A general approach to hand-eye calibration through the optimization of atomic transformations

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To operate adequately, robotic systems must have an accurate estimate of the pose of each sensor with respect to each other or to a common frame, a critical requirement for the process of data fusion. A well-known calibration problem is the hand-eye calibration (Fig. 1). It can be defined as the process of estimating the transformation between the end-effector (i.e., the hand of a robotic arm) and a camera (i.e., the eye) mounted somewhere on that end-effector.

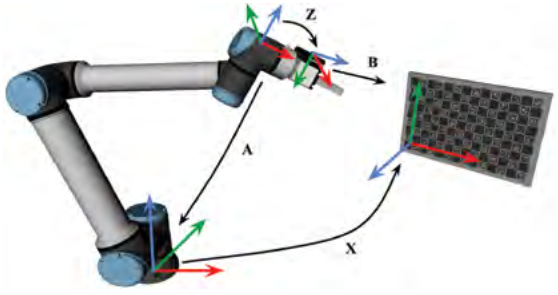

FIGURE 1
Visual representation of the hand–eye problem. A represents the known geometric transformation from the hand to the robotic arm base, B denotes the known transformation from the eye to the calibration pattern, X specifies the unknown transformation from the robotic arm base to the world object, and Z is the unknown transformation from the hand to the eye.

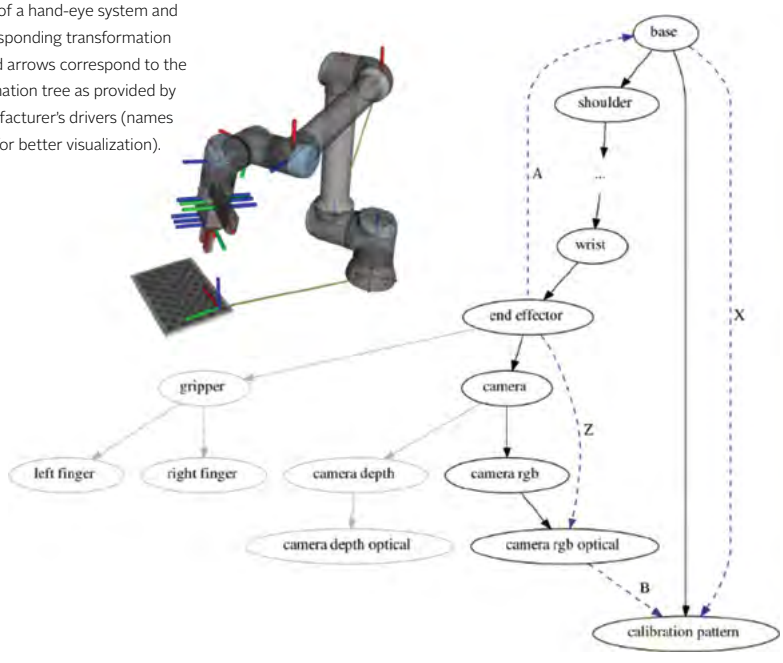

FIGURE 2
Example of a hand-eye system and the corresponding transformation tree: Solid arrows correspond to the transformation tree as provided by the manufacturer's drivers (names adapted for better visualization).

Our proposal for general hand–eye calibration makes use of a bundle adjustment like optimization framework for intrinsic and extrinsic calibration anchored on the reprojection error. Furthermore, it requires the definition of a transformation tree graph (Fig. 2), which contains topological information about the relationship of coordinate frames in the system. This data structure enables the efficient retrieval of the unique topological route from one point in the graph to another, i.e., the path from one frame to another. By preserving the original complete chain of partial transformations, it is possible to generalize the entirety of the hand–eye calibration problem. We refer to these transformations as atomic transformations, in the sense that they are not aggregated, i.e., they are indivisible. The method that we propose uses these atomic transformations to formulate the optimization procedure. As such, we refer to it as ATOM.

Our approach is seamlessly integrated with the robot operating system framework (ROS) and allows for the interactive positioning of sensors and labeling of data, facilitating both the data acquisition and labeling and the calibration procedures. Results show that the proposed approach can handle any calibration use case with a minimal initial configuration. The approach is compared with several other state-of-the-art hand–eye calibration algorithms and the results show that the approach produces accurate calibrations when compared to the state of the art.