SAPHARI

SAFE AND AUTONOMOUS PHYSICAL HUMAN-AWARE ROBOT INTERACTION

SEVENTH FRAMEWORK PROGRAMME

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Deliverable 2.3.1

Compliant robot body

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Lead beneficiary for this milestone: DLR	**Revision:** 1

Nature: R	**Dissemination Level:** PU
R = Report P = Prototype D = Demonstrator O = Other	PU = Public PP = Restricted to other programme participants (including the Commission Services) RE = Restricted to a group specified by the consortium (including the Commission Services) CO = Confidential, only for members of the consortium (including the Commission Services)

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qbmate

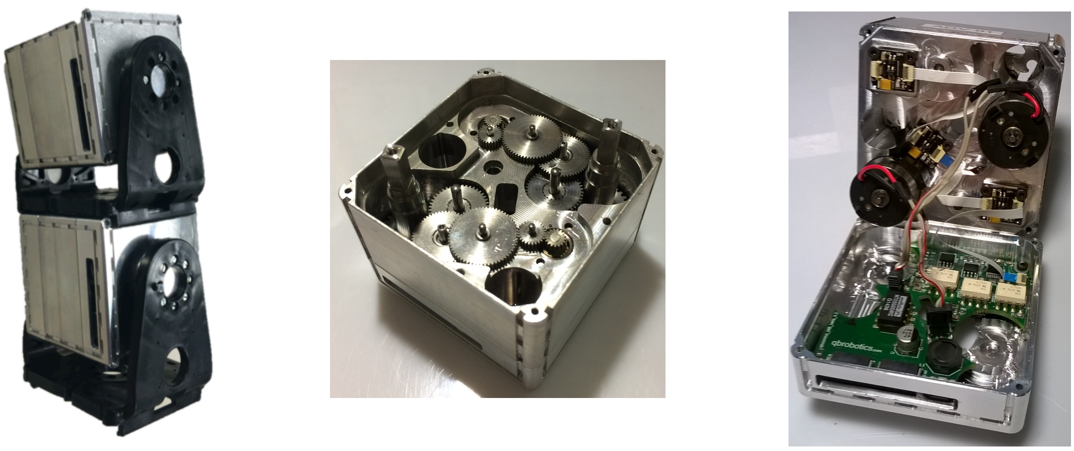

Fig. 1 The picture shows: on the left the external appereance of the *qbmove advanced* together with its compatibility inside the mechanical, electrical and software framework of the platform; on the centre the mechanical implementation of the custom gearboxes and on the rigth the custom electronic (control, power and sensors) integrated in the mechanical frame of the *qbmove advanced*

The new and complete release of the qbmove advanced, which preliminary implementation and technology was reported in MS33, has been finalised in collaboration with qbrobotics and it is ready to be integrated in the the qbmate humanoid upperbody, and much more in general in the qbmate robotic platform. Fig. 1 (left) shows the external appearance of the device, highlithing the aluminium frame rehalization and its family feeling, that make the unit completely compatible (in mechanics, software and electronics) with the other devices of the qbmate framework. In Fig. 1 (center) is shown the internal architecture of the customised integrated gearbox unit of the system. Fig. 1 (right) show the lower level level of the qbmove advanced highlighting the custom electronic board, customised electric prime movers and the three position sensors.

As shown in picture Fig. 1 (rigth) the qbmate upper body unit has been completely finalised. This upperbody count, in its basic implementation, of 12 actuated DoF. (two for the necks, four for each arm and two for end effector). The number of DoF can be increased up to fourteen actuated DoF if the addition of a two DoF. torso is taken in consideration. Components of the platform (cameras, grippers etc), together with some examples of application of the complete platform were already reported in MS34, D.2.2.1, the third WP2 annual report and lives demos during review meetings.

Fig. 2 On the left is shown the complete assembly of the upperbody unit, on the rigth some details on the neck and gripper design are highlighted.

