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PRINCIPAL OF ARTIFICIAL INTELLIGENCE, INVERSE KINEMATIC, MACHINE SUPER INTELLIGENCE & ANALYSIS OF ROBOT MANIPULATORS

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***Abstract*— Artificial intelligence is a subpart of computer science, concerned with how to give computers the sophistication to perform intelligently, and to do so in increasingly range of wider realms. It participates thoroughly in computer science's passion for abstraction, programming and logical formalisms, and detail -- for algorithms over behavioural data, synthesis over analysis and engineering (how to do) over science (what to know). All the above make Al uncongenial to psychology, which tends to the opposite choice on almost every dimension mentioned -- for behavioural data, analysis and science. But psychology is bound to AI tightly and irrevocably. Their fates do worse than commingle, they co-terminate. Moreover, however annoying it may seem, Al (and computer science) can live and prosper without psychology, but not the other way around. Psychology cannot prosper without Al. The asymmetry arises because psychology docs not stand between Al and its proper goal -- how to make computers do neat things can be discovered without recourse to psychology, simply by experimenting with computers directly. Contrariwise, A I (and computer science) is developing the conceptual tools for understanding how information is processed, and* these tools arc indispensable for psychology to understand how information is processed by humans. However irrelevant particular Al systems realized in particular computer architectures might seem, the concepts, the tools of analysis and synthesis, and the general lessons arc all central to the progress of psychology in its own personal mission**

-- to understand the mind of man. The only way for psychology to avoid dependence on Al is to get there first, and there appears precious little likelihood of that at the moment (which is a different story for a different time).

***Index Terms*—** Inverse kinematics, Intelligence, AIXI, Manipulator, Cartesian coordinates.

I. INTRODUCTION

So goes the argument for why psychologists should -- indeed must --pay attention to a new major textbook in Al, which is what Nils Nilsson has written. As always, several platforms exist from which to deny this argument, ranging from forms of humanistic psychology to philosophical opinions on the deep deficiencies of discrete symbolic representations. From such platforms, the argument above has little force. For myself, I believe it.

Now, to the book. It is organized into nine chapters, plus a prologue (for the book) and a prospectus (for the future of Al), which provide a modest outer context, 'line central nine cover all the basic topics that are familiar in Al: the early chapters focus on search, the middle chapters on the predicate calculus, later chapters deal with planning and with object-centered representations (eg, semantic networks).

The uniform procedural mold Nilsson chooses to call production system; it may be more familiar to psychologists as the problem space. There is a tripartite division into a data structure (the global data base), a set of operators on that data structure, with conditions for when they apply and actions for what dicey do (hence, productions), and a scheme for deciding which operators to apply (the control system). Using production systems Nilsson effectively exhibits a substantial fraction of the basic procedural wisdom of Al.

Except for the choice of name, which is normally identified with a narrower species of Al system and may will put some Alerts off, I think this effort will be generally recognized by the field. The uniform representational mold Nilsson chooses is the predicate calculus, using it throughout die book to express all the knowledge in the global data base. The predicate calculus has a bad press in parts of Al, stemming from the intensive work in the late sixties on theorem proving programs (using a technique called resolution), which, though highly productive, revealed clearly the futility of domain-free techniques to provide a powerful enough reasoning engine (hence the reaction - "Well, that proved predicate calculus was the wrong thing to use"). However, formal logic embodies the fundamentals of how to express knowledge, and it is an essential tool.

At present AIXI is not widely known in academic circle, though it has captured the imagination of a community interested in new approaches to general purpose artificial intelligence, so called artificial general intelligence (AGI).

Optimality of AIXI Hutter has proven that universal agents converge to optimal behavior in any environment where this is possible for a general agent. He further showed that the result holds for certain type of Markov decision processes, and claimed that this should generalize to related classes of environments.

Universal Intelligence Measure. If AIXI really is an optimally intelligent machine, this is suggested that we may be able to turn the problem around and use universal artificial intelligence theory to formally define a universal measure of machine intelligence.

Fundamental Temporal Difference Learning. Although deriving practical theories based on universal artificial intelligence is problematic, there still exist many opportunity for theory to contribute to the development of new learning techniques, albeit on a somewhat less grand scale.

