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Mechatronics Engineering on the Example of a Multipurpose Mobile Robot

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Abstract. This paper presents the patented mechanical concept for steering and level control of a mobile robot equipped with four driving units and the methods that lead to the development of this mechatronic system. The mobile robot exhibits excellent maneuverability and considerable advantages when moving in difficult environments such as rough landscapes. The paper discusses a refined approach to develop mechatronic systems which is based on the well-known V-model. The refined approach allows a conscious planning and control of a mechatronic design process.

Introduction

Today most competitive products combine mechanical, electrical, and software subsystems and components and should therefore be referred to as mechatronic products. The product development process of mechatronic products is characterized by numerous interfaces, cross-domain functions, and high complexity. The planning, execution, and controlling of such processes requires elaborate strategies, methods, and tools. This paper describes a combination of many approaches to mechatronic design. This combination which was developed over the last years at the Hochschule Ravensburg-Weingarten takes into account technical aspects but also the aspects of process planning, execution, and control. Therefore the term "mechatronics engineering" was chosen to describe this approach.

Nowadays one can observe a dynamic development of mechatronic systems such as mobile robots [1, 2, 3]. In this rich field of innovation an unusual diversity of realized concepts can be detected. This gives a hint that until now no dominant concepts have prevailed and that the most promising ideas are yet to be found. Intensive investigations in this field have already fostered many ideas. Special attention deserve wheel-driven robots due to their specific advantages as efficiency, speed, and operation robustness. In literature [4, 5, 6] such robots are presented and discussed in detail. However, the first prominent disadvantage of many wheel-driven robots is the limited capability for maneuvers in limited space when compared e.g., to robot equipped with legs. The second prominent disadvantage in this comparison is the problematic usage of wheel-driven robots in difficult environments such as uneven landscapes. In this paper the authors present a new patented concept which is based on an innovative steering system and a system for level and inclination control of a robot chassis. The steering system is based on the utilization of torque and speed differences of drive motors. The torque of drive motors is used to set the desired angular position of four legs to which the four drive wheels are fixed. In the moment when the desired angular position is achieved, a passive electromagnetic brake is actuated until another a moment in time when another steering angle is desired [7, 8]. This solution allows the robot to move in any direction (moving along any straight line, rotation around the centre of the robot, rotation around any point and combinations thereof) [9]. This capability can be particularly useful for instance in buildings with limited space (e.g. production lines). The second innovative characteristic of the presented concept is the capability to change the level and the inclination of the robot chassis. This system for the control of level and inclination permits to maintain a horizontal inclination of the platform independently from the shape of the terrain or encountered obstacles. This characteristic is intended to improve the possibility to move on uneven surfaces, but can also improve the dynamic capabilities of the mobile robot for instance if the robot chassis is tilted in opposite direction of centrifugal forces. A mobile robot combining both innovations is currently being realized which was named “Robot 3D”. The main objective of the first prototype is to test its behavior when subjected to changing environment conditions (e.g. uneven surfaces, centrifugal force).

Mechatronics Engineering

Mechatronics is commonly understood as a domain of technological science which contains the following knowledge fields: mechanical engineering, software engineering, electronical engineering, automation, and robotics. The term “mechatronics engineering” as an analogy to “systems engineering” also focuses on the organizational and process oriented aspects of the development of mechatronic products. Future mechatronic products can be characterized by the following features: multifunctionality, reliability, adaptability to changing conditions, flexibility and simplified service. This multitude of requirements requires specific processes. For mechatronics system development, a process model called V-model is suitable and generally the recommended one. The V-model is a graphical representation of the system development lifecycle. It was adopted by Germany federal administration to regulate a software development processes in 1997. After considerable adoption and modification, the V-model has been suggested by VDI Guideline 2206 as a “Design methodology for mechatronical systems” [10, 11]. Several researchers report current endeavors to apply and optimize this methodology for the product development of different mechatronic systems [12, 13]. Nowadays, the V-model has become a standard process model for mechatronic system development in many industrial companies. Generally, the V-model can be divided into three main sections and is always described in V shape. It consists of the System Design at the left side, the System Integration at the right side and the Domain-specific Design at the tail of the V-model. Fig. 1 shows the general structure of V-model.

