

AUTOMATIC ASSISTED CALIBRATION APPARATUS AND METHOD THEREOF

[0001] Cross-reference to related applications

[0002] This application claims the priority of the Chinese patent application CN202010924485.9 that submitted to the Chinese Patent Office on September 05, 2020, titled "automatic assisted calibration apparatus and method thereof", and its entire content is incorporated by reference in this application.

Technical field

[0003] The present application relates to the technical field of medical devices, in particular to an automatic assisted calibration apparatus and a method thereof.

Background

[0004] The TCP (Tool centre point) calibration of manipulator is the key link of manipulator application, also known as manipulator end tool, it is connected to the flange of manipulator. When the flange is connected and the position parameters are known, in order to obtain the positional parameters of the TCP relative to the flange, the four-point method can be used to calculate the TCP. When the end tool is a hollow tubular tool, auxiliary tools can be used to complete the manual point collection operation. The medical manipulator has high requirements for accuracy, the accuracy of the manual point collection often affected due to the uneven human force, also, the efficiency of manual point collection is relatively lower, prolonging the preoperative preparation time.

[0005] Summary of the invention

[0006] The objects of the present disclosure include, for example, to provide an automatic assisted calibration apparatus and method thereof to solve at least one of the problems raised in the above-mentioned background art.

[0007] The present disclosure provides the following technical solutions: an automatic assisted calibration apparatus, comprising a calibration steel ball, the outer surface of the calibration steel ball is sleeved with an auxiliary apparatus, and the auxiliary apparatus comprises a collar, the rear surface of the collar is equipped with a connecting column, the rear end edge of the collar is equipped with a chamfer, the outer surface of the connecting column is sleeved with a calibration tube, the calibration steel ball includes a positioning steel ball, and the front surface of the collar is provided with a sleeve groove, and the sleeve groove is sleeved on the outer surface of the steel ball, the outer surface of the positioning steel ball is equipped with a connecting rod, and the outer end of the calibration tube is equipped with a manipulator.

[0008] An automatic apparatus calibration method, comprises the following methods:

[0009] A. Install the calibration tube on the outer surface of the end of the manipulator;

[0010] The coordinate coefficient value of the center (Of) of the flange coordinate system is {Xf, Yf, Zf},

[0011] Similarly, the coordinate coefficient value of the center (Or) of the coordinate system of the manipulator base is {Xr, Yr, Zr},

[0012] Similarly, the coordinate coefficient value of the center (Ot) of the coordinate system of the calibration tube end is {Xt, Yt, Zt};

[0013] B. Fix a calibration steel ball with radius of r_b in the manipulator coordinate system, the calibration steel ball and the manipulator need to keep strictly relative fixation, and the calibration tube is installed on the outer surface of manipulator end flange simultaneously;

[0014] C. Install the auxiliary apparatus on the inner surface of the calibration tube, and buckle the auxiliary apparatus on the outer surface of the calibration steel ball, at which time the axis O1 of the calibration tube is set as a high line, the center of the calibration steel ball is set as a vertex, generating a conical surface with an apex angle of 120° , the intersection of the conical surface and the calibration steel ball is the movement route of the calibration tube;

[0015] D. Set the manipulator to impedance mode, and apply a certain force along the direction of the calibration tube axis O1 to the steel ball, the calibration tube is buckled on the surface of the steel ball, at which time the calibration tube axis O1 is L1, the generatrix of the conical surface is L2;

[0016] The positional data of L1 in space is :

$$T_1 = \begin{bmatrix} rL_1 & 0 & 0 & t_1 \\ 0 & rL_1 & 0 & t_2 \\ 0 & 0 & rL_1 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

[0017] The positional data of L2 in space is :

$$T_2 = \begin{bmatrix} rL_2 & 0 & 0 & t_1 \\ 0 & rL_2 & 0 & t_2 \\ 0 & 0 & rL_2 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

[0018] Since the two straight lines intersect at the center of the sphere, they are considered to be at the same position, but the directions are different, so the amount of movement performed by the manipulator is $T_3 = T_2^{-1} * T_1$;

[0019] E. On the movement trajectory of the manipulator, the positional data of the flange is collected at a certain angle every interval, and every 4 positional data is a group, and the TCP data is

obtained using the four-point method. When the error of the two groups of TCPs is less than the allowable value, the calculation will be stopped, otherwise repeat the above-mentioned automatic movement steps A-D.