II. MATHEMATICAL MODELLING AND KINEMATIC ANALYSIS

A. Overview

The conventional solution approach of kinematics is important in various fields of recent trend and modern technology, extending through computer graphics (e.g. animation character analysis) to expansion of space manipulation and simulators. All these fields of applications are fundamentally required to evaluate both orientation and position of the Cartesian coordinates of end effector and joint variables of robot manipulator. To evaluate the position and orientation of end effector and its joint variables one can adopt homogeneous transformation matrix method. This method is the conventional tool to describe the kinematic relationship of joint and links.

Moreover, this method of representation is used from many decades for tracing the end effector position of the robot manipulator. On the other hand, it is extremely redundant for the representation of 6-dof of a system. The redundancy generally consumes more computational cost and more storage space. This is also related to the problem of mathematical operations which generally creates more complexity. Therefore, many alternative methods for the representation of non-inertial coordinates and inertial coordinates have been introduced. The proposed method should always be less complex and computationally efficient for the representation of mechanism and transformation of the system.

B. Representation methods and kinematics

Kinematics can be understood with the system of links or chain connected with joints to create relative motion without analyzing the torque/forces or sources of the motion. Analytical study of the motion of robot link with respect to one fixed coordinate or base coordinate system with function of time could be understood as a robot kinematics. The kinematics of robot link also provides the study of its higher derivatives like velocity, jerk, acceleration etc.

C. Kinematic variables and parameters

A kinematic chain consists of kinematic pair of links which may be connected by revolute or prismatic joints subjected to rotational or translational degree of freedom. As explained in the literature there exist many approaches for the mathematical representation of kinematic chain. The major differences of these methods are the attachment of coordinate frames. Therefore Denavit-Hartenberg parameters [246], are commonly used.

Homogeneous transformation matrix based methods are better for placement of coordinate's frames to the links and joint variables. The method consists of four scalars which are known as DH parameters of kinematic chain. These scalars are used to define the geometry of link and relative displacement of joint. This method of representations reduces the mathematical/arithmetical operations for the kinematic description.

In the Figure below the position and orientation of the axis of joint can be determined with respected to the base coordinate X,Y and Z with minimum four parameters. To accomplish this, common normal OP between axis of joint and Z axis of the base frame has been drawn. Therefore the magnitude of common normal is representing length a, which is located from the d offset distance of Z axis from the origin of base frame to the point O. θ is the angle between OA which is parallel to x-axis with common normal OP. This angle represents the rotation about the z-axis which is measure in x- axis to the direction of common normal. Angle α represents the rotation of joint axis with PQ which is parallel to z-axis and measured in direction of z-axis. These four scalar a, θ, α and d are the parameters of Denavit Hartenberg parameters to represents the position of the axis of any joint in Cartesian coordinate system. In the later section detail discussion about these four parameters are given.

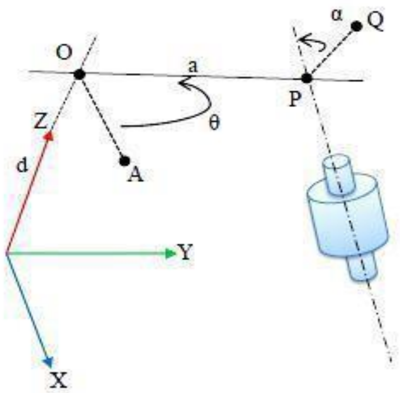

Figure - Position and direction of a cylindrical joint in a Cartesian coordinate frame.

D. DH-PARAMETERS

Now let us observe all characteristic properties of scalar parameters of DH method for modelling of considered kinematic pair in Figure Standard method of representation has been followed without altering the concern properties of kinematic pair.

