# Concept and Design of the Modular Actuator System for the Humanoid Robot MYON

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**Abstract.** When developing a humanoid robot, the choice of the system driving its joints is of crucial importance for the robot's robustness, technical reliability, ease of maintenance, as well as its degree of autonomy. Here, we present a novel, modular actuator system of the humanoid robot Myon. Both the concept of the actuator system and the composition of the individual modules which it consists of are described. In addition to the design of the robot's joints the way how the actuator components are integrated in the assembly of Myon is addressed. Finally, the characteristics of the different modes of actuating the joints by the actuator system are explained, and future prospects of its application considered.

**Keywords:** humanoid robot; modular actuators; compliant actuators; parallel actuation; serial elasticity.

## 1 Introduction

Humanoid robots nowadays are mainly being developed for research purposes. Here, their development is directed towards a multitude of research fields such as biped locomotion [1–4], interaction between man and machine [5–7], artificial intelligence [8], or for various servicing applications [7] where the robot is used as a tool.

For investigations in the area of motion control, like the locomotion of a humanoid robot, the design of the actuator system actuating the respective robot plays a crucial role. Different types of actuators are being applied here. The actuator systems most frequently used with humanoid robots are based on either electromechanical [1, 3, 7], pneumatic [4, 9], or hydraulic principles [6], respectively. These principles differ from each other in many regards. Some important properties concern their power density, energetic efficiency, structural shape, controllability, as well as the kind of energy supply. The latter is among the decisive aspects concerning the robot's quality of autonomy. For instance, robots based on pneumatic or hydraulic actuators are often linked to a stationary external energy supply [4]. Thus, their autonomy is restricted compared to robots which carry along a source of energy by themselves.

Furthermore, the compliance of the actuator system is an important attribute for the use with humanoid robots since this compliance may have a significant influence, e.g., on the energetic efficiency during walking movements, or on the shock tolerance of the robot's joints [4, 10]. Last but not least, the ease of the robot's serviceability is an important quality criterion, not only for routine maintenance but also for, e.g., making adjustments.

The objective of the present work was to develop a actuator system in a modular style which allows for an individual adaptation to the different joints of a humanoid robot. The advantage of a modular construction is that even complex yet stable structures can be generated with only few different components if they provide versatile linkage possibilities. In the first section the concept of the actuator system is explained. Further, it is illustrated how the single components of the actuator system are realized and implemented into the robot. Concluding, the advantages generated by the actuator system are shown.

## 2 Concept of MYON's Actuator System

The humanoid robot Myon (see figure 1, right panel) has a height of 1.25 m and weighs 15 kg. It was developed in line with the project ALEAR (Artificial Language Evolution on Autonomous Robots) [11] for which, among others, it provides a library of motion.

A central concept having been realized with the development of Myon is its modularity [12]. This modularity is split into two types. First, the modularity of

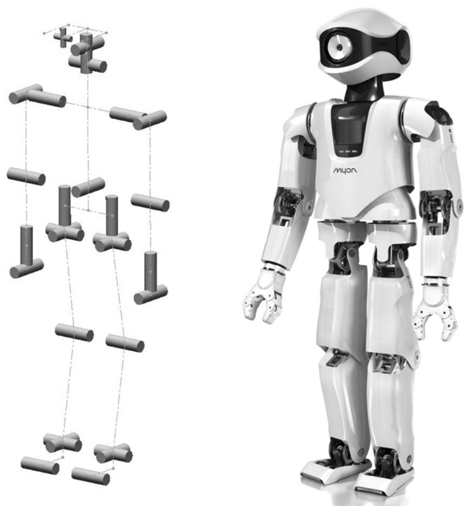

**Fig. 1.** Left panel, arrangement of Myon's individual joints. Right panel, the humanoid robot Myon.

the individual body parts: Each of these (head, torso, arms, and legs) represent a module which are autonomous with regard to sensor system, computation power, actuating elements and energy supply and which can be connected by an flange system. Second, the modularity of its inner configuration. This type of modularity concerns technical components which Myon consists of. These components comprise local processor nodes (called *AccelBoard3D*) [12], sensors, battery modules, adaptors, as well as the actuator system. Each of these components is to be considered a module being integrated in the robot at different positions but having one and the same general assembly (except for minor changes when needed for an adaptation to individual structural conditions in the robot). To guarantee the mobility of Myon, its actuating system was developed according to the following concept: Modular configuration, compliance, one single type of actuator and maintenance. The advantages and the relevance of this concept are elucidated more closely in the following.