The software platform is continuolsy under development and new features together with extended planning capabilities are in development and study. Particular emphasis is given on its ROS compatibility and integration. Fig. 4 show a photosequence extracted form and experiment where the uperbody unit is performing an hand-over task (as described in D2.3.1), as shown in Fig. 3 the planning and perception of the overall experiment are executed under a ROS and R-VIZ software environment.

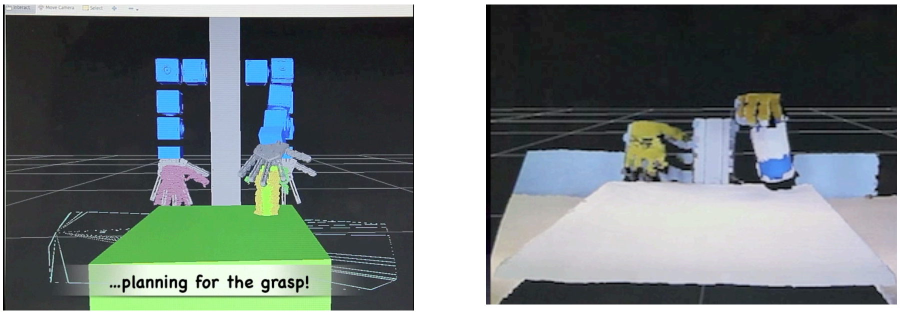

Fig. 3 The execution of the handover task is executed under a ROS and R-VIZ software environment.

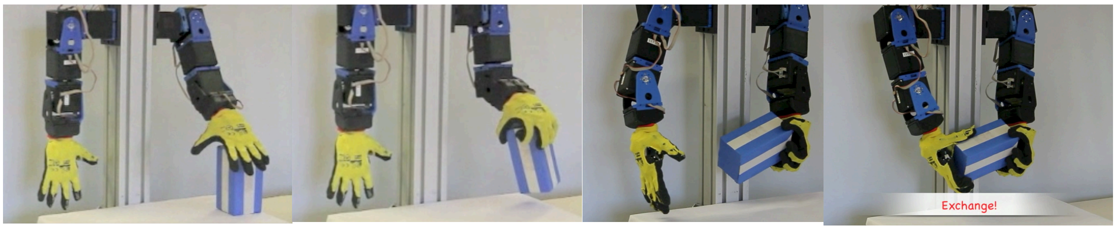

Fig. 4 The picture shows a sequence of snapshoot extracted from a experiment where the upperbody unit have to complete an handover task.

Design principles of the Series Elastic-Variable Damping/Clutch actuated dual arm system.

Design overview of the dual arm system

Using the final version of the Series Elastic Actuator and Variable damping/clutch (SEA-VPDA) unit developed in WP2 a dual arm mabipuation system was designed, Fig. 5. The size of the manipulator is approximately that of an adult human arm. Regarding the kinematics, three degrees of freedom are located at the shoulder complex and complemented by an additional degree of freedom for the implementation of the elbow flexion-extension DoF. The first three DoFs will reproduce, in sequence, the arm extension-flexion, adduction-abduction and humeral roll degrees of freedom accordingly with the ball-socket kinematic shoulder model. The range of motion of each joint is also reported in Fig. 5. The prototype of the SEA-Variable damping/clutch actuated Dual Arm system is currently under fabrication and it is expected to be operational shortly before the final review of the project.

