

Design of Modules and Components for Humanoid Robots

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1. Introduction

The development of a humanoid robot in the collaborative research centre 588 has the objective of creating a machine that closely cooperates with humans. The collaborative research centre 588 (SFB588) "Humanoid Robots - learning and cooperating multi-modal robots" was established by the German Research Foundation (DFG) in Karlsruhe in May 2000. The SFB588 is a cooperation of the University of Karlsruhe, the Forschungszentrum Karlsruhe (FZK), the Research Center for Information Technologies (FZI) and the Fraunhofer Institute for Information and Data Processing (IITB) in Karlsruhe.

In this project, scientists from different academic fields develop concepts, methods and concrete mechatronic components and integrate them into a humanoid robot that can share its working space with humans. The long-term target is the interactive cooperation of robots and humans in complex environments and situations. For communication with the robot, humans should be able to use natural communication channels like speech, touch or gestures. The demonstration scenario chosen in this project is a household robot for various tasks in the kitchen.

Humanoid robots are still a young technology with many research challenges. Only few humanoid robots are currently commercially available, often at high costs. Physical prototypes of robots are needed to investigate the complex interactions between robots and humans and to integrate and validate research results from the different research fields involved in humanoid robotics. The development of a humanoid robot platform according to a special target system at the beginning of a research project is often considered a time consuming hindrance. In this article a process for the efficient design of humanoid robot systems is presented. The goal of this process is to minimize the development time for new humanoid robot platforms by including the experience and knowledge gained in the development of humanoid robot components in the collaborative research centre 588.

Weight and stiffness of robot components have a significant influence on energy efficiency, operating time, safety for users and the dynamic behaviour of the system in general. The finite element based method of topology optimization gives designers the possibility to develop structural components efficiently according to specified loads and boundary conditions without having to rely on coarse calculations, experience or

intuition. The design of the central support structure of the upper body of the humanoid robot ARMAR III is an example for how topology optimization can be applied in humanoid robotics. Finally the design of the upper body of the humanoid ARMAR III is presented in detail.

2. Demand for efficient design of humanoid robots

Industrial robots are being used in many manufacturing plants all over the world. This product class has reached a high level of maturity and a broad variety of robots for special applications is available from different manufacturers. Even though both kind of robots, industrial and humanoid, manipulate objects and the same types of components, e.g. harmonic drive gears, can be found in both types, the target systems differ significantly. Industrial robots operate in secluded environments strictly separated from humans. They perform a limited number of clearly defined repetitive tasks. These machines and the tools they use are often designed for a special purpose. High accuracy, high payload, high velocities and stiffness are typical development goals.

Humanoid robots work together in a shared space with humans. They are designed as universal helpers and should be able to learn new skills and to apply them to new, previously unknown tasks. Humanlike kinematics allows the robot to act in an environment originally designed for humans and to use the same tools as humans in a similar way. Human appearance, behaviour and motions which are familiar to the user from interaction with peers make humanoid robots more predictable and increase their acceptance. Safety for the user is a critical requirement. Besides energy efficient drive technology, a lightweight design is important not only for the mobility of the system but also for the safety of the user as a heavy robot arm will probably cause more harm in case of an accident than a light and more compliant one. Due to these significant differences, much of the development knowledge and product knowledge from industrial robots cannot be applied to humanoid robots.

The multi-modal interaction between a humanoid robot and its environment, the human users and eventually other humanoids cannot fully be simulated in its entire complexity. To investigate these coherences, actual humanoid robots and experiments are needed. Currently only toy robots and a few research platforms are commercially available, often at high cost. Most humanoid robots are designed and built according to the special focus or goals of a particular research project and many more will be built before mature and standardized robots will be available in larger numbers at lower prizes. Knowledge gained from the development of industrial robots that have been used in industrial production applications for decades cannot simply be reused in the design of humanoid robots due to significant differences in the target systems for both product classes. A few humanoid robots have been developed by companies, but not much is known about their design process and seldom is there any information available that can be used for increasing the time and cost efficiency in the development of new improved humanoid robots. Designing a humanoid robot is a long and iterative process as there are various interactions between e.g. mechanical parts and the control system. The goal of this article is to help shortening the development time and to reduce the number of iterations by presenting a process for efficient design, a method for optimizing light yet stiff support structures and presenting the design of the upper body of the humanoid robot ARMAR III.

