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Computer Science

"Application of Genetic Algorithms to Multi-Agent Autonomous Pilot for Motorcycles"

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Abstract

The Physics behind motorcycle driving are well understood and implemented by studying the laws of kinetics and kinematics behind the operation of the single track motor vehicle.

In this thesis I propose to work with a application which is currently using OpenGL and implements an interactive motorcycle simulator which is based on the laws of physics. This application involves a multi-agent pilot capable of autonomously driving the vehicle using some configurable equations.

The proposal consists in applying of the genetic algorithms to find suitable values for the parameters of the pilot by testing it in a non graphical environment, and later visually verify the results of the genetic algorithms with graphical interface application.

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1. Literature Review

The first project in the field of bicycle dynamics was the (Olsen and Papadopoulos, 1988) was created to apply modern scientific techniques to the engineering problems of the bicycle. They applied the mathematics to include the important aspects of geometry and mass replacement. They selected to work on a basic bicycle model that had rigid knife edged wheels, a rigid rear frame including a rigidly mounted and immobile rider, and a rigid steer able front fork, including front wheel, stem, and handlebar. The equations they obtained were not as straightforward as mass or spring fitness, but rather involved functions of bicycle velocity, frame geometry, and various characteristics of the bicycle and rider's distribution of mass and also the leaning affects on steering and vice versa.

Another project taken by CBRP (Fuchs, 1998) considered minimizing the disturbing effects of steady crosswinds on single-track vehicles. The equation to calculate the equilibrium location of the center of pressure for zero steering angles in crosswinds - the 'trim equation' - has been derived. Using it, a single-track velomobile designer may trim his vehicle to achieve good handling characteristics under certain conditions (angle of attack); the torque that has to be exerted by the rider onto the handlebar may be minimized. But the fact that a vehicle is in trim at certain angles of attack does not assure safe handling in any situation that may be encountered in windy conditions on the street. For the first time it was mathematically shown that static stability of single-track vehicles in crosswinds is achieved when the center of pressure is in front of the center of mass. In this research they have not considered the dynamics of transition from one state of crosswind influence to another state of cross wind influence.

In the (Fajansa, 2000) considered centrifugal forces that will throw the bike over the side if the rider steers the handlebars in the opposite direction of the desired turn without first leaning the bike in to the turn. Leaning the bike into the turn allows gravitational forces to balance the centrifugal forces, leading to a controlled and stable turn. Thus steering a bike involves a complicated interaction between centrifugal and gravitational forces, and torques applied to the handlebars, all edited by the bike geometry.

One more research study which is of interest is (Vrajitoru, Mehler, 2004) which illustrates the application simulating a motorcycle that can be driven by both a human player and an autonomous pilot. The application is implemented based on the physical equations describing the vehicle's attributes, motion, and road behavior. This application aims at controlling the vehicle in a non deterministic way inspired from the behavior of a human driver and using the same kind of perceptual information to make decisions.

The project proposed for this thesis is a continuation of the project presented in (Vrajitoru, Mehler, 2004) .Starting from the existing model for the motorcycle and the pilot, we aim to apply genetic algorithms to configure the autonomous pilot.

2. Project Descriptions and Motivation

The paper which motivated my interests is (Vrajitoru, Mehler, 2004) in which they describe the motorcycle simulation implemented using the OpenGL library and providing real time interaction for a human player. They developed a visual interface that allowed a human user to change the point of view and drive the vehicle which in this case is a motorcycle. This application currently includes an autonomous pilot that can be toggled on and off and also a test circuit that human or automatic driver must attempt to complete. The autonomous pilot is a multi-agent probabilistic application with a separate configuration interface where each process is acting on one of the control units of the vehicle like gas, brakes, the handlebars (equivalent to the steering wheel for a car). The agents use some of the information about the current status of the vehicle to make a decision about an action to be taken on the control units they are in charge of. The information includes both status data, like the current speed, and perceptual data, like the visible distance on the road in the direction of movement, the lateral distance to the border of the road and current slope.

