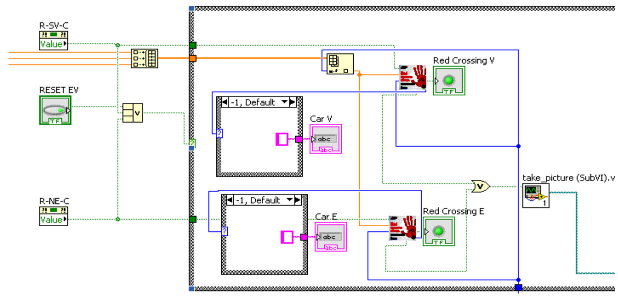


Figure 4. The Front Panel of the traffic signal controller

One of the things we wanted to simulate was a camera based red-light running detector in order to use it as a component of our intersection control system. In this simulation, red-light running is detected when a car passes a zebra crossing while the traffic light is red. This algorithm (figure 5) is simple to implement because it only requires the mentioned traffic camera and image processing techniques, but it imposes limitations on the type of camera that can be used. High speed cars can only be detected by high speed cameras, forcing an inferior limit on the camera's frame rate. If the frame rate requirements aren't met, the car might pass the zebra crossing too fast to be detected and, since cars than are running red lights do go at high speeds, a low frame rate camera would be impractical and unusable in these circumstances.

Our program can detect which car has run the red light, as can be seen in figure 6, while also taking a picture, in this case through a print screen function, of the intersection half a second after the car enters the zebra crossing zone. The picture is saved on the computer.





a) red-light running detector for the vertical road a) red-light running detector for the horizontal road

