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From MAS-Students_ss15

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Topic: Real World Optimization of Energy Efficient Vehicle Control
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Contents

Abstract

- Energy efficient vehicle control is able to reduce the energy consumption of vehicles

- Reduced energy consumption can save money and reduce CO_2 – emissions

- Optimal control strategies are hard to come up with, even for known tracks and when computed offline

- Real world applications need to handle
    - long distances
    - uncertainty & noise
    - unforeseen situations

- Previous approaches to energy efficient vehicle control include Optimal control theory and Graph search algorithms

- Solutions using optimal control theory can only be found under certain conditions

- Graph search algorithms need very much space to come up with good approximations

- One recent approach used artificial neural networks and evolutionary strategies to come up with an optimal control strategy in simulation

- Transferring evolved solutions from simulation into reality usually yields suboptimal results -> Reality Gap
- Approaches to overcome include
    - Adding noise to simulation
    - Use of more accurate simulation
    - Transferability

- The goal of this R&D is to design a controller for energy efficient vehicle

control for the real vehicle using
- Evolutionary approach
- Transferability approach
- Distance metric simulation vs real world
- Surrogate model

Introduction

- As driver trainings have shown optimizing driving behaviour can lead to decreased consumption of energy vehicles
- Although effect of trainings decrease over time, automated vehicle controllers could keep the effect
- Autonomous vehicle control is becoming reality fast
- Transportation sector could greatly benefit from decreased energy usage
- Environment would benefit from reduced CO_2-emissions
- Previous approaches to energy efficient control included
  - Optimal control theory
  - Dynamic Programming
  - GraphSearch (A-Star)
  - Evolutionary algorithms (only applied in simulation)
- Previous approaches have several drawbacks
  - Not usable in real-time
  - Very high memory usage
  - Need for discretization
  - Has not been evaluated on real device
  - Is not designed to overcome the reality gap
- This work is about using evolutionary algorithms to create an energy efficient vehicle controller and apply it to a real device
- More elaborate vehicle model will be created data driven
- Methods to overcome reality gap will be applied
- Real device will be used to evaluate controller and compare it to previous controllers

Problem Formulation

What is this project about?

- Creating an energy efficient vehicle control for a real-world vehicle using evolutionary algorithms

Why is it relevant?

- Energy-efficiency is important in transportation as even small improvements result in huge savings of energy

- There is still much room for improvements as even simple driver-training programs have yielded impressive results

What have other people done in this field?

- Driver trainings about efficient driving
- Use of optimal control theory
- Use of graph search algorithms
- Use of heuristics to prune search space
- Use of inverted system equations to avoid discretization
- Application of evolutionary algorithms to evolve a controller in simulation

Why is that not sufficient?

- Effects of trainings decrease over time
- Complexity and computation speed is not good enough for real time application
- Not all system equations can be inverted and it is non-trivial
- Vehicle control only developed in simulation without preparations for transfer to real world
- Transfer algorithms do not have many real world applications so far, only proof of concepts

What is the deficit addressed in this project?

- The controller so far has only been developed in simulation and not on the real device

State of the Art

Essays

Evolving Look Ahead Controllers for Energy Optimal Driving and Path Planning

Full reference: Gaier, A., & Asteroth, A. (2014, June). Evolving look ahead controllers for energy optimal driving and path planning. In Innovations in Intelligent Systems and Applications (INISTA) Proceedings, 2014 IEEE International Symposium on (pp. 138-145). IEEE.

Abstract: An evolved neural network controller is presented to solve the optimal control problem for energy optimal driving. A controller is produced which computes equivalent control commands to traditional graph searching approaches, while able to adapt to varied constraints and conditions.

Furthermore, after training, trivial amounts of computation time and memory are required, making the approach applicable for embedded systems and path planning applications.

Keywords:

Problem formulation

- Developing techniques for near energy-optimal control of vehicles using controllers that base their decisions on characteristics of the road.
- Developing control strategies that make the best use of the terrain.

Why is this still a problem?

- Engineering of transport systems resulted in efficient designs, but further optimizations are diminishing.
- Driver-training programs have yielded impressive results.
- Instead of being reduced, emissions caused by transportation drastically increased in 2005 and 2007.

State of the art

Energy-optimal control of commercial trucks and trains

- Energy-optimal control of experimental vehicles
- Energy-optimal control of hybrid gas-electric vehicles
- Finding fuel-optimal behavior of an experimental fuel-cell vehicle using optimal control theory and a simplified model of environment and vehicle
- It was found that only three commands are needed to produce an optimal strategy:
    - full power
    - maintain velocity
    - coast
- Reformulating the problem as a graph-search problem using A* and a special heuristic the number of nodes needed could be drastically decreased with still achieving nearoptimal solutions
- Using dynamic programming to reduce complexity and rounding errors from state space discretisation
- Using inverted system equations real valued controls could be used. But not all equations can be inverted and it is often non-trivial
- Avoiding numerical issues by first defining the boundary line between feasible and infeasible states. This reduced computation costs by an order of magnitude.
- Neuroevolution techniques have shown to be more effective on some benchmark tests than reinforcement learning techniques
- NEAT is the current most successful algorithm within neuroevolutionary algorithms

What is the author's contribution?

- Use of evolutionary algorithms instead of graph search algorithms
- Application of a state-of-the-art evolutionary algorithm to the energy-optimal control problem

How did the author's solution solve the addressed problem?

- By using the method of NEAT (NeuroEvolution of Augmented Topologies) the authors evolve a controller for an e-bike
- Use of simplified vehicle model
- Use of three motor commands
- Evolutionary algorithms do not need to work in a discretized state space, so rounding errors are no problem
- Evolutionary algorithms do not use state space models. Therefore increasing the complexity of the model does not have a huge effect on the space complexity.
- Using a local solution that calculates new commands at every meter, a deggree of precision can be achieved that is not possible for graph search in most scenarios.

Evaluation

- Comparison of performance on 35 routes with a Graph Search algorithm
- Training of net using cross-validation
- Training on 5 maps, testing on remaining 30
- 50 training runs, each containing of evolving a population of size 150 for 1000 generations.
- Comparison to graph search in three different resolution levels
- Performance is only slightly worse than the highest depth graph.
- Analysed in detail most solutions performed better
- Computation time was nearly instantaneous versus about 1 minute for an 8km route
- Space complexity was about 1KB versus 11GB

What are the scientific deficits of this approach?

- The approach taken uses a very popular algorithm from evolutionary algorithms, but it does not use any techniques to ensure that the evolved controller will be able to run on a real device. Where the authors can give a prove f concept that an evolutionary algorithm may be better suited than a graph search approach, like this it probably is not usable in practise. Although giving prove of concept was the author's goal and this is not a scientific deficit but a shortcoming of this approach so far.
  - Miglino, O., Lund, H. H., & Nolfi, S. (1995). Evolving mobile robots in simulated and real environments. Artificial life, 2(4), 417-434.
  - Jakobi, N., Husbands, P., & Harvey, I. (1995). Noise and the reality gap: The use of simulation in evolutionary robotics. In Advances in artificial life (pp. 704-720). Springer Berlin Heidelberg.
  - Koos, S., Mouret, J. B., & Doncieux, S. (2013). The transferability

approach: Crossing the reality gap in evolutionary robotics. Evolutionary Computation, IEEE Trans-actions on, 17(1), 122-145.

