Towards design and development of new joint modules for humanoid ergoCub 2.0

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ergoCub is a new humanoid robot platform aimed for ***ergonomic human-robot collaborations*** for ***heavy payload lifting*** in industrial warehouses and healthcare units in order to mitigate risks of musculoskeletal diseases for workers. This article presents design and development of a new compact joint module for ergoCub 2.0 with ***continuous torque*** of ***40.5 Nm*** and ***repeatable peak torque*** of ***77.5 Nm***, thus increasing ***torque density*** by ***+163%*** and ***power density*** by ***+61%***.

I. Joint Modules

Design requirements

- ***Maximize torque density and power density*** to fulfill human-robot ergonomic lifting of heavy payloads.
- ***Modular design*** to allow deployment for several humanoid joints with minimal modifications in commercial components.
- ***Hollow shaft design*** to allow routing of power and data cables through the joint.
- Compact and robust design with ***ease of maintenance***.

Proposed Joint Specifications

The proposed joint has a shape of a hollow cylinder with **OD Ø 75mm, ID Ø 15mm** and **length 92mm**. Fig. 1 shows a sectional view of the CAD (developed on *PTC CREO Parametric*) highlighting all the electro-mechanical components as specified below:

- Motor: ***TQ ILM 50x08 PMSM***; frameless motor
- Speed Reducer: ***HD CPL-20-160***; with gear reduction ***160:1***
- Motor Encoder: ***AVAGO AEDR-9830***; 16-bit reflective optical incremental encoder with custom disks
- Joint Encoder: ***RLS AKSIM-2***; 19-bit absolute magnetic encoder and disk

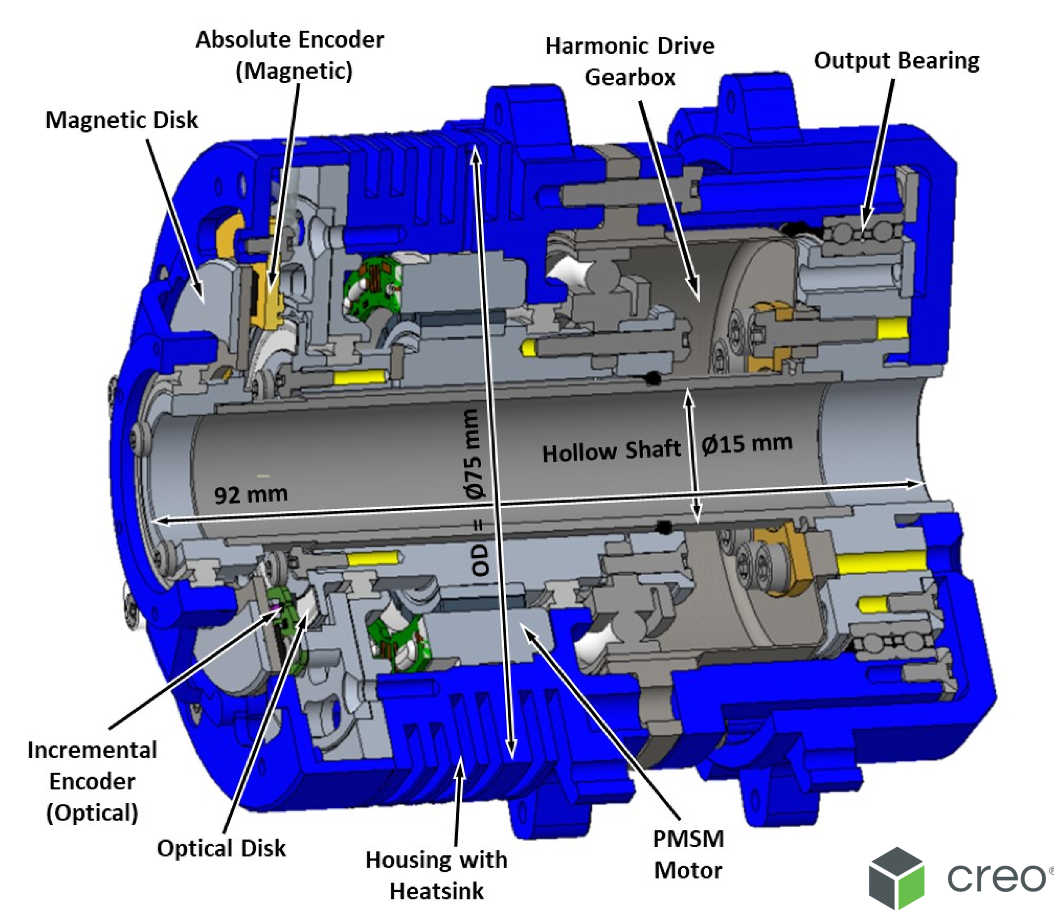

Fig. 1: Sectional CAD view of the joint module annotating all the components.

