

SPIDER robot arm:

Main features:

- 7 degrees of freedom
- Length: 1,8 m
- Mass: 60 Kg

Performance Requirements:

Free space operations

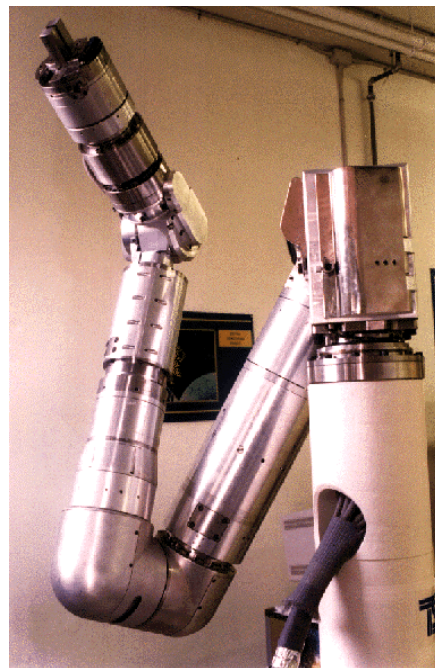
- Accuracy: < 2.5 mm, < 0.5 gradi
- Precision: < 1 mm
- Resolution: < 1 mm, < 0.05 gradi
- Velocity: $0.001 \div 0.1$ m/s, $0.001 \div 0.1$ rad/s

Proximity and contact operations

- Relative position measurement (vision sensor): 0.35 mm, 0.4 deg
- Linear distance range: ± 120 mm
- Linear distance resolution: 0.1 mm
- Contact force (0 g): 25 N (continuous -100 N per 10 s)



Europa Flight Segment Accomodation



Spider ARM

Modelica SPIDER model:

Three models have been developed in Modelica language (Dymola environment):

1. SPIDER open loop
2. SPIDER Joint Independent Control
3. SPIDER operational space motion control (free motion and contact)

1-SPIDER elettro-mechanical model (open loop):

It is constituted by various modules:

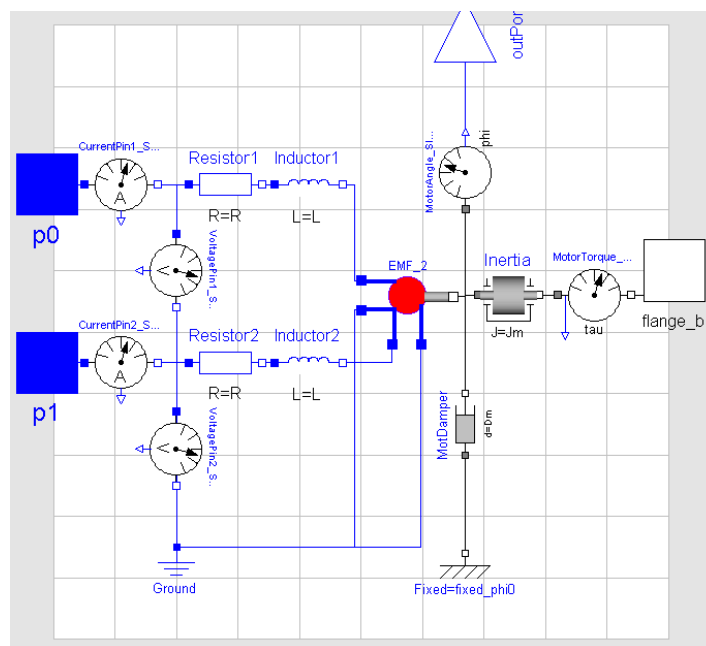
- ❑ Two-phase DC brushless motors
- ❑ Analogic current controllers
- ❑ Mechanical transmissions
- ❑ 7 d.o.f. rigid multi-body chain

Two-phase DC brushless motor:

The Dymola model of the motor describes the electrical dynamic of the two phases, the electro-mechanical conversion (block EMF_2), the equivalent inertia of the rotor, the viscous friction of the motor and it includes the encoder.