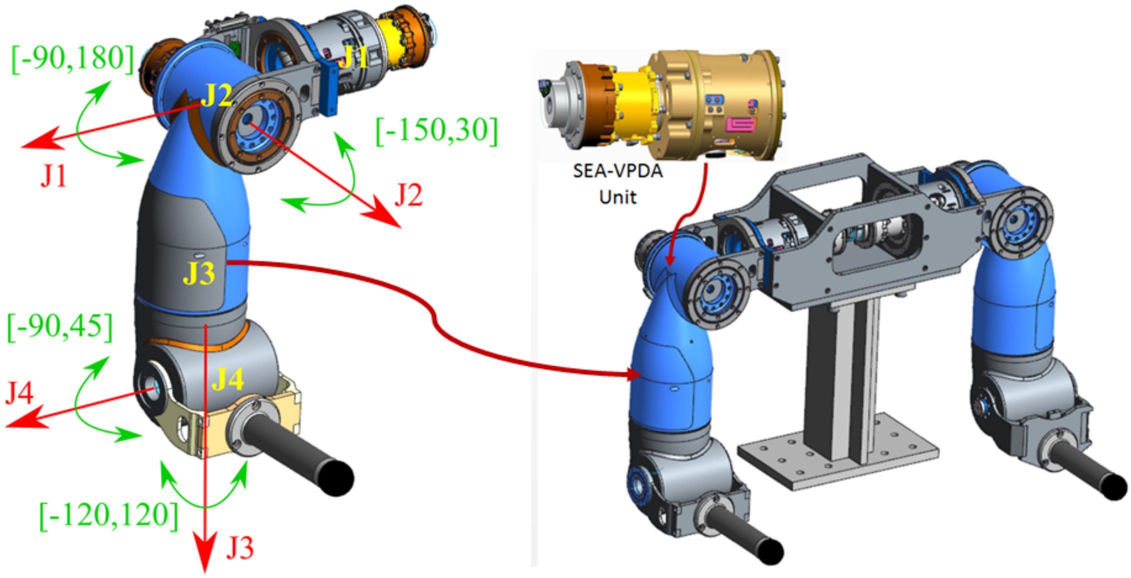

Fig. 5 3D CAD of the the SEA-VPDA dual arm manipulation system

The joints of the SEA-VPDA dual arm manipulation system are driven by the final implementation of the SEA-VPDA module that was realized using several updates with respect to the original implementnion including a progressively increasing stiffness Series Elastic Element Principle and a new realization of the variable damping subsystem.

Series elasticity design

The series elasticity in the final design of the joints was implemented using the elastic elememt shown in Fig. 6.

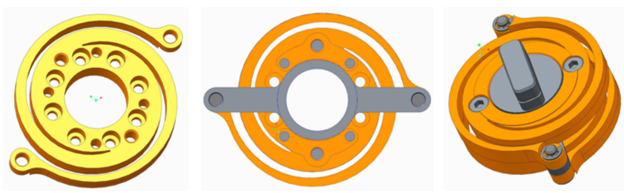

Fig. 6 Compliance system composed of two spiral springs implemented in parallel

The proposed mechanism is based on two spiral springs implelmented in parallel with each other. This compliance mechanism demonstrates a linear behaviour when loaded by torque values within the typical operational range due to its spiral profile. When torque increases, the spirals of the spring under compression deflect and come into gradual contact, thereby shortening the effective spiral length and increasing the apparent stiffness. This is a design feature which provides an appropriately low stiffnes in the operational range of the joint with a gradual stiffness increase up to a completely rigid at full deflection.

Variable Damping/Clutch design

Central to the development of the variable damping/clutch mechanism is the design of the linear drive. A schematic of the proposed final implemetation is shown in Fig. 7. The new mechanism relies upon a brushless DC motor connected to a ball-screw mechanism by means of gearing system, so that the geared rotary motion of the damping motor is transferred to the translational motion of the ball-screw nut. The ball screw mechanism is powered by a secondary gearing transmission system so that the geared motor can be embedded in parallel with the ball-screw apparatus and a radial or axial enlargement of the overall system is avoided. To ensure that the clutch disk moves always parallel with the ground, and to better replicate the idea of uniform pressure/wear, a parallelogram four-bar linkage is employed so that the coupler link motion is necessarily perpendicular to the ground link.