Table I shows a comparison of specifications of the proposed joint as compared to the previous ergoCub 1 joints (for the case of shoulder roll joint)

Table I : Performance comparison between ergoCub 1 joint and the proposed ergoCub 2.0 joint.

Parameter	ergoCub 1	ergoCub 2.0	Difference
Rated Torque [*Nm*]	13	40.5	+211.53 %
Peak Torque [*Nm*]	58	77.5	+33.62 %
Power [*W*]	110	210	+90.9 %
Weight [*kg*]	0.77	0.91	+18.18 %
Max. no load speed [*deg/sec*]	715	75	-89.45 %
Rated Torque Density [*Nm/kg*]	**16.88**	**44.5**	**+163.63 %**
Peak Torque Density [*Nm/kg*]	**75.32**	**85.16**	**+13.06 %**
Power Density [*W/kg*]	**142.86**	**230.77**	**+61.54 %**

II. Experimental Validation

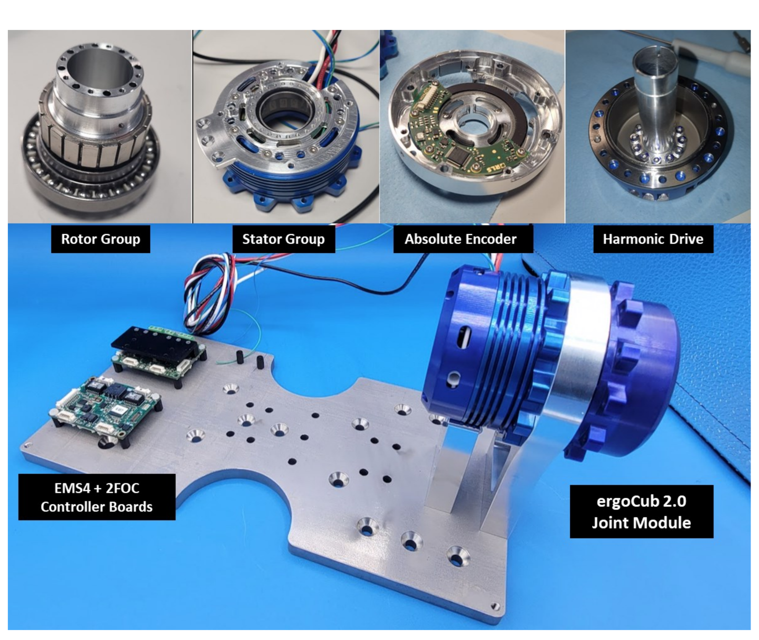

Fig. 2: Sub assemblies of the joint module and the experimental setup.

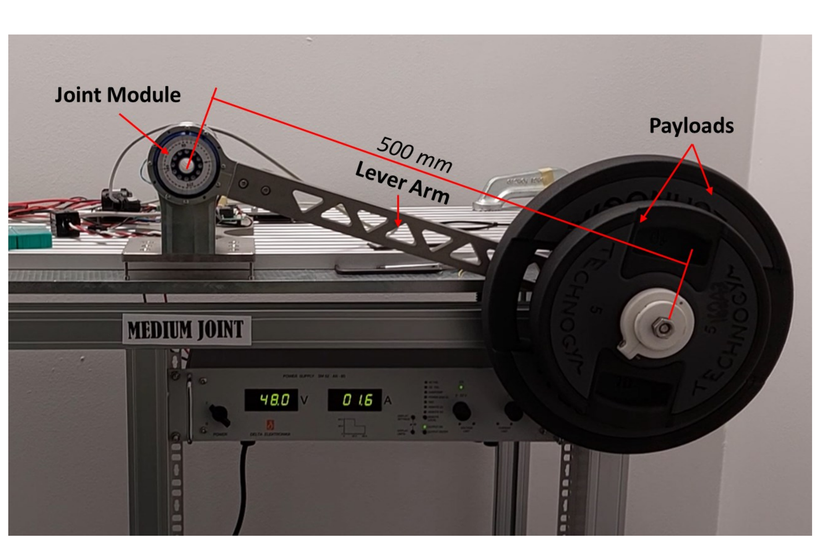

Fig. 3: Experimental setup with lever arm and payloads for joint characterization tests.

The components were fabricated with Aluminum alloy ***AA 7075-T6*** using CNC machining. Various sub assemblies are shown in Fig. 2. The joint is controlled using ***2FOC & EMS4*** motor control boards, developed within the facility.

