

# NAO and Other Robots Hand Eye Coordination and Kinematics Determination-A Review

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**ABSTRACT:** Nao robot is a humanoid robot developed by Aldebaran Robotics having its headquarters in Paris. It has been used widely in the research and education areas in various institutions. Making Nao control is not an easy task, it requires prior knowledge about its degrees of freedom (DOF) and its kinematics. Nao's hand eye coordination requires the control of arm through vision. It is observed that kinematics determination plays an important role in arm control. Various works on Nao robot in vision has been done. Grasping task of objects can be accomplished only after determining kinematics and having control on Nao's arms. This review covers Nao's and other robot's work in hand eye coordination and kinematics determination.

**KEYWORDS:** Degrees of freedom, vision, kinematics, hand eye coordination

## I. INTRODUCTION: IMPORTANCE OF HAND EYE COORDINATION AND KINEMATICS DETERMINATION

In robots, hand eye coordination refers to the communication between hand and eye to perform any task. The input to the vision is taken to the arms for further action. For e.g., in humans for writing, a hand should adjust to hold a pen to write and only then writing can be performed. The neurons sends signal to the hand for performing tasks. Similarly, in robot an input to the robot's vision is send as feedback to hands for performing tasks. Hand eye coordination in Nao robot helps in grasping of objects possible along with the kinematics determination. Kinematics determination means finding forward kinematics and inverse kinematics in order to study the degrees of freedom necessary for controlling movements. Direct kinematics deals with computation of the position of end effectors from joint parameters. Inverse kinematics is just opposite of direct kinematics which deals with computation of joint parameters from end effector's position.

## II. COMPLEXITIES IN HAND EYE COORDINATION AND KINEMATICS DETERMINATION

Real time control of hands of robot faces a number of challenges:

**1. Vision:** The robot's vision is an inevitable requirement for hand eye coordination. The type of inbuilt camera or mounted camera in the robot determines the camera parameters which are essential for vision in robot. Nao robot version 2.1 has top and bottom camera which limits the stereo vision, only monocular vision is possible. In many works, cameras or sensor are mounted on the robots to achieve the desired characteristics if not inbuilt in the robots.

**2. Movement of arms:** In robot's, arm control requires prerequisite knowledge about degrees of freedom of various links and joints associated with robot. For grasping task, it is very essential to know the angles with which it should be twisted or moved for accomplishment of a desired task. This needs to have a rigorous study about various links, joints and maximum angle rotations which are possible in the robot.

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Vol. 6, Issue 1, January 2017

**3. Visual servoing:** Robot should be able to move its head while detecting an object, or should be able to follow a manipulated path. The robot, if made to detect any object should follow the object to recognize it. This requires proper knowledge of its camera behaviors to make it follow an object efficiently. This is an essential task for making a Nao robot grasp an object.

**4. Cameras:** For the task of vision, cameras placed on the robot or the inbuilt camera plays an important role for the hand eye coordination. In many of the works, cameras are mounted on robots to achieve better vision properties or to enable stereo vision and get a global view. By doing so, 3D localization is made possible. In Nao robot, the work which could be done is the monocular vision as the version 2.1 has top and bottom cameras.

### III. PRIOR LITERATURE REVIEW

Various works have been reported over years on various aspects of hand eye coordination in robots [4]-[13]. Review papers have also been reported. There are works on kinematics determination [19]-[25]. Some more works on Nao are discussed here. Puheim proposed a work which controls the arm of Nao robot using Tracking-learning detection method [1]. Stereo vision cameras were mounted on the head of robot and back propagation algorithm was used. Shamsuddin proposed a review work in Nao control and motion exploration [2]. Nasrollahi proposed a work on humanoid soccer robot which uses fuzzy algorithms for improving performance and making an efficient decision system for playing game [3]. Melinte proposed a work for control of Nao robotic hand [4]. Dynamic gain of robot haptic feedback was determined by mapping using neural network. Wen proposed work on Nao robot arm kinematics [5]. It analyses upper limb topology and studies kinematic model. Simulations are done in MATLAB. Peipei proposed a work on vision localization in Nao [6]. The camera mounted on the head of Nao provides global vision while its own inbuilt camera provides local vision. In this Nao robot moves to a place avoiding collisions and grasps objects and it offers good performance on accuracy. Bo proposed a work in which CCD cameras are mounted on the end effector of robot for building up hand eye vision measuring system [7]. In [8], Allen proposed a robust system for tracking and grasping of moving object. The vision system does not require special lighting or object structure to compute motion. The control system is able to withstand sensor noise and triangulation error.

### IV. CATEGORIES OF VISION

**Monocular vision:** In this type, only single camera is used which is either inbuilt on the robot or mounted on the robot. In this, monocular vision positioning method is used in which the world coordinates are determined from pixel coordinates. Extrinsic and intrinsic parameters should be known for this method. This can be found by camera calibration.

**Intrinsic parameters:** These are the pixel coordinates of image with respect to corresponding coordinates in camera reference frame.

**Extrinsic parameters:** These parameters define alignment of camera reference frame with respect to the world reference frame.