[0020] In one or more embodiments, when the auxiliary is not used, the physical location of the calibration tube TCP point is located coincident with the calibration tube axis O1.

[0021] In one or more embodiments, when the auxiliary is used, the physical location of the calibration tube TCP point is located coincident with the calibration tube axis O1.

[0022] In one or more embodiments, after the auxiliary apparatus is installed at the front end of the calibration tube, the spherical center of the spherical surface on the auxiliary apparatus is set as the tool center point.

[0023] In one or more embodiments, the cross-section of the inner wall of the auxiliary apparatus is circular.

[0024] In one or more embodiments, the auxiliary is configured to use a concave spherical surface to cooperate with a calibration ball of the same size to assist the tool to determine a point not on the tool surface to be the tool center.

[0025] In one or more embodiments, the part where the top surface A1 of the calibration tube intersects with the inner wall is a standard circle, when the standard circle is buckled on the spherical surface, it is certain that the standard circle will through the center of the circle, and the straight line extending to the normal direction of the surface where the circle is located will pass through the center of the calibrated steel ball, and the distance between the center of the ball and the center of the circle remains unchanged.

[0026] In one or more embodiments, the calibration tube is a calibration tube of straight cylinder class.

[0027] In one or more embodiments, the calibration tube and the calibration steel ball that are buckled on the calibration steel ball spherical surface by the auxiliary apparatus are regarded as a whole, named as a tool, and the auxiliary apparatus is installed at the front end of the sleeve and the center of the sphere on the auxiliary is set as the tool center point.

[0028] In one or more embodiments, the physical position of the tool TCP point coincides with the axis O1 of the calibration tube, and there is a certain offset from the top surface A1 of the calibration tube, and the offset direction is the direction away from the tool.

[0029] In one or more embodiments, the offset distance of the physical position of the tool TCP point from the top surface A1 of the calibration tube is $\sqrt{r_b^2 - r_s^2}$, located on the side away from the calibration tube, and r_s is the radius of the inner wall of the sleeve.

[0030] In one or more embodiments, the offset distance of the tool TCP point from the calibration tube top surface A1 is determined by the auxiliary calibration tool size L_a , and L_a is the distance between the top surface A1 of the calibration tube and the spherical center of the concave surface of the auxiliary apparatus after the calibration tube is installed with the auxiliary apparatus.

[0031] In one or more embodiments, during use, the manipulator applies an appropriate amount of force in the axial direction of the calibration tube, and this direction is set as the Z-axis direction. At the same time, the manipulator is set to the impedance mode, at which time the rotational and translational damping in all directions is reduced, so that it can move more freely. Then, relatively movement is performed on the spherical surface according to the pre-set trajectory. At this point, the calibration tube and the steel ball that are buckled on the spherical surface of the calibration steel ball by the auxiliary tool can be regarded as a whole, that is, a new tool, and the relative rotation of the calibration tube around the surface of the steel ball can also be regarded as the fixed-point movement of the new tool. The relative movement is the rotation around the X and Y axes, and the amount of translation is set to 0. At this time, due to the force along the calibration tube, the damping of the manipulator is small, and with the help of auxiliary apparatus, the calibration tube is not easy to fall off, so the calibration tube starts to do automatic movement around the spherical surface without the need of positional data, and collect the positional data in real time, also use the four-point method to solve the TCP data.