The experimental setup consists of a lever arm attached to the output of the joint and additional payloads can be mounted onto the distal end of the lever as shown in Fig. 3.

To validate the joint design, we performed experiments to characterize three main parameters as described below:

Joint Characterization Tests

- **Max. no load speed: 75 deg/sec**
  The joint (without any additional payloads) was run in open loop mode, by increasing the input PWM signals and observing the maximum reachable speed.
- **Continuous torque: 40.5 Nm** (7.5 kg payload)
  The joint was set in position control mode and given a target position of 90 deg. Different payloads were tested to hold the position for at least 5 minutes. The maximum payload that achieves it without going into fault corresponds to the continuous torque.
- **Repeatable peak torque: 77.5 Nm** (15 kg payload)
  The joint was set in position control mode and given an input trajectory corresponding a pendulum motion. Different payloads were tested for at least 10 minutes. The maximum payload that achieves it without going into fault corresponds to the repeatable peak torque.

III. Sensorless Torque Estimation

Torque sensing at the joint level is considered essential for improving robot control especially for applications in human-robot collaborations.

Harmonic drive gearboxes have low torsional stiffness due to its elastic component called flexspline. The torsional deformation of the flexspline can be measured using two high precision encoders mounted on the joint. The corresponding torque can be estimated from the relations given in the datasheet of the harmonic drive.

Fig. 4 shows a digital twin model of the joint developed in Simscape environment of *Matlab & Simulink*. The stiction and frictional constants have been ***measured experimentally***.

- Stiction (*3.31 Nm*) : Minimum current required to start the motor rotation multiplied by the torque constant.
- Friction (*8.35 Nm/(rad/sec)*) : Slope coefficient of a straight line, interpolating the current vs speed plot, multiplied by the torque constant.

