Triassico: A Sphere Manipulating Apparatus

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Background

The Triassico was initially developed for the National Ignition Facility, of the Lawrence Livermore National Laboratory (Livermore, California, USA), as a sphere manipulation apparatus for R&D of the DT inertial confinement fusion fuel spheres. It is able to microscopically study the whole surface of millimeter sized spheres, or larger.

Methods

Three motorized driving rods are arranged so an equilateral triangle is formed by the rod's axes, on such triangle the sphere sits. Movement is achieved by rotating the axes with precise relative speeds and by exploiting the friction between the sphere and the axes surfaces. By rotating the rods with specific relative angular velocities, a net torque can be exercised on the sphere that will rotate. No repositioning of the sphere or of the motors is needed to cover the full surface with the investigating tools. There are no fixed positions on the sphere so a continuous movement with no blind spots can be achieved.

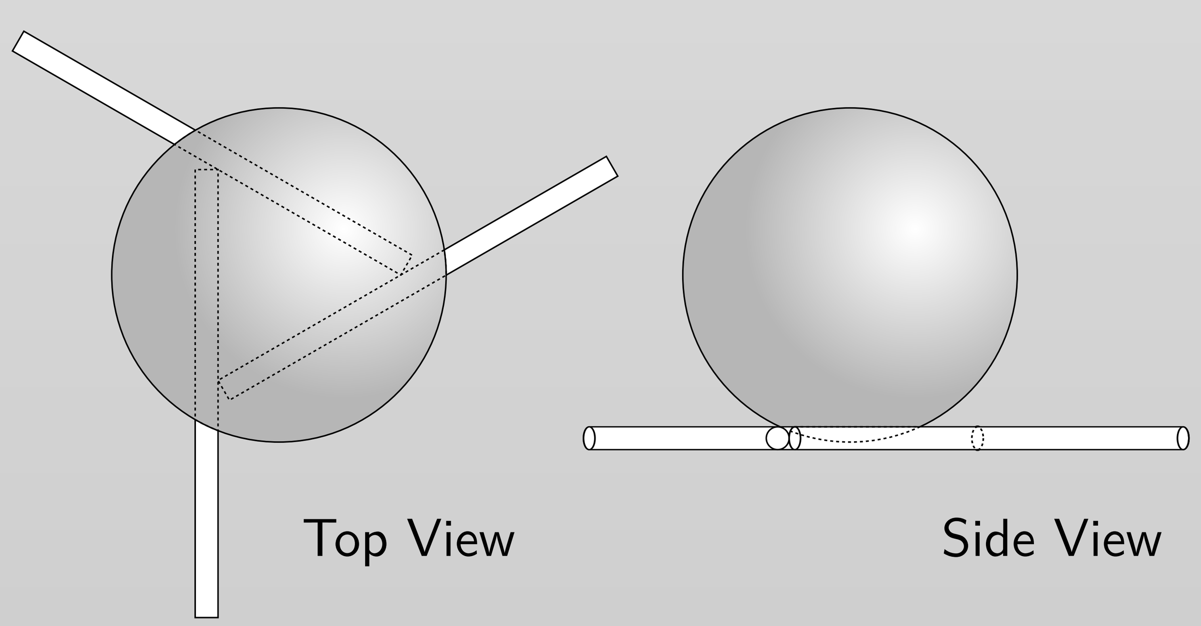

Figure : Rods disposition. The sphere can be held in place either by gravity or by an opposing trio of axes.

