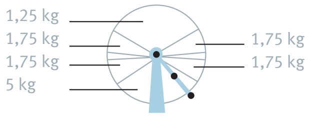
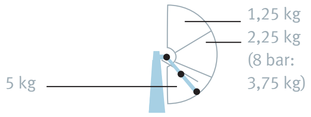
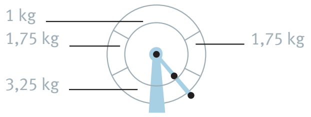
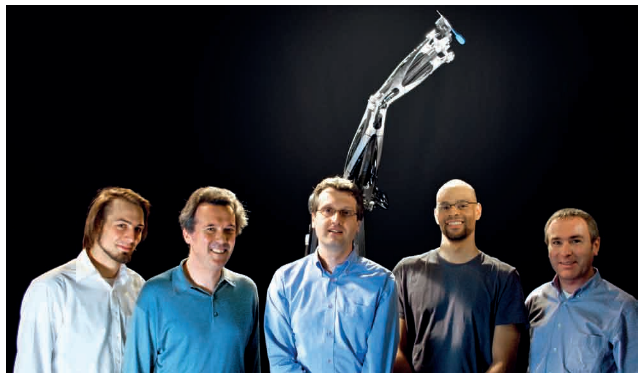
Technical data

General information:	
Kinematics	Serial 4-axis kinematics, rotatory joints
Actuators	12 pneumatic muscles
Sensors	1 inclination sensor, 3 potentiometers
Processor	Industrial PC, Dual-Core 2.66 GHz under Windows XP
Software	Matlab/Simulink with automatic code generation with RealTimeWorkshop for Windows Target
Masses (approx.)	rotor: 2 kg, upper arm: 2.2 kg, lower arm: 2.4 kg, hand: 0.2 kg
Air volume flow (at 6 bar)	typically: 60 L/min (600 W), maximum: 250 L/min (2,500 W)
Axis 1: shoulder joint	
Scope of movement	-90° ... +90°
Maximum payload	
Actuators	2 x 40 mm pneumatic muscles, max. 6 bar
Maximum angular velocity	570°/s
Maximum power output	372 W
Inherent flexibility	0.6 Nm/° (adjustable via pressure)
Axis 2: upper arm joint	
Scope of movement	-90° ... +90°
Maximum payload	
Actuators	4 x 20 mm pneumatic muscles, max. 6 bar
Maximum angular velocity	458°/s
Maximum power output	215 W
Inherent flexibility	0.2 Nm/° ... 0.6 Nm/° (adjustable via pressure)
Axis 3: elbow joint	
Scope of movement	-90° ... +90°
Maximum payload	
Actuators	4 x 10 mm pneumatic muscles, max. 8 bar
Maximum angular velocity	460°/s
Maximum power output	32 W
Inherent flexibility	0.057 Nm/° ... 0.073 Nm/° (adjustable via pressure)
Axis 4: wrist joint	
Scope of movement	-45° ... +45°
Actuators	2 x 10 mm pneumatic muscles, max. 8 bar



Project partners

Project initiator:
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Friedrich-Schiller-University of Jena:
Institute of Systematic Zoology and Evolutionary Biology with Phyletic Museum
Univ.-Prof. Dr. rer. nat. habil. Martin S. Fischer, Director
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Photos: scionic® I.D.E.A.L. and the respective universities

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AirArm – pneumatic 4-axis kinematics with inherent flexibility