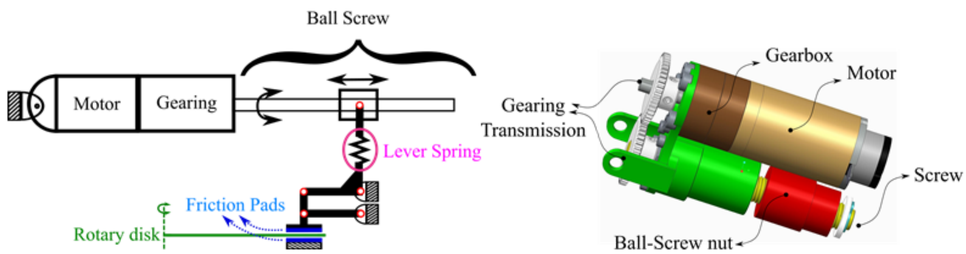

Fig. 7 Principle and 3D Cad design of the final variable damping mechanism

The parallelogram linkage is actuated through the connection of its upper crack link to the output crank link of an inverted slider-crank mechanism powered by the linear motion of its slider link, i.e. the nut of ball-screw mechanism. In order to enhance the force control perofmance of the mechanism, the output link of the inverted slider-crank mechanism is designed to be flexible and to provide a proportion of the force exrerted by the clutch disk. The L-shape link, which is in common with the aforesaid four-bar mechanisms, is therefore designed to be rigid on the parallelogram linkage part wihle preforming as a bi-directional spring on the slider-crank mechanism part. The design of this link is illustrated in Fig. 8.

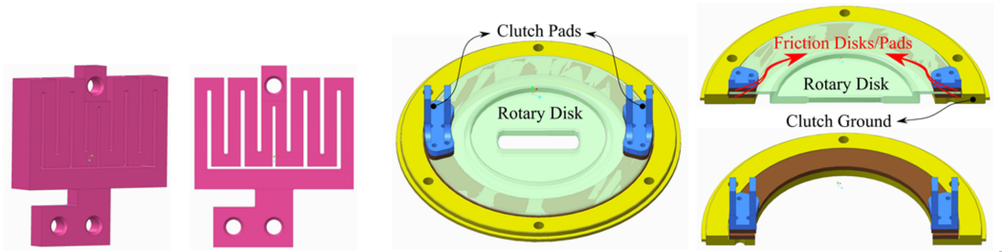

Fig. 8 The L-shape common link of the four-bar mechanisms and the linear drive unit of the variable damping/clutch module

The linear force generated by the mechanism described above is applied to clutch pads, when the clutch ground surface and the clutch pads are covered by a Kevlar fibre based friction material. In comparison with the first design in which the rotary disk is pressed to one frictional disk, the new design benefits from the compression of two frictional surfaces to the rotary disk. Fig. 8 on the right displays the friction disk arrangement of the proposed variable damping/clutch module.

SEA-VPDA Integration

The integrated SEA-variable damping/clutch mechanism is shown in Fig. 9. The lower side of the unit shows the complaint system in parallel to which the damping module describerd above operates.