From Figure link i-1 connected by cylindrical joint with link i, and i+1 link is consecutive link with same joint i. The attached coordinate frame with link i is orientated in such a way that the Zi axis is aligned with consecutive link i+1 and Xi-axis is aligned with common normal in between i and i+1. Base coordinate frame is situated at the intersection of common normal with i+1 axis. And the last coordinate Yi will be placed as per right hand rule which is yi = zi + xi. Therefore, from Table 4.1, DH- parameters can be defined as with considered geometry and orientation of associated links are as follows:

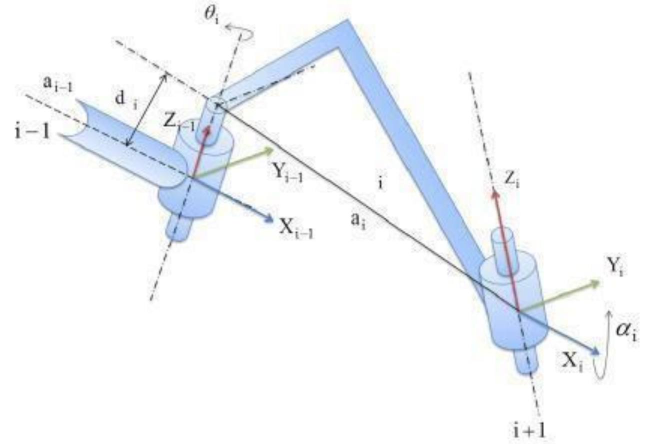

Figure - kinematic pair and DH parameters

E. DH-algorithm for frame assignment

In the DH algorithm, a base coordinate frame X0 , Y0 , Z0 is attached to fixed based of non-moving link and local coordinated will be fixed at each joint of moving links. The connected links i-1 to i, where i=1,2,3…n. Therefore, the basic steps of DH-algorithm for frame assignment are follows: Step 1 Base frame X0 , Y0 , Z0 typically attached to the fixed body at the origin in such a way that axis of rotation should coincident with the Z0 axis, while X0 will be places arbitrarily directed towards the perpendicular of the rotation axis or it can be understand with the forward reaching direction of manipulator. Using right hand coordinate rule, the last 0 Y axis can be placed i.e. Y0 = Z0 x X0.

Step 2 Following the second step the subsequent second joint i, rotation axis will be placed in the axis Zi-1, which goes to coordinates Xi-1, Yi-1, Zi-1. The second coordinate frame origin will be placed on the i-th joint axis at the end of the common normal away from the joint axis i-1 to the joint axis i. But in case if the joint axes i and i-1 are parallel and joint type is revolute then the origin of the frame will be simply imposed to second joint axis confirming that di=o. otherwise in case of prismatic joint the origin of frame can be places arbitrarily along the joint axis i. Final condition of intersection of I and i-1, the frame will be positioned at the point of intersection.

Step 3 For moving link i-1, axis Xi-1 where i=2,3,4,..n, will be directed towards the common normal axes of joint i and i-1 from i-1 to i. If the joint axes i and i-1 intersect, then axis Xi-1 will be perpendicular to the intersecting plane and can be directed towards arbitrarily perpendicular axis. The rotation angle □i, will be chosen by normal direction of Zi-1 axis, which is basically represented between the Xi-1 and X through rotation axis Zi-1. Therefore third axis Yi-1 can be evaluated similarly with right hand coordinate rule Yi-1 = Zi-1 × Xi-1.

Step 4 Now the placement of manipulator end effector coordinate frame Xe, Ye, Ze will be on the reference point of the gripper. Ze axis will be directed anywhere in the orthogonal plane of Xe , similar to step three , Xe will be aligned with common normal of Zei-1 and Ze. But in case of revolute joint axis of last joint, Ze will be considered as parallel to the previous joint axis. The last axis will be given as right hand coordinate rule Xe = Ze × Xe

Step 5 Finally after assignment of all coordinate frames for all links i=1, 2, 3, …, n, DH parameters can be evaluated and can be written in tabular form given in the next section and pictorial view is presented in above Figure.

F. Mathematical modelling of 3-dof revolute manipulator The mathematical modeling of forward and inverse kinematics of robot manipulator using homogeneous transformation matrix method with DH parameters is presented.

The purpose of this application is to introduce to robot kinematics, and the concepts related to both open and closed kinematics chains. The Inverse Kinematics is the opposite problem as compared to the forward kinematics, forward kinematics give the exact solution but in case of inverse kinematics it gives multiple solutions. The set of joint variables when added that give rise to a particular end effectors or tool piece pose.