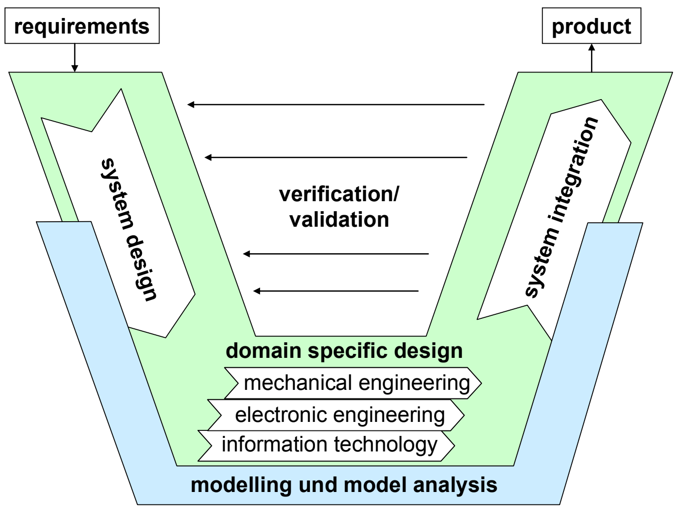


Fig. 1. General structure of the V-model [10]

The development methodology of mechatronical system according to the guideline VDI 2206 consists of two procedure schemes:

- the general problem-solving cycle on the micro-level, and
- the V-model on the macro-level.

In this regard micro-level can mean sequences of proceeding steps lasting from few hours up to some months. In any case these sequences do not reflect the complete design of a mechatronical product but a specific problem within this product development [14]. The notion macro-level names sequences of proceeding steps aimed at the complete development of a product or at least a major sub-system. The VDI 2206 provides a general procedure for process steps on the micro level or methodology known as ‘Problem-Solving Cycle’. It originates from systems engineering [15] as a guideline for a systems developer or engineer to be used during the problem solving processes along the development process of mechatronics system. This ‘Problem-Solving Cycle’ can be applied as a micro-level in the development process and is intended in particular to support the product developer engaged in the process to work on predictable, and consequently plan able subtasks, but also to solve suddenly occurring, unforeseeable problems. The VDI 2206 has recommended the usage of the V-model as a generic procedure (Macro-Level) for designing mechatronical systems. It is important to note that even on the macro level the V-Model does not necessarily represent the whole development process. On the contrary, a complete development process might consist of several re-runs of the V-model with increasing product maturity. This characteristic is highlighted in Fig. 2.

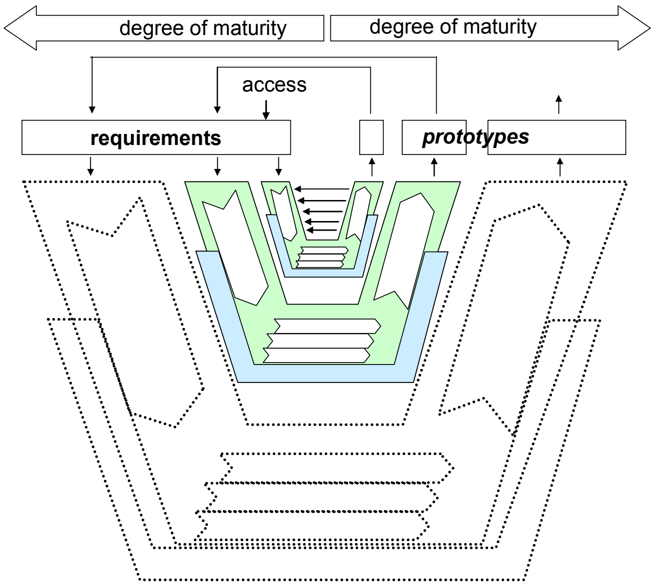


Fig. 2. Running through a number of macro-cycles [10]