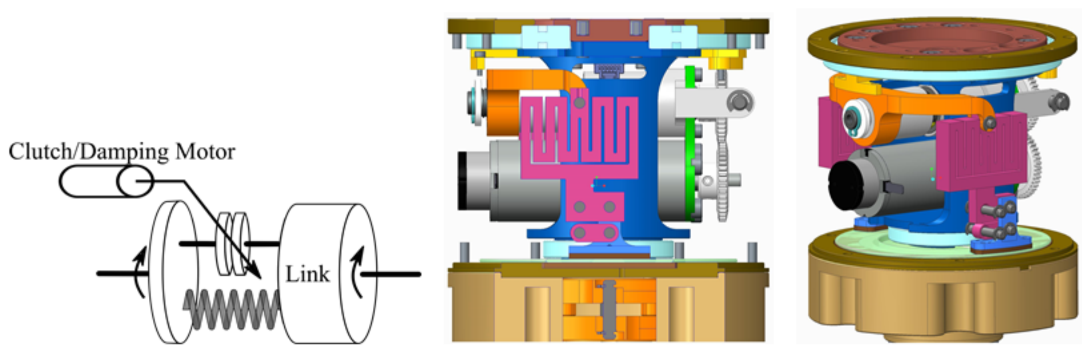

Fig. 9 The overall variable damping/clutch mechanism

As the geared output of the damping motor is transmitted to the ball-screw system, by means of the secondary gearing system, the linear motion of the ball-screw nut moves the coupler linkage of the inverted crank-slider mechanism. It rotates the L-shape link around the grounding pivot of this link (located at the corner of the “L”) while loading the spring of the upper side of this link. The rotary motion of the L-shape link therefore powers the parallelogram mechanism and drives the coupler link attached to the friction pad to press the rotary disk to the lower friction disk. The rotary position drive unit of the actuator is based on a brushless DC motor coupled with a harmonic drive whose output is connected to the variable damping/clutch compliant module through a torsionally flexible bar so that the position readings from the torsional bar ends can provide a measurement for the transmited torque. Fig. 10 shows the position drive unit coupled to the variable damping/clutch compliant module, as well as the scheme presenting the arrangement of mass/spring components.