Figure 5. Red-light running detector

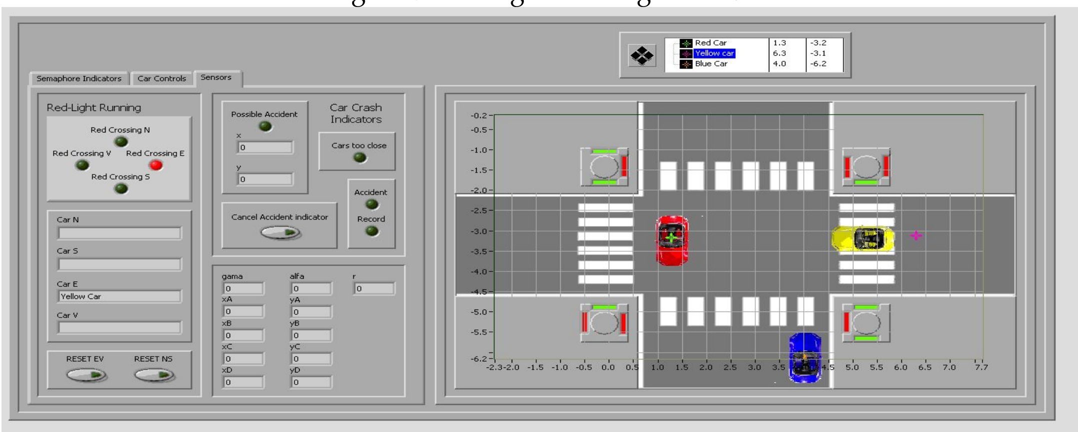
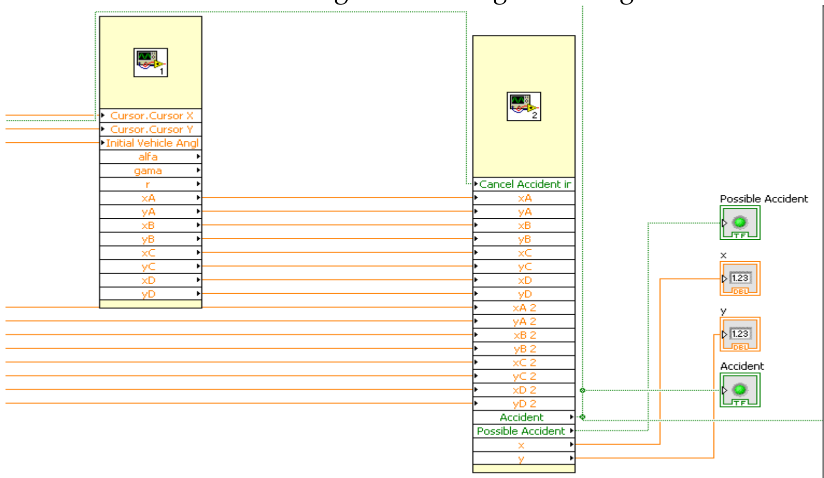
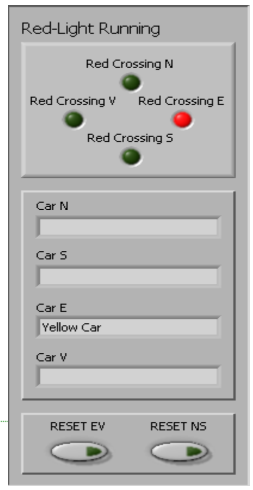
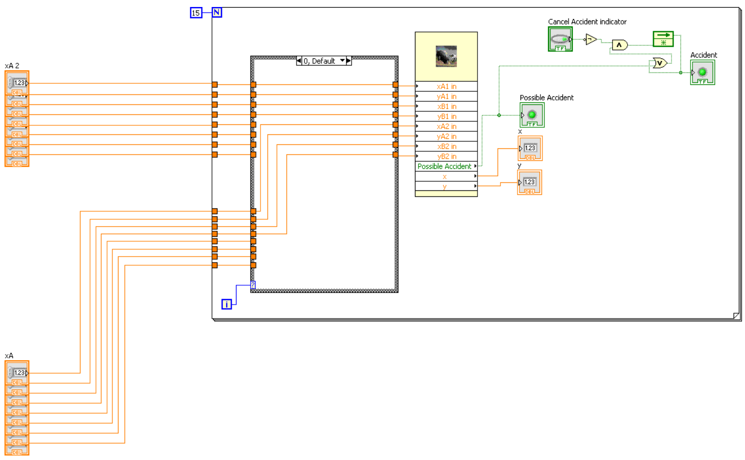


Figure 6. Red-light running indicators





a) Car edge detection b) Red-light running indicator



c) Accident detection

Figure 7. Crash detection code

The Car Crash detection system we propose is based on the proximity of the surfaces of any 2 cars from the 3 considered. The algorithm detects the geometrical intersection of the edges of the cars, being able to detect collisions from any angle, hence, making it functional no mater what the intersection geometry is.

In the program the cars have been given constant borders, but in a true intersection these borders are calculated automatically through a high speed traffic camera, as well as the registration number of the cars. In this program the 3 cars are known and recognized by their coordinates, but, in a true intersection, this data comes from traffic camera, which is, in our case, a simulated sensor (figure 7, 8).