The electro-mechanical conversion block offers the interesting possibility of simulating the effect of the most representative torque disturbances (due to the motor dynamic):

- ❑ ripple caused by phase torques unbalances
- ❑ ripple due to shape functions imperfections
- ❑ detent torque: it's present also when current is zero

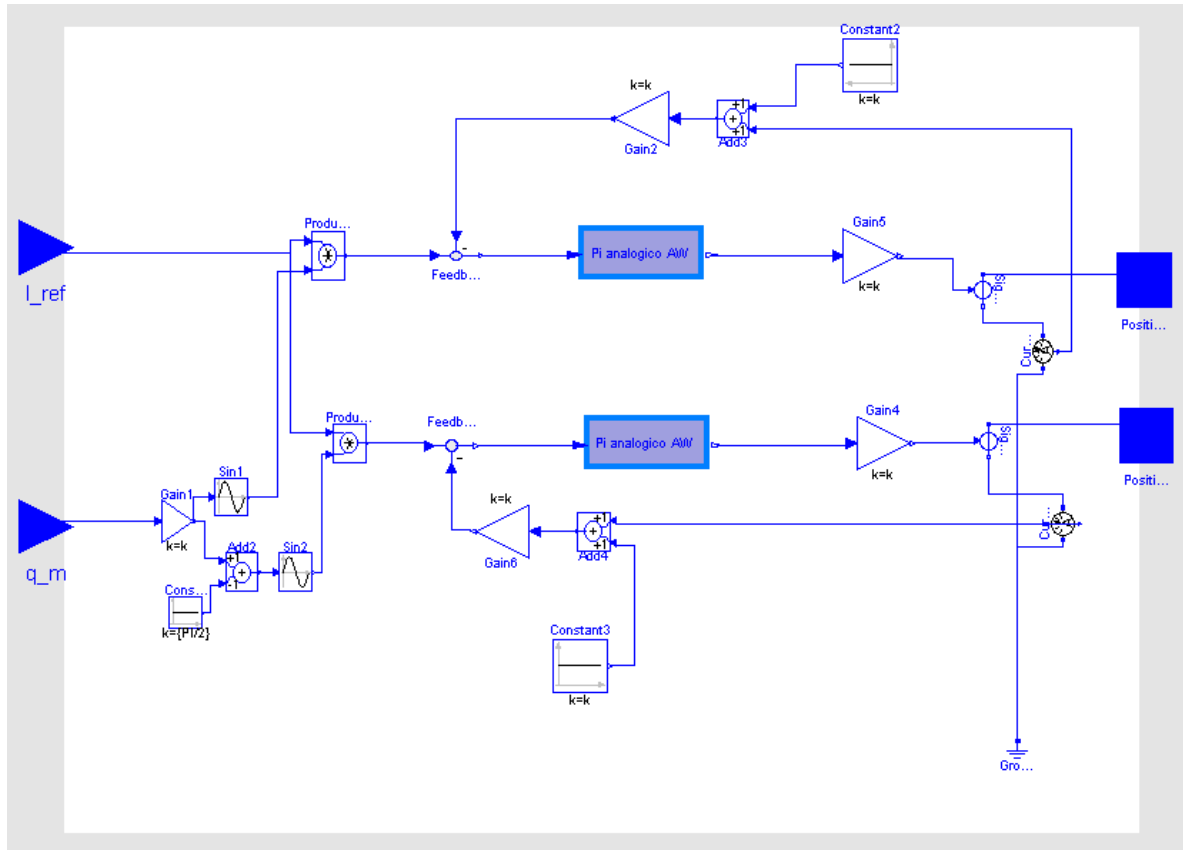


2-phase DC brushless motor

Analog current controller (NRPI module):

The Modelica realization provides two analog PI regulator with anti-windup compensation; besides, for time-scale reason, it substitutes the PWM with a simple linear amplifier.