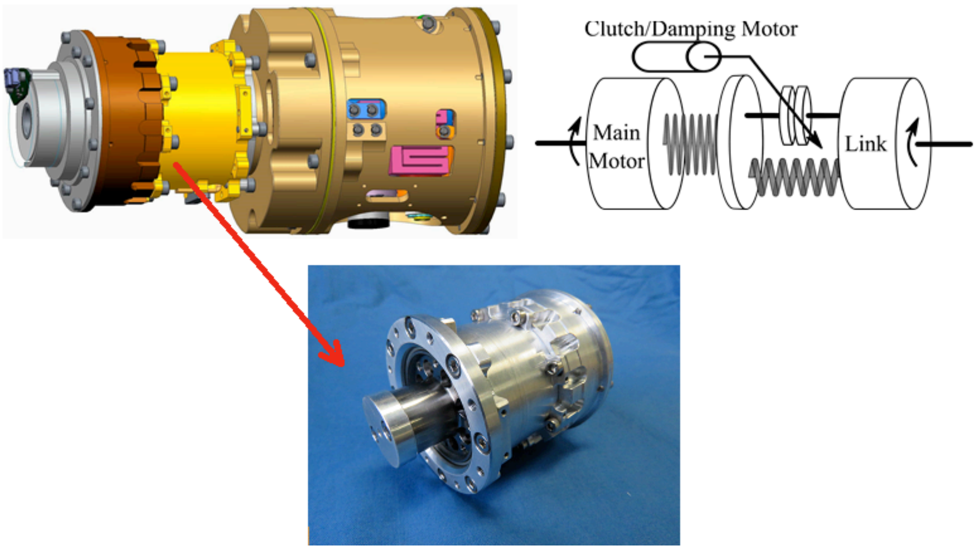

Fig. 10 The complete variable damping/clutch compliant actuation drive

The DLR Hand Arm System

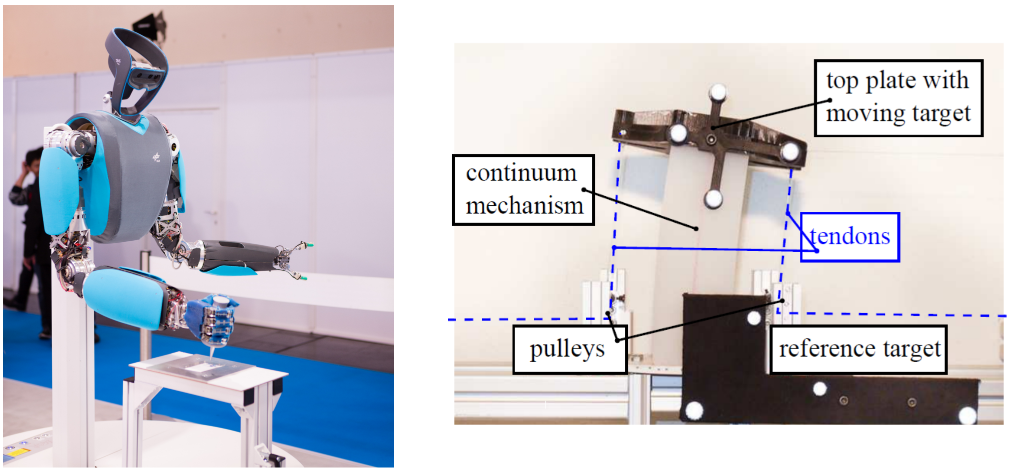

Fig. 11: Left: Full system with two arms and compliant torso; Right: Planar neck prototype

The DLR Hand Arm System in Fig. 11 left is extended by a second arm, a compliant non-actuated torso, and a neck to a total of 41 DoF. The torso can be used for whole body manipulation and the compliant housing helps to generate a robust grip and enhances robustness to impacts. The second arm (5 DoF) has a two finger setup (6 DoF) with an interface for several touch sensors.

Furthermore, the two arm system is extended by newly actuated neck/torso concept: A structurally flexible humanoid spine based on a tendon-driven elastic continuum (3 DoF). In the first step, the concept was tested on a planar testbed, see Fig. 11 right, which proved functionality and was then extended to a multiple DOF human-sized neck, see Fig. 12. The results of the neck will also validate if the concept is suitable as a torso actuation.

An actuated torso and neck increases the workspace of the arms and the range of view of the head drastically. If a passive elastic element is introduced, the mechanical robustness improves since it acts like a low pass filter to impacts, which enables the robot to work in unstructured environments. Especially for the torso, the elastic backbone works also as a passive gravity compensation, helping the mechanism in bended configuration to minimize the power consumption. If a tendon break occurs, the mechanism will not collapse and will still be able to move, at least in a smaller range. It is also beneficial for dynamic motions, since the torso can be moved energy efficiently while running and the head can easily follow moving objects. Moreover, impacts from each stroke are damped protecting the drivetrain.

To meet the specifications, the elastic backbone is designed out of silicone whereas a special interface between the silicone and the hard components is developed that ensures a high adhesion. Experiments on a preliminary planar showed the ability to move dynamically in the desired range of motion and with the mechanical robustness. The results are submitted to ICRA 2016. In the following the design of a modular multiple DOF test bed is explained, which can evaluate different tendon routing concepts in terms of functionality and modeling, see Fig. 12. Although the setup focuses on the specifications and explanations on the cervical part of the spine, this setup will also provide experience, whether such a mechanism could be used as a torso of a humanoid robot, since three axes of motions and their respective workspace are comparable.