What are the scientific contributions of this approach?

• The authors were able to show that using evolutionary algorithms for optimizing energy-efficient driving outperforms graph search algorithms in terms of computation time and space needed and produces solutions that are nearly as optimal as solutions from very detailed graph search algorithms. • As for this paper is very recent (2014) I am not able to quote any other work that supports my statement. Citeseer does not know this paper yet and google just gives one quote from a paper of the same authors.

Evolving neural networks through augmenting topologies

Full reference: Stanley, K. O., & Miikkulainen, R. (2002). Evolving neural networks through augmenting topologies. Evolutionary computation, 10(2), 99-127.

Abstract: An important question in neuroevolution is how to gain an advantage from evolving neural network topologies along with weights. We present a method, NeuroEvolution of Augmenting Topologies (NEAT), which outperforms the best fixed-topology method on a challenging benchmark reinforcement learning task. We claim that the increased efficiency is due to (1) employing a principled method of crossover of different topologies, (2) protecting structural innovation using speciation, and (3) incrementally growing from minimal structure. We test this claim through a series of ablation studies that demonstrate that each component is necessary to the system as a whole and to each other. What results is signicantly faster learning. NEAT is also an important contribution to GAs because it shows how it is possible for evolution to both optimize and complexify solutions simultaneously, offering the possibility of evolving increasingly complex solutions over generations, and strengthening the analogy with biological evolution.

Keywords:

What is the paper about?

- A new algorithm called NEAT for neuroevolution (NE), i.e. the design of the topology and the parameters of an artificial neural network using evolutionary techniques

Why is this relevant?

- NE has shown to be faster and more efficient than reinforcement learning methods on tasks as single pole-balancing and robot arm control
- NE is effective in continuous and high dimensional state spaces
- Memory can easily be represented through recurrent neural networks, which makes NE a natural choice for non-Markovian tasks.

What have others done and why is this not sufficient?

- Topology of ANN chosen before the experiment
- Research on algorithms that evolved the topology/structure of an ANN provided inconclusive answers about why evolving the topology is superior to using fixed topologies
  - Evolving topology lead to solving the hardest pole-balancing task so far, but could be achieved with randomly initialized topologies afterwards five times faster.
- Evolving topology and weights significantly enhances the performance of NE

What have the authors done and why is this better?

- Introduction of NeuroEvolution of Augmented Topologies (NEAT)
  - Use of historical markings to keep track of the same genes in different solutions -> Allows for an easy and meaningful application of the cross-over operator
  - Using speciation, i.e. compute the similarity of solutions and share their fitness if similar enough → Protection of new innovative solutions to give them time to develop their potential
  - Start with minimal solution and grew them more and more complex -> Algorithm will search low dimensional search space first which enhances performance

Evaluation

- Comparison to SOA approaches in the creation of XOR gates -> NEAT could outperform the other methods
- Comparison to SOA approaches in a double pole-balancing task -> NEAT could outperform the other methods
- Tested necessity of cross-over -> Significantly more evaluations needed to find a solution
- Tested necessity of speciation -> Failure in about 25% and about seven times more runtime
- Tested necessity of complexification -> Fixed ANN successful in about 20% and about

8.5 times slower

What are the scientific deficits of this approach?

What are the scientific contributions of this approach?

- Method to optimize architecture and weights – Chen, Yuehui, et al. "Time-series forecasting using flexible neural tree model." Information sciences 174.3 (2005): 219-235.

- Whiteson, Shimon, and Peter Stone. "Evolutionary function approximation for reinforcement learning." The Journal of Machine Learning Research 7 (2006): 877-917.
    - Clune, Jeff, et al. "Evolving coordinated quadruped gaits with the HyperNEAT generative encoding." Evolutionary Computation, 2009. CEC'09. IEEE Congress on. IEEE, 2009.
  - Approach to overcome "course of dimensionality"
    - Togelius, Julian, et al. "Search-based procedural content generation: A taxonomy and survey." Computational Intelligence and AI in Games, IEEE Transactions on 3.3 (2011): 172-186.

Explicit Fuel Optimal Speed Profiles for Heavy Trucks on a Set of Topographic Road Profiles

Full reference: Froeberg, Anders, Erik Hellstroem, and Lars Nielsen. Explicit fuel optimal speed profiles for heavy trucks on a set of topographic road profiles. No. 2006-01-1071. SAE Technical Paper, 2006.

Abstract: The problem addressed is how to drive a heavy truck over various road topographies such that the fuel consumption is minimized. Using a realistic model of a truck powertrain, an optimization problem for minimization of fuel consumption is formulated. Through the solutions of this problem optimal speed profiles are found. An advantage here is that explicit analytical solutions can be found, and this is done for a few constructed test roads. The test roads are constructed to be easy enough to enable analytical solutions but still capture the important properties of real roads. In this way the obtained solutions provide explanations to some behaviour obtained by ourselves and others using more elaborate modeling and numeric optimization like dynamic programming.

The results show that for level road and in small gradients the optimal solution is to drive with constant speed. For large gradients in downhill slopes it is optimal to utilize the kinetic energy of the vehicle to accelerate in order to gain speed. This speed increase is used to lower the speed on other road sections such that the total average speed is kept. Taking account for limitations of top speed the optimal speed profile changes to a strategy that minimizes brake usage. This is done by e.g. slowing down before steep down gradients were the truck will accelerate even though the engine does not produce any torque.

What is the paper about?

- How to drive a truck such that the fuel consumption is minimized?
- Finding an optimal strategy.
- Understanding of the energy usage of a heavy truck.
- Proving the correctness of previous results mathematically.

Why is this relevant?

- Fuel is a large part of the operating costs of heavy trucks. Reducing the need could save money.

What have others done and why is this not sufficient?

- Use of simple models.
- Use optimal control theory approach (e.g. dynamic programming) -> approximate solutions

What have the authors done and why is this better?

- Analytical derivation of efficient driving behaviour using a physical model of a heavy truck that can predict the fuel consumption while being manageable complex.
- Used model is very accurate and consists of:
  - Engine
  - Transmission
  - Final Gear
  - Wheels and Chassis
- Using this model and their mathematical approach, the results and derived behaviours are very accurate.

Evaluation

- The authors did not do a an evaluation in the sense of a simulation or real world experiments. Instead they created the physical model of a heavy truck and derived different optimal behaviour for different situations.
- They showed that:
  - for level roads maintaining a constant speed is optimal
  - for small gradients maintaining a constant speed is optimal
  - for steep uphill slopes maximum fuelling is optimal
  - for steep downhill slopes cutting off fuel until desired velocity is reached afterwards is optimal
  - when considering a maximum speed cutting of fuel to decelerate some time before the downhill slope to reach maximum velocity at the end of the slope is optimal. This point can be calculated.

What are the scientific deficits of this approach?