Myon consists of 26 active joints (see figure 1, left panel). They differ from each other in their performance characteristics concerning torque and angular velocity. Thus, the knee joint is actuated more strongly than that of the elbow. To allow for adapting the actuator system to the individual requirements of the different joints, it itself again consists of several *modules*. The actuator's performance characteristics can be adjusted by the choice of a certain combination of those modules.

This characteristic of *compliance* in particular provides protection against shock-kind torque impulses. Compliance in the joints, however, offers further advantageous properties, such as the possibility of an improved torque controllability, as well as an intermediary storage of kinetic energy [4].

The *modules* integrated in Myon are adjusted to each other concerning their capacity. This avoids a possible need of oversizing components, or of special additional elements between the components at their mechanical or electronic interfaces and facilitates their assembly [13]. For this reason, one and the same actuator type can be used for the actuation of the whole body of Myon, and the

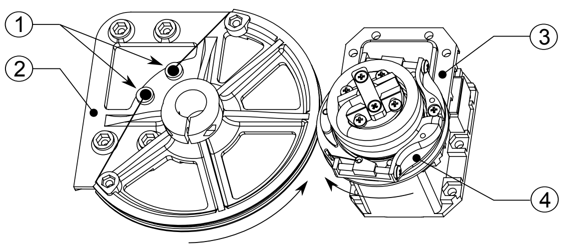


**Fig. 2.** Arrangement of the actuator components for actuating a joint. (1) shows, where the ends of the steel wire rope are mounted. (2) marks the pulley that is connected with the joint which shall be actuated. (3) represents the servomotor whose output shaft is mounted on the clutch (4). To transmit the torque between the clutch, both components are connected by the steel wire rope which is wired in a crosswise manner. Hence, the rotation of the pulleys is opposed, as shown by the arrows.

electronic interface of the *AccelBoard3D* needs to be configured for this actuator only. Furthermore, this allows for the use of a uniform type of the mechanical connection between actuator and joint in all positions of the robot.

A humanoid robot usually is a complex device. To ascertain its safe operation a fail-proof construction is required which also takes care of an easy maintenance. In particular, the actuator components should therefore be positioned in a manner providing simple serviceability.

## 3 Realization and Implementation

The actuator system of Myon relies on three components: Actuator, coupler, and steel wire rope. A joint which consists of these three components is depicted in figure 2. The electromechanically operating actuator (see figure 2, part number 3) converts electrical into mechanical energy and is connected with a coupling (see figure 2, part number 4). This coupling in turn is connected by a steel wire rope with a pulley (see figure 2, part number 2). Depending on its layout, this steel wire rope connection represents a transmission between actuator and joint. The application and layout of the three components depends on the specification of the joint to be driven. In addition, joints which are not directly driven by a servomotor are equipped with an absolute angle sensor in order to detect the exact position of the joint independently from the actuator system [14]. The realization of the actuator components is explained in detail in the following.

### 3.1 Realization of the Components

As basic device of the Myon actuator system an electromechanically operating servomotor type RX-28 is used (see figure 3, panel A). It already contains the power electronics needed for its operation and can be serially connected with further servomotors of the same type. In addition, this servomotor possesses an absolute manner working angle sensor for measuring the position of the actuator's output shaft. Up to four of such servomotors can be connected with one *AccelBoard3D* which in turn serves as a nodal point for its control.

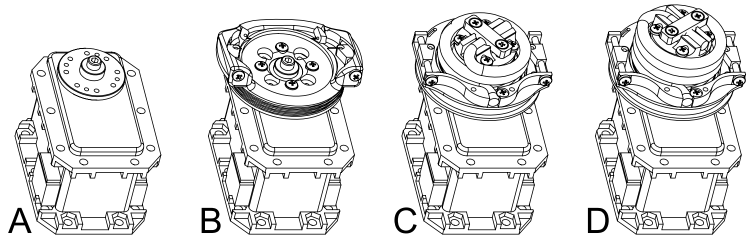


**Fig. 3.** Illustration of a single actuator in different configurations. (A) shows the RX-28 without any modifications. (B) shows the RX-28 combined with a rigid pulley, and (C) and (D) with a stiff (C) and less stiff (D) steel spring.

To generate a further transmission from the output side of the servomotor to the respective joint, a cable pull is applied. This consists of a pulley which is mounted on the servomotor, and another pulley placed on the respective joint. The pulley connected with the joint consists of ABS plastics and is manufactured by the Rapid prototyping. The transmission ratio is determined by the difference of either pulley's diameter. The pulleys themselves are connected with two steel wire ropes of 0.7 mm in diameter which withstand a traction of up to 400 N. Their ends are fastly bound to the pulleys (see figure 3, point 1). The cables are pre-stressed and therefore exert a drag force. To avoid that the axles on which the pulleys are mounted are being pulled together too strongly both cables between the pulleys run crosswise (see figure 2, 5). By this means the pulling forces are compensated during idleness of the actuator, thus reducing the load both on the bearings and the skeleton.