3. Design process for humanoid robot modules

The final goal of the development of humanoid robots is to reproduce the capabilities of a human being in a technical system. Even though several humanoid robots already exist and significant effort is put into this research field, we are still very far from reaching this goal. Humanoid robots are complex systems which are characterized by high functional and spatial integration. The design of such systems is a challenge for designers which cannot yet be satisfactorily solved and which is often a long and iterative process. Mechatronic systems like humanoid robots feature multi-technological interactions, which are displayed by the existing development processes, e.g. in the VDI guideline 2206 "design methodology for mechatronics systems" (VDI 2004), in a rather general and therefore abstract way. More specific development processes help to increase the efficiency of the system development. Humanoid robots are a good example for complex and highly integrated systems with spatial and functional interconnections between components and assembly groups. They are multi-body systems in which mechanical, electronic, and information-technological components are integrated into a small design space and designed to interact with each other.

3.1 Requirements

The demands result from the actions that the humanoid robot is supposed to perform. The robot designed in the SFB 588 will interact with humans in their homes, especially in the kitchen. It will take over tasks from humans, for example loading a dish washer. For this task it is not necessary, that the robot can walk on two legs, but it has to feature kinematics, especially in the arms, that enable it to reach for objects in the human surrounding. In addition, the robot needs the ability to move and to hold objects in its hand (Schulz, 2003).

3.2 Subdivision of the total system

The development of complex systems requires a subdivision of the total system into manageable partial systems and modules (Fig. 1). The segmentation of the total system of the humanoid robot is oriented on the interactions present in a system. The total system can be divided into several subsystems. The relations inside the subsystems are stronger compared to the interactions between these subsystems. One partial system of the humanoid robot is e.g. the upper body with the subsystem arm. The elements in the lowest level in the hierarchy of subsystems are here referred to as modules. In the humanoid robot's arm, these modules are hand-, elbow-, and shoulder joint. Under consideration of the remaining design, these modules can be exchanged with other modules that fulfil the same function. The modules again consist of function units, as e.g. the actuators for one of the module's joints. The function units themselves consist of components, here regarded as the smallest elements. In the entire drive, these components are the actuator providing the drive power and the components in the drive train connected in a serial arrangement, e.g. gears, drive belt, or worm gear transferring the drive power to the joint.

3.3 Selection and data base

Many components used in such highly integrated systems are commonly known, commercially available and do not have to be newly invented. However, a humanoid robot consists of a large number of components, and for each of them there may be a variety of technical solutions. This leads to an overwhelming number of possible combinations, which

cannot easily be overseen without help and which complicates an efficient target-oriented development. Therefore it is helpful to file the components of the joints, actuators and sensors as objects in an object-oriented classification. It enables a requirement-specific access to the objects and delivers information about possible combinations of components.

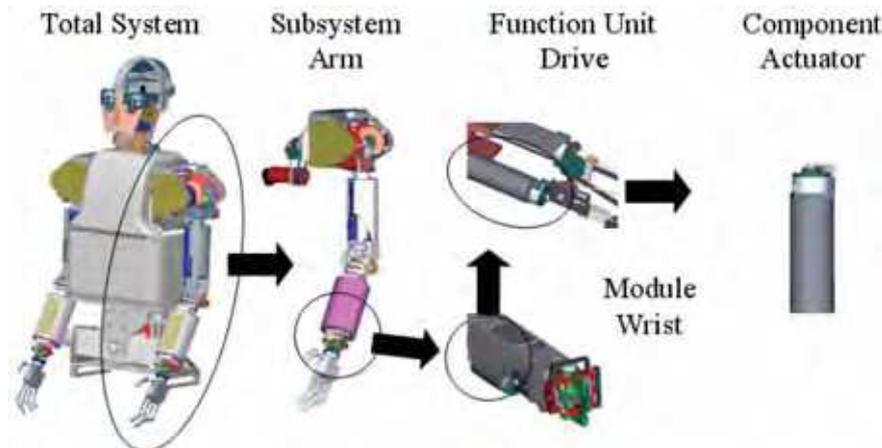


Fig. 1. Subdivision of the total system.

3.4 Development sequence

The development sequence conforms to the order in which a component or information has to be provided for the further procedure. The development process can be roughly divided into two main sections. The first section determines the basic requirements for the total system, which have to be known before the design process. This phase includes primarily two iterations: In the first iteration, the kinematics of the robot is specified according to the motion space of the robot and the kinematics again has to be describable in order to be controllable. In the second iteration, the control concept for the robot and the general possibilities for operating the joints are adjusted to the requirements for the desired dynamics of the robots. The second sector is the actual design process. The sequence in which the modules are developed is determined by their position in the serial kinematics of the robot. This means that e.g. in the arm, first the wrist, the elbow joint and then finally the shoulder joint are designed.

Since generally all modules have a similar design structure, they can be designed according to the same procedure. The sequence in this procedure model is determined by the interactions between the function units and between the components. The relation between the components and the behaviour of their interaction in case of a change of the development order can be displayed graphically in a design structure matrix (Browning, 2001). Iterations, which always occur in the development of complex systems, can be limited by early considering the properties of the components that are integrated at the end of the development process. One example is the torque measurement in the drive train. In the aforementioned data base, specifications of the components are given like the possibility for a component of the drive train to include some kind of torque measurement. It ensures that after the assembly of a drive train, a power measurement can be integrated.

