WHAT IS CLAIMED IS:

1. A method of teaching an articulated robot, the method comprising:

providing a first pin at a first location within a work station;

providing the articulated robot in an area adjacent to the work station, the articulated robot having a coordinate system, the articulated robot having an arm and an end effector that is configured to pivot with respect to the arm, the end effector having a workpiece receiver with a first protruding member and a second protruding member, the end effector having a through-beam sensor including a light emitter provided on one of the first protruding member and the second protruding member, the through-beam sensor further including a light receiver provided on an other of the first protruding member and the second protruding member, the through-beam sensor being configured to sense when an object is present between the light emitter and the light receiver;

moving the articulated robot to perform sensing operations in which the through-beam sensor senses the first pin, the sensing operations being performed while a position and/or an orientation of the end effector are varied for each sensing of the first pin to gather sensed position and orientation data, the sensing operations are performed such that the first pin is located at different distances between the light emitter and the light receiver as the articulated robot moves the through-beam sensor across the first pin for a plurality of parallel movements of the end effector; and

performing calculations on the sensed position and orientation data to determine the first location of the first pin with respect to the coordinate system of the articulated robot,

wherein the plurality of parallel movements includes:

a first movement in which the articulated robot moves the through-beam sensor in a first direction along a first path entirely across the first pin, the first pin being at a first distance between the light emitter and the light receiver when the through-beam sensor is moved along the first path across the first pin;

a second movement in which the articulated robot moves the through-beam sensor in a second direction along the first path entirely across the first pin, the second direction being opposite to the first direction such that the second movement is a reverse movement to the first movement; and

a third movement in which the articulated robot moves the through-beam sensor in a third direction along a second path entirely across the first pin, the second path being parallel to the first path, the first pin being at a second distance between the light emitter and the light receiver when the through-beam sensor is moved along the second path across the first pin, the second distance being different from the first distance.

2. The method according to claim 1,

wherein the end effector is configured to pivot with respect to the arm about a pivot axis, and

wherein the method further comprises performing calculations on the sensed position and orientation data to determine a distance extending in a direction normal to a light beam of the light emitter to the pivot axis, and an angle of the direction normal to the light beam with respect to the coordinate system of the articulated robot including an angular error of the end

effector.

3. The method according to claim 1, further comprising:

providing an optical target on a pivot axis of the end effector that is configured to pivot with respect to the arm;

providing a scanning device at a fixed position with respect to the coordinate system of the articulated robot;

using the scanning device to measure positional data of the optical target as the articulated robot is moved through a range of motion; and

performing a regression analysis on the positional data to determine link lengths of links of the robot arm.

4. The method according to claim 3, further comprising:

storing the link lengths on respective encoders of motors for rotating the links of the robot arm.

5. The method according to claim 1,

wherein the work station has a work location at a predetermined position and orientation with respect to the first location of the first pin, and

wherein the method further comprises using the first location of the first pin to determine the work location with respect to the coordinate system of the articulated robot.

6. The method according to claim 5,

wherein the work location overlaps the first location of the first pin in a horizontal plane.

7. The method according to claim 1,

wherein the articulated robot includes:

a base mounted in the area adjacent to the work station;

the arm includes:

a first arm member pivotally mounted to the base about a first pivot axis;

a second arm member pivotally mounted to the first arm member about a second pivot axis; and

a third arm member pivotally mounted to the second arm member about a third pivot axis; and

the end effector is pivotally mounted to the third arm member about a fourth pivot axis.

8. The method according to claim 1,

wherein sensing operations include:

a first sensing operation in which the articulated robot moves the through-beam sensor in a first linear motion across the first pin with the end effector in a first orientation; and

a second sensing operation in which the articulated robot moves the through-beam sensor in a second linear motion across the first pin with the end effector in the first orientation, and

wherein the first linear motion and the second linear motion constitute the plurality of parallel movements of the end effector.

9. The method according to claim 8,

wherein, in the first sensing operation, the first pin is a first distance between the light emitter and the light receiver when the through-beam sensor is moved across the first pin, and

wherein, in the second sensing operation, the first pin is a second distance between the light emitter and the light receiver when the through-beam sensor is moved across the first pin, the second distance being different from the first distance.

