Swarms of Cars: How to Automate Intelligent Drivers

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Abstract

Traffic accidents claim thousands of lives every year, and the number is going up. With today’s fast pace lifestyle, it is becoming harder to avoid the distractions that cause these tragedies. A solution must be developed to take driving out of the hands of humans and into something more reliable.

Despite having more distractions, more individuals, and immensely less brainpower than humans, small fish seem to have the collision problems of traveling in large groups figured out. Schools of fish move through a sea of predators, in groups of hundreds, in three dimensions with few to no collisions at all in their schools. It may prove useful to model fish schools in our search for safer automobile transportation.

1 Introduction

In 2004, 42,636 were killed in traffic accidents in the United States [1]. The 2005 statistics are predicted to be even higher. Many of these traffic accidents are caused by physical, chemical, or emotional distractions. Whether it be cellular devices, alcohol, or just road rage, removing these distractions is the key to preventing many traffic accidents. However, with today’s fast pace lifestyle, along with the sheer number of people who drive on America’s roads, this can be a particularly daunting task. A better solution may be to remove the person from the action of driving, allowing them to be distracted, and leaving the safety to the more reliable, and more predictable computer.

The goal of this research is to define a structure which can be used in an environment similar to what is in place. It is unreasonable to believe that all vehicles will be replaced at once with this or any other system. For this reason, it will be necessary to make the vehicle self-sufficient; it must get all its information from its environment and make its decisions on-board. The need for communications with other individuals must be minimal; it cannot be guaranteed that there are any other individuals. Input information can only reliably be obtained through the environment. It must also interact with environment and other individuals in it. In this respect, a SWARM intelligence algorithm seems perfect for the situation, since a SWARM unit can function by itself.

One can observe a school of fish and see the seemingly perfect structure of it. The school swims together, with very few collisions, despite having hundreds of individuals. They able to coordinate between hundreds of individuals in an instant, avoiding predators with one united motion. This paper suggests a structure for automated driving that with the design of the vehicle based on fish movement.

For the purposes of this research, the automated system will be narrowed to freeway driving; that is, high speed driving without stop signs or traffic lights. Also, assumptions must be made about the capability of the machinery and input mechanisms. The automobile must be able to accelerate, decelerate, and steer without user intervention. It should be able to calculate the speed and position
of all individuals and obstacles within some vicinity. It should also be able to know its own statistics, including stopping speed, acceleration rate, speed, and turning radius. It should have the ability to tell road from off-road (and avoid off-road), and know legal speed limits (this can be done with a detailed map and GPS locating service, which is currently available).

This paper is divided as follows. Section 2 is a background on fish schools, and the basis for this research. Section 3 describes a possible structure using this methodology, and the emergent system that arises from it. Section 4 compares this methodology against other proposed structures. Finally, in Section 5 the conclusion of this work is presented.

2 Inner Workings of a School

Schools of fish are an interesting part of the natural world. By itself, a schooling fish is a small, insignificant part of the sea. It is unintelligent and for our purposes uninteresting. However, when put in a group, they somehow organize into almost an organism in itself. The group will move as one, and divide and assimilate as needed to escape from predators [2]. It is unlikely that fish form into schools and behave in this manner purely by instinct. There is a communication system between fish which they use to coordinate their efforts. The fish’s sixth sense, the lateral line sensory system, is used for this purpose. The lateral line sensory system is a group of nerves that are found in all fish. It is used to sense small ripples of movement and energy in the water[3]. In this manner, fish can communicate with other fish in their immediate vaccinity. Schools form their characteristic movement abilities through the use of this sense. When one fish senses a predator or obstacles, it moves in a direction of its choice away from that obstacle. This throws a ripple that tells the fish in the area around them to move as well. It is also with this sensory system that fish can keep from running into each other while swimming in such close quarters.

Fish schools have no “leader” or central intelligence, they all work as a community, each pulling information from the fish and other environmental units around them, and reacting accordingly [2].

This sensory system is interesting because it helps the fish perform the function we wish to have in automobiles. An automated driving system that avoids obstacles, avoids collisions with other units, and is programatically independent is exactly what we need in terms of freeway driving, and it also gives us the option of seamless integration. If an automobile can simply pull information about placement and movement of other vehicles and obstacles on the road, then nationwide adoption of the technology will not be necessary for its usefulness.

3 The structure

Many systems have been designed to simulate the movements of fish schools, bird flocks, and herds of other animals. These systems, for the most part, have been designed from a computer graphics standpoint, for use in films to simulate animal movement. While the ultimate goal of the automated automobile and these systems is quite different, the method is very similar. In particular, there are 3 steering behaviors that are needed: Separation, Alignment, and Cohesion [4].

