Conceptual Design of Humanoid Robots

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1. Introduction

The development of a humanoid robot within the scope of special research area 588 has the objective of creating a machine that closely cooperates with humans. This leads to requirements such as little weight, small moving masses (no potential danger for persons in case of collision), as well as appearance, motion space, and work movements after the human model. One reason for the last point is the requirement for the robot to operate in surroundings designed for humans. Another aspect is the acceptance by technologically unskilled users, which is likely to be higher if the robot has a humanoid shape and calculable movements.

A humanoid robot is a highly complex mechatronical system, as the required functionality can only be achieved by the interplay of mechanical components with extensive sensor technology, state-of-the-art actuators and highly developed software. The development of mechatronical products is a major point of emphasis for research at our institute.

2. Development of an complex mechatronical system, e.g. humanoid robot

2.1 Definition of the term "Mechatronic"

In order to distinguish mechatronical systems from electromechanical systems, we define "Mechatronic" as follows [1]:
"Mechatronics is concerned with technological systems, consisting of mechanical, electrical/electronical, and information technological subsystems that are characterised by intensive interaction and cannot be developed separately and in independent discipline-oriented processes."

2.2 Product development process in Mechatronic

Successful development of complex mechatronical systems is only possible in close cooperation of specialists of the concerned fields of mechanics, electronics, and information technology (fig. 1). Discipline-oriented partial solutions cannot provide or only with significant delays the desired result.