- No use of other economic factors apart from fuel consumption
  - Passenberg, Benjamin, Peter Kock, and Olaf Stursberg. "Combined time and fuel optimal driving of trucks based on a hybrid model." Control Conference (ECC), 2009 European. IEEE, 2009.
- Not applicable to unknown tracks
  - Sahlholm, Per, et al. "A sensor and data fusion algorithm for road grade estimation." 5th IFAC Symposium on Advances in Automotive Control (2007). 2007.

What are the scientific contributions of this approach?

- Energy optimal control can be achieved using only three motor commands:
    - Full Power
    - Maintain Velocity
    - Coast
- Ivarsson, Maria, Jan Aslund, and Lars Nielsen. "Look-ahead control-consequences of a non-linear fuel map on truck fuel consumption." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile engineering 223.10 (2009): 1223-1238.
- Gaier, Adam, and Alexander Asteroth. "Evolving look ahead controllers for energy optimal driving and path planning." Innovations in Intelligent Systems and Applications (INISTA) Proceedings, 2014 IEEE International Symposium on. IEEE, 2014.
- Sahlholm, Per, et al. "A sensor and data fusion algorithm for road grade estimation." 5th IFAC Symposium on Advances in Automotive Control (2007). 2007.

Energy efficient control of rail vehicles

Full reference:

Golovitcher, Iakov M. "Energy efficient control of rail vehicles." Systems,Man, and Cybernetics, 2001 IEEE International Conference on. Vol. 1. IEEE, 2001.

Abstract:

This paper describes an analytical method of computation of optimal controls which minimize the energy consumption by rail or any other fixed path vehicles. A specific aspect of this problem is that the external forces applied to the vehicle and the maximum allowable speed depend on the coordinate of the vehicle. The known analytical solutions do not take this important feature into account. Classical numerical methods of optimization cannot be used by an on-board computer since they require significant computation time. We applied the maximum principle to determine: the set of optimal controls, the switching graphs and the optimality conditions. Based on these results, we developed an efficient computation algorithm without sacrificing the accuracy of the mathematical model. The paper is concluded with an example of optimal controls and discussion of some applications of the presented method.

What is the paper about?

- Analytical method for computation of optimal controls
- Minimize energy consumption for rail or other fixed path vehicles

Why is this relevan?

- Raising energy prices

- Environmental concerns

What have others done and why is this not sufficient?

- Classical numerical methods of optimization
  - Significant computation time
  - No real time calculations possible

- Applying analytical methods of optimal control theory
  - Simplified assumptions about tracks

- Set of optimal Controls for a short seciton of the track
  - Ignores some contstraints on the velocity

What have the author's done and why is this better?

- Analytical solution of optimization problem
- No simplifications
- Include steep climbs and descents
- Apply the maximum principle
- Use control-switching graphs to find a sequence of controls

How did they evaluate their solution?

- Computer simulation of calculated strategy
- Application of strategy on several known tracks and schedules
- Computed savings of 3% for subway lines not having any spare time
- Optimizing timetables for a long segment for local, intercity and freight traffic resulted in about 7% savings

Scientific deficits:

- Computations not during runtime
- System parameters are assumed to be known apriori
  - Gao, Shigen, et al. "Approximation-based robust adaptive automatic train control: an approach for actuator saturation." Intelligent Transportation Systems,IEEE Transactions on 14.4 (2013): 1733-1742.
  - Shigen, Gao, et al. "Characteristic model-based golden section adaptive control for high-speed train." Control Conference (CCC), 2012 31st Chinese. IEEE, 2012.
- Not suitable for high speed lines
  - Sicre, Carlos, et al. "Modeling and optimizing energy-efficient manual driving on high-speed lines." IEEJ Transactions on electrical and Electronic Engineering 7.6 (2012): 633-640.
  - Sicre, C., A. P. Cucala, and Antonio Fernandez-Cardador. "Real time regulation of efficient driving of high speed trains based on a genetic algorithm and a fuzzy model of manual driving." Engineering Applications of Artificial Intelligence 29

(2014): 79-92.

Scientific Contributions:

- Very efficient approach
  - Wang, Yihui, et al. "A survey on optimal trajectory planning for train operations." Service Operations, Logistics, and Informatics (SOLI), 2011 IEEE International Conference on. IEEE, 2011.
- Applicable for short distance lines only
  - Sicre, C., A. P. Cucala, and Antonio Fernandez-Cardador. "Real time regulation of efficient driving of high speed trains based on a genetic algorithm and a fuzzy model of manual driving." Engineering Applications of Artificial Intelligence 29

(2014): 79-92.

Determination of the fuel-optimal trajectory for a vehicle along a known route.

Full reference:

Kirschbaum, Frank, Michael Back, and Martin Hart. "Determination of the fuel-optimal trajectory for a vehicle along a known route." World Congress. Vol. 15. No. 1. 2002.

Abstract:

Integration of topology data of the entire road ahead into the powertrain control unit in combination with hybrid electric powertrains offers a huge potential for optimising the control strategy. The intension of the present paper is to show a methodology for computing the maximum potential of fuel saving over a specified route. For this offline calculation a non-linear state-space model of the longitudinal dynamics is used to find the fuel optimal trajectory using Bellman's Dynamic Programming (DP). As the model is of third order with three control inputs and DP can only be applied to systems with a maximum sum of inputs and states of four, the iterative variant of DP is used. This special method described in this paper allows the solution of optimization problems with a number of states and inputs up to six, without leading to insufferable computing times.

What is the problem adressed?

- Use topology of the road ahead to optimize the control strategy of a hybrid electric powertrain given
- Solving this problem as a non-linear dynamic optimization problem

Why is this relevant?

- Reduce energy/fuel consumption of cars

What have others done?

- Bellman's dynamic programming
  - Needs a lot of computing power and has high memory requirements for six or more inputs

How did the author's solution solve the addressed problem?

- Use of an iterative version of Bellman's dynamic programming
  - Conversion into time- and state-discrete problem -> leads to a recursive equation
  - Start with coarse discretization of state space and constrict the grid to the found location. Repeat with this finer grid.

Evaluation

- Implementation with C called BALU
- Sampling time equals 0.5 seconds
- Modelled vehicle based on super mini car with Diesel-engine and Common-Rail Direct Injection (CDI), synchronous electrical engine and a NiMH-Battery
- Particular application of noise to input signals
- First test: given slope of 19519m track
- Second test: Constant slope, but dynamic velocity profile

What are the scientific deficits of this approach?

' **Personal comments**'

- The authors do not say how many iterations they used. Do they use a fixed number of iterations or do they stop once a certain criterion is reached?
- The authors apply their method to two test tracks. First with only the slope given, second with a velocity profile. They compute the "optimal" controls, but they do not compare them to other controls. So there is no way of saying how good the computed control actually is.

' **Other papers** '

- Not suitable for real-time control
  - Sciarretta, Antonio, Michael Back, and Lino Guzzella. "Optimal control of parallel hybrid electric vehicles." Control Systems Technology, IEEE Transactions on 12.3 (2004): 352-363.
  - Kamal, Md Abdus Samad, et al. "Ecological vehicle control on roads with up-down slopes." Intelligent Transportation Systems, IEEE Transactions on 12.3 (2011): 783-794.
  - Kamal, Md, et al. "Model predictive control of vehicles on urban roads

for improved fuel economy." Control Systems Technology, IEEE Transactions on 21.3 (2013): 831-841.
- No information about traffic usable
    - Manzie, Chris, Harry Watson, and Saman Halgamuge. "Fuel economy improvements for urban driving: Hybrid vs. intelligent vehicles." Transportation Research Part C: Emerging Technologies 15.1 (2007): 1-16.
- No causal control law
    - Tate, Edward Dean, Jessy W. Grizzle, and Huei Peng. "Shortest path stochastic control for hybrid electric vehicles." International Journal of Robust and Nonlinear Control 18.14 (2008): 1409-1429.