3.5 Development of a shoulder joint

The development of a robot shoulder joint according to this approach is exemplarily described in the following paragraphs. For the tasks that are required from the robot, it is sufficient if the robot is able to move the arm in front of its body. These movements can be performed by means of a ball joint in the shoulder without an additional pectoral girdle. In the available design space, a ball joint can be modelled with the required performance of the actuators and sensors as a serial connection of three single joints. The axes of rotation of these joints intersect at one point. A replacement joint is used which consists of a roll joint, a pitch joint, and then again of another roll joint. The description of the kinematics can only be clarified together with the entire arm, which requires limiting measures, especially if redundant degrees of freedom exist (Asfour, 2003).

Information about the mass of the arm and its distribution are requirements for the design of the shoulder joint module. In addition, information about the connection of elbow and shoulder has to be available. This includes the components that are led from the elbow to or through the shoulder, as e.g. cables or drive trains of lower joints. The entire mechatronic system can be described in an abstract way by the object-oriented means of SysML (System Modelling Language) (SysML, 2005) diagrams, with which it is possible to perform a system test with regard to compatibility and operational reliability. It enables the representation of complex systems at different abstraction levels. Components that are combined in this way can be accessed in the aforementioned classification, which facilitates a quick selection of the components that can be used for the system. In addition, it makes a function design model possible at every point of the development.

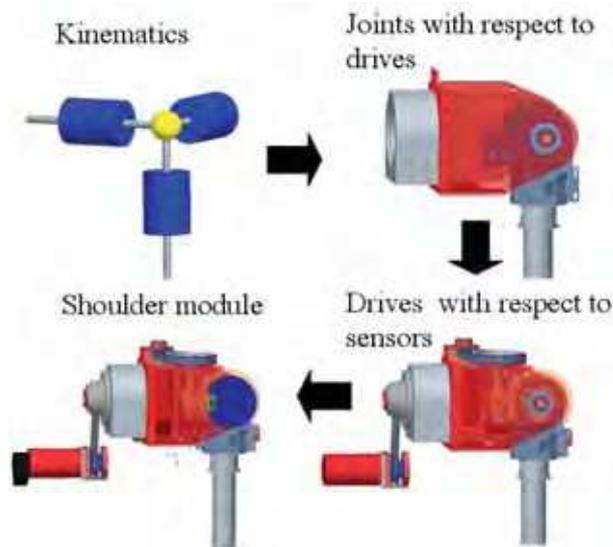


Fig. 2. Design of the shoulder module.

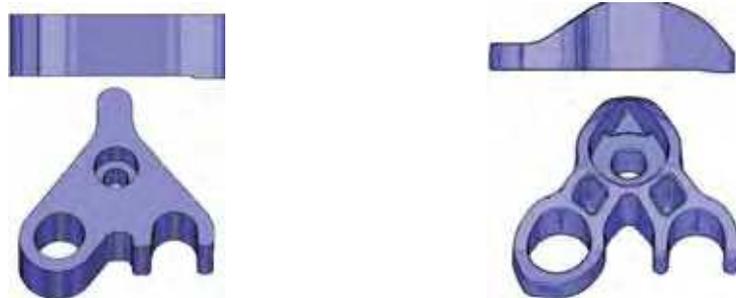
In the development of the shoulder module (Fig. 2), at first the function units of the joints for the three rotating axes are selected according to the kinematics. Then, the function unit drive, including the actuators and the drive trains, are integrated. Hereafter, the sensors are selected and integrated. In order to prevent time consuming iterations in the development,

the components of the total system, integrated at a later stage, are already considered from the start with regard to their general requirements for being integrated. Examples for this are the sensors, which can then be assembled without problems since it is made sure that the already designed system offers the possibility to integrate them. During the next step the neighbouring module is designed. Information about the required interface of the shoulder and the mass of the arm and its distribution are given to the torso module.

4. Topology optimization

Topology optimization is used for the determination of the basic layout of a new design. It involves the determination of features such as the number, location and shape of holes and the connectivity of the domain. A new design is determined based upon the design space available, the loads, materials and other geometric constraints, e.g. bearing seats of which the component is to be composed of.

Today topology optimization is very well theoretically studied (Bendsoe & Sigmund, 2003) and applied in industrial design processes (Pedersen & Allinger, 2005). The designs obtained using topology optimization are considered design proposals. These topology optimized designs can often be rather different compared to designs obtained with a trial and error design process or designs obtained upon improvements based on experience or intuition as can be deduced from the motor carrier example in Fig. 3. Especially for complex loads, which are typical for systems like humanoid robots, these methods of structural optimization are helpful within the design process.