Movement Algorithm

An algorithm, that takes into account the kinematics constraints, was developed. The algorithm minimizes the number of rotations needed by the rods, in order to efficiently select a particular position on the sphere surface. A rod must be elected as the **driving rod**, the sphere will rotate with an axis parallel to the driving one. The sphere angular velocity (ω_S) is opposite to the driving rod's one (ω_r) and the other **auxiliary rods** must follow the relationships:

$$\vec{\omega}_1 = \omega_r \hat{x}_1 \quad \vec{\omega}_2 = -\frac{\omega_r}{2}\hat{x}_2 \quad \vec{\omega}_3 = \frac{\omega_r}{2}\hat{x}_3. \tag{1}$$

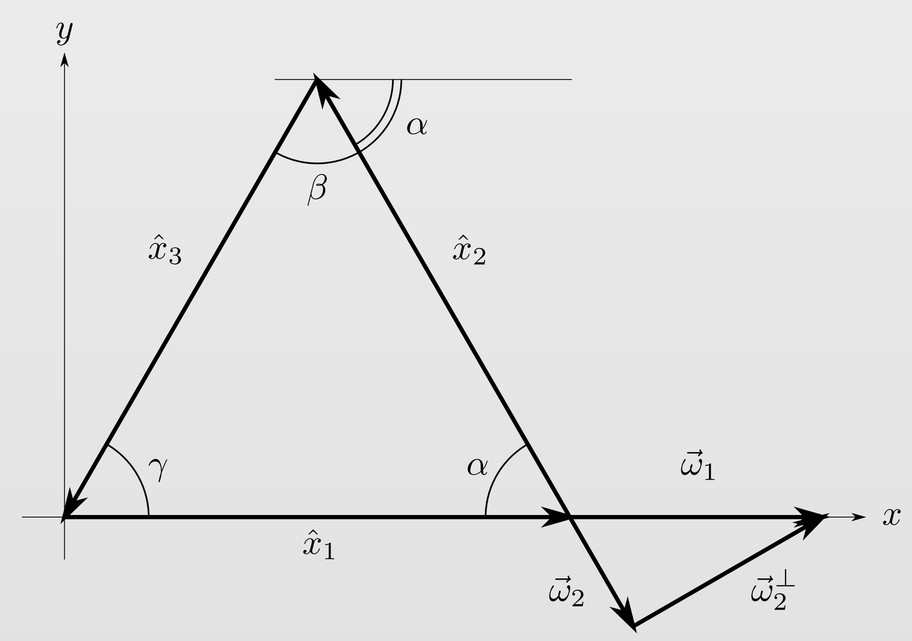

Figure : Decomposition of the **driving rod** angular velocity, $\vec{\omega}_1$, on an **auxiliary rod**, $\hat{x}_2$. $\vec{\omega}_2$ rotation transferred to the rod; $\vec{\omega}_2^{\perp}$ rotation orthogonal to the **auxiliary rod**, thus a slippage of the sphere along the rod direction.

In general two moves, with two different axes, are required to reach any destination from a starting point. Not all combinations of axes can be suitable for a given start and stop.

