Institute for Design and Control of Mechatronical Systems

Diploma Thesis:

Time Optimal Open Loop Control of Mechatronical Systems by Genetic Algorithms

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Finished: August 2012

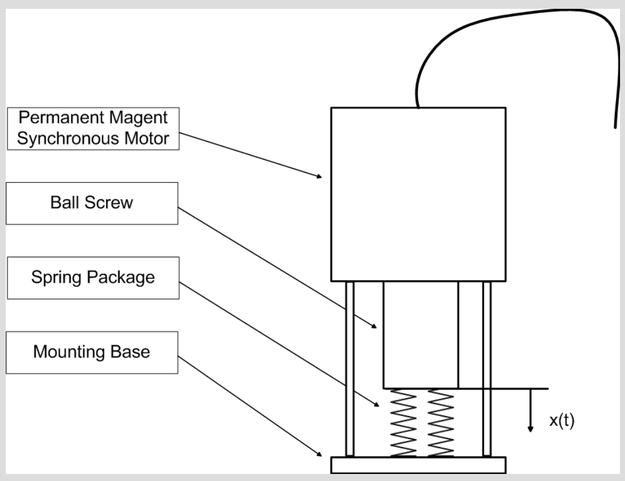
This thesis deals with the generation of time optimal trajectories including practical specifications. The aim is to develop a method to obtain time optimal trajectories which bring the system from one state to another as fast as possible under certain constraints. These constraints are of practical nature and could be for example:
the impact speed of a piston or simply constraints on the energy consumption of a system. Due to the practical nature of the constraints the cost function may become very complex and hardly to handle by conventional optimization methods.

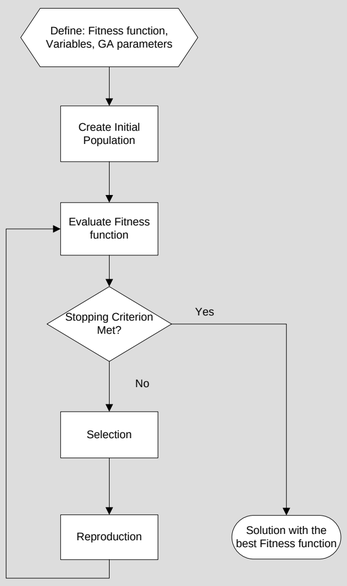
Introduction

Optimal control is conceivably one of the most fascinating fields of research in control theory. Although a wealth of literature is available on this subject there is no general procedure to obtain an optimal control trajectory for a generic optimization problem and general classes of systems. Furthermore in industrial applications only practical specifications instead of an analytical form of a certain reference trajectory are given. These aspects could be for example: the maximum allowed impact speed of a valve, the minimum time to move from one point to another or simply constraints on the energy consumption. Of course time optimality is frequently required in practical Applications. All these requirements must be included into a cost function. This may end in a very complex form, which can hardly be handled in traditional optimization methods. Besides there are also various aspects influencing the system itself, which make the problem of finding an optimal solution very challenging including the following: (1) The dynamics of the system is nonlinear. (2) A non analytical description of the system is available, e.g. a look-up table. (3) Time-varying disturbances are present.
(4) The control and state variables can vary only within limited bounds.
In the last 15 years researchers headed to a qualitatively different approach to solve optimization problems using *Evolutionary Algorithms (EA).* There exist many different versions of *EA's which all have* one similarity:
they are based on the principle of "survival of the fittest" to determine the optimal solution.