Design space for topology optimization

Constructional implementation

Fig. 3. Topology optimization of a gear oil line bracket provided by BMW Motoren GmbH.

The standard formulation in topology optimization is often to minimize the compliance corresponding to maximizing the stiffness using a mass constraint for a given amount of material. Compliance optimization is based upon static structural analyses, modal analyses or even non-linear problems e.g. models including contacts. A topology optimization scheme as depicted in Fig. 4. is basically an iterative process that integrates a finite element solver and an optimization module. Based on a design response supplied by the FE solver like strain energy for example, the topology optimization module modifies the FE model.

The FE model is typically used together with a set of loads that are applied to the model. These loads do not change during the optimization iterations. An MBS extended scheme as introduced by (Häussler et al., 2001) can be employed to take the dynamic interaction between the FE model and the MBS system into account.

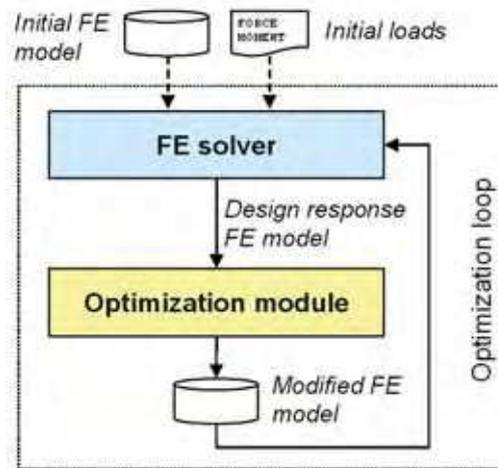


Fig. 4. Topology optimization scheme.

4.1 Topology optimization of robot thorax

The design of the central support structure of the upper body, the thorax, of the humanoid robot ARMAR III was determined with the help of topology optimization. The main functions of this element are the transmission of forces between arms, neck and torso joint and the integration of mechanical and electrical components, which must be accommodated for inside the robot's upper body. For instance four drive units for the elbows have to be integrated in the thorax to reduce the weight of the arms, electrical components like two PC-104s, four Universal Controller Modules (UCoM), A/D converters, DC/DC converters and force-moment controllers.



Fig. 5. Topology optimization of the thorax.

The left picture in figure 5 shows the initial FE model of the available design space including the geometric boundary conditions like the mechanical interfaces for the adjoining modules neck, arms and torso joint as well as the space reserved for important components like computers and controllers. Together with a set of static loads, this was the input for the optimization process. The bottom left picture shows the design as it was suggested by the optimization module after the final optimization loop. This design was then manually transferred into a 3d model in consideration of manufacturing restrictions. The picture on the right in Fig. 5 shows the assembled support structure made from high-strength aluminium plates. The result of the optimization is a stiff and lightweight structure with a total mass of 2.7 kg.

5. The upper body of ARMAR III

ARMAR III is a full-size humanoid Robot which is the current demonstrator system of the collaborative research centre 588. It consists of a sensor head for visual and auditory perception of the environment, an upper body with two arms with a large range of motion for the manipulation of objects and a holonomic platform for omni-directional locomotion. ARMAR III has a modular design consisting of the following modules: head, neck joint, thorax, torso joint and two arms which are subdivided into shoulder, elbow, wrist and hands. The head and the holonomic platform were developed at the Research Center for Information Technologies (FZI), the hands were developed at the Institute for Applied Computer Science at the Forschungszentrum Karlsruhe (Beck et al, 2003; Schulz 2003). The modules for neck, torso and arms shown in the following figure were designed and manufactured at the Institute of Product Development (IPEK) at the University of Karlsruhe (TH).



Fig. 6. The upper body of the humanoid robot ARMAR III.

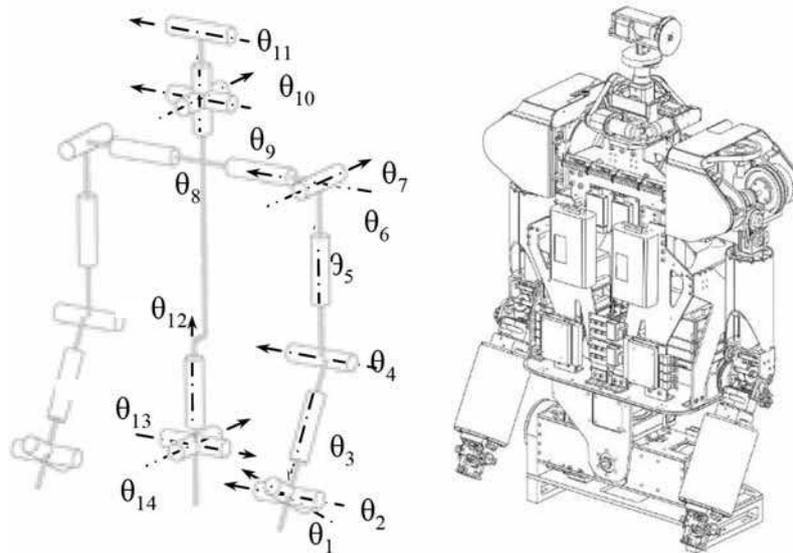


Fig. 7. Kinematics and CAD model of upper body of ARMAR III.