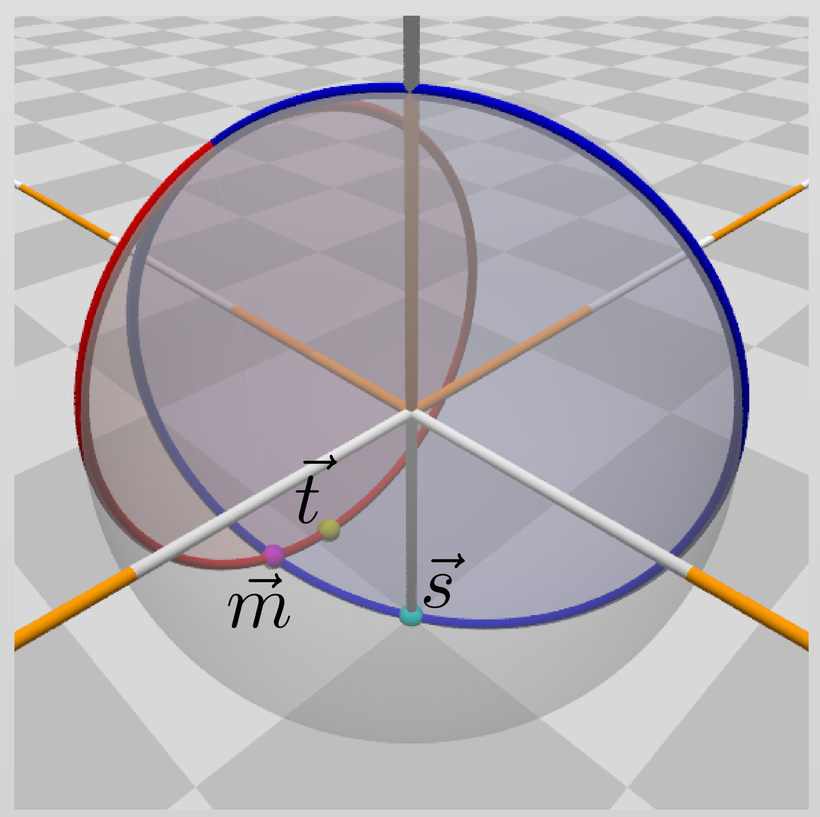

Figure : A movement from $\vec{s} = (\vartheta, \varphi)_s$ to $\vec{t} = (\vartheta, \varphi)_t$, is split in two phases and stops at the **midpoint** $\vec{m} = (\vartheta, \varphi)_m$. The first phase will be driven by the i-th rod and the second by the j-th rod: $(\vartheta, \varphi)_s \xrightarrow{i} (\vartheta, \varphi)_m \xrightarrow{j} (\vartheta, \varphi)_t$.

With a suitable choice of axes the problem of the **midpoint** determination can be reduced to a one-dimensional root finding algorithm:

$$\hat{c} = \hat{x}_i, \quad \hat{a} = \hat{z}, \quad \hat{b} = \hat{c} \times \hat{a}. \tag{2}$$

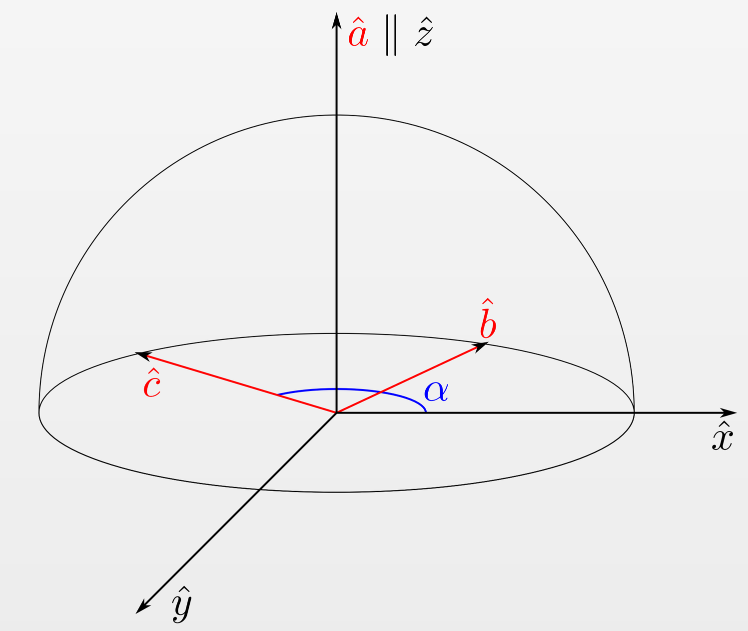

Figure : Coordinate system in which the first driving rod is taken as the $\hat{z}$ axis of a spherical coordinate system. $\hat{x} \rightsquigarrow \hat{a}$, $\hat{y} \rightsquigarrow \hat{b}$, $\hat{z} \rightsquigarrow \hat{c} = \hat{x}_i$.

The **midpoint** can be determined by finding the root of $f(\omega)$:

$$\vec{m}(\omega) = R\left[\cos\omega \sin\psi \; \hat{a} + \sin\omega \sin\psi \; \hat{b} + \cos\psi \; \hat{c}\right] \tag{3}$$

$$\cos\psi = \frac{\vec{s} \cdot \hat{x}_i}{R} \tag{4}$$

$$f(\omega) = \left[\vec{m}(\omega) - \vec{t}\right] \cdot \hat{x}_j = 0. \tag{5}$$