3.1 Separation

Separation is the tendency for an individual to try to stay a safe distance from the other individuals in its area. In fish schools as well as the computer graphics algorithm, three dimensions are important, while in our case only 2 are necessary. Also different is the algorithm itself. Fish school simulations can set the separation distance as a constant number, creating a circular (or spherical) area which no other units should enter. In the case of an automated vehicle, to fit in with current standards, a function must be created. Vehicles should be allowed to be closer if they are not directly in front of the individual. They also must stay on the road if it is possible to do so without collision.
In the above figure, the derived motion from the position of the other units could very well place our vehicle on the shoulder or siderail. This particular algorithm should be adapted. In many defensive driving classes, it is suggested to leave one car length per ten miles per hour of velocity between the vehicle and the vehicle immediately in front of it. This is a good rule of thumb, but this may be better represented by the speed and stopping power of the vehicle. More specifically, the distance from the leading vehicle should be the distance traveled while decelerating from the current speed, plus some buffer necessary between the leading vehicle and the unit at stop.

\[ x = \frac{-v^2}{2a} + b \]

In this equation, \( x \) is the distance, \( v \) is the current speed, \( a \) is the desired deceleration rate, and \( b \) is the desired buffer. The variables \( a \) and \( b \) can be set to make a user comfortable.

Since the highway is two dimensional, any vehicle in the area must be taken into account. Keeping all vehicles this distance away is very restrictive, and could cause problems given the finite width of the roadways. If the definition of the buffer is extended to be the distance to keep all vehicles at the same relative speed away, we can apply a sine function to the above equation to create an elliptical area around the vehicle.

\[ x = \sin(\theta)\left(\frac{-v^2}{2a}\right) + b \]

In the above equation, \( \theta \) is the angle relative to the vehicle, with 0 starting at the right side of the vehicle. \( x \) is the distance from the vehicle that will be considered in the separation area at the given theta. The rear of the vehicle can be ignored with respect to measuring the stopping distance. This distance will be calculated by the other vehicles that are to the rear. That is:

\[
\theta \leq \pi : \quad x = \sin(\theta)\left(\frac{-v^2}{2a}\right) + b \\
\theta > \pi : \quad x = b
\]

This creates a new separation zone similar to this figure (not to scale).

While this creates a reasonable separation zone, an escape algorithm must be adapted as well. Refering to the first figure, the unit moves towards the vector equal to the average of the inverse distances of all units in the separation zone; in this case it turns around and to the right[4].

\[ V = -\frac{\sum_{i=0}^{n} 1/d_i}{n} \]

Where \( V \) is the moving vector, and \( n \) is the number of intruding vehicles.

This is not an acceptable solution for the road, where in general turning and heading in the opposite direction is frowned upon. However, the general rule is still viable with the assumption that all the vehicles in the separation zone are traveling in the same general direction as the vehicle. Since this is the case, the function can be used as is for the horizontal component, and relatively for the forward component; that is, the vehicle does not turn around, but rather slows down.

This system is useful in collision avoidance. Vehicles are not exclusive to the group of objects to avoid; foreign objects and “off-road” should also be considered.

### 3.2 Alignment

Alignment is the tendency of the individual to steer itself to point the same direction as other units around it. This is
interesting in the functions of normal, non-evasive maneuvering. The general methodology is shown in this figure:

In this case the unit adjusts its steering to the average direction of all the vehicles in its alignment sight. Because of the nature of freeways, this must also be adapted. A percentage of American highways and freeways have no dividing space between vehicles traveling in opposite directions. In this case, the vehicle may get conflicting inputs, some traveling in the correct direction, and others in the opposite direction. To solve this, a heavy weight may be placed on units traveling in the same forward direction as the vehicle, or the vehicle may only take into account other units with velocities that are within a certain threshold of its own. The second solution also removes pieces debris and anything else the system may mistake for a unit from being calculated in the average angle function. It also, in most circumstances, removes vehicles exiting the freeway, as general driving rules dictate slowing down for exit ramps.