10. The method according to claim 8,

wherein sensing operations include:

a third sensing operation in which the articulated robot moves the through-beam sensor in a third linear motion across the first pin with the end effector in a second orientation, the second orientation being different than the first orientation; and

a fourth sensing operation in which the articulated robot moves the through-beam sensor in a fourth linear motion across the first pin with the end effector in the second orientation;

wherein the third linear motion and the fourth linear motion are parallel linear movements of the end effector, and

wherein the third linear motion and the fourth linear motion are non-parallel to the first linear motion and the second linear motion.

11. The method according to claim 1,

wherein the moving of the articulated robot to perform the sensing operations includes:

initially moving the end effector to a predetermined approximate location of the first pin; and

moving the end effector in an area around the predetermined approximate location of the first pin until the through-beam sensor senses the first pin.

12. The method according to claim 1, the method further comprising:

providing a second pin at a second location within a work station;

moving the articulated robot to perform further sensing operations in which the through-beam sensor senses the second pin, the further sensing operations being performed while the position and/or the orientation of the end effector are varied for each sensing of the second pin to gather further sensed position and orientation data, the further sensing operations are performed such that the second pin is located at different distances between the light emitter and the light receiver as the articulated robot moves the through-beam sensor across the second pin; and

performing calculations on the further sensed position and orientation data to determine the second location of the second pin with respect to the coordinate system of the articulated robot.

13. The method according to claim 12,

wherein the work station has a work location at a predetermined position and orientation with respect to the first location of the first pin and the second location of the second pin, and

wherein the method further comprises using the first location of the first pin and the second location of the second pin to determine the work location with respect to the coordinate system of the articulated robot.

14. The method according to claim 1,

wherein the articulated robot is moved to perform twenty or more sensing operations, and

wherein the performing of calculations on the sensed position and orientation data includes performing a regression analysis on the sensed position and orientation data.

15. The method according to claim 14,

wherein the performing of calculations on the sensed position and orientation data includes performing a least squares approximation and a numerical search on the sensed position and orientation data to determine the first location of the first pin with respect to the coordinate system of the articulated robot.

16. The method according to claim 1,

wherein the sensing operations are performed by both:

moving the end effector away from the first pin such that the through-beam sensor moves across the first pin in a first direction; and

moving the end effector toward the first pin such that the through-beam sensor moves across the first pin in a second direction opposite to the first direction, and

wherein the method further comprises using the sensed position and orientation data obtained by moving the end effector away from the first pin and moving the end effector toward the first pin to determine hysteresis error in the through-beam sensor.

17. The method according to claim 1,

wherein the plurality of parallel movements are a plurality of parallel linear movements of the end effector.

18. An articulated robot comprising:

an arm;

an end effector that is configured to pivot with respect to the arm, the end effector having a workpiece receiver with a first protruding member and a second protruding member;

a through-beam sensor provided on the end effector, the through-beam sensor including a light emitter provided on one of the first protruding member and the second protruding member, the through-beam sensor further including a light receiver provided on an other of the first protruding member and the second protruding member, the through-beam sensor being configured to sense when an object is present between the light emitter and the light receiver; and

a controller including at least one processor defining a coordinate system for the articulated robot, the at least one processor being configured to control one or more motors of

the articulated robot to move the arm and the end effector to perform sensing operations in which the through-beam sensor senses a first pin provided at a first location within a work station, the sensing operations being performed while a position and/or an orientation of the end effector are varied for each sensing of the first pin to gather sensed position and orientation data, the sensing operations are performed such that the first pin is located at different distances between the light emitter and the light receiver as the articulated robot moves the through-beam sensor across the first pin for a plurality of parallel movements of the end effector, the at least one processor being configured to perform calculations on the sensed position and orientation data to determine the first location of the first pin with respect to the coordinate system of the articulated robot,

wherein the plurality of parallel movements includes:

a first movement in which the articulated robot moves the through-beam sensor in a first direction along a first path entirely across the first pin, the first pin being at a first distance between the light emitter and the light receiver when the through-beam sensor is moved along the first path across the first pin;

a second movement in which the articulated robot moves the through-beam sensor in a second direction along the first path entirely across the first pin, the second direction being opposite to the first direction such that the second movement is a reverse movement to the first movement; and

a third movement in which the articulated robot moves the through-beam sensor in a third direction along a second path entirely across the first pin, the second path being parallel to the first path, the first pin being at a second distance between the light emitter and

the light receiver when the through-beam sensor is moved along the second path across the first pin, the second distance being different from the first distance.