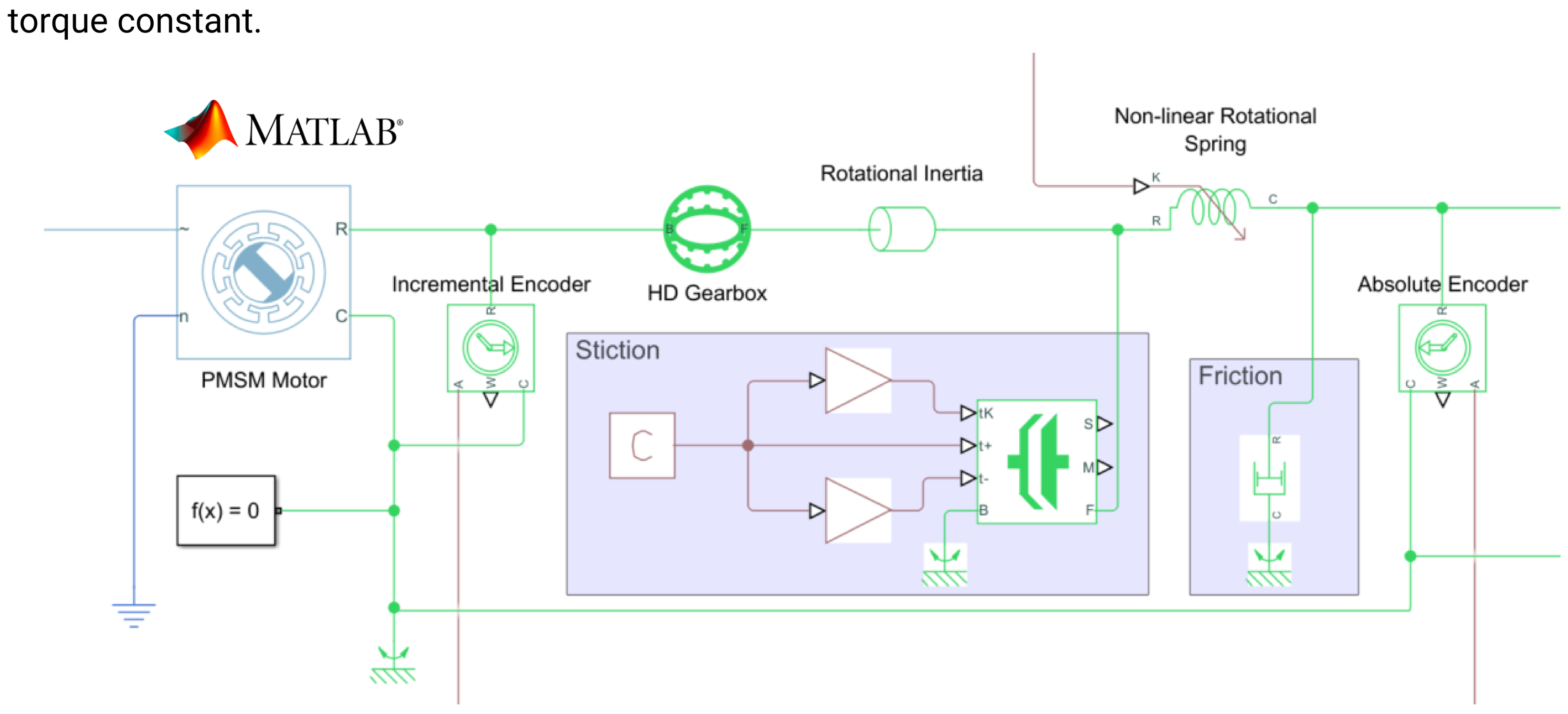

Fig. 4: Digital twin of the joint module developed on *Matlab & Simulink*.

Fig. 5 shows the plot from the simulation results. The reference torque is constant amplitude sinusoid wave (blue straight line) and the estimated torque from measured torsion is shown in green dotted line. RMS error is 0.72.

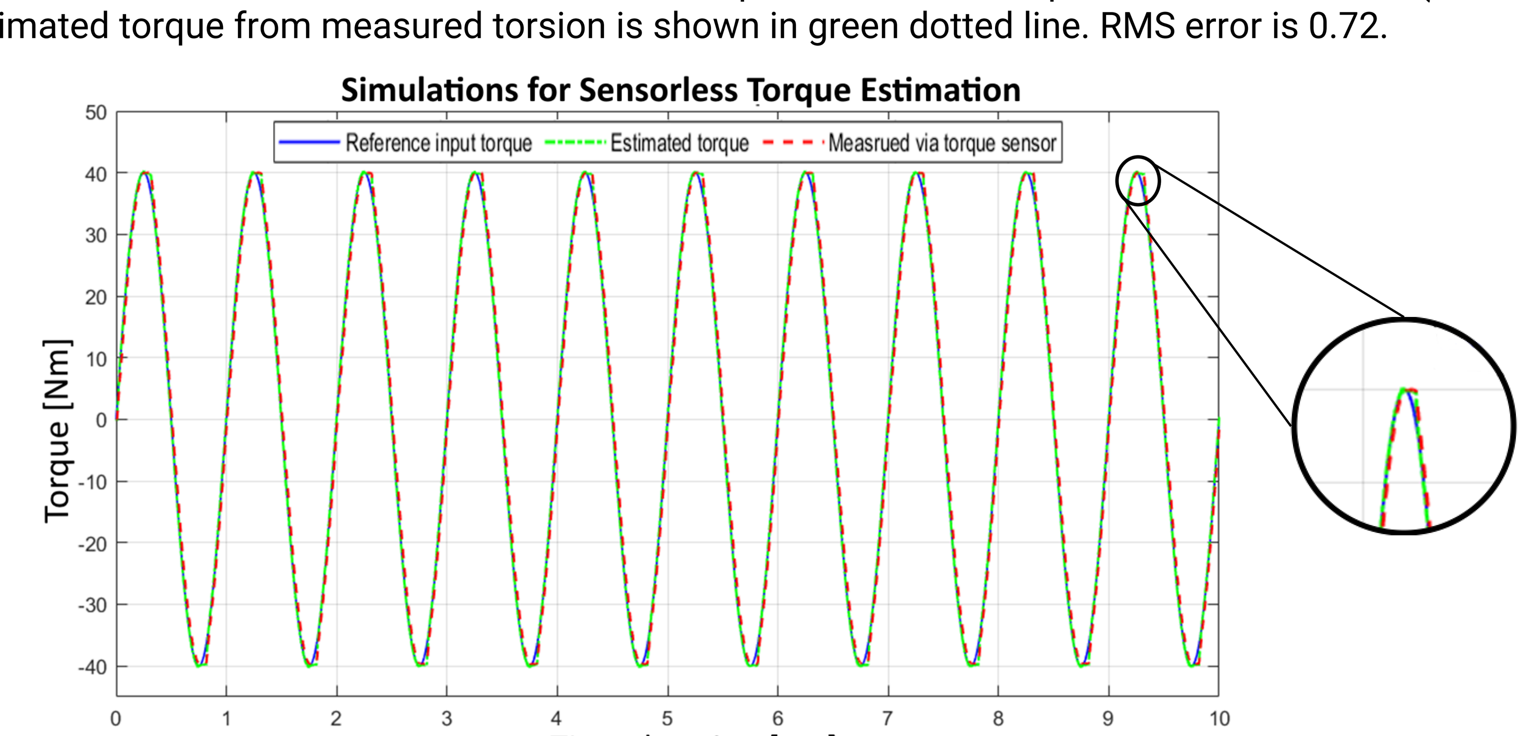

Fig. 5: Simulation results for sensorless torque estimation.