Validation of the Method

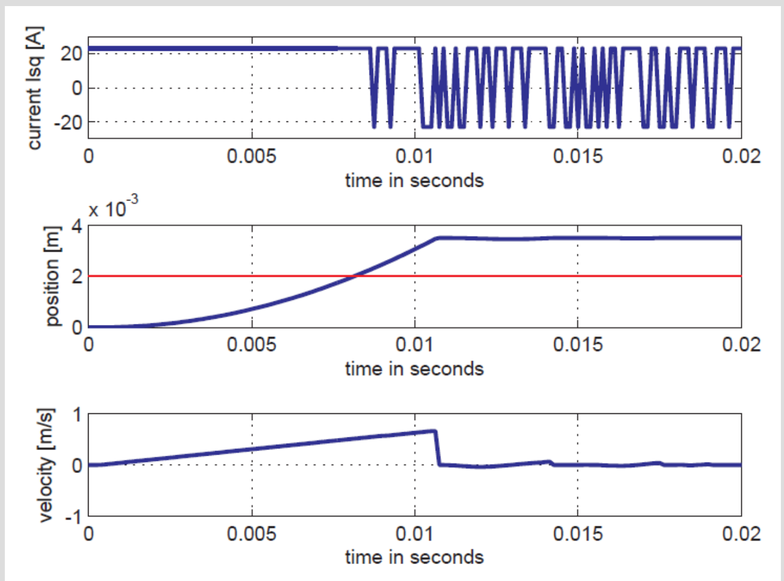
- Electrical Valve:
  - Permanent Magnet Synchronous Motor (PMSM) interacting with a spindle on a spring package
- Objective:
  - Move the valve from starting to end position
    - Minimizing the time necessary
- Constraints:
  - Overshoot
  - Impact Velocity
  - Mechanical Stop
  - Limited Motor Current





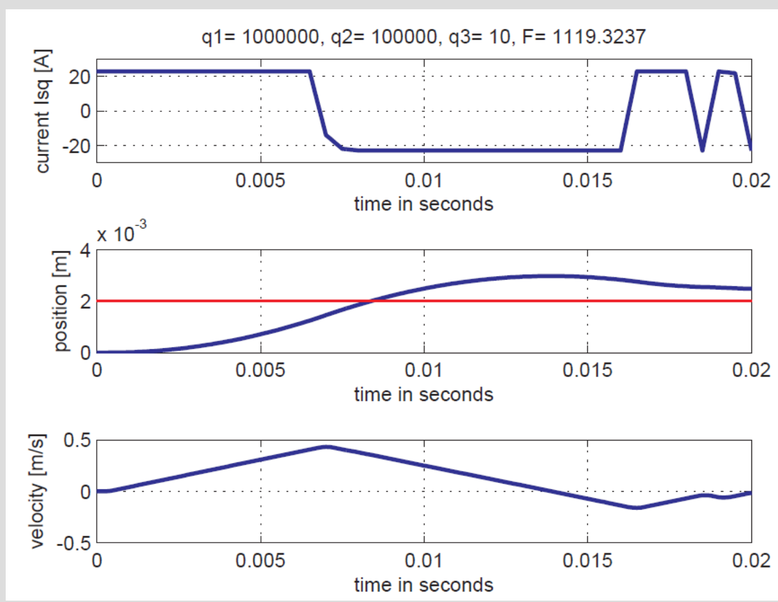
Time Optimal Solution

$$J_1 = t_{pos} \qquad t_{pos} = 8.25\,\mathrm{ms}$$



More Complex Cost function

$$J_3 = q_1 \sum_{n=0}^{N} [y(n) - y_{end}]^2 + q_2\, t_{pos} + q_3 \sum_{n=0}^{N} [v(n)]^2 \qquad N = \frac{t_{sim}}{T_s}$$



Conclusions and Outlook

Especially when practical specifications like bounds on several states are required, or models including look-up tables or non algebraic functions are used, traditional methods fail or the complexity increases dramatically. This is the point where *Genetic Algorithm's can prove their strength.*
In future work, especially in problems requiring greater accuracy *Evolutionary Algorithm's* could be used to provide an initial guess for additional methods based the *Calculus of Variations or Direct Transcription.*
Also parameterization with B-Splines could shorten the computation time and further improve the solution.