

CLASSIFICATION OF AXES OF ROTATION IN ENGINEERING GRAPHICS

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Abstract: In engineering graphics, the notion of rotation about axes plays a fundamental role in modeling, visualizing, and transforming objects in space. This paper provides a systematic classification of axes of rotation as used in engineering graphics and technical drawing. After an introductory discussion of the geometric and kinematic basis of rotation, we define and categorize the axes of rotation (fixed axes, moving axes, instantaneous axes, central axes, principal axes, etc.). We analyze their properties, interrelationships, and relevance in 2D/3D engineering drawing and CAD modeling. Finally, we summarize the main categories and highlight implications for drawing transformations and visualization.

Keywords: engineering graphics; rotation axes; classification of axes; fixed axis; moving axis; instantaneous axis; central axis; screw axis; principal axes; projection axis; view transformation; rigid body rotation; kinematics; geometric modeling; CAD visualization.

Introduction. Rotation is one of the fundamental rigid-body motions in engineering graphics, along with translation. In the representation of mechanical bodies, components, and their motion, rotation about an axis allows the depiction of orientation changes, section views, auxiliary views, and projection techniques. In technical drawing and CAD, selecting appropriate axes of rotation is essential for performing transformations, generating views, and ensuring clarity in representation.

In the context of mechanical engineering and graphics, one often needs to formalize *which* axis is chosen (its spatial placement, whether fixed or moving, instantaneous or global), and how that classification affects the resulting geometry and interpretation. This article aims to present a clear taxonomy of axes of rotation, grounded in kinematic theory and geometric considerations, and to show how the classification is applied in engineering graphics.

In Section 2 we review the fundamental definitions and mathematical foundations of rotation. In Section 3 we present the classification of axes of rotation, describing each class, their properties, and examples. In Section 4 we discuss implications for engineering graphics, projection and transformation. Finally, in Section 5 we offer conclusions and directions for further study.

Foundations: Rotation and Axes: A rotation is a rigid motion in which every point of a body moves along a circular arc about a common line (the axis of rotation), through the same angle (in a given instant). In three dimensions, a proper rotation (excluding reflections) can be represented by a 3×3 orthogonal matrix R with determinant $+1$, belonging to the special orthogonal group $SO(3)$.

Axis-angle and eigenstructure viewpoint. Any rotation in 3D (except the identity) can be uniquely characterized by an **axis** (a unit vector) and an **angle** of rotation about that axis (Rodrigues' rotation formula). The axis corresponds to the eigenvector with eigenvalue 1 in the

rotation matrix. In other words, the rotation leaves that axis line invariant while moving every perpendicular direction by the angle.

This axis–angle formalism underpins the classification of axes: we must distinguish between axes fixed in space, axes attached to bodies, and instantaneous axes of motion.

Kinematic and geometric constraints. In mechanical systems or graphical transformations, axes of rotation may be constrained by bearings, joints (e.g. revolute joints), or by the choice of coordinate system. The relative motion of bodies may force axes to change orientation, translate, or “instantaneously” appear only at certain instants.

Classification of Axes of Rotation. Below is a proposed taxonomy of axes of rotation as used in engineering graphics, kinematics, and mechanical representation.

Class	Definition / Characteristic	Key Properties	Typical Use / Example
Fixed (Absolute) Axis	An axis that is stationary (fixed) in the global reference frame and does not translate or reorient	The body rotates about a fixed, unchanging line in space	In simple rotary machines where a shaft rotates about a fixed supporting frame
Moving (Body-Attached) Axis	An axis rigidly attached to the body; as the body moves, the axis moves/rotates with it	The axis may translate or reorient relative to global frame, though it may be internally “fixed” to the body	In mechanisms where parts rotate about axes attached to moving links
Instantaneous (Relative) Axis	At a given instant, the relative rotation between two bodies can be represented by an instantaneous axis	It is valid only at that moment; the axis may shift over time	In planar kinematics, the “instantaneous center of rotation” of a body
Central Axis / Pole Axis	In spatial motion, the central axis is the line about which the motion can be decomposed into a rotation plus translation (screw axis)	Combines rotational and translational component (in helical motion)	In helical screw drives or twist motions
Principal Axes	Axes where bodies have diagonal inertia tensor (mass moment of inertia)	Orthogonal axes in which rotational behavior is simplified (no cross-coupling)	In rigid-body dynamics, sometimes used for visualization or modal decomposition
Projection / View Axes	Axes chosen for projecting the model (e.g. for auxiliary views, rotations to view planes)	May be arbitrary or canonical, used to reorient the model for drawing	In engineering graphics, rotating the object about certain axes to expose hidden faces or generate view

Below is an expanded discussion of each.

Fixed (Absolute) Axis. A fixed or absolute axis remains at a constant position and orientation in space. The body rotates around it without shifting the axis. Graphically, this is the simplest scenario: one draws arcs about a fixed line. In mechanical context, a shaft mounted in bearings that do not move is a fixed axis.