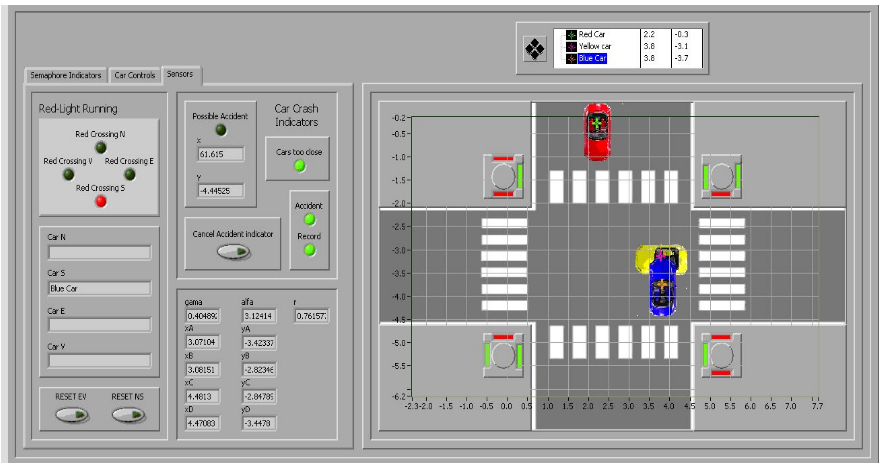


Figure 8. Car Crash Panel

This detector is activated when the program sense that 2 cars are considered "too close", meaning that the distance in between them is under a certain limit. The program automatically pre-selects the 2 "closest" cars in the intersection, therefore the 2 cars that are most likely to collide, and it applies the car crash detection algorithm to it (figure 9).

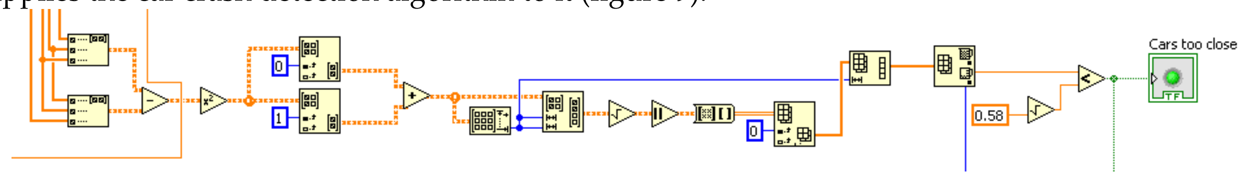
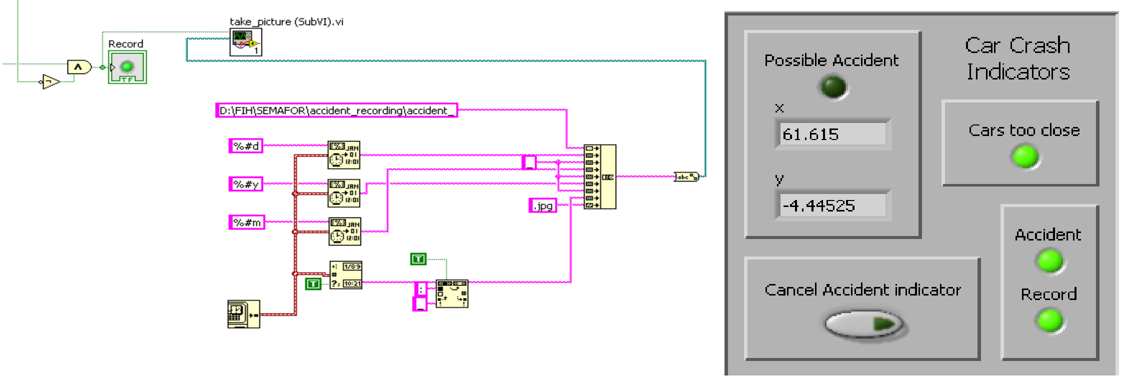


Figure 9. "Cars too close" pre-selector

This can prove to be advantageous when a large number of cars are in the intersection. The algorithm then calculates if an accident is likely to happen and, if it is, computes the probable collision point and indicates this possibility. When the collision does occur, the accident is recorded through a programmatic print screen function and saved on the computer (figure 10). The picture is taken the moment the 2 cars collide.

The collision is indicated on the screen through a series of light indicators in order to alert the authorities (figure 10).



a) "Take picture" function b) Car Crash Indicators while recording

Figure 10. The record function

If implemented in a real intersection with real traffic cameras, the program will be installed on a computer at a police station, monitoring the intersection from there. The connection between the traffic sensors and the actual hardware on which the program runs can be made through both wired on wireless means. Documentation on traffic infrastructures using Wireless Sensor Network (WSN) exists in scientific literature [6]. This will make it possible for the authorities to be alerted instantaneously and from a trustworthy source. The police force is than able to see exactly what happened and to act swiftly according to the situation. The program also

They also have the identification data of the colliding cars, possibly solving hit-and-run situations. The program continues to indicate the accident until it is reset through the Cancel Accident Indicator button.

