Myon: Concepts and Design of a Modular Humanoid Robot Which Can Be Reassembled During Runtime

Manfred Hild, Torsten Siedel, Christian Benckendorff, Matthias Kubisch, and Christian Thiele

Neurorobotics Research Laboratory
Humboldt-Universität zu Berlin
Unter den Linden 6
10099 Berlin, Germany
{hild|siedel|benckend|kubisch|thiele}@informatik.hu-berlin.de

We describe the design concepts of the modular humanoid robot Myon, which can be disassembled and reassembled during runtime. The body parts are fully autonomous in a threefold sense: they all possess their own energy supply, processing power, and a neural network topology which allows for stand-alone operation of single limbs. The robot has especially been designed for robustness and easy maintenance. It exhibits a combination of an endoskeleton with an exoskeleton, the latter of which can manually be detached without the need for technical equipment. One of the essential parts is a novel flange which firmly connects the body parts mechanically, whilst at the same time relaying the power supply lines and sensorimotor signals. We also address the details of the antagonistic and compliant actuation system which not only protects the gears against high impact forces but also enables biologically inspired joint control.

Keywords: Humanoid robot; Modular architecture; Power autonomy; Antagonistic actuation.

1. Introduction and Design Concepts

Humanoid robots are highly complex systems and as such prone to damages and malfunctioning. This is especially true if not only an upper torso with head and arms is used, but the full body, e.g. to test and analyze sensorimotor loops for walking motions and stable standing. There are several approaches to remedy the situation, depending on the experimental settings that are planned to be addressed with the humanoid platform. If full autonomy is not needed, then energy supply and processing power can be placed outside the robot and the bare skeleton can be optimized for maximal mechanical robustness. Also, the type of the actuators plays a crucial role. Pneumatic-driven humanoid robots can withstand a drop from more

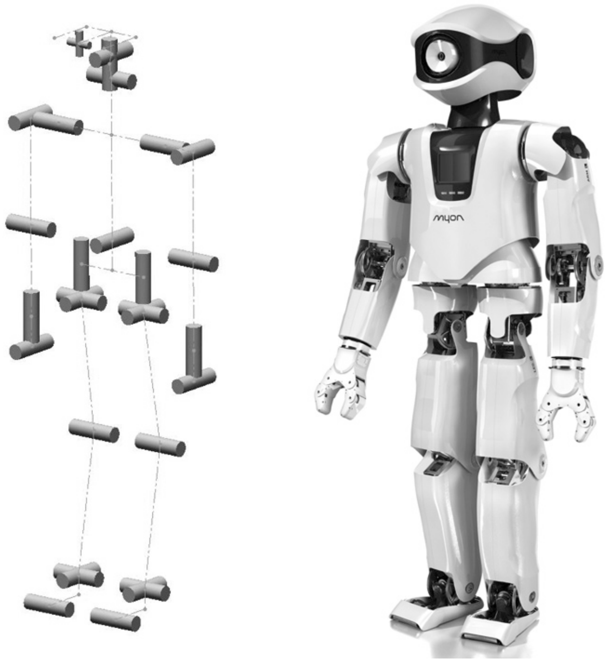

Figure 1. The humanoid robot Myon. Left: Schematic diagram of the joints' positions and orientations. Right: Image of the functional robot including the exoskeleton shells. The exoskeleton is a structural element which prevents the inner endoskeleton from external torsional loads. Furthermore, the electronic components are protected from mechanical impacts and the user from crushing injuries.

than one meter height onto the ground without any problem, although it has to be noted, that pneumatic actuators have much longer response times than electric motors.[1] Hence, if the robot needs to be mobile within the experimental setting then electric actuators and on-board batteries have to be used. The robot Myon, which is shown in Figure 1, has been designed for experiments on artificial language evolution[2] and therefore needs to be able to autonomously wander around, recognize and manipulate different objects, and communicate with other robots. Moreover, the robot is also to be used as a research platform for biologically inspired behavior control, using tight sensorimotor loops and antagonistic joint actuation. As recently stated by Migliore et al.,[3] the vast majority of walking robots still loses energy by ignoring the potential benefit of using passive elastic components at their joints. On Myon, elastic components could be incorporated in a very compact way along with the antagonistic actuation system. This not only opens up the research field of energy-efficient walking behaviors, but in the first instance protects the gears against high external impact forces.

In the following, we outline the overall system architecture and focus on the robot's modularity and the antagonistic actuation system. We additionally address the system's power autonomy, the compliance of the actuation system, and the flange design which allows the robot's body parts to be detached and re-attached during runtime.