The size of the design space and the motion space of ARMAR III are similar to that of a human person with a height of approximately 175 cm. The main dimensions of the upper body can be seen in Fig. 8.

Table 1 gives an overview of the degrees of freedom and the motion range of all modules. Both arms have seven degrees of freedom. The three degrees of freedom in the shoulder provide a relatively wide range of motion. Together with two degrees of freedom in the elbow as well as in the wrist, the arm can be used for complex manipulation tasks that occur in the primary working environment of ARMAR III, the kitchen. Compared with other humanoid robots, the arm of ARMAR III provides large and humanlike ranges of motion. The neck joint with four degrees of freedom allows humanlike motion of the head.

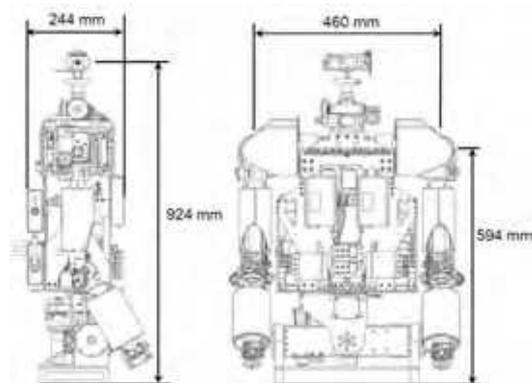


Fig. 8. Dimension of upper body.

Degree of freedom	Part	D.O.F	amount	total
	Wrist	2	2	4
	Elbow	2	2	4
	Shoulder	3	2	6
	Neck	4	1	4
	Torso	3	1	3
Upper body				21
Range of motion	Wrist	θ_1	-30° to 30°	
		θ_2	-60° to 60°	
	Elbow	θ_3	-90° to 90°	
		θ_4	-10° to 150°	
	Shoulder	θ_5	-180° to 180°	
		θ_6	-45° to 180°	
		θ_7	-10° to 180°	
	Neck	θ_8	-180° to 180°	
		θ_9	-45° to 45°	
		θ_{10}	-45° to 45°	
		θ_{11}	-60° to 60°	
	Torso	θ_{12}	-180° to 180°	
		θ_{13}	-10° to 60°	
		θ_{14}	-20° to 20°	

Table 1. Degrees of freedom with range of motion.

5.1 Shoulder joint

The shoulder joint is the link between the arm and the torso. In addition to the realization of three degrees of freedom with intersecting axes in one point, the bowden cables for driving the elbow joint are guided through the shoulder joint from the elbow drive units in the torso to the elbow. The drive units of all joints are designed in a way, that their contributions to the inertia are as small as possible. Therefore the drive unit for panning the arm (Rot. 1), which has to provide the highest torque in the arm, is attached directly to the torso and does not contribute to the inertia of the moving part of the arm. The drive units for raising the arm (Rot. 2) and turning the arm around its longitudinal axis (Rot. 3) have been placed closely to the rotational axes to improve the dynamics of the shoulder joint. In order to achieve the required gear ratios in the very limited design space, Harmonic Drive transmissions, worm gear transmissions and toothed belt transmissions have been used.

These elements allow a compact design of the shoulder with a size similar to a human shoulder. As all degrees of freedom are realized directly in the shoulder, the design of the upper arm is slender. The integration of torque sensors in all three degrees of freedom is realized in two different ways. For the first degree of freedom strain gages are attached to a torsion shaft which is integrated in the drive train. The torque for raising and turning the arm is determined by force sensors that measure the axial forces in the worm gear shafts. In addition to the encoders, which are attached directly at the motors, angular sensors for all three degrees of freedom are integrated into the drive trains of the shoulder joints. The position sensors, which are located directly at the joints, allow quasi-absolute angular position measurement based on incremental optical sensors. A touch-sensitive artificial skin sensor, which can be used for collision detection or intuitive tactile communication, is attached to the front and rear part of the shoulder casing (Kerpa et al., 2003).

