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Planning for mechatronics systems—Architecture, methods and case study

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ABSTRACT

Mechatronic systems are a relatively new class of technical systems. The integration of electro-mechanical systems with hard- and software enables systems that adapt to changing operation conditions and externally defined objective functions. To gain superior system performance from this ability, sophisticated decision making processes are required. Planning is an ideal method to integrate long-term considerations beyond the time horizon of classical controlled systems into the decision making process. Unfortunately, planning employs discrete models, while mechatronic systems or controlled systems in general emphasize the time continuous behavior of processes. As a result, deviations of the actual behavior during the execution from the planned behavior plan cannot be entirely avoided. We introduce a hybrid planning architecture, which combines planning and learning from artificial intelligence with simulation techniques to optimize the general system behavior. The presented approach is able to handle the inevitable deviations during plan execution, and thus maintains feasibility and quality of the created plans.

1. Introduction

Technical systems and machines are designed to fulfill tasks for humans. Technical progress continuously broadens the spectrum of tasks and improves the quality of task fulfillment. Quality can be measured in various dimensions, application dependent and independent examples are: timeliness, resource consumption, processing accuracy (e.g. in case of machining tools), or comfort and driving pleasure (e.g. in case of vehicles). Usually, it is not possible to determine the relative importance of these qualities during the design of the systems because they usually depend on the current application situation. Thus, it is desirable that technical systems are able to adapt the relationships between these qualities or objectives depending on the current situation.

The term mechatronics refers to the close integration of electro-mechanical systems, electronics and information technology (Isermann, 2005). Typically, a mechatronic system consists of mechanical skeleton, actuators, sensors, controllers, signal conditioning/modification devices, computer/digital hardware and software, interface devices, and power sources (Kelly and De Silva, 2004). To handle the complexity induced by so many different types of components, mechatronic systems are usually hierarchically structured (VDI, 2004, The Association of German Engineers) and a mechatronic system is usually composed by a number of function modules which realize specific sub functions.

In particular the integration of information technology enables mechatronic systems to adapt their behavior according to dynamic environments. The information processing in mechatronic and similar engineering system is often based on artificial intelligence and soft computing methods, e.g. for prediction (cf. Cheng et al., 2005; Lin et al., 2006; Ramasso and Gouriveau, 2010) for model predictive control (cf. Martinez et al., 1997; Zamerreño and Vega, 1999; Wang et al., 2005), state estimations (cf. Lin and Yang, 2003; Li et al., 2006, and diagnosis (cf. Miguel and Blazquez, 2005; Lebaroud and Clerc, 2009).

The information processing in advanced mechatronic systems is often organized by a multi-level-control system (Isermann, 2005). Basically, the lower level of information processing can be handled with established methods from control engineering, focusing on safety and stability of the controlled processes. On the higher level of information processing, in particular on the level of management, new methods and algorithms are required.

1.1. Motivating example and use case

The railway vehicle *RailCab* is a good motivating example for planning in mechatronic systems as well as demonstrator for the use case in Section 6. It is developed within the project

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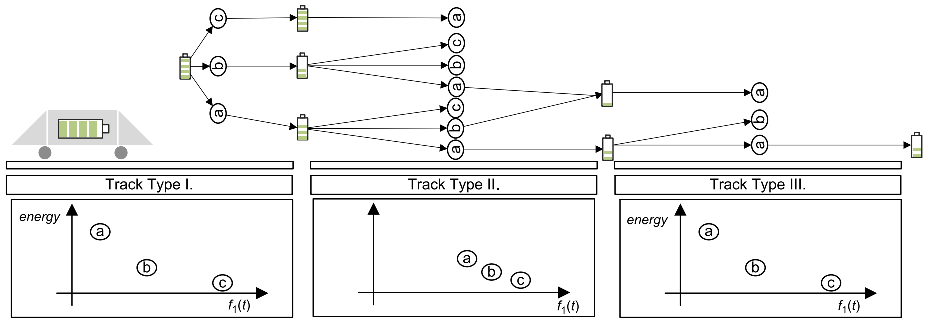

Fig. 1. Sketch of the considered planning problem.