This program represents an open loop program on intersection control. A closed loop version would be able to control intersection traffic.

4.CONCLUSION

The crash rate in an intersection is primarily determined by the characteristics of the intersection, such as different intersection shapes, the number of intersection legs, the number of lanes, whether it is signalized or not, the traffic volume, the rural / urban setting, the types of vehicles using the intersection, the average traffic speed, the median width and the road turn types.

Therefore, the complex nature of intersection collisions requires systems that warn drivers about possible collisions. This demonstrates the need for a fast and accurate collision detection system. In this paper we present just such a system [2]. Our program uses LabVIEW technology to simulate an intersection of two roads of equal priority and capacity with traffic lights as can be seen from a traffic camera situated directly above the intersection. The traffic camera works as a sensor for both the red-light running detector and the collision detector. Typical red-light running detectors use speedometers embedded in the pavement to determine if a particular car will be able to stop before entering the intersection and, if not, use the camera to photograph or to film the event. We used image processing in order to detect red-light running, needing only the camera with the condition that the camera be a high-speed camera, real-time programming being mandatory. Using a regular camera and speedometers might seem less costly, but, since a high-speed camera is already necessary for the collision detection algorithm, employing them as red-light running sensors will provide a lower cost. But the angle at which the high-speed camera has to be positioned in order to recognize the license plate number could be problematic and the intersection might need multiple cameras in order to get a precise detection. Also, the high speed camera system is easier to install and to maintain. The speedometers have to be embedded into the pavement and are more exposed to the elements than the camera placed high above. There are advantages and disadvantages to each method but that doesn't mean that they are not mutually exclusive. Speedometers could be used along with the high-speed camera for a more precise identification of a traffic violation.

When red-light running detectors are installed at a road crossing or an intersection, the yellow interval of the stop lights is usually increased in order to avoid rear-end collisions caused by sudden stops. Traffic signal timing is very important in an intersection. A properly timed traffic lamp can provide the following benefits:

- ✓ the safe and efficient movement of pedestrians and cars;
- ✓ the decrease of the frequency and severity of some types of crashes, etc.

These benefits are only achieved if the traffic lamps are timed according to the needs of the people that pass through the intersection, which are different for every intersection. The traffic signal controller at an intersection should implement timing settings designed specifically for that intersection [10].

Our project can be further improved in a very large number of ways, one of which being the inclusion of the system per whole as a component of a multiway intersection traffic control system.

Our project already offers the possibility for the traffic signals to be controlled from a distance which would make it suitable for both centralized and distributed traffic control systems. It would also be a way of deviating traffic from an accident site, allowing for the police and the ambulance to get there in time, but also to prevent other unwary drivers from colliding with the crashed vehicles; chain events of this sort having been known to happen in intersections. Another result of this would be reduced traffic delay, such a system being adaptable enough to ensure an optimal traffic flow. The particularities of each intersection could be taken into consideration and their needs met while also maintaining an organized and efficient movement of vehicles over a large road segment, covering several consecutive intersections. Such a system would provide better performance than a static signaling system [9].

Another improvement could be an adaptive intersection control system capable of detecting the number of cars in the intersection and adjusting the traffic signal timing according to it. These systems count the number of vehicles entering a certain junction and exiting from a certain junction in real time. This detection is then used to command a controller that adjusts the traffic light timing. In our case, the timing signal could be controlled from the accident monitoring station, from its PC microprocessor. In our case, the intersection is monitored visually through image processing, but devices designed especially for this purpose, traffic monitoring systems, can also be added [7] [8] [13].

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