What are the scientific contributions of this approach?

- can be used as a basis of comparison for evaluating the quality of other control strategies
    - Sciarretta, Antonio, Michael Back, and Lino Guzzella. "Optimal control of parallel hybrid electric vehicles." Control Systems Technology, IEEE Transactions on 12.3 (2004): 352-363.
- Can find a global optimum for a track
    - Kamal, Md Abdus Samad, et al. "Ecological vehicle control on roads with up-down slopes." Intelligent Transportation Systems, IEEE Transactions on 12.3 (2011): 783-794.
    - Kamal, Md, et al. "Model predictive control of vehicles on urban roads for improved fuel economy." Control Systems Technology, IEEE Transactions on 21.3 (2013): 831-841.

Reading Reports

The transferability approach: Crossing the reality gap in evolutionary robotics

Full reference: Koos, Sylvain, Jean-Baptiste Mouret, and Stéphane Doncieux. "The transferability approach: Crossing the reality gap in evolutionary robotics." Evolutionary Computation, IEEE Transactions on 17.1 (2013): 122-145.

Abstract: The reality gap, which often makes controllers evolved in simulation inefficient once transferred onto the physical robot, remains a critical issue in evolutionary robotics (ER). We hypothesize that this gap highlights a conflict between the efficiency of the solutions in simulation and their transferability from simulation to reality: the most efficient solutions in simulation often exploit badly modeled phenomena to achieve high fitness values with unrealistic behaviors. This hypothesis leads to the transferability approach, a multiobjective formulation of ER in which two main objectives are optimized via

a Pareto-based multiobjective evolutionary algorithm: 1) the fitness; and 2) the transferability, estimated by a simulation-to-reality (STR) disparity measure. To evaluate this second objective, a surrogate model of the exact STR disparity is built during the optimization. This transferability approach has been compared to two reality-based optimization methods, a noise-based approach inspired from Jakobi's minimal simulation methodology and a local search approach. It has been validated on two robotic applications: 1) a navigation task with an e-puck robot; and 2) a walking task with a 8-DOF quadrupedal robot. For both experimental setups, our approach successfully finds efficient and well-transferable controllers only with about ten experiments on the physical robot.

Reading Report

This paper deals with the problem of the reality gap and introduces an approach to overcome this problem. One major problem of evolutionary robotics is that good or optimal solutions for controllers found via evolution in simulation transformed onto the real robot perform significantly less good. According to the authors this may be because of inaccurate simulations and evolutionary algorithms exploiting these faulty parts of simulations. But evolution on real robots is very time consuming and therefore not possible for most scenarios.

The authors suggest an approach that tries to only rely on the accurate parts of the simulation. To achieve this they introduce a value that indicates how well a solution transfers to the reality. This is called the transferability approach.

The approach creates and updates a surrogate model that maps a controller to a transferability value which describes how close the simulated behaviour is to the behaviour when transferred to the real robot. The search for a good controller is thus a multi-objective optimization. The fitness of a controller is determined by its behavioural fitness together with its transferability and its diversity.

Every now and then one promising controller of a population is transferred to the real robot and the surrogate model is updated. This approach uses only a few experiments on the real robot by searching for good solutions in simulation and reality while avoiding to exploit inaccuracies of the simulation.

The authors tested their approach in two experiments and compared it to some other approaches. They compared it to purely simulation based approaches with small variations, to two reality based approaches and to a noise-based approach introduced by Jakobi et Al.

The first experiment was performed on a two wheeled robot that had to turn into the right direction at a T-cross depending on some light signals. The second experiment was performed on a four-legged robot to create a controller for moving.

In both experiments the approaches based on simulation only (or with performing only a few experiments on the real robot afterwards) experienced the most problems with the reality gap. They performed much worse when transferred into reality. The real robot based approaches performed bad in the first, but quite good in the second experiment, probably because task was easier in the second experiment. The noise-based approach performed better then those former approaches, but overall the transferability approach provided the best solutions.

A closer analysis of the robustness of a solution and its transferability showed that the correlation is low, meaning that a robust solution is not a solution that can behaves similar in reality and vice versa.

Scientific Deficits

- Need for multiple evaluations on real robot not always feasible
  - Duarte, Miguel, Sancho Oliveira, and Anders Lyhne Christensen. "Automatic synthesis of controllers for real robots based on preprogrammed behaviors." From Animals to Animats 12. Springer Berlin Heidelberg, 2012. 249-258.

Scientific Contributions

- Method to overcome reality gap that is not overly dependent on simulation details
  - Duarte, Miguel, Sancho Oliveira, and Anders Lyhne Christensen. "Automatic synthesis of controllers for real robots based on preprogrammed behaviors." From Animals to Animats 12. Springer Berlin Heidelberg, 2012. 249-258.
  - Cully, Antoine, and Jean-Baptiste Mouret. "Behavioral repertoire learning in robotics." Proceedings of the 15th annual conference on Genetic and evolutionary computation. ACM, 2013.
  - Francesca, Gianpiero, et al. "AutoMoDe: A novel approach to the automatic design of control software for robot swarms." Swarm Intelligence 8.2 (2014): 89-112.
  - Lehman, Joel, et al. "Encouraging reactivity to create robust machines." Adaptive Behavior (2013): 1059712313487390.

Noise and the reality gap: The use of simulation in evolutionary robotics

Full reference: Jakobi, Nick, Phil Husbands, and Inman Harvey. "Noise and the reality gap: The use of simulation in evolutionary robotics." Advances in artificial life. Springer Berlin Heidelberg, 1995. 704-720.

Abstract: The pitfalls of naive robot simulations have been recognized for areas such as evolutionary robotics. It has been suggested that carefully validated simulations with a proper treatment of noise may overcome these

problems. This paper reports the results of experiments intended to test some of these claims. A simulation was constructed of a two-wheeled Khepera robot with IR and ambient light sensors. This included detailed mathematical models of the robot-environment interaction dynamics with empirically determined parameters. Artificial evolution was used to develop recurrent dynamical network controllers for the simulated robot, for obstacle-avoidance and light-seeking tasks, using different levels of noise in the simulation. The evolved controllers were down-loaded onto the real robot and the correspondence between behaviour in simulation and in reality was tested. The level of correspondence varied according to how much noise was used in the simulation, with very good results achieved when realistic quantities were applied. It has been demonstrated that it is possible to develop successful robot controllers in simulation that generate almost identical behavior in reality, at least for a particular class of robot-environment interaction dynamics.

Reading Report

In other related work there have been made some assumptions about what has to be fulfilled to result in as small a gap of performance between simulation and reality with respect to evolutionary robotics. This study takes some of these assumptions and tests them in some experimental settings.