Figure shows the basic joint configuration of 3-dof revolute planar manipulator and Figure represents the model of Cincinnati Milacron T3 and used as 3-dof planar manipulator. Figure shows the simulation of 3-dof revolute planar manipulator using DH procedure. Position and orientation of the end effectors can be written in terms of the joint coordinates in the following way,

Table: DH-parameters for 3-dof revolute manipulator

Sl.	θ_i (degree)	d_i (mm)	a_i (mm)	α_i (degree)
1	θ1	0	a1	0
2	θ2	0	a2	0
3	θ3	0	a3	0

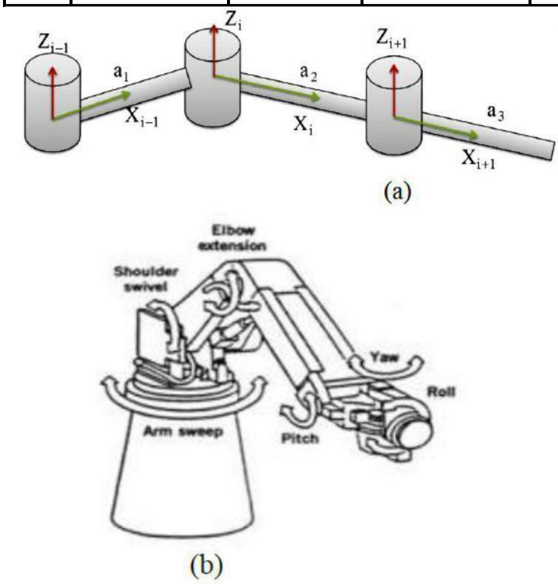

Figure: Planar 3-dof revolute manipulator

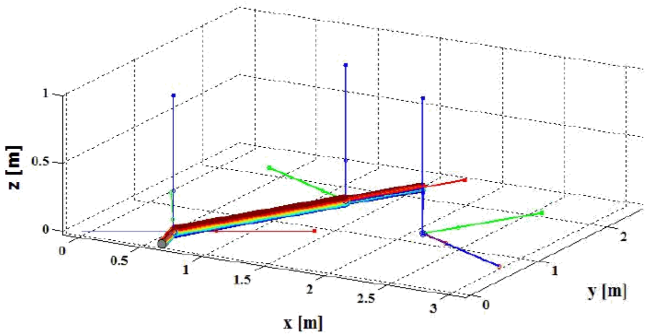

Figure Coordinate frames of 3-dof revolute manipulator

Transformation matrix will be given by equation:

$$A_{i-1,i} = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i & 0 & a_i\sin\theta_i \\ 0 & 0_i & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_{i-1,i} = \begin{bmatrix} c_{123} & -s_{123} & 0 & a_1c_1 + a_2c_{12} + a_3c_{123} \\ s_{123} & c_{123} & 0 & a_1s_1 + a_2s_{12} + a_3s_{123} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where, $c_1 = \cos\theta_1$, $s_1 = \sin\theta_1$, c = Cos $(\theta_1 + \theta_2)$, $s_{12} = \sin(\theta_1 + \theta_2)$, $c_{123} = \cos(\theta_1 + \theta_2 + \theta_3)$ and $s_{123} = \sin(\theta_1 + \theta_2 + \theta_3)$

Therefore forward kinematics is given by,

$$X = a_1c_1 + a_2c_{12} + a_3c_{123}$$

$$Y = a_1s_1 + a_2s_{12} + a_3s_{123}$$

$$\phi = \theta_1 + \theta_2 + \theta_3$$

ϕ represents orientation of the end effector. All the angles have been measured counter clockwise and the link lengths are assumed to be positive going from one joint axis to the immediately distal joint axis. However, to find the joint coordinates for a given set of end effectors coordinates (*x*, *y*,

ϕ); one needs to solve the nonlinear equations for θ_1, θ_2 and θ_3.