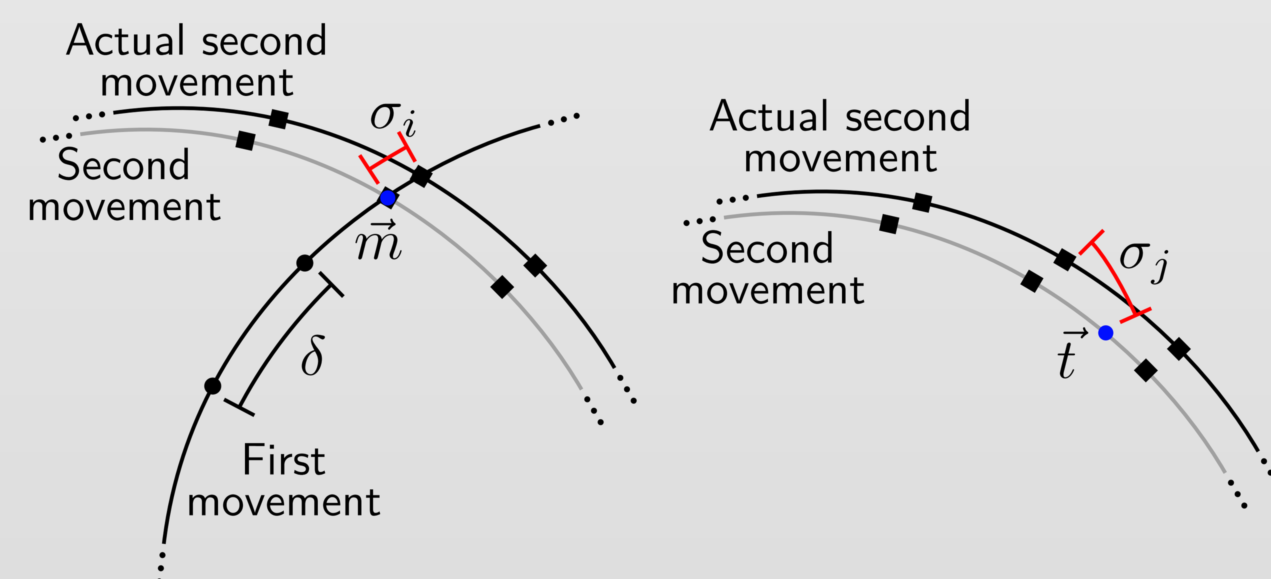

Figure : Movement errors due to a step-wise movement.

The lower-bound of the positioning error in a step-wise motion, with step size δ, is given by:

$$\sigma_j \geq \sqrt{2}\delta. \tag{6}$$

Apparatus

The apparatus was engineered by FMB Informatica s.n.c. (Bassano del Grappa, Italy) and Inel Elettronica s.r.l. (Mussolente, Italy). It is composed of a stage with six stepper motors that control the sphere movements. The stage can be positioned in any orientation because the sphere is trapped inside the rods. The sphere can have dimensions varying from 1 mm to 2 mm; bigger spheres can be manipulated, with a modification of the stage. The step size is $\delta = 0.8\,\mu\text{m}$ and thus the positioning error is $\sigma_j \geq \sqrt{2}\delta = 1.1\,\mu\text{m}$.