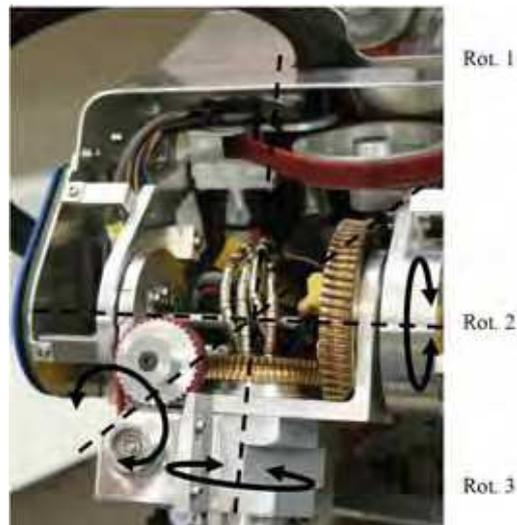


Fig. 9. Side view of the shoulder joint.

5.2 Elbow joint and upper arm

The elbow joint of ARMAR III has two degrees of freedom. These allow bending as well as rotating the forearm. The drive units, consisting of motor and Harmonic Drive transmissions, are not in the arm, but are located in the thorax of the robot. Thus the moving mass of the arm as well as the necessary design space are reduced, which leads to better dynamic characteristics and a slim form of the arm. The additional mass in the thorax contributes substantially less to the mass inertia compared to placing the drive units in the arm.

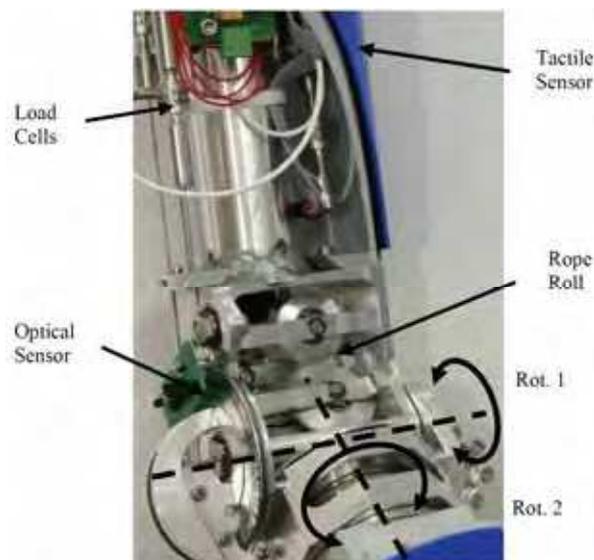


Fig. 10. Elbow joint.

Due to this concept, load transmission is implemented with the use of wire ropes, which are led from the torso through the shoulder to the elbow by rolls and bowden cables. In order to realize independent control of both degrees of freedom, the wire ropes for turning the forearm are led through the axis of rotation for bending the elbow. With altogether twelve rolls, this rope guide realizes the uncoupling of the motion of bending the elbow from rotating the forearm. In contrast to the previous version of the elbow, where the steel cables were guided by Bowden cables, this solution leads to smaller and constant friction losses which is advantageous for the control of this system.

Similar to the shoulder, the angular measurement is realized by encoders attached directly to the motors as well as optical sensors that are located directly at the joint for both degrees of freedom. In order to measure the drive torque, load cells are integrated in the wire ropes in the upper arm. As each degree of freedom in the elbow is driven by two wire ropes the measuring of force in the wire ropes can be done by differential measurements. Another possibility for measuring forces offers the tactile sensor skin, which is integrated in the cylindrical casing of the upper arm.

By placing the drive units in the thorax, there is sufficient design space left in the arm which can be used for electronic components that process sensor signals and which can be installed in direct proximity to the sensors in the upper arm.

5.3 Wrist joint and forearm

The wrist has two rotational degrees of freedom with both axes intersecting in one point. ARMAR III has the ability to move the wrist to the side as well as up and down. This was realized by a universal joint in very compact design. The lower arm is covered by a cylindrical casing with an outer diameter of 90 mm. The motors for both degrees of freedom are fixed at the support structure of the forearm. The gear ratio is obtained by a ball screw and a toothed belt or a wire rope respectively. The load transmission is almost free from backlash.

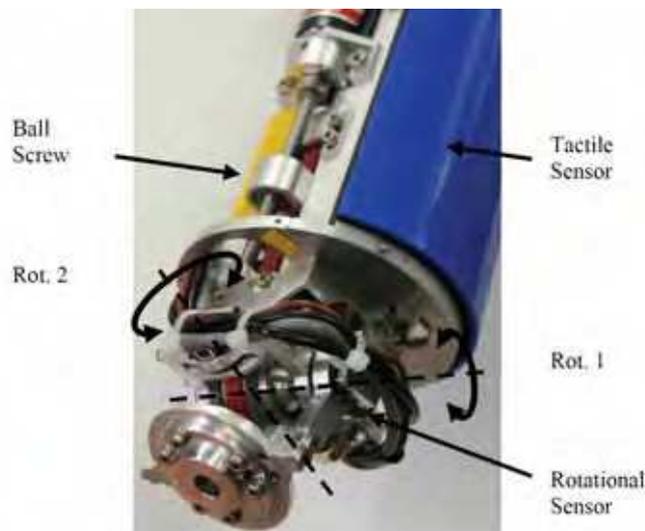


Fig. 11. Forearm with two degrees of freedom in the wrist.