When transferring evolved control systems for mobile robots from simulation to real robots it could often be observed that the robot performs much worse than in the situation. Related studies have suggested several methods to keep this reality gap as small as possible. Two of them are the careful design of the simulator by using empirical data and the use of noise and noise resistant control systems such as neural networks.

The authors of this study use the Khepera robot to evolve neural control systems for obstacle avoidance and light seeking behavior and then analyze the effect of noise applied to the simulation on the resulting behavior of the real robot.

The Khepera robot is a small, cylindrical robot with six front and two back infra-red sensors which can also be used in another mode to sense ambient light. The robot has been developed to enable users to use and test their own control systems. The simulation used in the experiments was built using empirical data from the real Khepera robot to model the input of the sensors and the effects of the actuators. The controlling neural net has been evolved using artificial evolution.

In their experiments the authors used three different levels of noise: none, Gaussian distributed according to empirical data and Gaussian distributed with double standard deviation. They tested those noise levels in two different scenarios: Obstacle avoidance and light seeking. In the obstacle avoidance scenario the robot had to drive as fast and as straight lined as possible while avoiding pillars placed in an arena. In the light seeking scenario the robot had to reach a light source mounted on one wall of an empty arena. For comparing the simulated and the real robot's behavior the authors used some video

processing technique to obtain the trajectory of the real robot.

Using double deviated noise or no noise at all resulted in bad performances for both tasks, obstacle avoidance and light seeking. The best results have been made for the noise level similar to that of the real environment.

The authors could be convinced that it is possible to transfer from simulation to real robots without loosing much performance, but they are still skeptical if this still holds for more complex tasks.

Scientific Deficits

- Approach may be infeasible if complexity of robot increases
  - Matarić, Maja, and Dave Cliff. "Challenges in evolving controllers for physical robots." Robotics and autonomous systems 19.1 (1996): 67-83.

Scientific Contributions

- Using minimal Simulations to cross reality gap
- Use noise in simulation

Evolving coordinated quadruped gaits with the HyperNEAT generative encoding

Full reference:

Clune, Jeff, et al. "Evolving coordinated quadruped gaits with the HyperNEAT generative encoding." Evolutionary Computation, 2009. CEC'09. IEEE Congress on. IEEE, 2009.

Abstract:

Legged robots show promise for complex mobility tasks, such as navigating rough terrain, but the design of their control software is both challenging and laborious. Traditional evolutionary algorithms can produce these controllers, but require manual decomposition or other problem simplification because conventionally-used direct encodings have trouble taking advantage of a problem's regularities and symmetries. Such active intervention is time consuming, limits the range of potential solutions, and requires the user to possess a deep understanding of the problem's structure. This paper demonstrates that HyperNEAT, a new and promising generative encoding for evolving neural networks, can evolve quadruped gaits without an engineer manually decomposing the problem. Analyses suggest that HyperNEAT is successful because it employs a generative encoding that can more easily reuse phenotypic modules. It is also one of the first neuroevolutionary algorithms that exploits a problem's geometric symmetries, which may aid its performance. We compare HyperNEAT to FT-NEAT, a direct encoding control, and find that

HyperNEAT is able to evolve impressive quadruped gaits and vastly outperforms FT-NEAT. Comparative analyses reveal that HyperNEAT individuals are more holistically affected by genetic operators, resulting in better leg coordination. Overall, the results suggest that HyperNEAT is a powerful algorithm for evolving control systems for complex, yet regular, devices, such as robots.

Reading Report

This paper is about the creation of a modular neural net controller for quadruped gait using generative encodings.

In the introduction the authors motivate their work by some facts found in other studies and by the lack of studies focused on this particular objective. Related studies showed that by using generative encodings more complex and modular phenotypes can be produced. Also modular neural networks tend to evolve more effective gaits for legged robots. There have been studies using generative encodings, but those did not focus on the use of modular neural networks or did not have the computational possibilities to sufficiently produce data to prove their results.

The generative encoding used in the paper is called HyperNEAT, which uses the principles of the NeuroEvolution of Augmented Topologies (NEAT) algorithm. It produces Compositional Patterns Producing Networks (CPPNs). Evolving CPPNs exhibits the repetition of themes, symmetries and hierarchies, with and without variation. CPPNs can be used to generate neural networks. Mutation is used to change the CPPNs. The NEAT algorithm can be applied to the CPPNs, because their structure is similar to a population of neural networks. NEAT is unique in three main ways:

- It starts with small genomes that encode simple networks and slowly makes them more complex via mutation (adding of nodes).
- It uses a fitness-sharing mechanism that preserves diversity in the
- It uses historical information to perform crossover in an effective way.

As a control algorithm in the experiments another implementation of NEAT is used, the so called Fixed-Topology NEAT (FT-NEAT), which uses a direct encoding.

The results of the experiments show HyperNEAT vastly outperforming FT-NEAT at every generation. Also experiments had to be stopped eventually due to computational reasons, it seemed unlikely for FT-NEAT to close up to HyperNEAT afterwards. Interesting is the difference in fitness in the very first generation. Even randomly generated CPPNs are sometimes able to produce the coordination of legs that facilitates movement.

In the end, the solutions of HyperNEAT very often produced synchronized motion between the legs. Also reappearing patterns occurred. The results of FT-NEAT were not unable to come up with synchronization or repeating

patterns, but it was much more uncommon. Most solutions of FT-NEAT fell over eventually. Looking at the joint values over time the joints of HyperNEAT are far more coordinated. Mutations to a generative encoding tend to be much less damaging when simultaneously evolving morphologies and controllers. Also studying the effects of mutation and crossover when appeared solely showed that the effect of mutation was much more beneficial to HyperNEAT than to FT-NEAT. Having a closer look at crossover, HyperNEAT far more created offspring whose fitness lied between those of its parents. The reasons have yet to be analysed.

Summarizing HyperNeat created far better results. One reason is the ability to reuse neural modules and thus more easily coordinate the behaviours of a robots leg. Another reason might be the ability of HyperNEAT to exploit symmetry.

Scientific Deficits

Scientific Contributions

Evolutionary multi-objective optimization: a historical view of the field

Full reference:

Coello, Carlos A. Coello. "Evolutionary multi-objective optimization: a historical view of the field." Computational Intelligence Magazine, IEEE 1.1 (2006): 28-36.

Abstract:

This article provides a general overview of the field now known as "evolutionary multi-objective optimization," which refers to the use of evolutionary algorithms to solve problems with two or more (often conflicting) objective functions. Using as a framework the history of this discipline, we discuss some of the most representative algorithms that have been developed so far, as well as some of their applications. Also, we discuss some of the methodological issues related to the use of multi-objective evolutionary algorithms, as well as some of the current and future research trends in the area.

Reading Report

This article gives a historical overview over the developments of the field called "evolutionary multi-objective optimization", which describes the use of Evolutionary Algorithms to solve multi-objective optimization problems.

The authors start their article by providing the basic concepts. They first describe a multi objective problem (MOP) as a problem which has at least two objectives that needs to be optimized. These objectives might be constrained and they are usually in conflict with each other. Most MOPs have multiple

solutions. The goal is to find the Pareto optimal solutions, meaning that no decrease of one criterion causes an increase in another criterion.