[0032] In one or more embodiments, when the difference between the multiple TCP data is less than the allowable error, the movement is stopped, and output the calculation result.

[0033] Compared with the prior art, the beneficial effects of the present disclosure are: the present disclosure provides a fast, easy-to-operate and accurate method for the TCP calibration of the tubular tool, and the use of the auxiliary apparatus can reduce the risk of ball detachment by restricting the movement during the movement of the tool with the calibration steel, thereby realizing the automatic calibration process; the method of using a tool to hold the calibration steel ball is easier to operate and implement than the traditional TCP calibration, which needs to touch the tip precisely at a certain point; using a fully automatic calibration method can avoid the error caused by manual operation, thus improve and the efficiency of transportation and point collection through automatic calculation and automatic testing, thereby reducing the preoperative preparation time.

Description of drawings

[0034] Figure 1 is a schematic diagram showing a tubular calibration method provided by the present disclosure;

[0035] Figure 2 is a schematic view showing the calibration step of the sleeve calibration method provided by the present disclosure;

[0036] Figure 3 is a schematic diagram of a calibration steel ball and auxiliary apparatus provided by the present disclosure;

[0037] Figure 4 is a schematic diagram of the schematic structure of the calibration steel ball and auxiliary apparatus provided by the present disclosure;

[0038] Figure 5 is a schematic structural diagram of the auxiliary apparatus provided by the present disclosure;

[0039] Figure 6 is a schematic view showing a schematic structure of the auxiliary apparatus provided by the present disclosure;

[0040] Figure 7 is the auxiliary apparatus calibration method cross-sectional schematic diagram that this disclosure provides;

[0041] Figure 8 is a schematic diagram of the calibration structure provided by the present disclosure.

[0042] In the figure: 1, calibration steel ball; 11, positioning steel ball; 12, connecting rod; 2, calibration tube; 3, auxiliary apparatus; 31, collar; 32, chamfer; 33, connecting column; 34, sleeve; 4, manipulator.

Detailed description

[0043] The technical solutions in the embodiments of the present disclosure will be clearly and completely described below with reference to the accompanying drawings in the embodiments of the present disclosure. Obviously, the described embodiments are only a part of the embodiments of the present disclosure, rather than all the implementations. Based on the embodiments in the present disclosure, all other embodiments obtained by those of ordinary skill in the art without creative efforts shall fall within the protection scope of the present disclosure.

[0044] Please refer to Fig. 1-4, the present disclosure provides a technical scheme: according to the automatic auxiliary calibration apparatus of the present disclosure, it includes a calibration steel ball 1, and the outer surface of the calibration steel ball 1 is sleeved with auxiliary apparatus 3, and the auxiliary apparatus 3 includes collar 31, the rear surface of the collar 31 is equipped with a connecting column 33, the rear edge of the collar 31 is equipped with a chamfer 32, the outer surface of the connecting column 33 is sleeved with calibration tube 2, and the calibration steel ball

1 includes a positioning steel ball 11, a sleeve groove 34 is formed on the front surface of the collar 31, the sleeve groove 34 is sleeved on the outer surface of the steel ball 11, the outer surface of the positioning steel ball 11 is equipped with a connecting rod 12, and the outer end of the calibration tube 2 is equipped with the manipulator 4.

[0045] An automatic apparatus calibration method is provided in present disclosure, comprises the following methods:

[0046] A. Install the calibration tube 2 on the outer surface of the end of the manipulator 4;

[0047] For example, the coordinate coefficient value of the center (Of) of the flange coordinate system is {Xf, Yf, Zf};

[0048] Similarly, the coordinate coefficient value of the center (Or) of the coordinate system of the manipulator 4 base is {Xr, Yr, Zr};

[0049] Similarly, the coordinate coefficient value of the center (Ot) of the coordinate system of the calibration tube 2 end is {Xt, Yt, Zt}.