My goal in this project is to apply genetic algorithms (GAs) to configure these agents. Thus, each agent has a behavior determined by a set of equations involving some coefficients and thresholds,

as I shall briefly describe in the next section. All of these are currently configured by a human player by trial and error, which is a time consuming and imprecise process.
By applying the GAs to find the optimal values for all of the coefficients involved in the equations of the agents the process of deriving a good behavior for the autonomous pilot can be made automatic. In the same time I hope to achieve a better performance than it is possible by simply adjusting these parameters by hand.

3. Algorithms, Models, and Methodology

3.1 Physical Model of the vehicle

This section provides the information regarding the physical equations in conjunction with the GA to configure each of the agents and to control their behavior.
The motorcycle is currently modeled as a coupled system with a certain number of degrees of freedom wheels spinning, handlebars turning around its axis, and the entire vehicle leaning left and right. The motion of the vehicle is non holonomic, the motion being focused on the direction of movement and is described by the following equations.

Acceleration:

Let us consider the following notations:
_ $s(t)$ the spacial position of the object at time t,
_ $v(t)$ the momentary speed or velocity, $v(t) = s'(t)$,
_ $a(t)$ the momentary acceleration, $a(t) = v'(t) = s''(t)$.
By applying the Newton's laws of motion, we can describe the following system of equations describe the spatial position of the motorcycle at the moment $t + \Delta t$ by

$$s(t + \Delta t) = s(t) + v(t)\,\Delta t + a(t)\,\Delta t^2 / 2$$

$$v(t + \Delta t) = v(t) + a(t)\,\Delta t \qquad (1)$$

In our case, the acceleration is defined by the amount of gas supplied to the engine by the throttle, by the force applied to the brakes, by the friction force, and by the gravitational force. The system is set in such a way that a given amount of gas supplied to the engine can only lead to accelerating the vehicle up to a speed limit depending on the amount of gas. This simulates the engine limitations of a real vehicle. Let us denote by $sl(s(t))$ the angle made by a tangent to the road in the direction of movement with the horizontal plane.

The following is the equation is used to determine the acceleration applied to the vehicle.

$$a(t) = throttle(t) + g\, sin(sl(s(t)) - k\, g \cos sl(s(t)) - Dv^2 \qquad (2)$$

In this equation, the first term represents the amount of gas supplied to the engine, the second one the amount of gravitation applied to the vehicle in the direction of movement, $g = 9{:}8\ m/s^2$ where g is the gravitational acceleration on the surface of the Earth, and on the slope of the road at the current point in space in the direction of movement. The third term represents the acceleration generated by the friction force, where k is a constant specific to the surface material. The last term represents a drag force, where the coefficient D is determined by the force applied to the brakes and the engine brake. This prevents the speed of the vehicle from increasing infinitely.

The Handlebar

A special model is necessary to explain the behavior of the motorcycle when the lateral axis of the handlebar is not orthogonal to the central axis of the motorcycle. Let $ha(t)$ be the angle made by the plane of the front wheel with the central plane of the motorcycle and let ds be the horizontal distance covered by the vehicle is the lapse of time Δt. We would like to determine the new angle between these two plane after Δt, $ha(t + \Delta t)$ and the new position $s(t + \Delta t)$.

To simplify the model, we can consider that if the distance ds is greater than the distance between the centers of the wheels, then the direction of movement is simply rotated by the angle $ha(t)$ and the new position is calculated by translating the vehicle by the distance *ds* in the new direction of movement. This idea is illustrated by Figure 1.