Inverse kinematics,

$$\theta_2 = a\tan 2(s_2, c_2) = a\tan 2(\pm\sqrt{1-(c_2)^2}, \frac{x^2 + y^2 - a_1^2 - a_2^2}{2a_1a_2}$$

$$\theta_1 = a\tan 2(y, x) - a\tan 2(k_2, k_1)$$

Where,

$k_2 = a_1 + a_2\cos\theta_2$ and $k_1 = a_2s_2$

$$\theta_3 = \phi - \theta_1 - \theta_2$$

III. INTELLIGENT TECHNIQUES FOR INVERSE KINEMATIC SOLUTION

Cognitive process of learning and using it for decision making in case of hard to understand processes has been well appreciated by the community researchers. Now a days, human beings are grasping the intelligence from the nature and are trying to implement into the machine. The purpose is to retrieve end effector position of a robot manipulator, which can work in uncertain and cluttered environment on the basis of knowledge or information so as to learn complex nonlinear functions from outside information without the use of mathematical structures or any geometry. The intelligent methods mimic the cognition and consciousness in many aspects like they can learn from the experience or previous training then it can be universalize to that domain for testing, basic concept is the mapping of input output variables faster than conventional methods so as to reduce the computational cost. So the motivation is to reduce the computational cost and consequently increase the speed for robust control. On the other hand, inverse kinematic mapping for any configuration of robot manipulator can be analytically done but the process will be long and slow for real time control.

As explained in previous chapter the inverse kinematic solution of robot manipulator is difficult if following the conventional methods. The difficulty arises due to fact that inverse kinematic equations are not true function and gives multiple solutions. In addition, input-output mapping of inverse kinematics problem is non-linear and tendency of the solution is qualitatively differs when end effector position changes within the workspace. On the other hand, conventional methods yields efficient solution of inverse kinematics but suffer some drawbacks like complex structure of manipulator or higher dof can be time consuming and mathematically difficult to obtain results, singularities occurs in some cases etc. Therefore, considering overall complexity of inverse kinematic solution and search for efficient intelligent techniques like artificial neural network (ANN), fuzzy logic, ANFIS and hybrid neural network will be fruitful. ANNs are extensively adopted technique to solve inverse kinematics problem and generally offers an alternative approach to handle complex, NP-hard and ill-conditioned problems. ANN models can acquire previous knowledge or information from examples and are able to tackle noisy and inadequate data and to learn non-linear problems. Once the adopted neural network models are trained then it can perform prediction of output with higher computational speed. These models are appropriate in modelling and implementation of system with complex mappings. A detail introduction of different adopted models of ANN has been presented in this chapter.

However, ANN is quite adaptive to the system and does not requires higher level of programing but apart from this it has some drawback like selection of ANN architecture, numerical computation for weight updating (i.e. Gradient descent learning, Levenberg-Marquardt based back propagation learning etc.), etc. In contrast above discussed nature of ANN models, it is required to set some rules for fuzzy logic to avail the advantages of interpretability and transparency of the method. Fuzzy logic requires the prior knowledge of the problem and based on the experience of expert decision that makes use of linguistic information on the basis of hit and trial method. Therefore, from last decades, fuzzy logic becomes an alternative method over conventional techniques for nonlinear inverse kinematic solutions. The main idea behind this algorithm is if-then logic which is inherent to expert decision. However, this algorithm is based on trial and error logic therefore it can be fruitfully merged with ANN models. Fuzzy logic has different membership function which is fixed and might be arbitrarily. And the shape of the function relies on few parameters and this can be optimized using ANN back propagation rule. This method is known as adaptive neural-fuzzy inference system (ANFIS). Therefore, hybridization of ANN with fuzzy can give benefits of both method. However, the major drawback of ANFIS is stuck in local optimum point. Therefore to overcome this problem the wise decision is to adopt some metaheuristic algorithm for the optimization of weight and bias of ANN models. Therefore, in this chapter hybrid ANN models are developed to overcome the problem of ANN and ANFIS with the hybridization strategy. Detail discussion of ANN models, ANFIS and hybrid ANN has been presented in the later section.

IV. OPTIMIZATION APPROACH FOR INVERSE KINEMATIC SOLUTION

Optimization is the method which yields best solution of a problem having number of variables and alternatives. From the definition, it includes the phenomenon or some biological concept in our daily life that inspires to minimize the energy, computational cost, mathematical operations, time, etc. and maximizes efficiency, profits, power etc. with the help of some direct and indirect parameters. For example, computation of inverse kinematics problem of robot manipulator with the direct relation of considered torque, energy and time to be minimized to get the desired position. In this example joint variables can be calculated after optimization of the position error, torque, energy etc.

