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# Fused-like angles: replacement for roll-pitch-yaw angles for a six-degree-of-freedom grating interferometer

**Key words:** Fused-like angles; Grating interferometer; Six-degree-of-freedom measurement; Representation of orientation

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# Motivation

In current research on the model and algorithm for six-degree-of-freedom (six-DOF) grating interferometer, the roll-pitch-yaw angles (RPY angles) are widely used for the orientation representation. However, RPY angles may cause two problems in six-DOF grating interferometer and thus are not suitable in this case:

1. When describing complicated rotations around multiple axes, RPY angles are valid only with a pre-determined rotation order, which is not a certain state of orientation to be measured.
2. In RPY angles, the definitions of angles in the second and third orders are related to the former rotation step(s), which will cause errors.

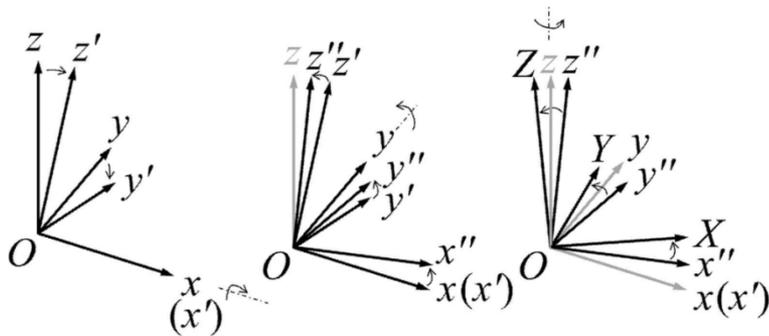
# Main idea

1. There is a type of orientation representation based on vector projections, i.e., the “fused angles” in robotics.
2. Based on the vector projections, a novel orientation representation is defined for the application of six-DOF grating interferometer; it can describe a clear state of orientation and avoid the errors in definitions.

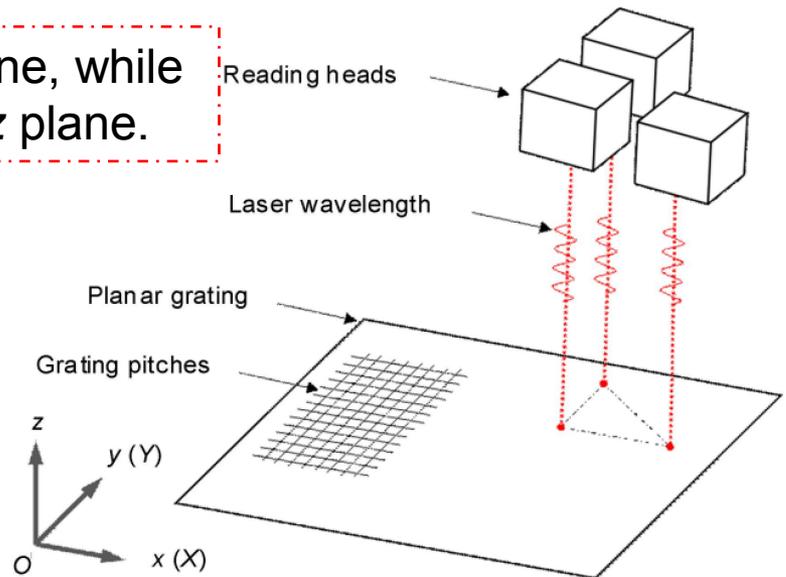
# Method

The problems in describing the complicated rotations of grating interferometers are analyzed. The rotation-order-related angle definitions will result in the angle and the laser benchmark located in intersecting planes, which will cause errors in traceability.

The pitch angle is defined in the  $x'Oz'$  plane, while the laser benchmark is parallel to the  $xOz$  plane.