2. Overall Properties

The robot has especially been designed for robustness and easy maintenance. It exhibits a combination of an endoskeleton with an exoskeleton, the latter of which can manually be detached without the need for technical equipment. All in all, the robot is 1.25 m tall and weighs 15 kg, including the shells (see Table 1). It consists of six body parts (head, torso, arms, and legs) which are fully autonomous in terms of energy supply, processing power, and neural network topology. This way, single body parts can

Table 1. Overview of the robot's mass, degrees of freedom (DOFs), and number of actuators. Except for the eye, a single type of actuator is used for all joints. Joints which need a large amount of torque, e.g. the knee, are driven by several actuators in parallel.

Module	Mass (kg)	Joint	DOFs (number)	Actuators (number)	Actuators (type)
Head	1.4	Eye	4	4	Micro servo
		Neck	3	3	RX-28
Arm (2x)	1.1	Shoulder	1	1	RX-28
		Elbow	1	1	RX-28
		Wrist	1	1	RX-28
Gripper (2x)	0.2	Fingers	1	1	RX-28
Torso	2.5	Shoulder (2x)	1	2	RX-28
		Waist	1	1	RX-28
		Leg (2x)	1	1	RX-28
Leg (2x)	3.0	Hip	2	5	RX-28
		Knee	1	3	RX-28
		Ankle	2	5	RX-28
		Toe	1	–	passive
Shells (total)	2.5		–	–	
Total	15.0		32	48	

be operated stand-alone using the distributed local processing nodes and special neuro-modules[4] as control structures. One of the essential parts is a novel flange which firmly connects the body parts mechanically, whilst at the same time relaying the power supply lines and sensorimotor signals.

3. System Architecture

The inner system architecture is shown in Figure 2. Each body part exhibits an *Energy Module* built of four Lithium-ion polymer batteries (3.55 Ah at 14.8 V, nominal) and an analog circuit which guarantees lossless energy balancing between all body parts. They are connected using a multi-core bus, the so-called *Extended Spinal Cord*, which transfers energy, sensorimotor data at a rate of 4.5 MBaud, and a control signal which is used to switch the robot on and off. Processing is done by 25 distributed processing nodes. They are called *AccelBoard3D*, since they also possess a 3-axis acceleration sensor, despite the Cortex-M3 RISC processor running at 72 MHz. Actuators and additional sensors are connected to each *AccelBoard3D*. The robot MYON does not exhibit a central processor, but the head features an *Field Programmable Gate Array* (FPGA) for image processing (see *BrainModule* in Figure 2).

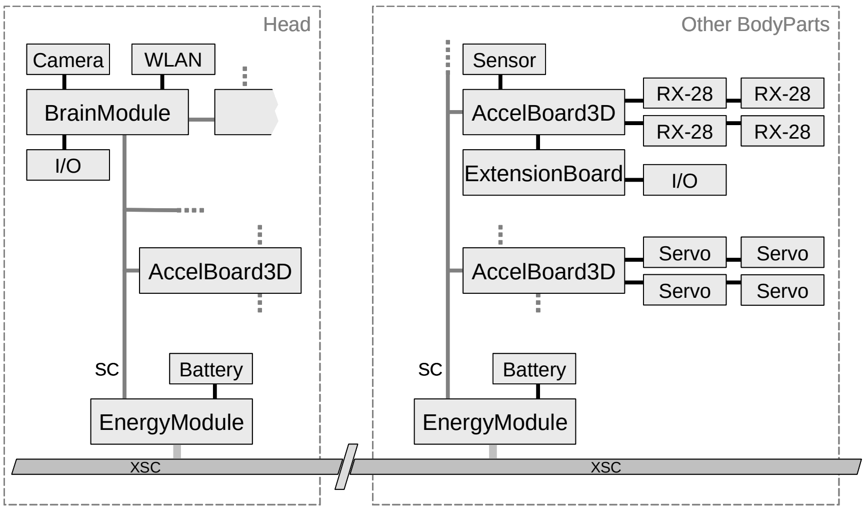

Figure 2. System architecture of the robot MYON. Components within each body part are connected via the so-called *Spinal Cord* (SC), whereas the body parts are connected by the *Extended Spinal Cord* (XSC) which includes several additional lines for energy transfer as well as a control line for quick shutdown of the robot.

4. Runtime Modularity

The body parts of the robot Myon can be detached and reattached during runtime, since every body part is fully autonomous, having its own power supply, computational power, as well as a special firmware which allows for hot plugging and respects the topological structure of the underlying recurrent neural control network. Figure 3 shows the robot's torso and the battery pack which can be inserted and removed easily. The flange design can be seen in Figure 4 in more detail. It consists of two interlocking rings which guarantee a mechanically firm connection. This is very important, e.g. for the legs, where large forces have to be transmitted between the limb and the torso. The electrical connection is placed in the middle of the flange. It relays the *Extended Spinal Cord* (XSC) as shown in Figure 2.