The NRPI module allows to set the value of the current offset, useful to simulate sensor polarization, for example. Making this, the module can reproduce a torque disturbance on the motor (ripple).



NRPI module

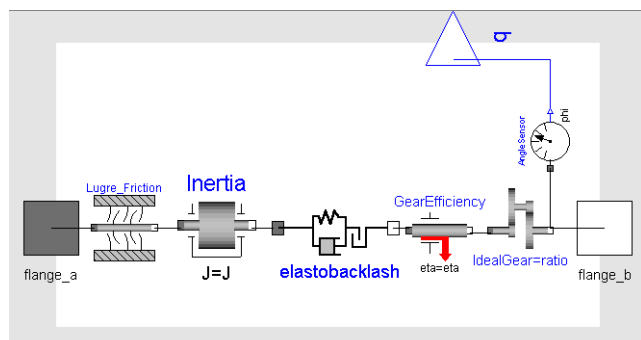
Mechanical Transmission:

The transmission boxes used in SPIDER robotic arm (Harmonic Drive) present one or more reduction stages; they're affected by friction, torsional flexibility and backlash problems, so a good mathematical model of such a gear train cannot neglect these phenomena.

A realistic transmission model has been built using the Rotational objects taken from Modelica Standard Library; the model includes:

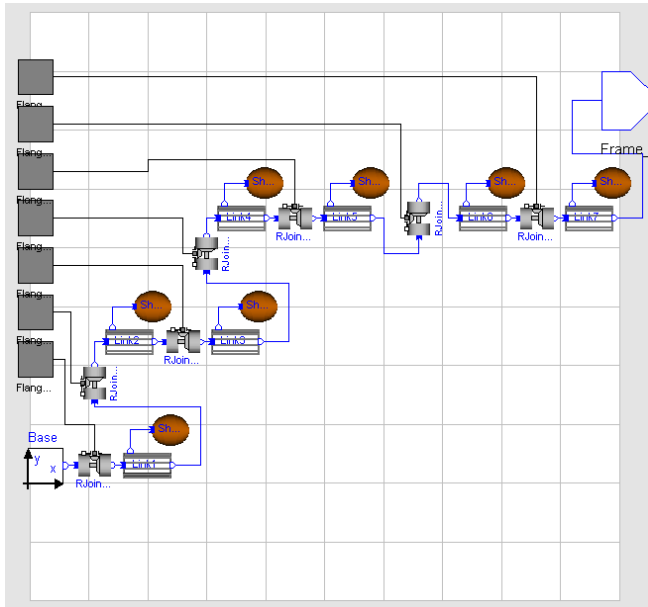
1. a continuous-nonlinear friction model (LuGre)
2. a model able to simulate mechanical efficiency
3. an equivalent gear train inertia model
4. a model of torsional flexibility, damping and backlash
5. an ideal reducer model

Gear train



Mechanical chain:

SPIDER mechanical chain model has been realized making use of the Modelica Multi-body objects; the result is a 7 d.o.f rigid multi-body chain, that offers also the possibility of simulating the presence of payload. The “standard” SPIDER mechanical chain is an open loop, because it’s assumed that robot is in free motion condition. Anyway, assuming a flat wall as environment, both elastic or perfectly stiff, it has been possible to manage contact situation (closed loop chain).