In our approach the V-model is the central model of the interdisciplinary product development process. Complex models of product development processes often are confused with schedules. However, many authors [16, 17, 18] point out that product development is never a sequential process. Product development of conventional and mechatronic products is always characterised by iterations and jumps between certain stages. The V-model as a process map shows the way from requirements to a market-ready product on a logical level. However, in analogy to a map of a landscape it cannot tell you where you are or where you should be at a certain time. The “process map” V-model needs to be accompanied by project plans showing phases and milestones. It is important to note that phases in project plans often have similar names to elements of process maps, but that the meaning is different. Phases in project plans may consist of several iterations and jumps to other elements of process maps. A phase in a project plan can best be characterised by the input and the output but not by the detailed steps to be performed. Therefore a process map, such as our proposed V-model is needed in order to show logical relationships and to assign appropriate strategies and tools to certain steps of a product development process. In the VDI 2206 a cascaded arrangement of several V-models is proposed for long-term product development processes (Fig. 2). Similarly, also in Systems Engineering [15] phases such as preliminary study, main study and detail study are proposed, which all treat with the same system but on different levels of refinement and detail. Our experience in this project and in similar adjacent projects underlines the cyclic nature of mechatronic design. It is helpful to understand the most abstract phases of the project plan as cycles through V-models. This makes sure that all aspects of a mechatronic design are considered and are at least consciously verschoben. Fig. 3 shows a possible combination of a project plan (upper plan) and a process map. It is important to note that such a direct combination is not always sensible as intermediate milestones might be necessary for controlling the development process of a mechatronic product.

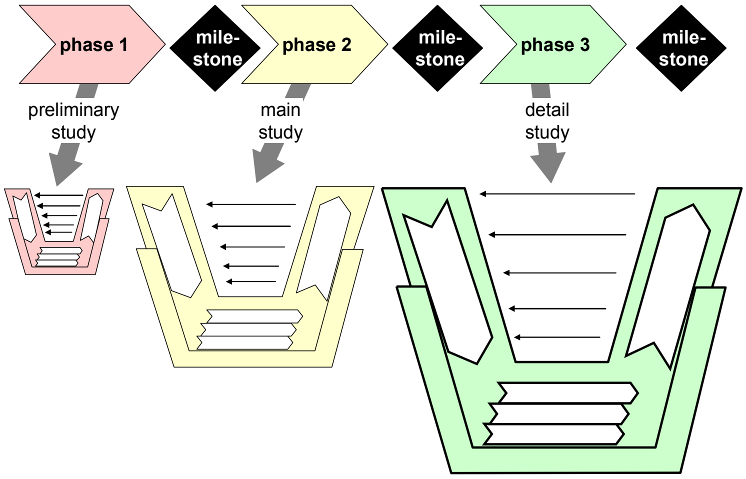
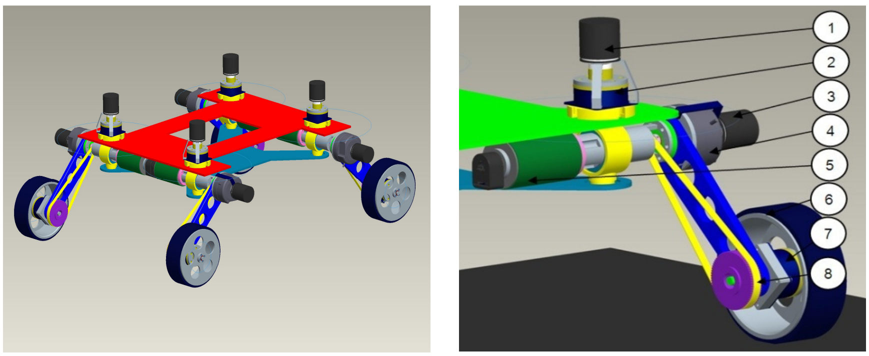


Fig. 3. Combination of V-model and project plan

Design overview

The mechanical design of the mobile robot consists of four identical drive modules. This kind of modular approach reduces the manufacturing costs and enhances the robustness. Two different variants of the drive modules were developed and tested. The variants differ in the way the power is transferred from the motor to the wheel and in the way the angular position of the robot leg can be changed. The following figure presents the first solution (Fig. 4).



1 – absolute encoder
2 – passive brake
3 – active brake
4 – absolute encoder
5 – motor with encoder
6 – wheel
7 – passive brake
8 – bottom gear-wheel

Fig. 4. First design of chassis and driving module

In this solution no specific steering mechanism for setting the angular position of the vertical axis (and by this the wheel) is existing. Steering is done by controlling the speed of the motor (5) in a proper way, which is possible with the information from the position sensor (1). The implemented axle control algorithm continuously traces positions of all the axles and adjusts properly the velocities of the motors. When the correct position of the axle is achieved the brake (2) gets the signal from the motor controller and is actuated in order to keep the axle in the desired angular position. The task of active brake (4) is to keep the robot leg in the desired position. A change of the angular position of the leg is possible when the active break (4) is released and the passive break (7) is blocked. The latter break blocks the axis at the drive wheel. In this case the bottom gear-wheel is rolling up on the toothed belt. Simulations and tests showed an imperfection in this solution. The velocity vector is not tangent to the circle the wheel is moving on in certain maneuvers. Fig. 5 gives an overview of the problem. To solve it the wheel has to be kept tangent to the circle, or should be shifted closer to rotation axis to minimize R.