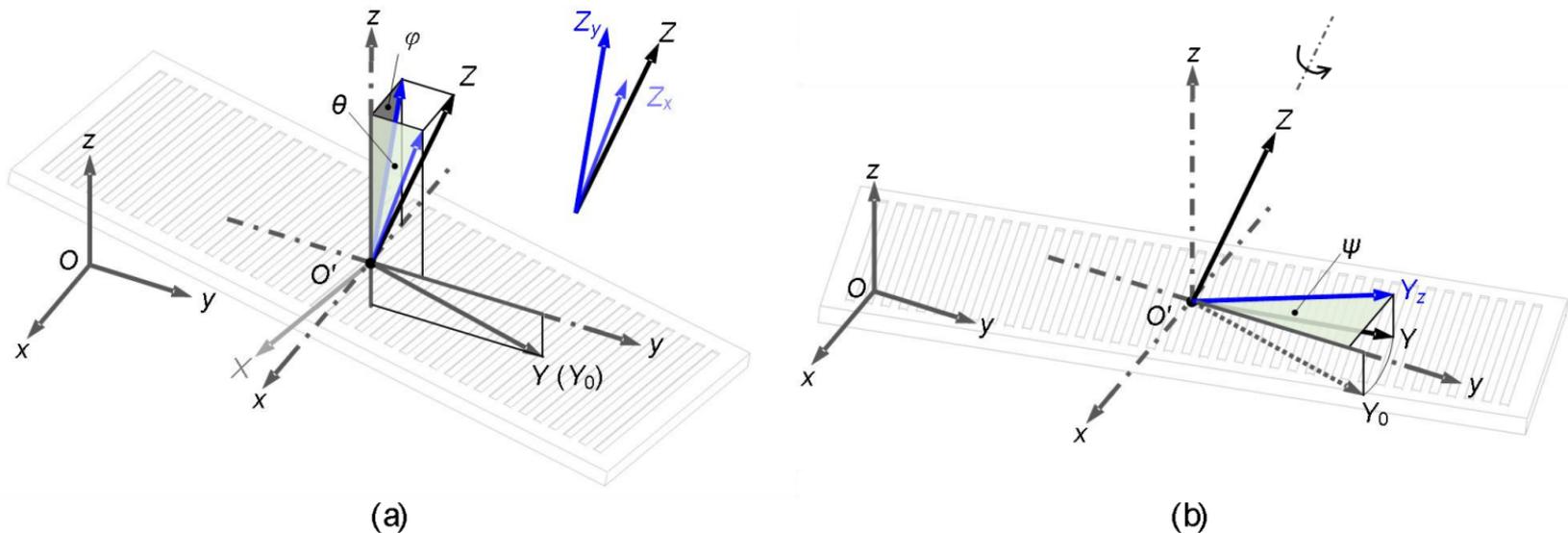
**Fig. 2** Schematic of three rotation steps of extrinsic custom-RPY angles



**Fig. 4** Benchmarks of a typical six-DOF grating interferometer

# Method (Cont'd)

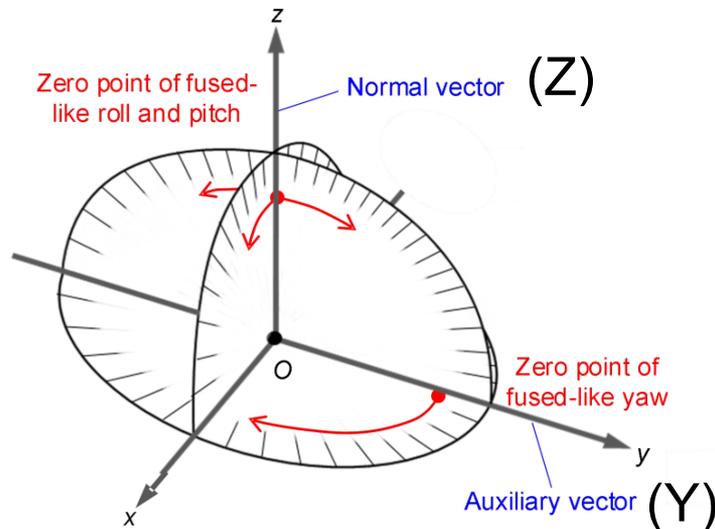
To overcome the disadvantages of RPY-angles, a novel orientation representation based on vector projections is proposed, and it is named “fused-like angles.”



**Fig. 6** Diagram of the fused-like angles: (a) roll and pitch; (b) yaw

# Method (Cont'd)

The three components of fused-like angles are independent and could be expressed by simple sinusoidal equations. This also means that the fused-like angles are addable and thus suitable for the incremental grating interferometer.



**Fig. 5 Two vectors for defining the three fused-like angles (Zero points are determined by the vectors as well)**

Fused-like angles:

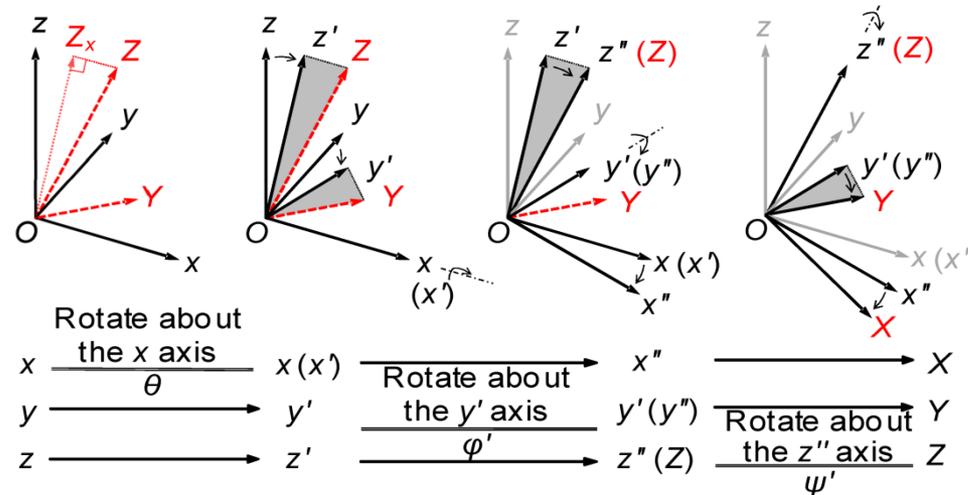
Roll  $\theta = \arctan(-Z_2 / Z_3),$

Pitch  $\varphi = \arctan(Z_1 / Z_3),$

Yaw  $\psi = \begin{cases} \arctan(-Y_1 / Y_2), & Y_2 \geq 0, Y_1 \leq 0, \\ \pi - \arctan(Y_1 / Y_2), & Y_2 < 0, \\ 2\pi + \arctan(-Y_1 / Y_2), & Y_2 \geq 0, Y_1 > 0, \end{cases}$