The authors then give reason to why evolutionary algorithms are used for these kind of problems. The reasons given are that mathematical programming techniques are dependent on the shape of the pareto front and have problems with certain kind of shapes. Also they tend to give only one solution per run. EAs do not have these problems with the shapes and always provide multiple solutions.

In the following part the authors shortly describe the origin of the field. Although there have been early attempts of using EAs for MOPs, the first to have designed an multi-objective evolutionary algorithm (MOEA) is considered David Schaffer in the mid-1980s, called VEGA. The authors divide the development in this area into two generations. The first generation which emphasises on simplicity and the second generation emphasising efficiency.

The first generation was characterized by the simplicity of the algorithms proposed. There were only few comparisons between proposed algorithms and there were no standard test functions available.

According to the authors the second generation started when elitism became a standard mechanism in MOEAs, which is said to be done by Eckart Zitzler. There have been many aspects emphasised in this generation, the main one being efficiency.

After giving the historical overview of the field, the authors discuss methodological issues, applications, the current research trends and the future trends before giving a conclusion.

In the methodological issues section the authors describe the introduction of methods to measure performance. It could be shown eventually that using unary methods is not reliable. Binary methods have been used instead. Also the introduction of test functions is described, which are now scalable and widespread. Today, researchers usually validate their MOEAs with problems having three or more objective functions and 10 or more decision variables.

The applications of MOEAs are divided into three main areas, which are then further divided into more specialized areas. The three main areas are engineering, industrial and science.

The paper emphasizes some of the current interesting trends, which are:

- Use of relaxed forms of pareto dominance
- Transormation of single-objective problems into multi-objective problems
- Use of alternative bio-inspired heuristics for MOA

As future research trends the authors see:

- Parameter Control
- Minimum number of fitness function evaluations that are actually required

to achieve a minimum desirable performance with an MOEA?
- Development of implementations of MOEAs that are platform and programming language independent
- How to deal with problems that have "many" objectives?

Scientific Deficits

Scientific Contributions

- Historical review of evolutionary multi-objective optimization
    - Burke, Edmund K., Jingpeng Li, and Rong Qu. "A hybrid model of integer programming and variable neighbourhood search for highly-constrained nurse rostering problems." European Journal of Operational Research 203.2 (2010): 484-493.
    - Woldesenbet, Yonas Gebre, Gary G. Yen, and Biruk G. Tessema. "Constraint handling in multiobjective evolutionary optimization." Evolutionary Computation, IEEE Transactions on 13.3 (2009): 514-525.
    - Wu, L. H., et al. "Environmental/economic power dispatch problem using multi-objective differential evolution algorithm." Electric Power Systems Research 80.9 (2010): 1171-1181.

Fitness sharing and niching methods revisited

Full reference:

Sareni, Bruno, and Laurent Krähenbühl. "Fitness sharing and niching methods revisited." Evolutionary Computation, IEEE Transactions on 2.3 (1998): 97-106.

Abstract:

Interest in multimodal optimization function is expanding rapidly since real-world optimization problems often require the location of multiple optima in the search space. In this context, fitness sharing has been used widely to maintain population diversity and permit the investigation of manly peaks in the feasible domain. This paper reviews various strategies of sharing and proposes new recombination schemes to improve its efficiency. Some empirical results are presented for high and a limited number of fitness function evaluations. Finally, the study compares the sharing method with other niching techniques

Reading Report:

In genetic algorithms the fitness landscape may contain multiple local optima and solutions may get stuck into not global ones. There are several techniques to obtain and uphold diversity in populations, thus being able to cover multiple

optima in parallel. Niching methods are a class of methods that have been developed to reduce the genetic drift caused by selection operators. In this paper fitness sharing and some crowding methods are investigated and compared when used in multimodal optimization tasks.

Fitness sharing applies penalties to individuals according to the number of other individuals in their neighborhood, hence supporting individuals being spread over the fitness landscape. A low Recombination rate and some further constraints are applied to prevent the creating of "lethals", i.e. individuals formed from parents of different optima who will most probably perform bad. The drawback of fitness sharing is that some a-priori knowledge is needed to determine appropriate values for the neighborhood threshold. Also the computational cost of determining the neighborhood and the fitness may be costly.

Besides fitness sharing this paper investigates some crowding techniques and clearing.

Standard crowding uses only a small fraction of the population to reproduce and create offspring. This offspring then replaces the most similar individuals from a randomly taken subset of the population. But according to replacement errors this technique has been shown to be limited for multimodal function optimization.

Deterministic Crowding (DC) instead compares the created offspring only to the nearest parents and only replaces them if the offspring's fitness is higher.

Restricted tournament selection (RTS) is very similar to standard crowding, but the offspring replaces the other individual only if its fitness is higher.

Clearing is some form of fitness sharing technique where a factor k limits the number of individuals in a single niche. Only the top k individuals get a shared fitness, the rest will get a bad one to be discarded.

Experiments with a high number of fitness function evaluations and with a limited number showed that clearing works best given that the niche radius and the niche capacity are being estimated correctly. Fitness sharing works well on easy problems, but fails for harder problems. From the crowding techniques RTS works slightly better than DC.

Scientific Deficits

Scientific Contributions

- Showed that Deterministic Crowding is unable to maintain a proportional distribution of individuals across niches
    - Li, Xiaodong. "Niching without niching parameters: particle swarm optimization using a ring topology." Evolutionary Computation, IEEE Transactions on 14.1 (2010): 150-169.
- Showed that clearing achieves good results at maintaining population

diversity
- Chen, Li, James McPhee, and William W-G. Yeh. "A diversified multiobjective GA for optimizing reservoir rule curves." Advances in Water Resources 30.5 (2007): 1082-1093.
  - Presentation of main principles of fitness sharing and review of its development
    - Mendoza, Franklin, Jose L. Bernal-Agustin, and José Domínguez-Navarro. "NSGA and SPEA applied to multiobjective design of power distribution systems." Power Systems, IEEE Transactions on 21.4 (2006): 1938-1945.

Abandoning objectives: Evolution through the search for novelty alone

Full reference:

Lehman, Joel, and Kenneth O. Stanley. "Abandoning objectives: Evolution through the search for novelty alone." Evolutionary computation 19.2 (2011): 189-223.

Abstract:

In evolutionary computation, the fitness function normally measures progress toward an objective in the search space, effectively acting as an objective function. Through deception, such objective functions may actually prevent the objective from being reached. While methods exist to mitigate deception, they leave the underlying pathology untreated: Objective functions themselves may actively misdirect search toward dead ends. This paper proposes an approach to circumventing deception that also yields a new perspective on open-ended evolution. Instead of either explicitly seeking an objective or modeling natural evolution to capture open-endedness, the idea is to simply search for behavioral novelty. Even in an objective-based problem, such novelty search ignores the objective. Because many points in the search space collapse to a single behavior, the search for novelty is often feasible. Furthermore, because there are only so many simple behaviors, the search for novelty leads to increasing complexity. By decoupling open-ended search from artificial life worlds, the search for novelty is applicable to real world problems. Counterintuitively, in the maze navigation and biped walking tasks in this paper, novelty search significantly outperforms objective-based search, suggesting the strange conclusion that some problems are best solved by methods that ignore the objective. The main lesson is the inherent limitation of the objective-based paradigm and the unexploited opportunity to guide search through other means.