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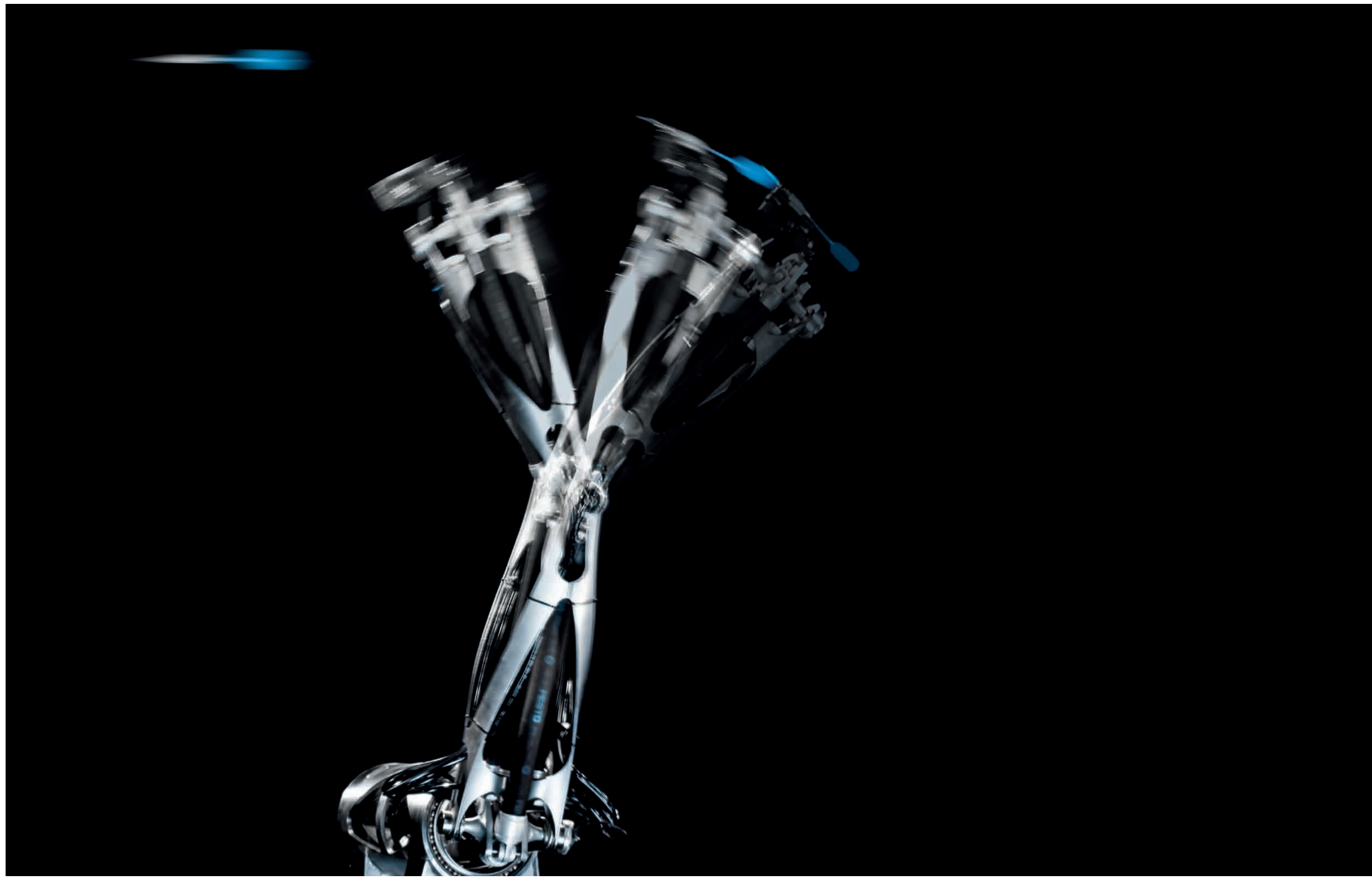


AirArm throws dart

Info

4-axis kinematics
Active support for human operators in their working environment relies on assistance systems that meet the highest demands in terms of dynamics, flexibility and gripping technology – requirements that are currently only inadequately fulfilled by classical handling technology and robotics without hazard, since such systems are designed more with a view to rigidity and positional accuracy and can endanger a human operator with their structurally determined large masses.

With the “AirArm” project, the Bionic Learning Network of Festo has realised the favourable dynamics and flexibility of human arm movements as a free technical rendering in a technological medium, through inspiration from nature and using industrial components from automation technology.

As a technology-carrier, the bionic AirArm provides insights that will expedite the development of assistance robots at the human-machine interface – for example in workshop production or in rehabilitation. The arm kinematics and actuators are not affected by harsh ambient conditions; the resistant system can be used for instance in applications with exposure to dust or water.

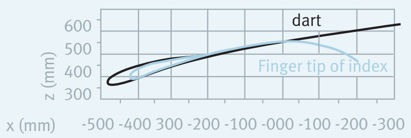
Whereas gripping movements within the scope of operation are normally described in Cartesian coordinates, AirArm is located by means of joint coordinates. It will be further developed in terms of handling technology and robotics and become available for further applications.