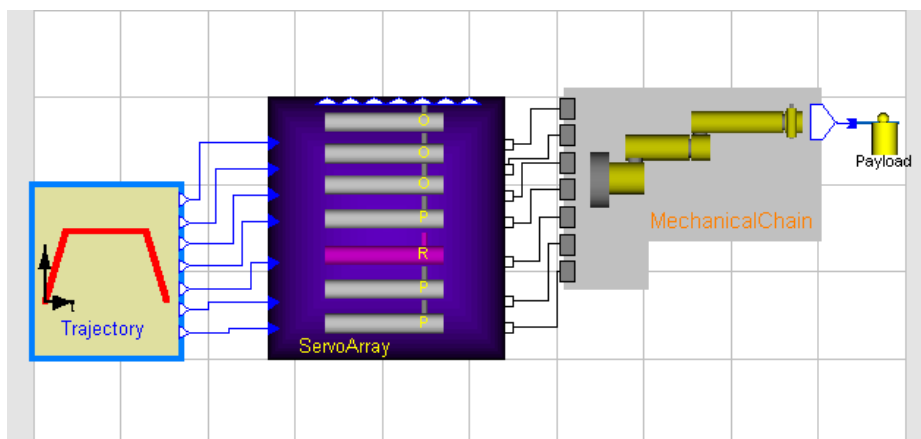


SPIDER multibody chain

2-SPIDER JIC control:

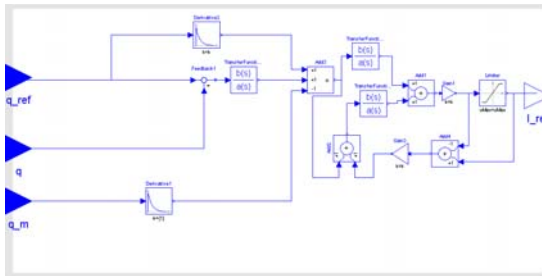
The seven degree of freedom SPIDER model allows user to simulate the dynamic behaviour of this manipulator when it’s controlled through the traditional JIC motion control (P_PI regulator on each axis). The robot is supposed to operate in microgravity condition, so gravity acceleration value, in the mechanical chain, is set to zero.

Each regulator requires the joint position set-point as input, which can be conveniently provided by the block called TRAJECTORY (interpolator in the joint space, which is able to generate each of the seven joint trajectories according to a trapezoidal profile of speed).

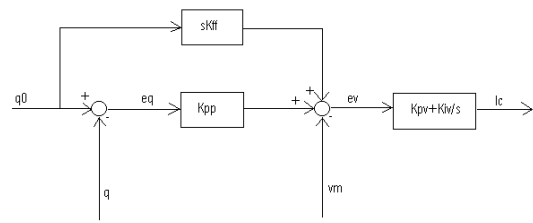


SPIDER JIC control model

The control takes advantage of the presence of two resolvers for each joint (motor and load side) and it's formed by an inner loop (PI), projected for motor velocity control, and by an outer loop (P), destined to control joint position. It's also present a velocity feed-forward in the inner loop, and anti-windup compensation as well.



Dymola P_PI control

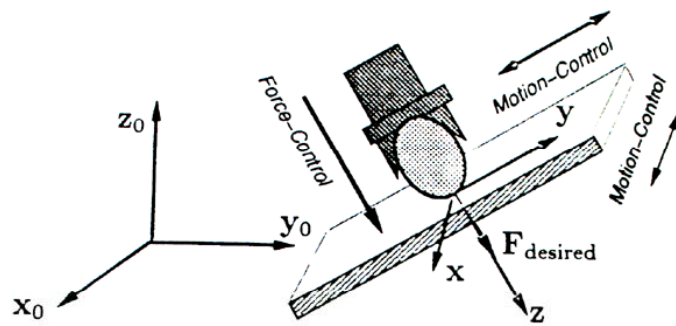
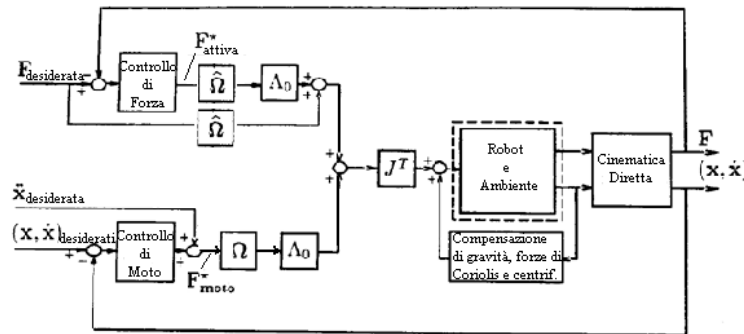