Reading Report:

A very common approach in evolutionary robotics is to use a fitness function to

optimize solutions with respect to one (or more) objectives. But there have been many cases where this did not work out. Using an objective might even sabotage the effort of finding a good solution for this exact objective.

Based on many researches from AI, AL, evolutionary computation and biology the researchers propose not using a fitness function with one (or more) objectives, but to use an approach that searches for new behaviour instead. Based on biological observations high selective pressure may result in pruning paths to optimal solutions.

One promising and popular approach in neuro-evolution is NEAT. It starts off with very simple networks and complexifies them over time while keeping the individual networks diverse. The authors extended the NEAT-approach to look for novelty of behaviour instead of optimizing an objective.

Because NEAT evolves more and more complex networks, also the possible behaviour becomes more and more complex. Thus the search for novelty searches more and more complex, but different behaviour. To find novel behaviours the authors use a metric which assigns values according to the distance to the k nearest neighbours. Once a novel solution has been found, it is added into a permanent archive to keep track of all novel behaviours and to be able to find new novel behaviour.

The authors performed two experiments to compare novelty search to objective and random search. The first experiment was a robot trying to reach a goal position inside of a maze within a given time. Two maps have been created and tested, where both maps contained deceptive dead ends. The objective function gives a score that is higher the closer the robot is to the goal. The novel metric gives a high score if a robot ends up at a position that has not been visited before.

On the easier map fitness and novelty based NEAT were able to find solutions. The novelty based NEAT took significantly less evaluations to reach a solution and the complexity of the evolved network was significantly lower than that of the fitness based NEAT. The random NEAT performed very bad.

On the second map fitness based NEAT was only successful in 3 out of 40 runs. Novelty based NEAT was able to solve this map in 39 out of 40 runs.

The authors used some modifications to the novelty metric and to the maze, but novelty search was most of the time significantly better than fitness based search without loosing performance significantly, even when the behaviour characterization became more complex.

In a second experiment the authors used a more complex task. Controllers had to be evolved for controlling a biped walking robot. In the end, the novelty approach significantly outperformed the fitness approach as well.

Scientific Deficits

Scientific Contributions

- Better exploration of problem state without getting stuck in local optima
  - Clune, Jeff, Jean-Baptiste Mouret, and Hod Lipson. "The evolutionary origins of modularity." Proceedings of the Royal Society of London B: Biological Sciences 280.1755 (2013): 20122863.

Training urban bus drivers to promote smart driving: A note on a Greek eco-driving pilot program

Full reference:

Zarkadoula, Maria, Grigoris Zoidis, and Efthymia Tritopoulou. "Training urban bus drivers to promote smart driving: A note on a Greek eco-driving pilot program." Transportation Research Part D: Transport and Environment 12.6 (2007): 449-451.

Abstract:

Economical, ecological and safe driving (eco-driving) is aimed at reducing fuel consumption, greenhouse gas emissions and accidents. Eco-driving is concerned about driving in a way compatible with modern engine technology: smart, smooth and safe techniques that lead to potential fuel savings of 10–15%. The Centre for Renewable Energy Sources of Greece conducted an eco-driving pilot study in collaboration with the Organization of Urban Transportation of Athens, and the Thermo-Bus Company to assess the effects of changing urban bus drivers' driving style.

Reading Report:

This paper is about a driving training for changing bus drivers' driving style and its effect on the fuel consumption.

The centre for renewable energy sources in greece in collaboration with Athen's urban transport organisation and the thermal bus company designed and created a bus driving training with the goal to reduce the energy consumption of buses. They designed a training course to provide knowledge to bus drivers to achieve the following goals:

- Reduce fuel consumption
- Improve road safety
- Decrease transport undertaking's maintenance cost
- Improve comfort of drivers and passengers
- Enhance transport supplier's profile

The training was divided into several phases:

- I: Design of pilot action
- II: Pre-training data collection

- III: Development of training material
- IV: Training courses execution
- V: Post training data collection
- VI: Data evaluation

Before the actual training of the drivers started, data about the current energy consumption was collected. The execution of the training courses happened in three steps. First the drivers drove around a 15km test track. Afterwards the seminar started and in the end the newly acquired skills have been applied to the test track again. After the training real world data have been collected again for some time.

Results show that during the training courses drivers had been able to decrease their fuel consumption by about 10% without losing a significant amount of time to pass the track. Post-training data showed a decrease by about 4.35%, reduced noise and maintenance costs.

Suggesting that each bus uses about 60000l of diesel a year, an average decrease of 4.35% would result in about 2610l per year per bus. This equals about 1697€. For a fleet of 1700 buses this would sum up to 2884900€. Continuing the training and achieving the 10% from the training could even result in savings of 6630000€ per year.

Scientific Contributions:

- Using more effective driving techniques can reduce fuel consumption, noise pollution and maintenance cost of vehicles
    - Santos, Georgina, Hannah Behrendt, and Alexander Teytelboym. "Part II: Policy instruments for sustainable road transport." Research in Transportation Economics 28.1 (2010): 46-91.
    - Beusen, Bart, et al. "Using on-board logging devices to study the longer-term impact of an eco-driving course." Transportation research part D: transport and environment 14.7 (2009): 514-520.
    - Liimatainen, Heikki. "Utilization of fuel consumption data in an ecodriving incentive system for heavy-duty vehicle drivers." Intelligent Transportation Systems, IEEE Transactions on 12.4 (2011): 1087-1095.

Scientific Deficits:

- Effect of courses decreases over time
    - Liimatainen, Heikki. "Utilization of fuel consumption data in an ecodriving incentive system for heavy-duty vehicle drivers." Intelligent Transportation Systems, IEEE Transactions on 12.4 (2011): 1087-1095.
    - Beusen, Bart, et al. "Using on-board logging devices to study the longer-term impact of an eco-driving course." Transportation research part D: transport and environment 14.7 (2009): 514-520.

An evolutionary program for a class of continuous optimal control problems

Full reference:

Smith, Stephen. "An evolutionary program for a class of continuous optimal control problems." Evolutionary Computation, 1995., IEEE International Conference on. Vol. 1. IEEE, 1995.

Abstract:

We describe an evolutionary programming technique for finding the solution to classical continuous optimal control problems, with or without free final time. We define a set of highly abstracted genetic operators to manipulate the gene pool in a `blind' but meaningful way. We apply the algorithm to Luus's (1990) highly non-linear model of oil-shale pyrolysis, and to an iso-thermal continuous stirred tank reactor with 3 independent control variables

Reading Report:

This article is about using an evolutionary programming technique to find a solution to classical continuous control problems. Other researchers divided the time domain into intervalls and created solutions for those intervalls using techniques like dynamical programming.

As for dividing the problem like this results in finding an optimal combination of parameter values, the authors approach is to use an evolutionary programming technique to solve it.