19. The articulated robot according to claim 18,

wherein the end effector is configured to pivot with respect to the arm about a pivot axis, and

wherein the at least one processor is further configured to perform calculations on the sensed position and orientation data to determine a distance extending in a direction normal to a light beam of the light emitter to the pivot axis, and an angle of the direction normal to the light beam with respect to the coordinate system of the articulated robot including an angular error of the end effector.

20. The articulated robot according to claim 18, further comprising:

an optical target provided on a pivot axis of the end effector that is configured to pivot with respect to the arm; and

a scanning device at a fixed position with respect to the coordinate system of the articulated robot, the scanning device being configured to measure positional data of the optical target as the articulated robot is moved through a range of motion,

wherein the at least one processor is further configured to perform a regression analysis on the positional data to determine link lengths of links of the robot arm.

21. The articulated robot according to claim 20, wherein the link lengths are stored

on respective encoders of the one or more motors for rotating the links of the robot arm.

22. The articulated robot according to claim 18, further comprising:

a base mounted in the area adjacent to the work station,

wherein the arm includes:

a first arm member pivotally mounted to the base about a first pivot axis;

a second arm member pivotally mounted to the first arm member about a second pivot axis; and

a third arm member pivotally mounted to the second arm member about a third pivot axis, and

wherein the end effector is pivotally mounted to the third arm member about a fourth pivot axis.

23. The articulated robot according to claim 18,

wherein the at least one processor is configured to control the one or more motors of the articulated robot to move the articulated robot to perform:

a first sensing operation in which the through-beam sensor is moved in a first linear motion across the first pin with the end effector in a first orientation; and

a second sensing operation in which the through-beam sensor is moved in a second linear motion across the first pin with the end effector in the first orientation,

wherein, in the first sensing operation, the first pin is a first distance between the light emitter and the light receiver when the through-beam sensor is moved across the first pin,

wherein, in the second sensing operation, the first pin is a second distance between the light emitter and the light receiver when the through-beam sensor is moved across the first pin, the second distance being different from the first distance, and

wherein the first linear motion and the second linear motion constitute the plurality of parallel movements of the end effector.

24. The articulated robot according to claim 18,

wherein the at least one processor is configured to control the one or more motors of the articulated robot to move the articulated robot to perform:

a first sensing operation in which the through-beam sensor is moved in a first linear motion across the first pin with the end effector in a first orientation; and

a second sensing operation in which the through-beam sensor is moved in a second linear motion across the first pin with the end effector in the first orientation,

a third sensing operation in which the through-beam sensor is moved in a third linear motion across the first pin with the end effector in a second orientation, the second orientation being different than the first orientation; and

a fourth sensing operation in which the through-beam sensor is moved in a fourth linear motion across the first pin with the end effector in the second orientation,

wherein the first linear motion and the second linear motion constitute the plurality of parallel movements of the end effector,

wherein the third linear motion and the fourth linear motion are parallel linear movements of the end effector, and

wherein the third linear motion and the fourth linear motion are non-parallel to the first linear motion and the second linear motion.

25. The articulated robot according to claim 18,

wherein the at least one processor is configured to control the one or more motors of the articulated robot to move the arm and the end effector to perform further sensing operations in which the through-beam sensor senses a second pin provided at a second location within the work station, the further sensing operations being performed while the position and/or the orientation of the end effector are varied for each sensing of the second pin to gather further sensed position and orientation data, the further sensing operations are performed such that the second pin is located at different distances between the light emitter and the light receiver as the articulated robot moves the through-beam sensor across the second pin, the at least one processor being configured to perform calculations on the further sensed position and orientation data to determine the second location of the second pin with respect to the coordinate system of the articulated robot, the at least one processor being configured to use the first location of the first pin and the second location of the second pin to determine the work location with respect to the coordinate system of the articulated robot.

26. The articulated robot according to claim 18,

wherein the at least one processor being configured to control one or more motors of the articulated robot to move the arm and the end effector to perform twenty or more sensing operations, and

wherein the at least one processor being configured to perform a regression analysis on the sensed position and orientation data.