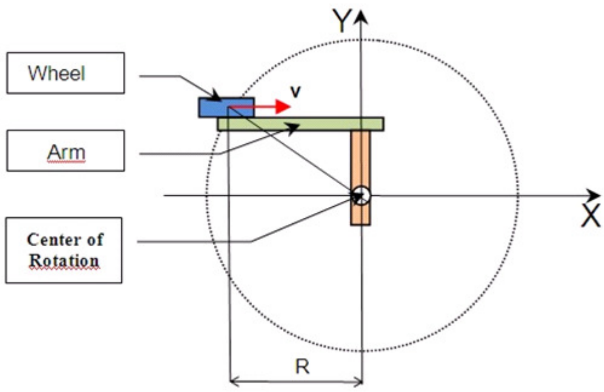
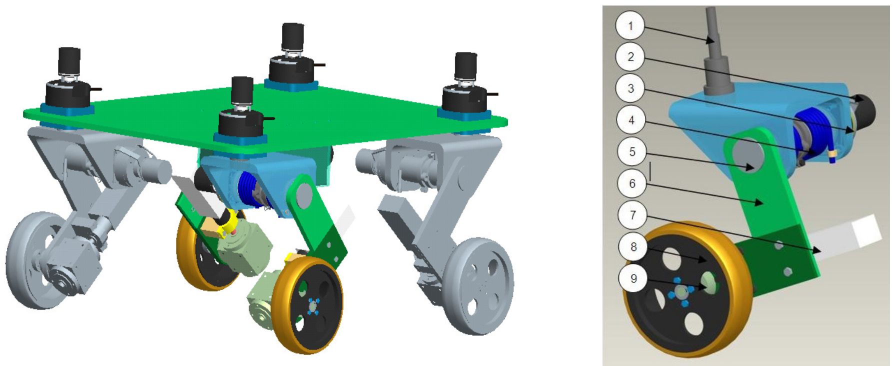


Fig. 5. Position of the wheel during certain maneuvers

The influence of this phenomenon could be eliminated by a refined solution. Fig. 6 shows the refined design of a drive unit. Two springs are used in the design of this module. The task of two springs is to decrease trembling between suspension and platform of robot. The advantage of this kind of suspension is that through a dynamic control of the torque differences between the drive modules it is possible to keep platform in horizontal plane and also to realize certain inclinations of the platform within certain limits. The angular position of the leg is controlled by a continuous motor velocity and torque control based on information from the inclination sensor (fixed in platform) and position encoders which provide the current angular position of the leg.



1 – vertical shaft
2 – absolute encoder
3 – passive brake
4 – spring
5 – horizontal shaft
6 – leg
7 – motor with encoder
8 – wheel
9 – passive brake

Fig. 6. Refined drive unit with a rigid connection of two leg segments

Conclusions

The product development of mechatronic systems such as mobile robots requires elaborate processes. In this paper some characteristics of such processes are discussed and hints for the planning, execution, and control of such processes is given. This strategies, methods, and tolls can be summarized under the term “mechatronics engineering”.

The application example of the paper is an innovative design of a wheel-driven mobile robot chassis. This solution is based on four identical driving modules with freely rotating vertical axles equipped with absolute position encoder and optional electromagnetic brakes intended to improve the controllability of the axles. Wheel movements are directly obtained from motor equipped with embedded position encoder. Such a design allows a variety at maneuvers, increases flexibility and decreases mechanical complexity of the robot. The main advantage of this robot is the superior maneuverability. The second main advantage is the possibility to control the inclination of the robot platform.

Future tasks in the scope of this project concentrate on further refinement of the mechanical design and on the preparation and testing of an optimum control system for the robot. The developed solutions are compared with the initial assumption and criterions which were determined at the beginning of this project.

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