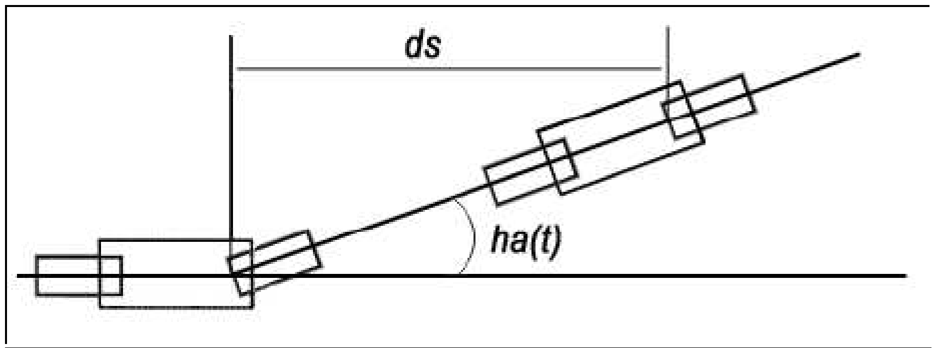

Figure 1: Change in direction due to the handlebar

In the case where the distance *ds* is smaller than the distance between the centers of the wheels, we determine the new direction of movement and the new orientation based on the idea that the front wheel will move in the direction that it is facing, which is given by the position of the handlebar. In this we have considered the back wheel continues along the former direction of movement while gradually changing its orientation to match the orientation of the front wheel. This is a small simplification of what happens in the case of a real motorcycle. The new direction of movement is given by the straight line between the centers of the wheels. Figure 2 illustrates the interpretation we have adopted for the second case.

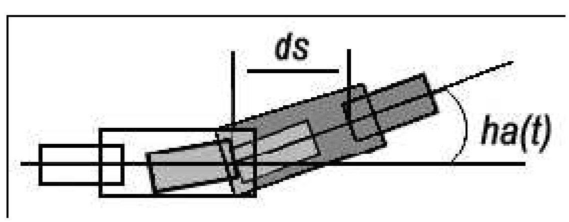

Figure 2: Change in direction due to the handlebar, short distance

<u>Change in direction by Leaning:</u>

When the vehicle is leaning laterally, instead of falling, it starts turning on a circle and its movement is determined by the centrifuge force:

$$F_c = m \omega^2 r \qquad (3)$$

where ω is the angular speed and r is the radius of the circle on which the object is turning. Calculating this radius is essential to determine the change in direction of movement due to leaning. If v is the horizontal speed, then we can define the angular speed as w = v/r, so the centrifuge force is equal to

$$F_c = m\ (v^2/r) \qquad (4)$$

A second force that interacts with the vehicle in the lateral movement is the lift force due to the friction with the air. We can adapt an equation taken from airplane wing simulation that computes the *lifting force* F_L(Vrajitoru, Mehler, 2004) as

$$F_L = ½(\rho\ v^2 S_{ref} C_L) \qquad (5)$$

In this equation ρ is the air density, that we can consider to be approximately ρ = 1:22145kg/m^3 at 0 altitude. S_{ref} is the reference area that we can compute as the horizontal projection of the vehicle. If Sv is the total porting lateral surface of the motorcycle and the driver, S_h the porting horizontal surface of the motorcycle, and a is the angle made by the vertical axis of the motorcycle with the horizontal plane, then

$$S_{ref} = Sv \cos\alpha + S_h \sin\alpha \qquad (6)$$

The last component of the lateral movement is the gravitational force itself, which has a norm equal to $g\ m$. From this force, we have to subtract the lifting force first. Starting from the same angle α, the resulting force which is vertical can be decomposed into a force oriented along the vertical axis of the motorcycle and another one that is orthogonal to the motorcycle. The rotation will be determined by the component that is perpendicular to the motorcycle axis. This component, that we call *central gravitation* and denote by Gc, is given by

$$Gc = (g\ m - F_L) \sin\alpha \qquad (7)$$

By imposing the condition that the central gravitational force should be equal to the centrifuge force, we can compute the rotation radius r:

$$r = m v^2 / ((g m - F_L) \sin\square \quad (8)$$

3.2 Example of an Agent -Throttle

The motorcycle is driven by several control units (CUs). Each of them is controlled by an independent agent with a probabilistic behavior. The agents are not active during the computation of each new frame simulating the evolution of the vehicle on the road, but only once in a while in a non-deterministic manner. This simulates the behavior or a human driver that may not be able to instantly adapt and take action based on the road situation and would require a certain reaction time. The minimal model requires a CU for the gas - throttle, which determines the acceleration, for the brakes, which can slow down or even stop the vehicle, and for the handlebar that controls the direction.