Therefore in broad sense, the major constituents of the optimization methods can be recognize as its objective function which is generally a quantitative expression of the system to be optimized and then the number of unknown parameters or set of variables that is required proper setting to yield optimum value, finally the number of constraints which gives the complete objective function for the concern domain. These three constituents is the basis to solve any optimization problem and their objective function (fitness function) formulations. On the other hand, the major objectives for optimizing of any function would be the convergence of the solution. Furthermore, optimization algorithms should always be flexible to manage various problem such as nonlinear, NPhard, discrete, multi-objective, multi-modal etc. Most important property of any optimization algorithms is to avoid the local optimum point.

V. UNIVERSAL ARTIFICIAL INTELLIGENCE

Having reviewed what intelligence is and how it is measured, we now turn our attention to artificial systems that appear to be intelligent, at least in theory. The problem is that although machines and algorithms are becoming progressively more powerful, as yet no existing system can be said to have true intelligence — they simply lack the power, and in particular the breadth, to really be called intelligent. However, among theoretical models which are free of practical concerns such as computational resource limitations, intelligent machines can be defined and analysed. In this chapter we introduce a very powerful theoretical model: Hutter's universal artificial intelligence agent, known as AIXI.

A full treatment of this topic requires a significant amount of technical mathematics.

The goal here is to explain the foundations of the topic and some of the key results in the area in a relatively easy to understand fashion. For the full details, including precise mathematical definitions, proofs and connections to other fields, see (Hutter, 2005), or for a more condensed presentation (Hutter, 2007b).

VI. UNIVERSAL INTELLIGENCE MEASURE

“We need a definition of intelligence that is applicable to machine as well as humans or even dogs. Further, it would be helpful to have a relative measure of intelligence that would enable us to judge one program more or less intelligent than another, rather than identify some absolute criterion. Then it will be possible to assess whether progress is being made.” Johnson (1992)

A definition of machine intelligence: Consider again our informal definition of intelligence:

Intelligence measures an agent's ability to achieve goals in a wide range of environments.

Similarly, the environment must be able to send and receive signal. In our terminology we will adopt the agent's perspective on these communications and refer to the signals sent from the agent to the environment as action, and the signals sent from the environment to the agent as perceptions. Our definition of an agent's intelligence also requires there to be some kind of goal for the agent to try to achieve. Perhaps an agent could be intelligent, in abstract sense, without having any objective to apply its intelligence to. Or perhaps the agent has no desire to exercise its intelligence in a way that affects its environment. In either case, the agent's intelligence would be unobservable and, more importantly, of no practical consequence. Intelligence then, at least the concrete kind that interest us, comes into effect when the agent has an objective or goal that it actively pursues by interacting with its environment.

CONCLUSION

Inverse kinematics of any robot manipulator can generally be defined as finding out the joint angles for specified Cartesian position as well as orientation of an end effector and opposite of this, determining position and orientation of an end effector for given joint variables is known as forward kinematics. Forward kinematic having unique solution but in case of inverse kinematics it does not provide any closed form or unique solution thus it is require to have some suitable technique to resolve the problem for any configuration of robot manipulator. Hence, inverse kinematics solution is very much problematic and computationally expensive. For real time control of any configuration manipulator will be expensive and generally it takes long time. Most of the robotic applications are dependent on the joint variables of manipulator due to fact that the requirement of the desired position of the end effector. For the computing the analogous joint angles at high speed requires inverse kinematic transformation of each joint.

Therefore, the current research work proposes inverse kinematic solution for various configurations of robot manipulator. The basic kinematics and mathematical modelling of the configurations are discussed thoroughly and subsequently kinematic analyses of selected configurations have been done. The concept and application of neural network models for inverse kinematic resolutions are discussed in length. To overcome the drawbacks of ANN model hybridization with optimization algorithms and their strategies are also made. In chapter 6, numerical solutions of the inverse kinematic problem of selected manipulator based on metaheuristic algorithms have been made. Optimization approaches are used to transform the kinematic mapping problem of the manipulators into constrained non-linear metaheuristic models. This approach gives the freedom to direct search of feasible configuration space of the robot end effector to 284 yield the joint variables of the manipulator with the minimization of position and orientation of end effector. The present work is summarized with the concluding remarks in the next section stating that contributions of the present research work.

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