[0050] B. Fix a calibration steel ball 1 with radius of r_b in the manipulator 4 coordinate system, the calibration steel ball 1 and the manipulator 4 need to keep strictly relative fixation, and the calibration tube 2 is installed on the outer surface of manipulator 4 end flange simultaneously.

[0051] C. Install the auxiliary apparatus 3 on the inner surface of the calibration tube 2, and buckle the auxiliary apparatus 3 on the outer surface of the calibration steel ball 1, at which time the axis O1 of the calibration tube 2 is set as a high line, the center of the calibration steel ball 1 is set as a vertex, generating a conical surface with an apex angle of 120° , the intersection of the conical surface and the calibration steel ball 1 is the movement route of the calibration tube 2;

[0052] D. Set the manipulator 4 to impedance mode, and apply a certain force along the direction of the calibration tube 2 axis O1 to the steel ball, the calibration tube 2 is buckled on the surface of the steel ball, at which time the calibration tube 2 axis O1 is L1, the generatrix of the conical surface is L2.

[0053] The positional data of L1 in space is :

$$T1 = \begin{bmatrix} rL_1 & 0 & 0 & t_1 \\ 0 & rL_1 & 0 & t_2 \\ 0 & 0 & rL_1 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

[0054] The positional data of L2 in space is :

$$T_2 = \begin{bmatrix} rL_2 & 0 & 0 & t_1 \\ 0 & rL_2 & 0 & t_2 \\ 0 & 0 & rL_2 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

[0055] Since the two straight lines intersect at the center of the sphere, they are considered to be at the same position, but the directions are different, so the amount of movement performed by the manipulator 4 is $T_3 = T_2^{-1} * T_1$.

[0056] E. On the movement trajectory of the manipulator 4, the positional data of the flange is collected at a certain angle every interval, and every 4 positional data is a group (include but not limited to four positional data), and the TCP data is obtained using the four-point method. When the error of the two groups of TCPs is less than the allowable value, the calculation will be stopped, otherwise repeat the above-mentioned automatic movement steps A-D.

[0057] This method carries out fully automatic calibration by the combination of force control and auxiliary tool, which do not require manually adjusting the position and posture of the manipulator, and also collecting data, this process is all automatically carried out to achieve displacement operation by the control equipment of the manipulator, and the corresponding force data is collected. Data is then used for the four-point method calculation, and the automatic process is performed to reduce the error caused by manual operation, and it also reduces the workload, and improve the calibration speed.

[0058] The method uses four-point method principle to calibrate TCP, but is not limited to the data of collecting four points to calibrate, it automatically collects and calculates multiple groups of TCP data, only when error is less than allowable range then output the TCP value, using a similar structure and method.

[0059] The present disclosure has adopted two schemes of auxiliary apparatus 3 and calibration tube 2 to be sleeved on the outer surface of steel ball and carry out the calculation of the tool center point, to be used for calibrating the manipulator, the test method of the two schemes are the same, the only difference is the ways of using the calibration tube 2 or the auxiliary apparatus 3. This can ensure the accuracy of the calibration result as long as the machining accuracy of the parts is guaranteed.

[0060] Specifically, when not using auxiliary apparatus 3, the physical position of the calibration tube 2 TCP point is positioned to coincide with the calibration tube 2 axis O1, and the calibration tube 2 axis is O1, as shown in figure 1 and figure 7, and the top surface of calibration tube 2 is A1.

[0061] Specifically, when using the auxiliary apparatus 3, the physical position of the TCP point of the calibration tube 2 is positioned to coincide with the axis O1 of the calibration tube 2, and the

auxiliary apparatus 3 can be mounted on the front end of the calibration tube 2, the spherical ball on the auxiliary apparatus 3 can be seen as the tool center point, shown in Figure 7, the auxiliary apparatus 3 is installed and matched with the calibrated tool, so the auxiliary apparatus 3 can be suitable to not only when the inner wall of the tool is circular; the innovation and protection point of the auxiliary apparatus 3 is, using concave spherical surface and the calibration steel ball 1 of the same size can help the tool to determine a point not on the tool surface as the tool center.