The alignment zone should be larger than the separation zone, to increase population of vehicles included in the average angle function. However, the elliptical shape of the separation zone should because of the one directional nature of freeways. In any situation where the steering angle must be changed, the vehicles to the rear should not factor in, as they have less information about the road ahead, and may skew the average angle function, resulting in understeering. On the same note, those vehicles not directly in front of the unit may have larger or smaller steering angles necessary to make a certain bend. The vehicle directly in front have the most accurate information regarding the steering angle, and therefore these should be weighted heavier than those in other lanes.

\[ x = m (\sin(\theta)(-v^2/(2a)) + b) \]

In this equation, \( m \) is the multiplier to the separation zone, to create a larger but similar area for the alignment zone. Reactions to alignment zone changes should be delayed by a period of time equal to the average distance of the vehicles from the unit divided by the current velocity. This is to avoid the situation of early steering, since the vehicle is only taking into account those vehicles in front of it. If this is not implemented, the system will move more like schools of fish, in that all the units in the system will steer in one direction at the same time. This could cause a catastrophe, since the roads have very specific turning areas.

### 3.3 Cohesion

Cohesion is the tendency of units in the system to move closer to the average position of the other units[4]. This rule works in direct opposition to the separation behavior, but is none the less necessary. Units must be close enough to each other to pull information from the units around it. In the same way that this works in opposition to the separation algorithm, its algorithm is the opposite.

\[ V = \frac{\sum_{i=0}^{n} 1/d_i}{n} \]

The only difference between this function and the separation function is this moves the vehicle towards the rest of the “flock” (note the lack of an inverse sign in this equation). This system works as secondary to the separation function; that is, if both these functions require the vehicle to move, the separation function will always win.

The cohesion zone should be a static circle, as large as the range of vision for the vehicle. This is because the cohesion zone should be actively searching for “flock” members to share information. As in the alignment algorithm, it is necessary to ignore those vehicles traveling in the opposite direction, for risk of the vehicle turning around at an incorrect time.
3.4 Emergent System

These three behaviors define all the movements of one vehicle. By itself, the vehicle is mostly uninteresting, and simply dodges and mimics the objects around it. However, when it is placed into a group, a system emerges that is greater than the sum of the parts. Take, for example, the illustration below:

In this situation, the gray area is the alignment zone, and the blue vehicles are those the unit will mimic. If these are driven by human drivers, then the unit will mimic the motions of those vehicles. However, if the vehicles are also run by this system, then they are in turn mimicking the vehicles in their line of sight. This effectively gives our unit an extended line of site, to avoid obstacles early on, that would not be seen otherwise until much later. If this effect continues, and the line of sight is extended even further, it will result in smaller overall changes to avoid obstacles, which results in greater comfort for the passengers.

Another emerging behavior is the tendency of the system to group together and find the least amount of congestion. For this to happen, the separation algorithm must be changed slightly. Rather than just applying the vector, it should strive to find the path with the smallest negative y component vector that does not result in a collision. If this is the case, the vehicle will move to the path that it requires it to slow down the least. Since the cohesion behavior is still in place, all units behind this vehicle will move towards this path as well, keeping all the vehicles moving at the fastest pace possible.

4 Comparison

Researchers at UC-Berkeley have designed the Automated Highway System with funding from the US Department of Transportation [5]. They created a hierarchical control architecture based on “platoons”. Vehicles are separated into platoons, and are separated by small distances, and the platoons are then separated by larger distances. Vehicles move through five maneuvers: join, split, lane change, entry, and exit. These are all coordinated to avoid collision. The vehicles all communicate between each other and with the higher level “master” to avoid congestion and larger collisions.[5]

There are upsides and downsides to any system, and automated driving systems are no exception. The system described in this research provides an autonomous solution for highway driving, while the AHS is based on a large hierarchy controlling all vehicle movement. The autonomous solution has the advantage of being easily integrated into the current system. It can also use only its current environment to drive itself and avoid collisions. AHS has the advantage of knowing all the road conditions and congested areas, and coordinating with the vehicles accordingly to assure safe, smooth travel.

A problem with the autonomous solution is that it cannot “see” very far ahead of its path. It cannot avoid major congestion, only minor congestion as discussed earlier. If there is a tree blocking the road ahead, it cannot know to change paths before it can actually see the tree. AHS has an issue with the single point of failure. A single bug or missed signal could shut down the entire highway system across the country. The autonomous system does not suffer from this problem.

The best solution may be a hybrid of the two systems. A system that drives locally using autonomous methods, but uses a large networked service to do dynamic path selections based on congestion is a viable solution that could be implemented into our current driving force.

5 Conclusion

This paper demonstrated an automated driving system based on SWARM flocking behavior. It provided an overview of the problems with the traditional flocking algorithms and provided theoretical solutions for these
problems. It compared the system to another system trying to solve the same problems. Future considerations may include algorithms for city driving, as well as algorithms for entering and exiting the highway.

References