P_PI control scheme

3-SPIDER operational space control:

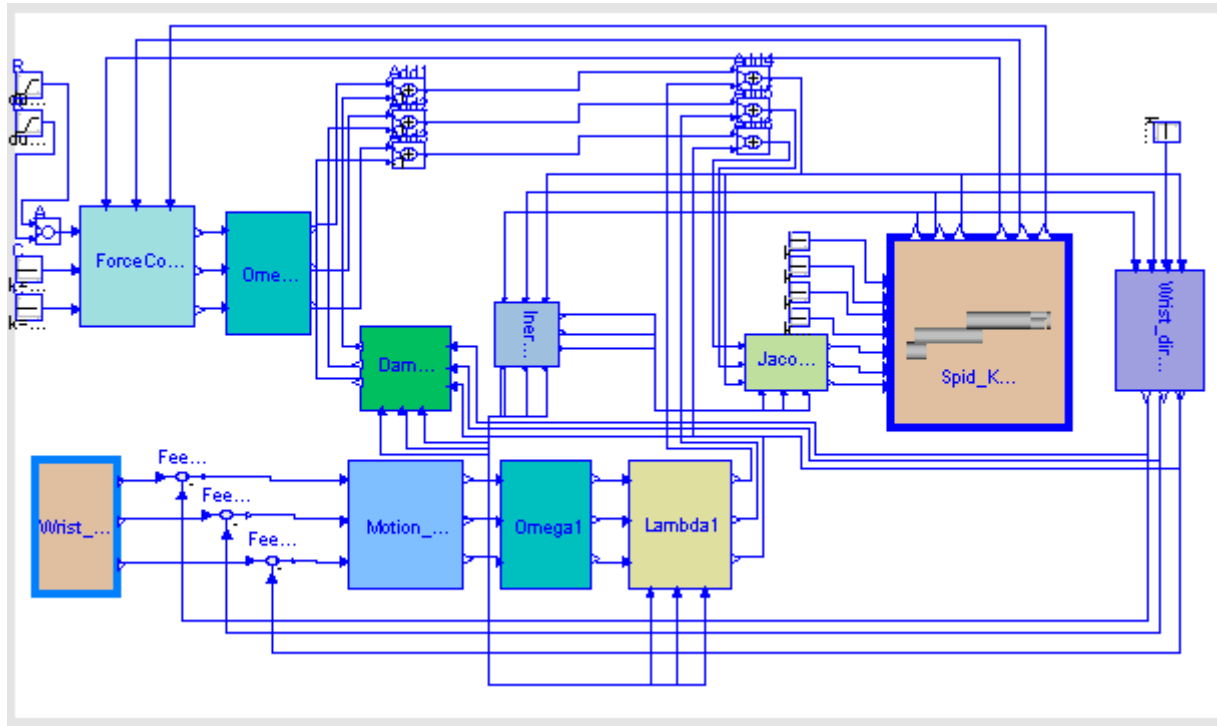
This simplified version of SPIDER (3 d.o.f.) gives to the user the possibility of testing the performances of the operational space control / inverse dynamic (prof. Khatib's control), moving the first three joints of the robot. That concurs to move the end-effector of SPIDER, like if it was a material point, along a trajectory of the cartesian space which must be included in the operational envelope of the robot. The trajectory has to be planned in order to avoid kinematic singularities. At the same time, it's possible to make the robot interact with environment, in a geometric subspace orthogonal to that of motion.

The theoretical control scheme can be subdivided into two control loops: motion control and force control:



Operational space control philosophy

The Dymola/Modelica implementation has been made taking account of the necessity of minimize computational weight, so inverse dynamic/kinematic (in practice inertial properties in operational space and differential kinematic) is computed only one time in the time interval, without useless repetitions. These data are then communicated to every block needing them through vectorial channels.



3-DOF SPIDER arm with operational space control