Since the axis is invariant in the global frame, the representation of rotation is straightforward: coordinates of points are rotated about a known fixed line.

Moving (Body-Attached) Axis. When the axis is rigidly attached to the body, as the body moves, the axis may translate or rotate relative to the global frame. That is, the axis itself is not fixed in space but is “carried” by the body’s motion. In graphic transformations or CAD, one often defines a local axis system (body-fixed) and expresses rotations relative to it.

In such a case, successive rotations relative to body-fixed axes can lead to noncommutative effects (order matters). This is especially important in compound rotations: if one rotates about a body-attached axis, then about a second axis attached to the body, the result differs from doing them in reverse order.

Instantaneous Axis (Instantaneous Center / Relative Axis). In relative motion of two bodies, at a given instant there may exist an axis (or point) about which relative rotation occurs. In planar motion, this is the well-known instantaneous center of zero velocity. In three-dimensional kinematics, the instantaneous screw axis (or helical axis) gives the instantaneous motion decomposition into rotation plus translation along that axis.

Such axes do not persist over time; they change as the bodies’ motions evolve. For graphics, understanding the instantaneous axis is useful in animating or predicting motion, but less in static drawing.

Central or Screw Axis. When a body undergoes a general rigid motion that includes both rotation and translation (a screw motion), there exists a central axis or screw axis: a line along which the motion can be considered as a pure rotation plus a translation along the same axis. Geometrically, any spatial rigid motion can be decomposed into a rotation about some axis plus translation along that axis (Chasles’ theorem). The central axis is unique (unless the motion is pure translation).

In CAD or kinematics, screw axes are important in mechanism design, helical transmissions, robotics, and motion planning.

Principal Axes. From a different perspective (mass/inertia), a rigid body has principal axes—three mutually orthogonal axes through its center of mass in which the inertia tensor is diagonal. If rotation about one of these axes occurs, the angular momentum aligns with the angular velocity vector. In graphics and mechanics, orienting the body along principal axes simplifies dynamic analysis.

Though not necessarily axes of rotation chosen for viewing, principal axes are often used in simulation, modal analysis, and understanding rotational stability.

Projection / View Axes in Engineering Graphics. In technical drawing, one often rotates the object about a chosen axis (view axis) to bring a particular face into view (auxiliary view, sectional view, pivoting). These axes are not dictated by the object’s physical constraints but by graphical convenience.

For instance, one might choose to rotate about an axis that lies in a plane parallel to the view plane, or about an axis perpendicular to one of the principal directions, so that hidden features are exposed clearly.

Thus this classification is more about *graphical usage* than kinematic realism.

Implications in Engineering Graphics and Projection. Sequence of Rotations & Noncommutativity. When multiple rotations are applied sequentially, the order matters unless axes coincide. Rotating first about axis A and then about axis B generally leads to a different orientation than reversing the order, especially if axes are body-attached or moving axes. In engineering graphics, when generating views via successive rotations, one must fix the correct sequence.

Choice of Axis in Generating Views. To produce auxiliary or inclined views, one often rotates the model about an auxiliary axis that lies in a base plane to bring a plane into parallelism with the projection plane. The choice of this axis is guided by clarity of representation and minimizes distortion.

Because the axis may be temporarily “constructed,” this is akin to choosing a temporary “projection / view axis” as in classification.

Compound Rotations and Euler Angles. In CAD and graphics, complex orientation changes are often parameterized by Euler angles (three successive elemental rotations) or quaternions. These can be visualized as rotations about axes which may be fixed or moving depending on the convention (intrinsic vs extrinsic rotations). The behavior and interpretation of axes under different parameterization schemes are intimately related to our classification.

Visualization and Annotation in Drawing. When annotating rotation in technical drawings, one often indicates the axis, direction of rotation (arrow), and angle. The axis may be hidden (dashed line) or visible. It is essential to clarify *which* axis is meant (fixed in drawing coordinate, body axis, or projected axis) to avoid ambiguity. Graphically, the axis representation must be consistent across views: for example, in multi-view projection, the axis might project as a point or a line, depending on orientation. Understanding which class the axis belongs to helps in correctly representing it.

Conclusion

In this paper, we have proposed a clear classification scheme for axes of rotation in the domain of engineering graphics:

- **Fixed (absolute) axes**, which remain stationary in the global frame.
- **Moving (body-attached) axes**, which move with the object.
- **Instantaneous (relative) axes**, valid at a specific time for relative motion.
- **Central / screw axes**, combining rotation and translation.
- **Principal axes**, from inertial properties of the body.
- **Projection / view axes**, chosen for drawing purposes.

Each class has distinct geometric and kinematic properties, and the choice among them depends on the application: pure mechanical motion, visualization, drafting, or simulation. Recognizing these categories aids in selecting appropriate axes for rotations, ensuring clarity and correctness in drawing transformations, view generation, and annotation.

For further work, one could explore algorithms for automatically selecting “optimal” view axes in CAD, or formally mapping among axis classes under complex motion (e.g. converting a moving axis representation into instantaneous axes over time).

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