[0062] Specifically, the part where the top surface A1 of the calibration tube 2 intersects with the inner wall is a standard circle, when the standard circle is buckled on the spherical surface, it is certain that the standard circle will through the center of the circle, and the straight line extending to the normal direction of the surface where the circle is located will pass through the center of the calibrated steel ball 1, and the distance between the center of the ball and the center of the circle remains unchanged. For the calibration tube 2 of the straight tube, the axis O1 of the calibration tube 2 must pass through the center of the sphere, as shown in figure 1 and figure 7. However the method is not limited to a straight tube. For other tubular structures when the top surface and the inner wall intersect forms a circle, the calibration method of using the calibration steel ball 1 to assist the calibration tube 2 is still applicable.

[0063] Specifically, the calibration tube 2 and the calibration steel ball 1 that are buckled on the calibration steel ball spherical surface by the auxiliary apparatus 3 are regarded as a whole, named as a tool, and the auxiliary apparatus 3 is installed at the front end of the sleeve and the center of the sphere on the auxiliary 3 is set as the tool center point.

[0064] Specifically, the physical position of the tool TCP point coincides with the axis O1 of the calibration tube 2, and there is a certain offset from the top surface A1 of the calibration tube 2, and the offset direction is the direction away from the tool.

[0065] Specifically, the offset distance of the physical position of the tool TCP point from the top surface A1 of the calibration tube 2 is $\sqrt{r_b^2 - r_s^2}$, located on the side away from the calibration tube 2, and r_s is the radius of the inner wall of the sleeve.

[0066] Specifically, the offset distance of the tool TCP point from the calibration tube 2 top surface A1 is determined by the auxiliary calibration tool size L_a , and L_a is the distance between the top surface A1 of the calibration tube 2 and the spherical center of the concave surface of the auxiliary apparatus 3 after the calibration tube 2 is installed with the auxiliary apparatus 3.

[0067] While using, the manipulator 4 applies an appropriate amount of force in the axial direction of the calibration tube 2, and this direction is set as the Z-axis direction. At the same time, the

manipulator 4 is set to the impedance mode, at which time the rotational and translational damping in all directions is reduced, so that it can move more freely. Then, relatively movement is performed on the spherical surface according to the pre-set trajectory. At this point, the calibration tube 2 and the steel ball 1 that are buckled on the spherical surface of the calibration steel ball by the auxiliary tool can be regarded as a whole, that is, a new tool, and the relative rotation of the calibration tube 2 around the surface of the steel ball 1 can also be regarded as the fixed-point movement of the new tool. The relative movement is the rotation around the X and Y axes, and the amount of translation is set to 0. At this time, due to the force along the calibration tube 2, the damping of the manipulator 4 is small, and with the help of auxiliary apparatus, the calibration tube 2 is not easy to fall off, so the calibration tube 2 starts to do automatic movement around the spherical surface without the need of positional data, and collect the positional data in real time, also use the four-point method to solve the TCP data.

[0068] When the difference between the multiple TCP data is less than the allowable error, the movement is stopped, and output the calculation result.

[0069] Although embodiments of the present disclosure have been shown and described, it will be understood by those of ordinary skill in the art that various changes, Modifications, substitutions and alterations, the scope of the present disclosure is defined by the appended claims and their equivalents.

Industrial Applicability

[0070] The present disclosure provides a fast, easy-to-operate and accurate method for the TCP calibration of the tubular tool, and the use of the auxiliary apparatus can reduce the risk of ball detachment by restricting the movement during the movement of the tool with the calibration steel, thereby realizing the automatic calibration process; the method of using a tool to hold the calibration steel ball is easier to operate and implement than the traditional TCP calibration, which needs to touch the tip precisely at a certain point; using a fully automatic calibration method can avoid the error caused by manual operation, thus improve and the efficiency of transportation and point collection through automatic calculation and automatic testing, thereby reducing the preoperative preparation time.