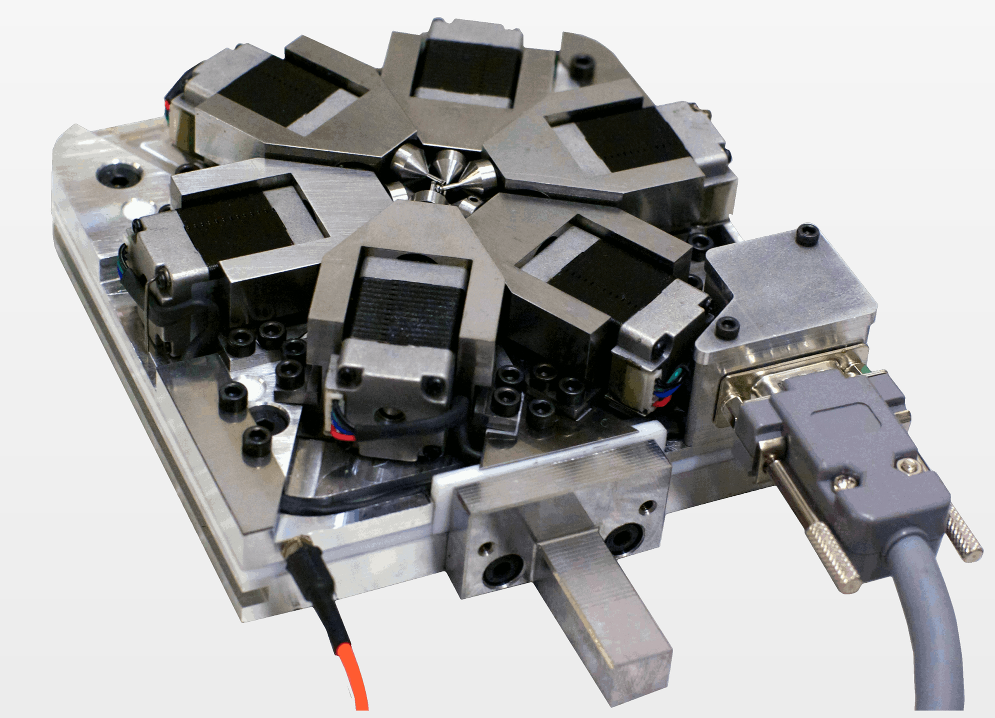

Figure : Stage that holds the spheres.

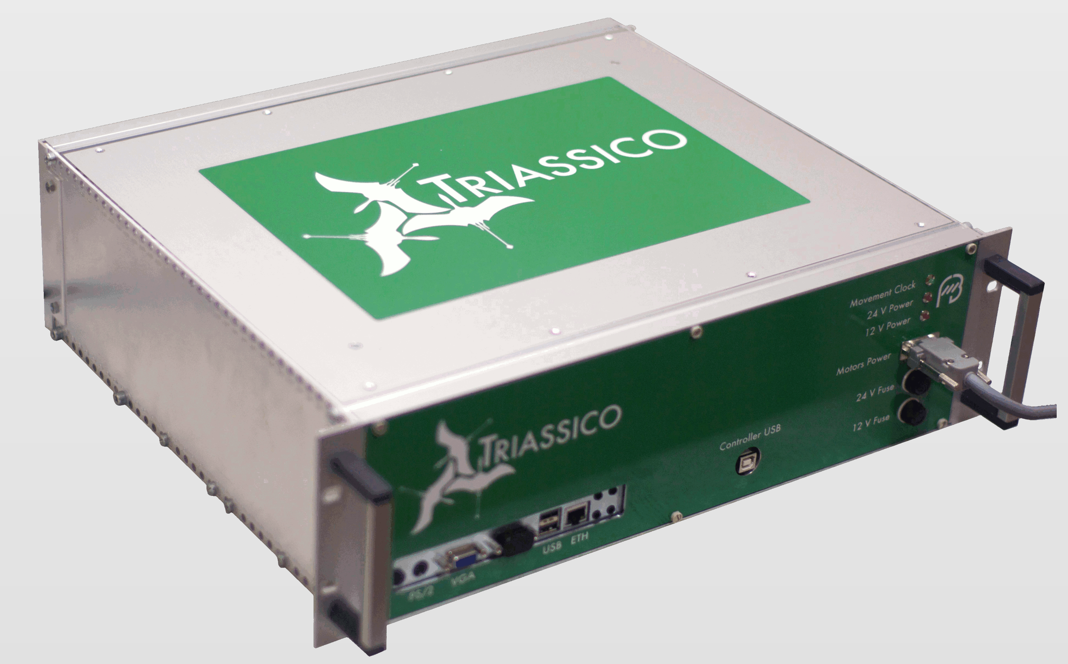

Figure : Controller rack of the system. It has an embedded computer for the movements calculations.

(a) Top view (b) Side view

Figure : Close-up of the sphere held by the stage

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