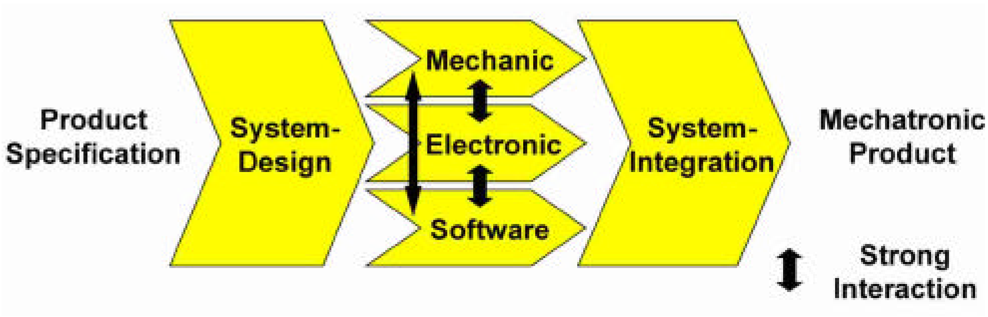

Fig. 1: Product development process in Mechatronic

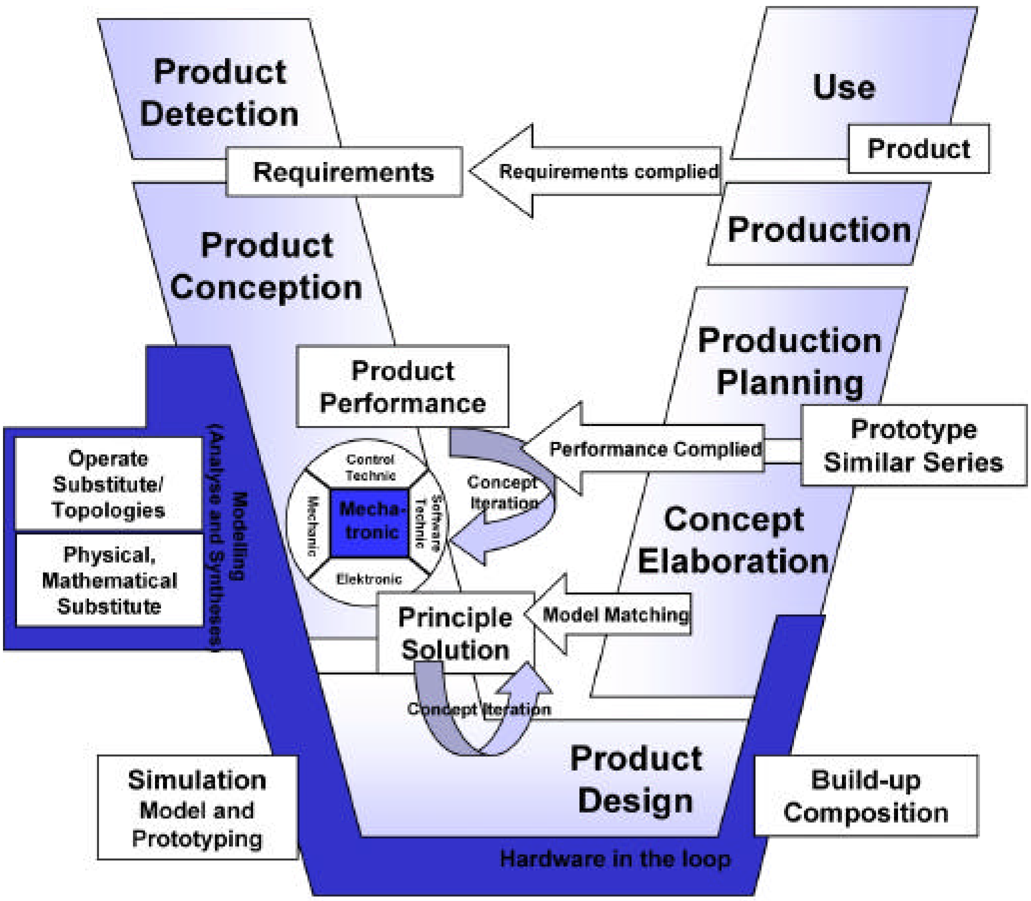

Fig. 2: V-model. Reference for developing mechatronical products

The development of technological systems can be carried through according to the V-model (fig. 2) [2]. After analysing all demands on the total system, the subfunctions and subsystems simultaneously being developed by the cooperating development teams are defined (left branch of the V-model). After verifying the subfunctions and testing the subsystems (e. g. the robot wrist including all actuators and sensors), the subsystems are gradually integrated and then the initial operation phase can begin (right branch of the V-model). The working structures with the necessary working surface pairs and connecting channel and support structures are defined according to the element model “working surface pairs & channel and support structures” developed at the Institute of Machine Design and Automotive Engineering [3].

The development of technological systems is originally an iterative process involving the development of physical and mathematical models. These models help to verify hypotheses and to simulate and therefore predict properties. Additionally the model helps to gather information, which is not available from the real system, e. g. the tensile stress of certain construction components. Due to the complex hybrid structure, model development and simulation are of even greater significance when the mechatronical product development process is concerned. As tools and software are very much discipline-oriented and can very often not communicate, the process is even more difficult. This is an important research task in the field of mechatronics. The over-all solution, which is still in the conceptual and design phase of the developing process, can be contributed to build up the prototype. This is the current stage of the humanoid robot at the University of Karlsruhe. The construction of the prototype is also an iterative process into which experiences from preceding development stages are to be included.

2.3 DIC-method, team-oriented development with internal competition

The DIC-method (development by internal competition) is a way to increase the efficiency of team-oriented development processes. The incentive of internal competition between development teams of the same enterprise is used for finding the optimal solution. The competing teams are presented with the same terms of reference.

Several development teams consisting of specialists of all the concerned subjects worked in competition in order to develop concepts for several subsystems of a humanoid robot for a period of approximately six months. By using the approaches of concurrent engineering and the DIC-method, a large number of different methods of resolution were developed (fig. 3). Each of these concepts consists of a multitude of component solutions for the mechanical structure of individual joints, sensor, and actuators. This large number of conceptual suggestions is the basis for the currently continuing development.

Fig. 3: Different concepts of a humanoid robot

2.4 The demonstrator

The upper body considered optimal for a robot, developed according to the methods described, is currently being assembled at the Institute for Machine Design and Automotive Engineering. Its proportions correspond to those of an average woman with a height of 165 cm. A special emphasis has been put on the development of the arm mechanics. The robot's arm of the first development stage will be equipped with 7 degrees of flexibility (fig. 4). As a principle, only lightweight materials were used and the electric drive units were placed in the thorax in order to design a lighter arm. Three different principles are used to connect the motors and the joints. The power transmission to the wrist will be hydraulic for the first prototype. For the elbow, rope pulls will be used and the shoulder will be driven directly. This concept allows a minimal weight for the arm of only about 2, 5 kg [4]. Three different measuring principles

are applied for measuring the torsion angles, depending on the available construction space and the required accuracy. The torsion angles in the shoulder are measured absolutely by optical encoders, the ones in the elbow by precision rotary potentiometers, the ones in the wrist using a new type of magnetoresistive angular sensors [5].
The neck joint (fig. 4) is equipped with four degrees of flexibility. Three rotation axes are situated in the lower neck segment and another one on the upper side of the neck, which allows the nodding of the head. The electrical motors are moved by the others as little as possible.
For the pan-tilt units for moving the stereo camera system, a mechanism is implemented that allows each camera to move independently by two degrees of flexibility. It is driven by highly dynamic, brushless electric motors that are also stationary for dynamic reasons. As a high degree of accuracy is required for the angle measurement of the cameras, the high-resolution optical encoder is used here.

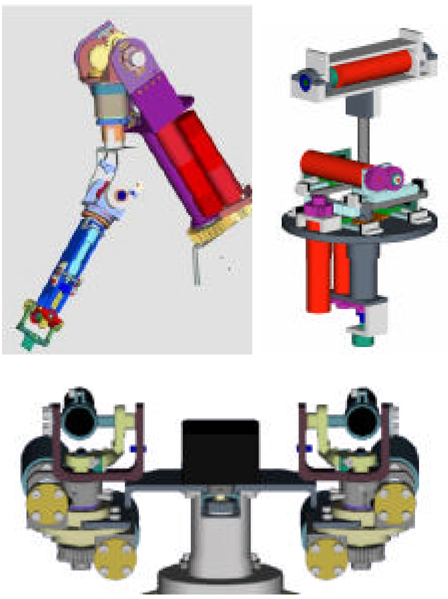

Fig. 4: Components of the humanoid robot currently being assembled (arm, neck and pan-tilt unit)

3. Summary

For the development of a complex mechatronical system of a humanoid robot, a combination of the development methods concurrent engineering and DIC has proven to be target-oriented. In total, 33 different solutions that all fulfilled the requirements were developed in a brief period of time. The most promising concepts were then selected. They are currently being realised as the first prototype.

4. References

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