Claims

1. An automatic auxiliary calibration apparatus, including standard steel balls (1), characterized in that, the outer surface of the calibration steel ball (1) is sleeved with auxiliary apparatus (3), and the auxiliary apparatus (3) includes collar (31), the rear surface of the collar (31) is equipped with a connecting column (33), the rear edge of the collar (31) is equipped with a chamfer (32), the outer surface of the connecting column (33) is sleeved with calibration tube (2), and the calibration steel ball (1) includes a positioning steel ball (11), a sleeve groove (34) is formed on the front surface of the collar (31), the sleeve groove (34) is sleeved on the outer surface of the steel ball (11), the outer surface of the positioning steel ball (11) is equipped with a connecting rod (12), and the outer end of the calibration tube (2) is equipped with the manipulator (4).

2. An automatic apparatus calibration method, which is used in the automatic auxiliary calibration apparatus according to claim 1, characterized by the following steps:

A. Install the calibration tube (2) on the outer surface of the end of the manipulator (4);

Set the coordinate coefficient value of the center (O_f) of the flange coordinate system is $\{X_f, Y_f, Z_f\}$;

Similarly, the coordinate coefficient value of the center (O_r) of the coordinate system of the manipulator 4 base is $\{X_r, Y_r, Z_r\}$;

Similarly, the coordinate coefficient value of the center (O_t) of the coordinate system of the calibration tube 2 end is $\{X_t, Y_t, Z_t\}$;

B. Fix a calibration steel ball (1) with radius of r_b in the manipulator (4) coordinate system, the calibration steel ball (1) and the manipulator (4) need to keep strictly relative fixation, and the calibration tube (2) is installed on the outer surface of manipulator (4) end flange simultaneously;

C. Install the auxiliary apparatus (3) on the inner surface of the calibration tube (2), and buckle the auxiliary apparatus (3) on the outer surface of the calibration steel ball (1), at which time the axis O_1 of the calibration tube (2) is set as a high line, the center of the calibration steel ball (1) is set as a vertex, generating a conical surface with an apex angle of 120° , the intersection of the conical surface and the calibration steel ball (1) is the movement route of the calibration tube (2);

D. Set the manipulator (4) to impedance mode, and apply a certain force along the direction of the calibration tube (2) axis O_1 to the steel ball, the calibration tube (2) is buckled on the surface of the steel ball, at which time the calibration tube (2) axis O_1 is L_1 , the generatrix of the conical surface is L_2 ;

$$T_1 = \begin{bmatrix} rL_1 & 0 & 0 & t_1 \\ 0 & rL_1 & 0 & t_2 \\ 0 & 0 & rL_1 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

The positional data of L1 in space is

$$T_2 = \begin{bmatrix} rL_2 & 0 & 0 & t_1 \\ 0 & rL_2 & 0 & t_2 \\ 0 & 0 & rL_2 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

The positional data of L2 in space is

Since the two straight lines intersect at the center of the sphere, they are considered to be at the same position, but the directions are different, so the amount of movement performed by the manipulator (4) is $T_3 = T_2^{-1} * T_1$;

E. On the movement trajectory of the manipulator (4), the positional data of the flange is collected at a certain angle every interval, and every 4 positional data is a group, and the TCP data is obtained using the four-point method. When the error of the two groups of TCPs is less than the allowable value, the calculation will be stopped, otherwise repeat the above-mentioned automatic movement steps A-D.