The following overview mirrors the application oriented reception of methodology, measurements and simulations of academic partners:

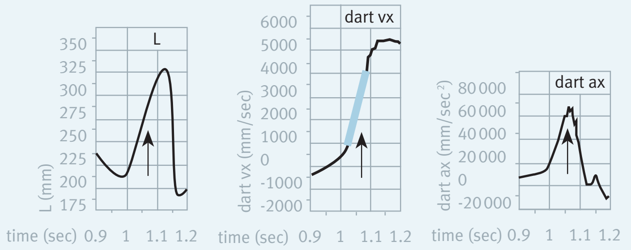

Experimental setup for dart throwing. Markers are applied to the shoulder, elbow and wrist joints.

Human and machines in comparison
As an example of dynamic movement, AirArm throws a dart. By means of a special end effector, the dart is held in place with an electromagnet; at the time of release, the magnet is deactivated and the dart is thrown. The trajectory is determined by the synchronous movement of the shoulder and elbow joints. High-speed image analysis of the trajectory shows a transfer of angular momentum from the upper arm to the lower arm and to the dart.

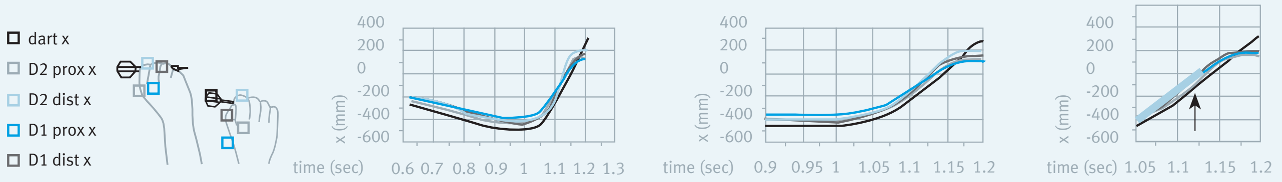
At about the time of release the shoulder joint almost comes to rest, with only the elbow joint continuing to rotate. The shoulder joint subsequently accelerates once more, and the rotation of the elbow almost ceases. However, the tool centre point (TCP) describes a continuous motion throughout the act of throwing. While this does not reproduce the movements of the human arm on a 1:1 basis, it reflects the human strategy: bionics instead of biomimikry, in this case anthropofunctionality. By analogy with reaching movements in a hemispherical space, the trajectories are verified on the basis of human movement patterns using the system Qualisys® with high-speed images (1,000 frames per second) and real-time motion recordings.



Human dart throw: trajectories of dart and finger tip
Dart and finger seperate jerk-free



Vertical arrows indicate time of dart release
Left: distance L between index finger tip and shoulder joint
Center: horizontal velocity vx of dart
Right: horizontal acceleration ax of dart



Examplification of fast yet smooth motions in human dart throwing. D1 ist thumb, D2 is index, prox and dist are markers at base and tip of finger. Diagrams from left to right zoom into time scale with the focus on seperation of dart and fingers. Fingers act as guidance for dart, the release of dart takes less than 50 msec.

Low mass for greater dynamics
The following graphs allow estimates of the absolute accelerations and velocities attainable by AirArm.

The motion was measured at the elbow joint and the TPC under acceleration or deceleration at maximum pressure (8 bar). These measurements yielded a TPC acceleration of up to 12 g (g = acceleration due to gravity). Discernible is a TCP velocity of 9 m/s without load; this is reduced to just under 4 m/s under a load of 4 kg.

Inherent flexibility
The flexibility of a joint of AirArm may be defined as the ratio of bending angle to torque. For the purpose of measurement only the pressure regulation of AirArm is activated, but not its positional regulation. An appropriate pressure is applied to the muscles, so that AirArm assumes the reference position for measurement. The flexibility is reflected by the gradients of the characteristic curves, whereby a higher gradient indicates greater flexibility. Conversely, lower flexibility of a joint means greater rigidity.

In the following graphs for the upper arm joint, flexibility is illustrated by way of example at various pressures. Flexibility decreases overall with increasing torque (non-linear increase in rigidity).