# Method (Cont'd)

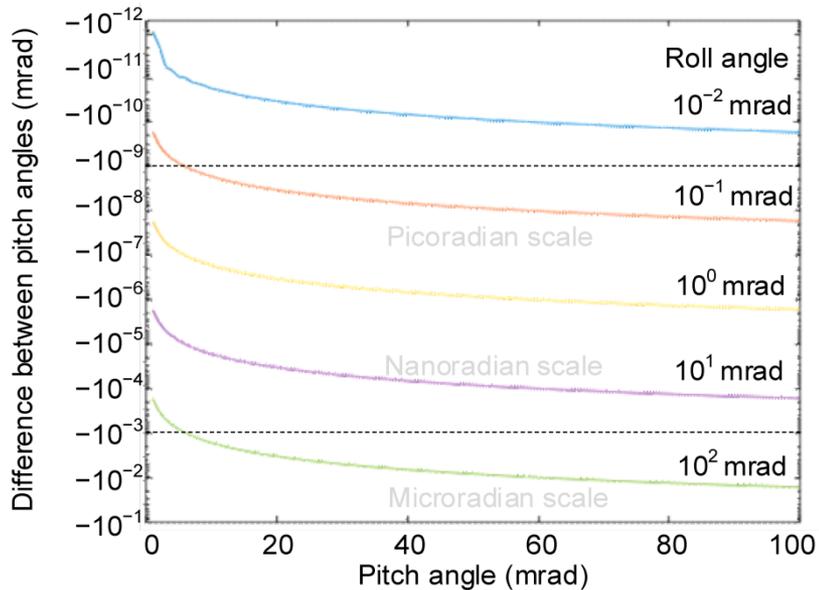
The fused-like angles could be converted to the RPY-angles. Since the fused-like angles are strictly based on the framework coordinate system, the angle differences between the fused-like angles and RPY-angles are the errors in traceability caused by the RPY-angles.



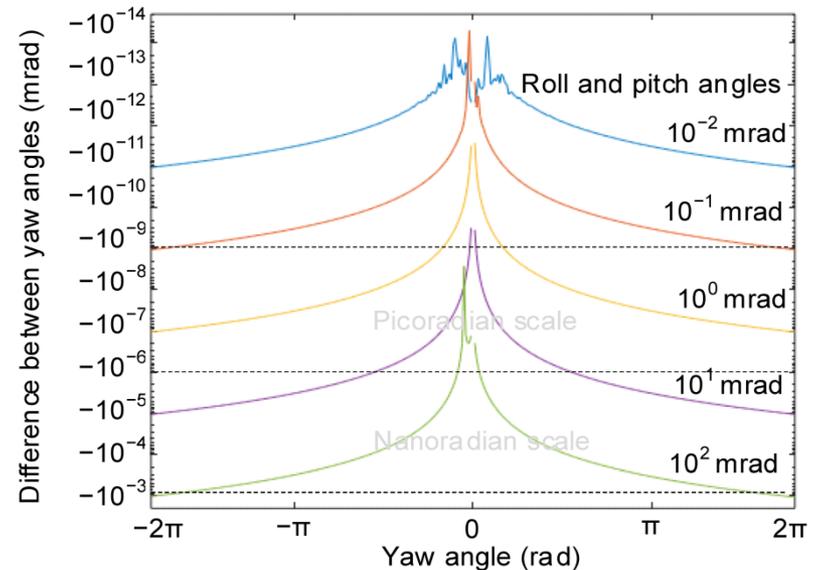
**Fig. 7 Connecting the intrinsic custom-RPY angles and fused-like angles with three sequential rotations**

# Major results

Simulation results of differences in pitch and yaw angles (the errors in traceability caused by the RPY-angles).



**Fig. 8** Difference between the fused-like and RPY pitch angles (custom-RPY pitch–fused-like pitch) with different roll angles



**Fig. 9** Difference between the fused-like and RPY yaw angles ( $-|\text{custom-RPY yaw} - \text{fused-like yaw}|$ ) with different roll and pitch angles  
Roll and pitch angles are the same for each curve

# Conclusions

- A new representation method, named “fused-like angles,” is proposed to describe the orientations in a six-DOF grating interferometer as the replacement for the currently used RPY angles.
- The definitions of fused-like angles are based on vector projections on the framework coordinate system, and have the advantage of being independent and addable. Fused-like angles could avoid the error in traceability caused by RPY angles.