3. An automatic apparatus calibration method according to claim 2, characterized in that, when not using auxiliary apparatus (3), the physical location of the calibration tube (2) TCP point is located coincident with the calibration tube (2) axis O1.
4. An automatic apparatus calibration method according to claim 2, characterized in that, when using the auxiliary apparatus (3), the physical location of the calibration tube (2) TCP point is located coincident with the calibration tube (2) axis O1.
5. An automatic apparatus calibration method according to claim 4, characterized in that, the auxiliary apparatus (3) can be mounted on the front end of the calibration tube (2), the spherical center of the spherical surface on the auxiliary apparatus (3) is set as the tool center point.
6. An automatic apparatus calibration method according to claim 5, characterized in that, the cross-section of the inner wall of the auxiliary apparatus (3) is circular.
7. An automatic apparatus calibration method according to any claim of 4~6, characterized in that, the auxiliary device (3) is configured to use concave spherical surface and the calibration steel ball (1) of the same size can help the tool to determine a point not on the tool surface as the tool center.
8. An automatic apparatus calibration method according to claim 3 or 4, characterized in that, the part where the top surface A1 of the calibration tube (2) intersects with the inner wall is a standard circle, when the standard circle is buckled on the spherical surface, it is certain that the standard circle will through the center of the circle, and the straight line extending to the normal direction of

the surface where the circle is located will pass through the center of the calibrated steel ball (1), and the distance between the center of the ball and the center of the circle remains unchanged.

9. An automatic apparatus calibration method according to claim 8, characterized in that, the calibration tube (2) is a calibration tube (2) of straight cylinder class.

10. An automatic apparatus calibration method according to claim 9, characterized in that, the calibration tube (2) and the calibration steel ball (1) that are buckled on the calibration steel ball spherical surface by the auxiliary apparatus (3) are regarded as a whole, named as a tool, and the auxiliary apparatus (3) is installed at the front end of the sleeve and the center of the sphere on the auxiliary (3) is set as the tool center point.

11. An automatic apparatus calibration method according to claim 10, characterized in that, the physical position of the tool TCP point coincides with the axis O1 of the calibration tube (2), and there is a certain offset from the top surface A1 of the calibration tube (2), and the offset direction is the direction away from the tool.

12. An automatic apparatus calibration method according to claim 11, characterized in that, the offset distance of the physical position of the tool TCP point from the top surface A1 of the calibration tube (2) is $\sqrt{r_b^2 - r_s^2}$, located on the side away from the calibration tube (2), and r_s is the radius of the inner wall of the sleeve.

13. An automatic apparatus calibration method according to claim 11, characterized in that, the offset distance of the tool TCP point from the calibration tube (2) top surface A1 is determined by the auxiliary calibration tool size L_a , and L_a is the distance between the top surface A1 of the calibration tube (2) and the spherical center of the concave surface of the auxiliary apparatus (3) after the calibration tube (2) is installed with the auxiliary apparatus (3).

14. An automatic apparatus calibration method according to any claim of 2~13, characterized in that, the manipulator (4) applies an appropriate amount of force in the axial direction of the calibration tube (2), and this direction is set as the Z-axis direction. At the same time, the manipulator (4) is set to the impedance mode, at which time the rotational and translational damping in all directions is reduced, so that it can move more freely. Then, relatively movement is performed on the spherical surface according to the pre-set trajectory. At this point, the calibration tube (2) and the steel ball (1) that are buckled on the spherical surface of the calibration steel ball by the auxiliary tool can be regarded as a whole, that is, a new tool, and the relative rotation of the calibration tube (2) around the surface of the steel ball 1 can also be regarded as the fixed-point movement of the new tool. The relative movement is the rotation around the X and Y axes, and the amount of translation is set to

0. At this time, due to the force along the calibration tube (2), the damping of the manipulator (4) is small, and with the help of auxiliary apparatus, the calibration tube (2) is not easy to fall off, so the calibration tube (2) starts to do automatic movement around the spherical surface without the need of positional data, and collect the positional data in real time, also use the four-point method to solve the TCP data.

15. An automatic apparatus calibration method according to claim 14, characterized in that, when the difference between the multiple TCP data is less than the allowable error, the movement is stopped, and output the calculation result.