### 3.2 Implementation of the Components

The coupling module has been realized in three variants (cf. figure 3). Each of these variants comprises the mounting interfaces for the servomotor output and the attachment of both steel cables. Therefore the coupling also constitutes one of the two pulleys which enable an additional transmission. Coupler B (fig. 3) consists of ABS plastics and has been manufactured by the Rapid prototyping method. In contrast, couplings C and D are made of aluminum and equipped with torsion springs. They represent serial resilience and confer compliance to the actuator system at their installation positions. Both torsion springs exhibit a linear spring characteristic. The working spring rate $k$ of the coupler C is $k_1 = 163\, mNm/^\circ$, and that of the coupler D is $k_2 = 100\, mNm/^\circ$.

Fig. 4, on the left side shows a mounted coupler of type D, and on the right side its individual main components. To adjust the tension of the cables even after their mounting there are two cable clamp screws (1) as well as two cable clamp slides (2) located at the drive side ring (4) of the coupling at the

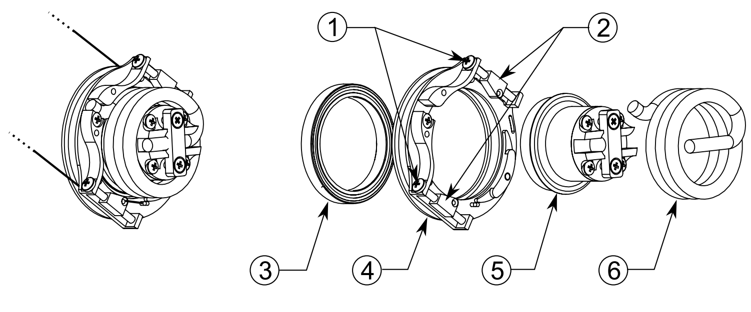


**Fig. 4.** Left panel, a mounted coupling of type D with implied ends of the steel cables; right panel, exploded view of a coupling of type D with numbered single components. (1) Cable clamp screws, (2) cable clamp slide, (3) ball bearing, (4) drive side ring, (5) drive shaft, (6) torsion spring.

latter of which the ends of the steel cables are attached. By turning the cable clamp screws, the cable tension is adjusted due to a simultaneous change in the position of the cable clamp slides. The drive side ring (4) is rotatable bedded on the drive shaft (5) by a ball bearing (3). The torsion spring (6) is, on its right end, connected with the drive shaft (5), and on its left end with the drive side ring (4). Due to this arrangement the drive side ring (4) and the drive shaft (5) can contort relative to each other depending on the torque impact.

The design of a actuator system for a particular joint directs itself according to the requirements given by this joint. To such requirements there belong the characteristics of maximum torque, maximum angular velocity, maximum angular deflection range, as well as the spatial situation around the joint. Furthermore, the weight of the actuator system is an important factor which is strongly influenced by the inclusion of additional servomotors and couplings. Joints which have to exert a strong torque can either be enforced by several servomotors, or/and another transmission ratio by means of the pulleys. In table 1 all actuator system variations with respect to the actuation of joints are listed.

As can be seen, the modules of the actuator system are integrated in Myon in different configurations. Simple joints such as that of the wrist are equipped with only one servomotor but no further actuator components. In contrast the ankle roll joint, as the strongest of all, is being actuated by four servomotors, and an additional transmission. As depicted in fig. 5, both the couplings and the pulleys are mounted on the exterior of the robot's skeleton which significantly facilitates

**Table 1.** Listing of Myon's active joints. For every joint, the construction regarding the number of used servomotors, type of coupling, gear ratio and operating range is listed. Furthermore, it can be seen which joints are equipped with an additional angle sensor.

| **MYON's joints actuation** | | | | | | |
|---|---|---|---|---|---|---|
| **Part** | **Joint** | **Number of Actuators** | **Type of Clutch** | **gear ratio** | **Operating Range** | **Angle Sensor** |
| Head | Pitch | 1 | A with Spring | 1:1 | 78° | no |
| | Roll | 1 | A | 1:1 | 110° | no |
| | Yaw | 1 | A | 1:1 | 180° | no |
| Arm | Shoulder Roll | 1 | B | 1:2 | 144° | yes |
| | Elbow | 1 | B | 1:2 | 127° | yes |
| | Wrist | 1 | A | 1:1 | 290° | no |
| Torso | Shoulder Pitch | 2 | C | 1:1.65 | 235° | yes |
| | Waist Roll | 1 | C | 1:4 | 60° | yes |
| | Hip Yaw | 1 | B | 1:2.73 | 80° | yes |
| Leg | Hip Roll | 2 | D | 1:2.5 | 60° | yes |
| | Hip Pitch | 3 | D | 1:2.5 | 129° | yes |
| | Knee | 3 | D | 1:2.5 | 171° | yes |
| | Ankle Roll | 1 | C | 1:2.5 | 30° | yes |
| | Ankle Pitch | 4 | B | 1:2.5 | 129° | yes |

their accessibility. Moreover, this assembly offers the possibility of exchanging servomotors without the need of dismantling surrounding structures.