"Neue Bahntechnik Paderborn" (NBP) (cf. Henke et al., 2008) and consists of small autonomously driven rail-bound vehicles.

Fig. 1 shows an example of a planning problem: A RailCab has to travel along a number of track sections. A track section is a cut-out from the railway network, which is characterized by certain features (e.g. amount of track excitation, slope, etc.) and does not contain a switch (cf. Schmidt et al., 2008 regarding the extraction of track sections). Regarding their properties, track sections are grouped into classes (I and II in Fig. 1). On each track section, the RailCab has to choose from different alternative behaviors or *operation modes* (a–c), which represent trade-offs between objective functions (e.g. minimization of the body movement or energy losses) and the consumption of energy from the onboard storage. In combination, the *operation modes* and the state of charge (*SOC*) of the RailCabs onboard energy storages define the state space sketch in Fig. 1. A planning procedure explores this state space and defines for each track section which operation mode should be executed. As a general constraint, the *SOC* can never be below 0 and the availability of operation modes depends on the current state of charge. An appropriate planning procedure should select the operation modes in such a way that an objective function f is optimized overall track sections.

1.2. Contributions

In this paper we will define a class of planning problems to model the decision making process in the management level of mechatronic systems and introduce an architecture for the management level of mechatronic systems. Furthermore, we demonstrate how methods from artificial intelligence like planning, machine learning, and probabilistic reasoning are employed to manage the basic mechanical and electrical processes in complex mechatronic systems. Our approach is to use planning for the determination of suitable objective functions for each sub-module in a mechatronic system. The planning process integrates several planning techniques and simulation in order to handle the challenges in mechatronic domains. Hybrid planning can be split up into four activities:

1. Initial planning.
2. Analyzing plan actions in simulation.
3. Modify plan.
4. Execute and monitor the currently active plan.

Basically it integrates several planning techniques and simulation. Just-in-case planning provides a number of alternative plans prior to the execution of a task assigned to a mechatronic systems, reflecting the uncertainty present in most application domains of mechatronic system. Simulation, interleaved with the execution of a plan, analyses the feasibility and applicability of single operations in the plan. Online planning is designed to provide real-time decision making in all situations, where no appropriate alternative plan was proactively created. In order to integrate the existing approaches Just-in-case or conditional planning and online planning into an architecture for decision making in mechatronic systems, these methods had to be examined and refined to meet the specific requirements of mechatronic applications.

1.3. Structure of the paper

The paper is structured as follows: the next section introduces a planning model for mechatronic systems. The third section describes the general problem addressed by the hybrid planning, reviews the related work regarding discrete–continuous planning, and briefly discusses the two building blocks which can be implemented with standard methods, offline planning and simulation. Since extensions of existing just-in-case and online planning approaches are presented, these two planning methods are discussed in Sections 4 and 5. We will give a brief introduction to the general planning concept, discuss the relevant state of the art and introduce the specific realization for planning in mechatronic systems. The sixth section introduces the RailCab case study in more details and presents experimental results regarding the planning process. The seventh section discusses the results and gives an outlook to future work.

2. Planning for mechatronic systems

Planning concerns the determination of the future state of something, usually it is about the future course of actions in order to accomplish something (van Wezel and Jorne, 2001). This definition of planning is also suitable for planning for mechatronic systems. The planning for mechatronic system is the search for sequence of executed functions (e.g. *accelerate*—following an acceleration profile, *drive at continuous speed*, *brake*—following a deceleration profile) in order to fulfill a job or task assigned to the mechatronic system. Examples of such tasks are the transportation of goods (in case of a vehicle) or the processing of a work piece in a machining center. Thus, usually tasks can be defined by a state before the execution (good is in place A, work piece is not processed) and a state after the execution (good is in place B, work piece is processed).

Adaptive mechatronic systems are able to execute a function in different ways. From the planning perspective, these different ways are distinguished from each other by how well they achieve the possible objectives and how they change the system state. We refer to these different implementations of functions as *operation modes*. The planning process does not consider the specific technical implementation of an operation mode; instead it focuses on the relationship of objective achievement and change in system state, in particular resource consumption.