Each of these control units is independently adjusted by an agent. The behavior of the agents depends on the status of the vehicle and is intended to drive the motorcycle safely in the middle of the road and at a speed as close as possible to a given limit. Each agent can have its own rate of interference with the coordination of the vehicle, and in our case, the agents controlling the throttle and the handlebar are in general more active than the agent controlling the brakes.

This following gives the brief overview of how the throttle agent works.

This CU and its corresponding agent control the amount of gas that is supplied to the engine and determines the acceleration that the vehicle is submitted to.

This agent takes as input information the current speed, the front distance, the lateral distances, and the slope. The agent has three speed thresholds that it is using to adapt the amount of gas with the aim of adjusting the speed: a minimal threshold, that determines the minimal speed that the vehicle should have at any time; the maximal threshold, that represents the maximal speed at which the driver feels safe driving the vehicle, and the speed limit, which is an exterior measure that does not depend on the performance of the vehicle and of the driver.

The agent will attempt to keep the vehicle speed above the minimal threshold and below the maximal one, and also below the speed limit but not too different from it. If the lateral distance to the left is too far from the lateral distance to the right, the speed must be decreased because the road is most probably turning. The same rule applies to the visible distance in front of the driver: a short distance represents an unsafe road situation and the speed has to be decreased. Let $tr(t)$ be the amount of gas going to the engine at the moment t, which in turn determines the acceleration of the vehicle. Let us also denote by lat_{norm} the normalized of the difference between the left and right distances as shown in Equation 9 and by $lat_{abs} = |lat_{norm}|$ the absolute value of this quantity.

$$lat_{norm} = (leftd - rightd)/\max(leftd; rightd) \qquad (9)$$

Equation 10 presents the condition that must be fulfilled for the throttle to be increased or opened, which results in a higher acceleration followed by an incrementation of the speed. In this equation, v_{low} is a lower limit for the speed, thr_{lat} is a threshold under which we consider that the difference between the left and right distances is still safe, thr_{front} is the threshold for the safe front distance, v_{limit} is an upper speed limitation, like the legal speed limit on that road, and c_{tr} is a constant.

$$\begin{array}{ll} v(t) < v_{low} & \text{or} \\ lat_{abs} > thr_{lat} & \text{and} \\ front > thr_{front} & \text{and} \\ v(t) < v_{limit} & \text{and} \\ v(t) < c_{tr} \_ tr(t) & \end{array} \qquad (10)$$

Let us denote by tr_{lat} a quantity indicating if the normalized absolute difference between the left and right distances is safe for the vehicle's current speed, as shown in Equation 11.where c_{vlat} and *pvlat* are constants. For higher values of the speed, the safe difference is smaller.

$$trlat = lat_{abs} - (C_{vlat})/(1+v(t))^{1/pvlat}) \qquad (11)$$

Let us denote by tr_{fr} a quantity indicating if the front distance is safe for the vehicle's current speed, as shown in Equation 12 where $c_{v\,fr}$ and $pvfr$ are constants.

$$tr_{fr} = (c_{vfr} / (1+v(t))^{1/pv\,fr}) - front \tag{12}$$

Equation 13 represents the condition to be fulfilled for the throttle to be decreased or closed, which will have the effect of slowing down the vehicle under the influence of the friction force.

$$v(t) > v_{limit} \text{ and } tr_{lat} > 0 \text{ and } tr_{fr} > 0 \tag{13}$$

Let us denote by $\Delta tr = tr(t + \Delta t) - tr(t)$. The equation governing the change in throttle that the agent will perform based on the current vehicle and road status is illustrated by Equation 14 where c_{incv}, c_{decv}, and c_{sl} are constants. The actual amount of the change is a probabilistic quantity equally distributed in a small neighborhood around the computed value.

$$\begin{aligned}\Delta tr = {} & c_{incv}(front - thr_{front})(v(t) - v_{low}) + \\ & c_{decv}((v(t) - vlimit) + t_{rlat} + t_{rfr}) + c_{sl}.slope\end{aligned} \tag{14}$$