The inclusion of several servomotors in a single joint actuation depends on the spatial conditions around the joint. As can be seen from figure 5, panels B, E, and F, in an ideal situation the servomotors and the connected couplings are located directly at the joint to be actuated. This minimizes structural loads by forces from the cable pull system. If the spatial situation does not allow for such an alignment, the servomotors can be, e.g., positioned consecutively, as shown in fig. 5, panels A, C and D. Due to this adaptability of the actuator system the available installation space can be optimally used.

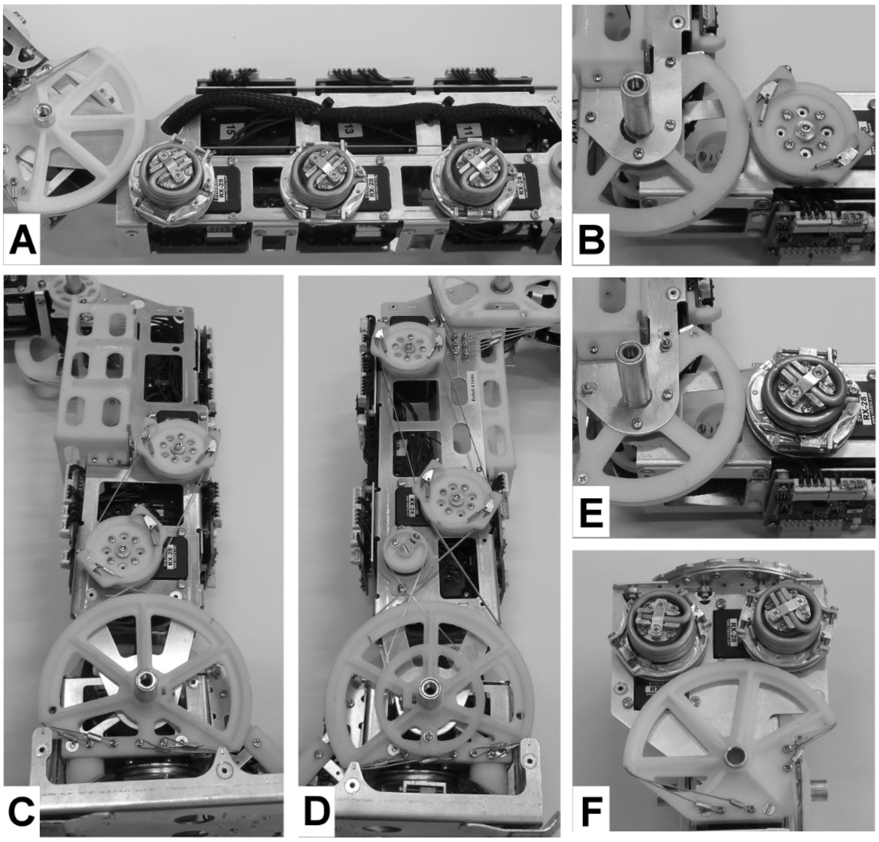

**Fig. 5.** Illustration of different joints of Myon. (A) Hip pitch, (B) elbow without compliance, (C) ankle pitch exterior, (D) ankle pitch interior, elbow with compliance, (F) hip roll.

## 4 Conclusion and Outlook

In this paper we have presented the composition of a novel, modular actuating system for movable robot parts and their integration into the apparatus' skeleton. We showed that by variation of only few but generally suitable actuator modules each joint of the humanoid robot Myon can be equipped. The application of serial resilience with heavily strained joints of the robot primarily provided shock resistance both of the joints and the actuator system. The arrangement of the actuator system components in an easily maintenance manner enables an uncomplicated exchange of the coupling components for, e.g., reasons of adjusting a joint's elasticity. For instance, the elbow joint as depicted in fig. 5, panel (B), and equipped with a rigid coupling variant B, can, as shown in fig. 5, panel (E), be modified with an elastic coupling C. More heavily strained joints of the robot are driven by up to four servomotors. In parallel with the number of actuators per joint, the amount of parameters available for steering purposes can be increased. This opens many new applications of Myon for research purposes. Among others, the possibility for antagonistic control of the joints connected with two or more actuators.

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