By arranging the motors close to the elbow joint, the centre of mass of the forearm is shifted towards the body, which is an advantage for movements of the robot arm. Angular measurement in the wrist is realized by encoders at the motors and with quasi-absolute angular sensors directly at the joint. To measure the load on the hand, a 6-axis force and torque sensor is fitted between the wrist and the hand (Beck et al., 2003) (not shown in Fig. 11). The casing of the forearm is also equipped with a tactile sensor skin. The support structure of the forearm consists of a square aluminium profile. This rigid lightweight structure offers the possibility of cable routing on the inside and enough space for mounting electronic components on the flat surfaces of the exterior.

5.4 Neck joint

The complex kinematics of the human neck is defined by seven cervical vertebrae. Each connection between two vertebrae can be seen as a joint with three degrees of freedom. For this robot, the kinematics of the neck has been reduced to a serial kinematics with four rotational degrees of freedom. Three degrees of freedom were realized in the basis at the lower end of the neck. Two degrees of freedom allow the neck to lean forwards and backwards (1) and to both sides (2), another degree of freedom allows rotation around the longitudinal axis of the neck. At the upper end of the neck, a fourth degree of freedom allows nodding of the head. This degree of freedom allows more human-like movements of the head and improves the robots ability to look up and down and to detect objects directly in front of it.

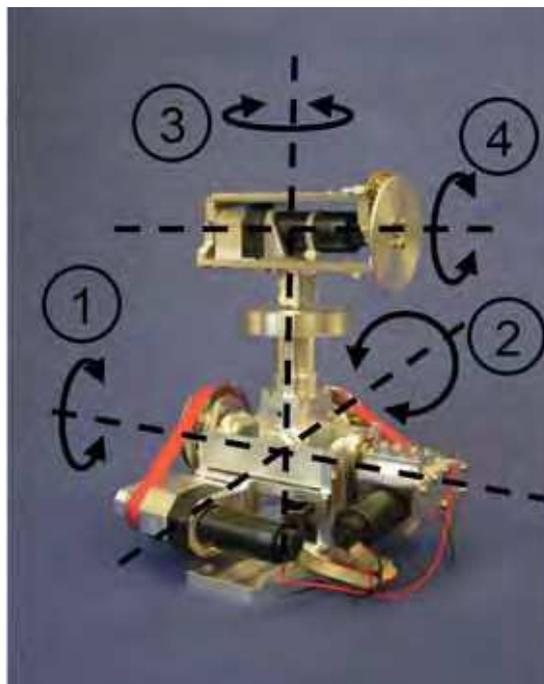


Fig. 12. Neck joint with four degrees of freedom.

For the conversion of torque and rotational speed, the drive train of each degree of freedom consists of Harmonic Drive transmissions either as only transmission element or, depending on the needed overall gear ratio, in combination with a toothed gear belt.

The drives for all degrees of freedom in the neck are practically free from backlash. The motors of all degrees of freedoms are placed as close as possible to the rotational axis in order to keep the moment of inertia small. The sensors for the angular position measurement in the neck consist of a combination of incremental encoders, which are attached directly to the motors, and quasi-absolute optical sensors, which are placed directly at the rotational axis. The neck module as depicted above weighs 1.6 kg.

5.5 Torso joint

The torso of the upper body of ARMAR III is divided into two parts, the thorax and the torso joint below it. The torso joint allows motion between the remaining upper body and the holonomic platform, similar to the functionality of the lower back and the hip joints in the human body. The kinematics of the torso joint does not exactly replicate the complex human kinematics of the hip joints and the lower back. The complexity was reduced in consideration of the functional requirements which result from the main application scenario of this robot in the kitchen. The torso joint has three rotational degrees of freedom with the axes intersecting in one point. The kinematics of this joint, as it is described in table 1 and Fig. 13, is sufficient to allow the robot to easily reach important points in the kitchen. For example in a narrow kitchen, the whole upper body can turn sideways or fully around without having to turn the platform. One special requirement for the torso joint is, that all cables for the electrical energy flow and information flow between the platform and the upper body need to go through the torso joint. All cables are to be led from the upper body to the torso joint in a hollow shaft with an inner bore diameter of 40 mm through the point of intersection of the three rotational axes. This significantly complicates the design of the joint, but the cable connections can be shorter and stresses on the cables due to compensational motions, that would be necessary if the cable routing was different, can be reduced. This simplifies the design of the interface between upper and lower body. For transportation of the robot, the upper and lower part of the body can be separated by loosening one bolted connection and unplugging a few central cable connections. Due to the special boundary conditions from the cable routing, all motors had to be placed away from the point of intersection of the three axes and the motor for the vertical degree of freedom Rot. 3 could not be positioned coaxially to the axis of rotation. The drive train for the degrees of freedom Rot. 1 and Rot. 3 consists of Harmonic Drive transmissions and toothed belt transmissions.