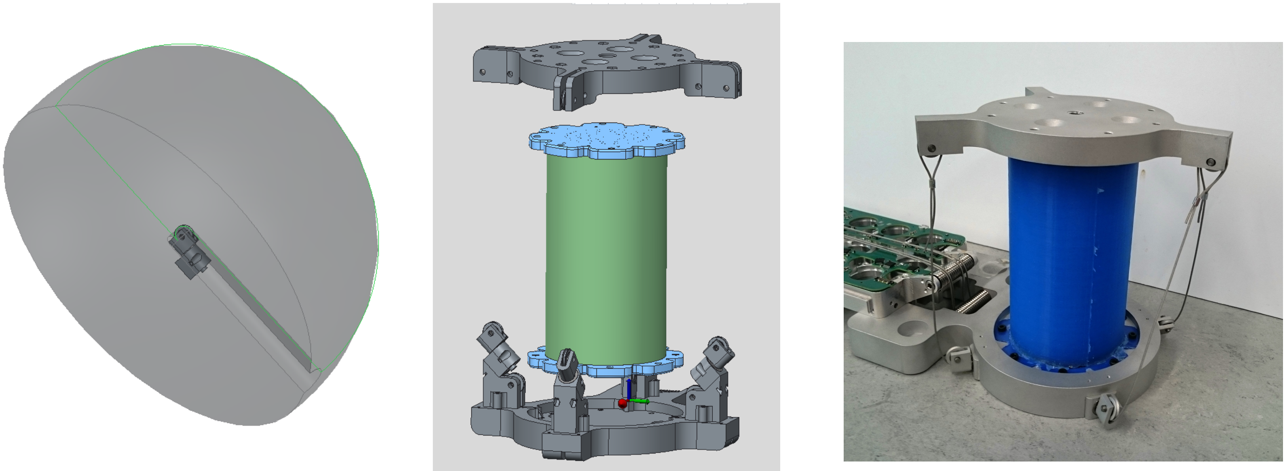

Fig. 12: Left: Workspace of the pulley; Middle: Changeable elastic spine; Right: Final setup

Tendon actuation provides flexibility in terms of the placement of the drives and it also provides the possibility to use larger and stronger motors, but the tendon actuation also inherits higher friction and additional designing effort, especially when the tendon has to be fully guided in different bending directions. For this purpose a special 2 DoF pulley was designed as shown in Fig. 12. Due to the routing through a hollow rotation axis which is supported by bearings, the pulley on the top can turn in each direction. Together with the change of the surrounding angle, the 2 DoF pulley provides a large workspace with low friction.

Since different tendon routings are going to be tested on the prototype, the top plate can be exchanged with different angles and distances, see Fig. 12 on the middle. To test different shapes of the continuum, the silicone cylinder is molded on two separated plates with anchors and cavities, which can be mounted in fixed angles on the bottom and top plate of the tendon mechanism. On the first multiple DoF setup, small motions are shown, see Fig. 13. The setup will be made of aluminum alloy to reach full forces in the tendons for final presentation.

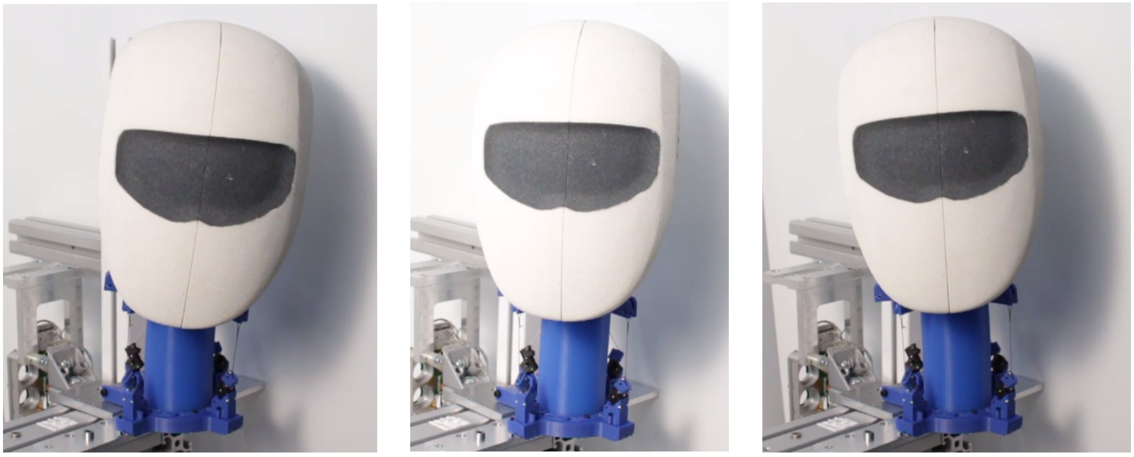

Fig. 13: Prelimary small motions on the 3D printed prototype