Within their approach the intervalls' boarders are not fixed but subject to evolution as well as the control functions describing the intervalls. The authors use four different mechanisms to change the gene representation of a solution:

- Random
- Perturbation of
    - Control space
    - t-points (intervalls)
- Cross-over
- Blend

The approach has been tested on two example problems.

- Oil-Shale Pyrolysis
- Isothermal Continuous Stirred Tank Reactor

For both problems, the authors designed the genes out of the given equations and then applied their algorithm to it. For both problems the solutions were comparable to those using other techniques. But the computation time was about four times faster.

Scientific Contributions:

- Representation of a seven-dimensional isothermal CSTR problem
  - Liu, An, Erwie Zahara, and Ming-Ta Yang. "A modified NM-PSO method for parameter estimation problems of models." Journal of Applied Mathematics 2012 (2012).
  - Khalik, Mostafa A., et al. "Parameter identification problem: Real-coded GA approach." Applied mathematics and Computation 187.2 (2007): 1495-1501.

Scientific Deficits:

- Large number of parameters needed
  - Ghosh, Arnob, et al. "A hybrid evolutionary direct search technique for solving Optimal Control problems." Hybrid Intelligent Systems (HIS), 2010 10th International Conference on. IEEE, 2010.

Eco-driving: An overlooked climate change initiative

Full reference:

Barkenbus, Jack N. "Eco-driving: An overlooked climate change initiative." Energy Policy 38.2 (2010): 762-769.

Abstract:

The actions individuals can take to mitigate climate change are, in the aggregate, significant. Mobilizing individuals to respond personally to climate change, therefore, must be a complementary approach to a nation's climate change strategy. One action item overlooked in the United States has been changing driver behavior or style such that eco-driving becomes the norm rather than the exception. Evidence to date indicates that eco-driving can reduce fuel consumption by 10%, on average and over time, thereby reducing CO2 emissions from driving by an equivalent percentage. A sophisticated, multi-dimensional campaign, going well beyond what has been attempted thus far, will be required to achieve such savings on a large scale, however, involving education (especially involving the use of feedback devices), regulation, fiscal incentives, and social norm reinforcement

Reading Report

- There are possible savings in fuel consumption of about 10%, which comes with an equivalent reduction of CO_2-emissions
- To prevent catastrophic climate change next to large emitters also individuals will need to take actions
- This article focusses on personal transportation, mainly automobile and light duty vehicles

- Several ways for individuals to reduce their greenhouse gases associated with personal transportation
    - purchase more fuel efficient cars
    - purchase vehicles that utilize low-carbon fuels (electricity, natural gas, ethanol)
    - reduce their vehicle miles through carpooling and use of public transportation
    - operate their current vehicles more energy efficient
- Attention on the latter
- Behaviours that are controlled by individuals (like household energy and personal transportation) lie around 32% - 41% of total CO_2-emissions
- Studies showed that energy savings of 20%-25% in households are feasible while maintaining the existing standard of living.
- Achieve individual behaviors to change is not an easy task as history showed
- Around 90% of personal transportation emissions emanate from personal vehicles.
- By purchasing new and more efficient cars huge savings are possible. This is due to the fact that the industry developed larger cars with more horsepower over the last years instead of more energy efficient ones.
- Renewing the car fleet by purchasing new cars will take time, as for only about 7% of the cars get exchanged every year.
- Actions such as carpooling also yield much saving potential, but the individual's resistance is quite high.
- Changing the driving style from a rather "aggressive" one to a more refined style could result in large fuel savings. This style is referred to as "eco-driving"
- Eco-driving includes
    - Accelerating moderately
    - Anticipating traffic flow and signals
    - Avoiding sudden starts and stops
    - Maintaining an even driving pace
    - Driving at or safely below the speed limit
    - Avoid excessive idling
- Advantages of eco-driving include reducing individual's costs and producing safety-benefits
- A former program to decrease fuel consumption has been stopped in the 1980s because of public indifference (low fuel prices) and the Reagan Administration's de-emphasis of energy issues
- Eco-driving program directors claim that CO_2 reductions can be had both quickly and cost-effectively from eco-driving programs
- In normal situations one-time trainings result in up to 5% savings, with support beyond initial training this could increase to about 10%.
- If every driver in the USA would increase their savings by 10%, this would be equivalent to a reduction of 100 million metric tons of CO_2.
- Assuming that a program could only reach one third of the drivers, this would still be equal to taking nearly 6 million cars off the road.

- Savings could result in about $214 to $428 per household per year.
- Steps to constitute a more prominent role of eco-driving in the USA
  - There needs to be a public awareness and information campaign
  - Reducing and senforcing interstate speed limits
  - Make eco-driving training widely available
  - cost-sharing the costs of purchasing and installing driver feedback devices
- enlisting the services of social-marketing experts for the essential norm-creation process

Scientific Contributions

- simple yet effective approaches, which can achieve approximately 8–20% reduction in fuel consumption and GHG emissions from road transportation
  - Guo, Chenjuan, et al. "Ecomark: evaluating models of vehicular environmental impact." Proceedings of the 20th International Conference on Advances in Geographic Information Systems. ACM, 2012.
- drivers do benefit from in-vehicle feedback systems in reducing fuel consumption
  - Dogan, Ebru, Linda Steg, and Patricia Delhomme. "The influence of multiple goals on driving behavior: The case of safety, time saving, and fuel saving." Accident Analysis & Prevention 43.5 (2011): 1635-1643.
- If speed control traffic signals modify the behavior of the drivers by inducing a speed reduction, they will also result in a decrease in relative

pollutant emissions

-
  - De Coensel, Bert, et al. "Effects of traffic signal coordination on noise and air pollutant emissions." Environmental Modelling & Software 35 (2012): 74-83.

Scientific Deficits

- eco-driving limited to driver actions
  - Sivak, Michael, and Brandon Schoettle. "Eco-driving: Strategic, tactical, and operational decisions of the driver that influence vehicle fuel economy." Transport Policy 22 (2012): 96-99.

Conclusions

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Appendix

A. Online literature search

- scholar.google.com
- sciencedirect.com
- osti.gov
- diva-portal.org
- degruyter.com
- mitpressjournals.org
- ieeexplore.ieee.org
- dl.acm.org

B. Sources

'''B.1 List of searched journals

- todo
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'''B.2 List of searched conference proceedings

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'''B.3 List of searched magazines

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'''B.4 Other searched publications

- todo
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C. List of top research labs/researchers

- todo
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E. Planned structure of the report

- Abstract
- Introduction
- Problem Formulation
    - What is this project about?
    - Why is it relevant?
    - What have other people done?
    - Why is this not sufficient?
    - What deficits will be addressed in this project?

- State of the art
    - Energy efficient vehicle control
        - Optimal Control Theory
        - Dynamic Programming
        - Graph Search
        - Evolutionary Strategies
    - Evolutionary Strategies
    - The Reality Gap
    - Non-linear control

- Related work
- Basic Principles
    - Artificial Neural Networks
    - Evolutionary Algorithms
    - NEAT
    - Reality Gap
- Designing the Vehicle Model
- Extending NEAT
- Evaluation
    - Setup
    - Data

- Analysis
- Results
- Conclusions
- Future Work

D. Comments on content and structure of this report

Introduction

Problem Formulation

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