For the future operation of such systems, the rigidity could be varied by regulating flexibility. This would be of particular advantage for interaction with human operators.

Powerful regulation
The simulation model for AirArm can be used to test algorithms in place of the real system; it is realised as a Simulink block. An animated display of the robot is also rendered as a virtual reality model.

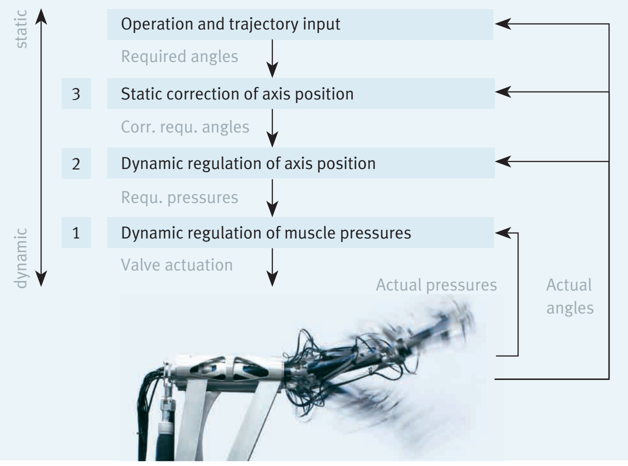
In accordance with the presentation, the regulation concept for AirArm is subdivided into several layers.

The upper levels primarily serve for static and the lower levels for dynamic correction:

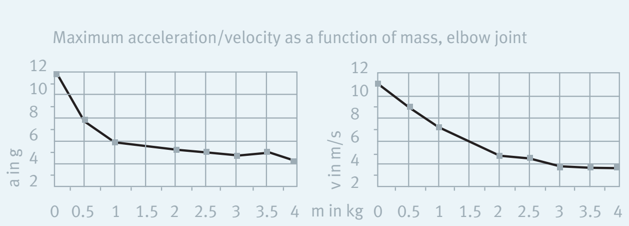
Level 1: Pressure regulation
Proportional valves without integrated pressure regulation are used to address the pneumatic muscles. A dynamic pressure regulation therefore has to be used to set and stabilise the desired muscle pressure.

Level 2: Positional regulation
The dynamic positional regulation serves to set the four axis angles in accordance with the prescribed “corrected required position”.

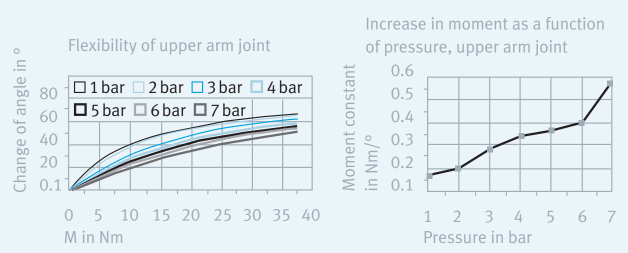
Level 3: Static correction
External disturbances (e.g. temperature fluctuations or unidentified load moments) lead to deviations between the model and reality, which in turn give rise to positional discrepancies. It is planned to rectify this situation by means of static corrections of the angular positions.



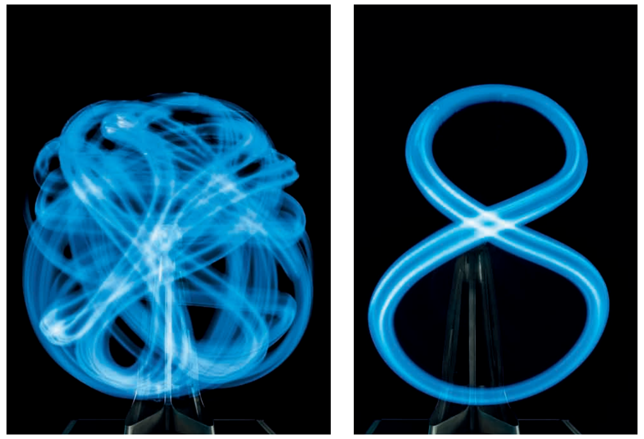
Hierarchy of AirArm regulating functions



Maximum acceleration and velocity attained as a function of payload



Flexibility and moment constant as a function of pressure


AirArm at maximum velocity and in harmonic motion