3.3 Introduction to Genetic Algorithms

Genetic algorithms (GA) (Holland, 1975; Goldberg 1989) are a part of evolutionary computing, which is a rapidly growing are in the field of artificial intelligence. These algorithms are based on Darwin's theory of evolution. That is the problems are solved by an evolutionary process which is used to optimize the solutions to a given problem (the solution is not always the best). A GA is an probabilistic algorithm used to find approximate solutions to difficult-to-solve problems through application of the principles of evolutionary biology to computer science. Genetic algorithms use biologically-derived techniques such as inheritance, mutation, natural selection, and recombination (or crossover).

Genetic algorithms are typically implemented as a computer simulation in which a population of abstract representations (called *chromosomes*) of candidate solutions (called *individuals*) to an optimization problem evolves toward better solutions.

This means that we are looking for optimal solution to an optimization problem within the search space which is the set of all possible chromosomes. Each point in the search space (chromosome) represents one possible solution to the problem. Traditionally, solutions are represented as binary strings of 0 and 1 value called *genes*. The evolution starts from a population of completely random individuals and happens in several generations. In each generation, multiple individuals are stochastically selected from the current population, modified (mutated or recombined) to form a new population, which becomes current population in the next iteration of the algorithm.

A measure of how good a solution is to solve the problem is called *fitness function,* is also necessary in the evolutionary process.

Operation of a GA

The algorithm begins with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one partially explained by the shemata theorem (Goldberg 1989). From the current individuals some are selected to form new solutions (offspring) .This process uses the fitness of each individuals such that the more suitable they are as solutions to the problem, the more chances they have to reproduce.

This is repeated until some condition (for example number of populations or improvement of the best solution) is satisfied.

Outline of the Basic Genetic Algorithm

1. **[Start]** Generate random population of *n* chromosomes (potential solutions for the problem)

2 **[Loop]** over the following steps until a convergence condition is satisfied.

   1. **[Fitness]** Evaluate the fitness *f(x)* of each chromosome *x* in the population
   2. **[New population]** Create a new population by repeating following steps until the new population is complete

3. **[Selection]** Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected)
4. **[Crossover]** With a crossover probability cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
5. **[Mutation]** With a mutation probability mutate new offspring at each locus (position in chromosome).
6. **[Accepting]** Place new offspring in the new population
7. **[Replace]** Use new generated population for a further run of the algorithm
8. **[Test]** If the end condition is satisfied, **stop**, and return the best solution in current population

3 **[Return]** the best solution in the last generation.

3.4 Genetic Representation of the Motorcycle Pilot

To apply the GAs to our problem we need to find a good representation of the potential solutions as chromosomes and to find a good fitness function.
The behavior of the agents is described by some equations. For example in section 3.2 we have introduced the throttle agent. The genetic representation of this agent starts with the sequence of all configurable parameters occurring in equations (9) to (14)

$$S = (lat_{norm}, leftd, rightd, v(t), v_{low}, lat_{abs}, thr_{lat}, front, thr_{front}, vr_{limit}, c_{tr}, tr(t), tr_{lat}, pvlat, tr_{fr}, c_{vfr}, pvfr, c_{incv}, c_{dec}, c_{sl})$$

These are all real numbers that we can further represent as a sequence of binary genes(for example 10 genes by parameter 1. For example if the $0 \leq thr_{front} \leq 10$,then the sequence 00….0 will represent $thr_{front} = 0$, 11…...1 will represent $thr_{front} = 10$, 10….0 for $thr_{front} = 5$, and so on.
The final chromosome is a concatenation of all these sequences of genes for all of the parameters.

The fitness function will be computed by viewing the motorcycle in a non graphical environment over the entire circuit using the real representation of the chromosome as configuration for the autonomous pilot. The criteria of fitness will involve how far the pilot went on the circuit before crashing or getting out of the road, and how far it completed the circuit in case of success.

At the end of experiments, the parameters derived by the GAs can be imported back into the graphical application for a visual verification of the quality of the solution.

4. References

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5. Appendices