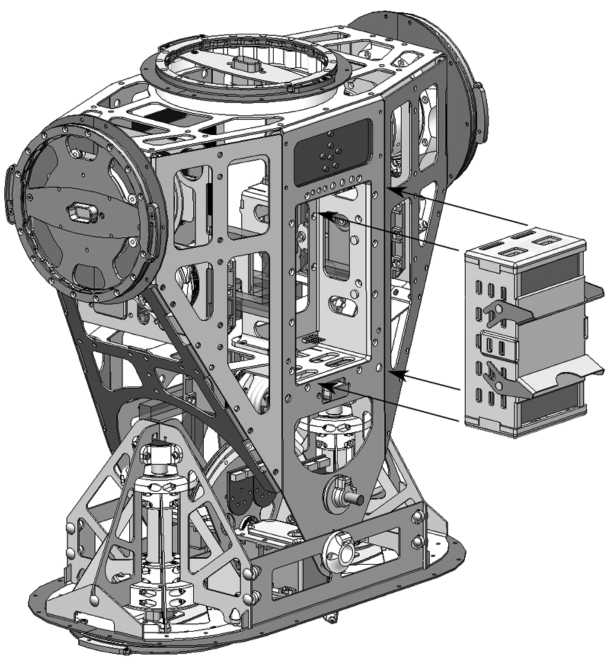

Figure 3. Construction of the robot's torso, exhibiting the flanges for the other body parts. The torso is made of aluminum and therefore only weighs 2.5 kg including actuators, electronics and batteries. The design of the battery pack allows for easy insertion and removal using a single hand.

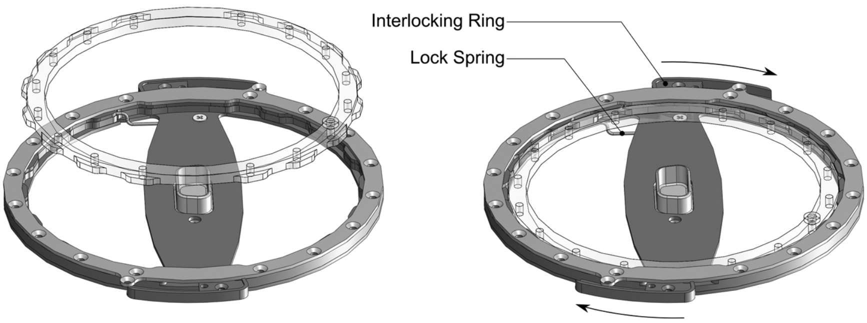

Figure 4. Detailed view of the novel flange which firmly connects the robot's body parts mechanically, whilst at the same time relaying the power supply lines and sensorimotor signals. The flange can be controlled using a single hand and allows for detachment and reattachment of body parts during runtime.

5. Power Autonomy

The power autonomy of the robot's body parts was a crucial design goal, since it enables stand-alone experiments with single limbs. An example of such an experiment is the stand up motion of a single leg, as presented by Hild and Kubisch.[5] Also the balance recovery reported by Kubisch et

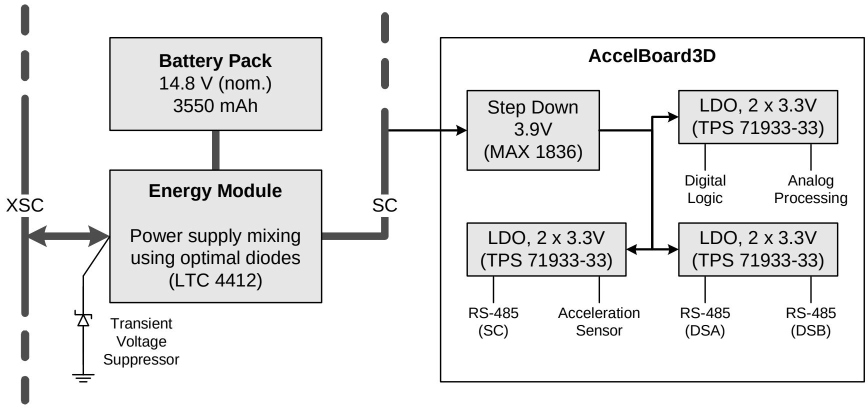

Figure 5. Power distribution within the robot. The *Extended Spinal Cord* (XSC) contains power lines from all body parts, whereas the *Spinal Cord* (SC) locally provides power within each body part (also see Figure 2). The SC power is predominantly recruited from the local battery pack, but other body parts can provide additional power if needed, e.g. during a knee bend. In order to save energy, and also to achieve maximum robustness against system failures, each *AccelBoard3D* processing node uses a step down converter (3.9 V) and six short-circuit-proof, low-drop-out voltage regulators (3.3 V each) for the different functional parts of the circuit, as indicated.