The drive train for the degree of freedom Rot.2 is different from most of the other drive trains in ARMAR III as it consists of a toothed belt transmission, a ball screw and a piston rod which transforms the translational motion of the ball screw into the rotational motion for moving the upper body sideways. This solution is suitable for the range of motion of 40°, it allows for a high gear ratio and the motor can be placed away from the driven axis and away from the point of intersection of the rotational axes.

In addition to the encoders, which are directly attached to the motors, two precision potentiometers and one quasi-absolute optical sensor are used for the angular position measurement.

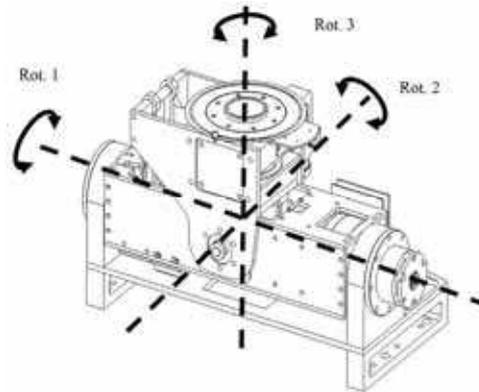


Fig. 13. Torso joint.

6. Conclusions and future work

Methods for the efficient development of modules for a humanoid robot were developed. Future work will be to create a database of system elements for humanoid robot components and the characterization for easier configuration of future humanoids. This database can then be used to generate consistent principle solutions for robot components more efficiently.

Topology optimization is a tool for designing and optimizing robot components which need to be light yet stiff. The thorax of ARMAR III was designed with the help of this method. For the simulation of mechatronic systems like humanoid robots, it is necessary to consider mechanical aspects as well as the behaviour of the control system. This is not yet realized in the previously described topology optimization process. The coupling between the mechanical system and the control system might influence the overall system's dynamic behaviour significantly. As a consequence, loads that act on a body in the system might be affected not only by the geometric changes due to optimization but also by the control system as well. The topology optimization scheme shown in Fig. 4 should be extended by means of integrating the dynamic system with a multi body simulation and the control system as depicted in Fig. 14.

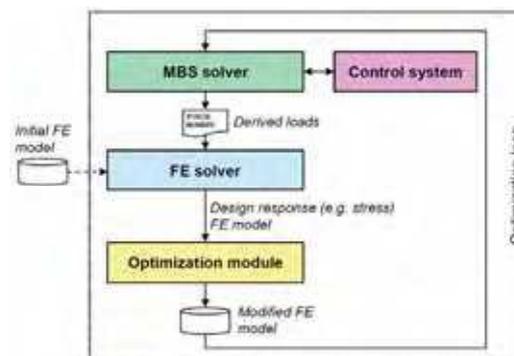


Fig. 14. Controlled MBS extended topology optimization.

The upper body of the humanoid robot ARMAR III was presented. The modules for neck, arms and torso were explained in detail. The main goals for the future work on ARMAR III

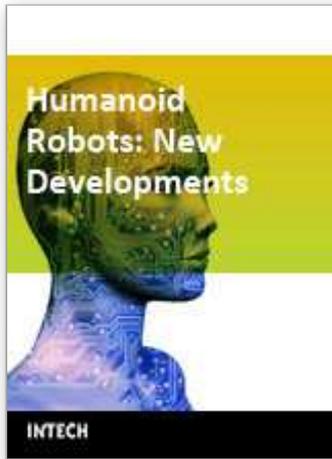
are to further reduce the weight and to increase the energy efficiency, increase the payload and to design a closed casing for all robot joints.

7. Acknowledgement

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Humanoid Robots: New Developments

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For many years, the human being has been trying, in all ways, to recreate the complex mechanisms that form the human body. Such task is extremely complicated and the results are not totally satisfactory. However, with increasing technological advances based on theoretical and experimental researches, man gets, in a way, to copy or to imitate some systems of the human body. These researches not only intended to create humanoid robots, great part of them constituting autonomous systems, but also, in some way, to offer a higher knowledge of the systems that form the human body, objectifying possible applications in the technology of rehabilitation of human beings, gathering in a whole studies related not only to Robotics, but also to Biomechanics, Biomimetics, Cybernetics, among other areas. This book presents a series of researches inspired by this ideal, carried through by various researchers worldwide, looking for to analyze and to discuss diverse subjects related to humanoid robots. The presented contributions explore aspects about robotic hands, learning, language, vision and locomotion.

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