27. The articulated robot according to claim 26,

wherein the at least one processor being configured to perform a least squares approximation and a numerical search on the sensed position and orientation data to determine the first location of the first pin with respect to the coordinate system of the articulated robot.

28. The articulated robot according to claim 18,

wherein the at least one processor is configured to control the one or more motors of the articulated robot to move the arm and the end effector to perform the sensing operations by both:

moving the end effector away from the first pin such that the through-beam sensor moves across the first pin in a first direction; and

moving the end effector toward the first pin such that the through-beam sensor moves across the first pin in a second direction opposite to the first direction, and

wherein the at least one processor is configured to use the sensed position and orientation data obtained by moving the end effector away from the first pin and moving the end effector toward the first pin to determine hysteresis error in the through-beam sensor.

29. The articulated robot according to claim 18, wherein the plurality of parallel movements are a plurality of parallel linear movements of the end effector.

30. A non-transitory computer readable medium storing a program which, when executed by one or more processors, cause the one or more processors to:

define a coordinate system for an articulated robot, the articulated robot including:

an arm;

an end effector that is configured to pivot with respect to the arm, the end effector having a workpiece receiver with a first protruding member and a second protruding member; and

a through-beam sensor provided on the end effector, the through-beam sensor including a light emitter provided on one of the first protruding member and the second protruding member, the through-beam sensor further including a light receiver provided on an other of the first protruding member and the second protruding member, the through-beam sensor being configured to sense when an object is present between the light emitter and the light receiver;

control one or more motors of the articulated robot to move the arm and the end effector to perform sensing operations in which the through-beam sensor senses a first pin provided at a first location within a work station, the sensing operations being performed while a position and/or an orientation of the end effector are varied for each sensing of the first pin to gather sensed position and orientation data, the sensing operations are performed such that the first pin is located at different distances between the light emitter and the light receiver as the articulated robot moves the through-beam sensor across the first pin for a plurality of parallel movements of the end effector; and

perform calculations on the sensed position and orientation data to determine the first location of the first pin with respect to the coordinate system of the articulated robot,

wherein the plurality of parallel movements includes:

a first movement in which the articulated robot moves the through-beam sensor in a first direction along a first path entirely across the first pin, the first pin being at a first distance between the light emitter and the light receiver when the through-beam sensor is moved along the first path across the first pin;

a second movement in which the articulated robot moves the through-beam sensor in a second direction along the first path entirely across the first pin, the second direction being opposite to the first direction such that the second movement is a reverse movement to the first movement; and

a third movement in which the articulated robot moves the through-beam sensor in a third direction along a second path entirely across the first pin, the second path being parallel to the first path, the first pin being at a second distance between the light emitter and the light receiver when the through-beam sensor is moved along the second path across the first pin, the second distance being different from the first distance.

31. The non-transitory computer readable medium storing a program according to claim 30,

wherein the end effector is configured to pivot with respect to the arm about a pivot axis, and

wherein the one or more processors are caused to perform calculations on the sensed

position and orientation data to determine a distance extending in a direction normal to a light beam of the light emitter to the pivot axis, and an angle of the direction normal to the light beam with respect to the coordinate system of the articulated robot including an angular error of the end effector.

32. The non-transitory computer readable medium storing a program according to claim 30,

wherein an optical target is provided on a pivot axis of the end effector that is configured to pivot with respect to the arm,

wherein a scanning device is provided at a fixed position with respect to the coordinate system of the articulated robot, the scanning device being configured to measure positional data of the optical target as the articulated robot is moved through a range of motion, and

wherein the one or more processors are caused to perform a regression analysis on the positional data to determine link lengths of links of the robot arm.

33. The non-transitory computer readable medium storing a program according to claim 32, wherein the link lengths are stored on respective encoders of the one or more motors for rotating the links of the robot arm.

34. The non-transitory computer readable medium storing a program according to claim 30,

wherein the one or more processors are caused to control one or more motors of the

articulated robot to move the arm and the end effector to perform twenty or more sensing operations, and

wherein the one or more processors are caused to perform a regression analysis on the sensed position and orientation data.

35. The non-transitory computer readable medium storing a program according to claim 30, wherein the plurality of parallel movements are a plurality of parallel linear movements of the end effector.