al.[6] uses only part of the robot, namely the torso with two legs. As the details of the power distribution reveal (see Figure 5), each body part can be driven by a mix of local power from the body part's own battery pack and the power from all other body parts which may more distant to the energy-consuming actuators, but which also may be not as exhausted as the local supply. Depending on the type of full body motion, a single battery pack is able to power the whole robot for twenty minutes or even longer. Surely, power can also be supplied via unconnected flanges (if not all body parts are used) or via an extra connector below the torso's battery pocket (see Figure 3).

6. Antagonistic Actuation

The robot exhibits 32 degrees of freedom which are driven by 48 actuators (see Table 1), i.e., several actuators (all of the type Robotis RX-28) drive the same joint, allowing for biologically inspired, antagonistic control strategies. Each actuator is equipped with a torsion spring, as shown in Figure 6. This spring provides a series elasticity which balances forces between actuators that drive the same joint. The spring stiffness is chosen so that high impact forces are damped enough not to break the actuator's gear in. Figure 7 shows a close-up of the ankle pitch joint, which is driven by four actuators.

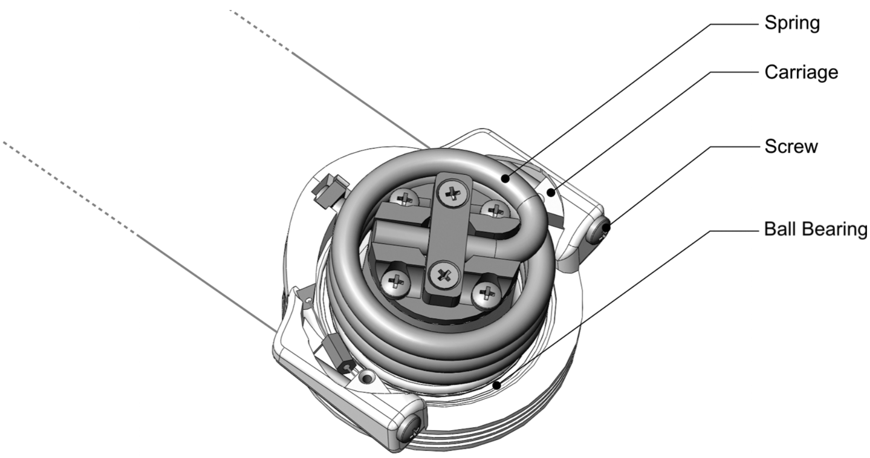

Figure 6. Detailed view of the torsion spring which is connected to each actuator in a compact way. The spring provides the necessary series elasticity to drive a single joint with multiple actuators in an antagonistic way. Forces are transmitted via wire ropes (also see Figure 7) which are clamped by a screw. Additionally, the spring also protects the actuator's gear from unforeseen high external impact forces.

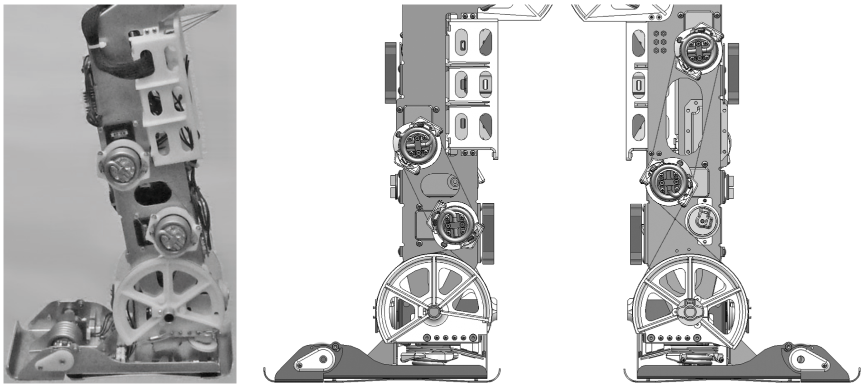

Figure 7. Detail of the ankle joint. Left: Photograph of the foot and leg without exoskeleton shells. Middle and Right: Schematic side views showing the four actuators (small circles) which drive the ankle pitch joint (big circle) via wire ropes.

7. Summary

We have described the modular humanoid robot MYON, which can be disassembled and reassembled during runtime, since all body parts are fully autonomous. The robot is robust and easy to maintain due to its exoskeleton and special flanges. In addition, MYON exhibits an antagonistic actuation system which enables researchers to study biologically inspired control strategies.

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