IV. Outlook

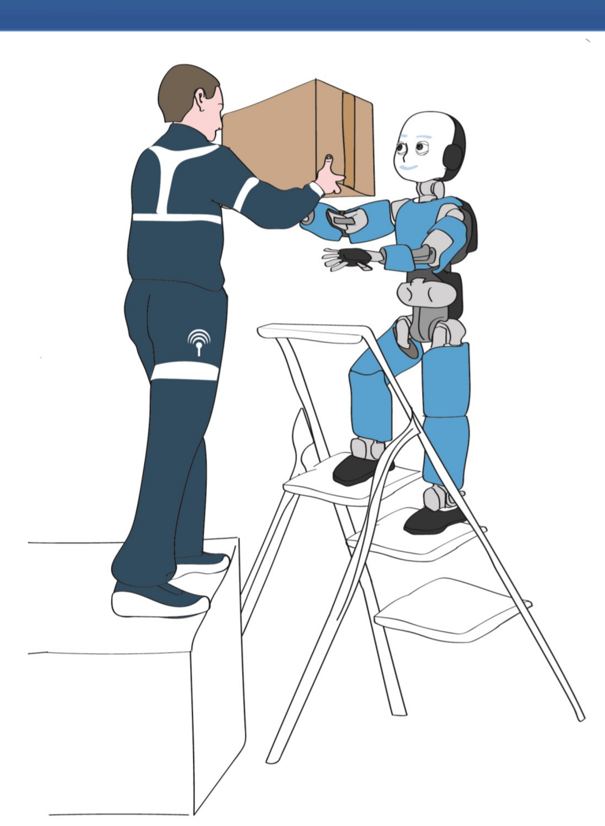

Fig. 6: Concept for application scenario of human-robot collaborations in warehouses.

The next steps towards the design and development of ergoCub 2.0 humanoid for achieving ergonomic human-robot collaborations for heavy payload lifting (as shown in Fig. 6) will involve :

- Testing of the torque estimation model on the real setup.
- Developing several versions of such joint modules, namely *small, medium and large*, by changing the combinations of commercial components.
- Deploying these joint modules on the forthcoming version ergoCub 2.0.

Fig. 7 shows a concept design for an upperbody deploying the proposed joint for 3 DOF shoulder joints (pitch, roll & yaw) and the elbow joint.

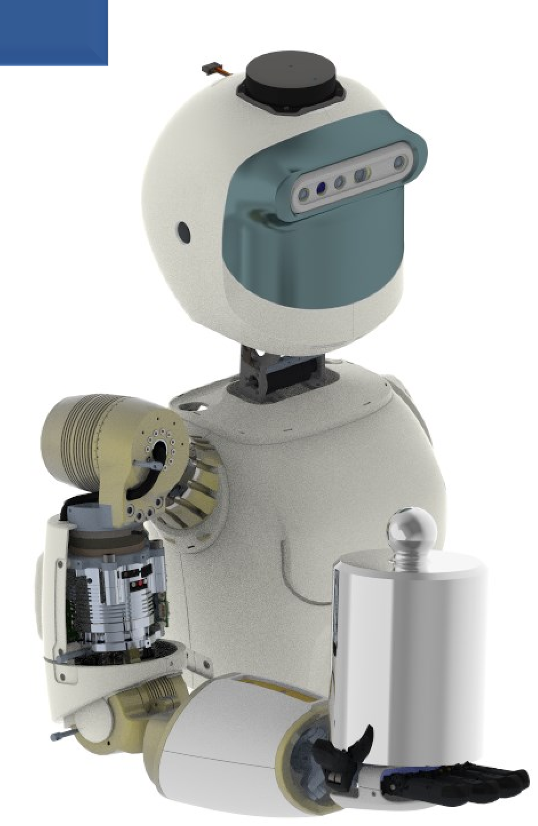

Fig. 7: Concept design rendering of ergoCub 2.0 upperbody with proposed joint modules.

IEEE-RAS HUMANOIDS 2023
AUSTIN, USA
DECEMBER 12-14, 2023

The paper was supported by the Italian National Institute for Insurance against Accidents at Work (*INAIL*) for ***ergoCub*** project.
The authors would also like to thank fellow colleagues at iCubTech and Mechanical Workshop Facilities at IIT for their support on this paper.