**Stereo vision:** In this two cameras are used which are either inbuilt or mounted on the robot. This is done to obtain 3D positioning and for the depth estimation. Triangulation is done to obtain 3D positioning. It consists of four steps. They are as follows:

- i. **Image acquisition:** In this, the corner extraction is done and then the intrinsic parameters and extrinsic parameters are computed.
- ii. **Image rectification:** In this, the image is made to go through certain process for identicalness.
- iii. **Correspondence matching:** In this, if projection of image points can be identified, then the shape of object can be reconstructed.
- iv. **Depth estimation:** In this, the same 3D points are need to be obtained in camera images. Finding same 3D points on different camera images is difficult. Hence, depth estimation is needed.

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### V. DIFFERENT TECHNIQUES OF CAMERA CALIBRATION

Different techniques of camera calibration which are incorporated with the calibration software developed by Dr. Jean-Yves Bouguet are the following:

- i. Corner Extraction: In this images which are to be calibrated are fed and then corners are extracted and then repositioning is done to obtain intrinsic and extrinsic parameters.
- ii. Calibration using Zhengyou Zhang's data: This allows us to change intrinsic camera model by choosing which parameters are to be optimized.
- iii. Calibration using Heikkil's data: This computes calibration parameters for planar and non planar rigs.
- iv. Calibration using Backstein and Halir's data: Calibration method that calculates intrinsic and extrinsic parameters.

### VI. DIFFERENT HAND EYE COORDINATION TECHNIQUES PREVIOUS WORKS IN NAO AND OTHER ROBOTS

Kumaresan has introduced a technique of hand eye coordination in which the combination of fuzzy logic and mathematical closed forms are used [9]. This has been done on a 6 DOF manipulator SCORBOT-ER VII. The fuzzy logic algorithm is designed for determination and fuzzification of input, selection of fuzzy rules and for defuzzification and computation of outputs. The fuzzy logic algorithm guides the robot to go to the exact position. Jianbo Su , Hongyu Ma and Zhiwei Luo proposed a calibration free method of hand eye coordination based on extended state observer [10]. The extended state observer is used to find different state variables of the system and external disturbances. The observer and controller designs are independent of system configuration. Kuhn proposed a method of hand eye coordination based on neural network which uses Self-Organising Maps to achieve the task [11]. This approach mainly involves camera control to project the object on the image plane, coarse positioning of the arm and fine positioning based on visual feedback. Ghadirzadeh proposed a sensorimotor contingencies based method to perform hand eye coordination [12]. A PR2 robot is used, the system deals with non linearities and no calibration is used. Gaskett proposed a control model using motor- motor mapping , a combination of open and closed loop control [13]. Behera proposed a model in which kohonen self organizing maps are used for solving hand eye coordination problem [14]. In [15], Beale proposed a work in which statistical model has been derived for vision system and Langrangian model for robotic arm. This method is used for catching a moving object and is robust to noisy data when position of object is estimated. In [16], Schmerling proposed a goal directed learning for hand eye coordination. In this paper, goal babbling concept is investigated, that requires head and arm motor control. Additional kinematic model is also dealt which maps arm configuration and image space to head configuration. In [17], Shibata proposed a model in which reinforcement learning is used for hand eye coordination. After learning robot could become to reach its hand to the target. In [18], Jafari proposed a work in which a new hybrid method of performing hand eye coordination is used. COERSU robot has been used in this work, neuro-fuzzy networks contribute to find the optimum position of robotic tip to grasp the object.

### VII. INVERSE KINEMATICS DETERMINATION PREVIOUS WORKS IN NAO AND OTHER ROBOTS

In [19], Crenganis has implemented Adaptive Neuro-Fuzzy Inference System(ANFIS) for solution of serial redundant robot kinematics. In this, kinematic analysis is based on the redundancy circle method. Using fuzzy logic and ANFIS the robot arm is placed in certain position to avoid obstacles or to have a collision free trajectory. In [20], Amore proposed analytically based kinematic identification scheme for serial link manipulator. In [21], Son proposed a model in which a hybrid algorithm is proposed which combines differential evolution algorithm and back propagation algorithm. This hybrid algorithm trains neural network model for inverse kinematics identification of industrial robot manipulator. This algorithm provided fast convergence and better precision than other approaches. In [22], Mukherjee proposed a method for identification of inverse kinematic of Nao robot using Kinect. The Kinect sensor is used to obtain coordinates of the shoulder, elbow and wrist joints of the robot. The model is then used to train the neural

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Vol. 6, Issue 1, January 2017

network and the inverse kinematic model is solved using ANFIS. The Moore-Penrose pseudo-inverse of the Jacobian is then used to iteratively solve the inverse kinematic problem. In [23], Kuo proposed a method, in which SCORBOT robot is used. Encoders are conventionally used to sense the joint angles, and then the direct kinematics is used to calculate the pose of the end-effector. D-H parameter is calculated through experiments. In [24], Aleksandrovic proposed a work in which a manipulator similar to Delta robot is taken and its degree of freedom has been calculated analytically. After that, the inverse and forward kinematics is solved in explicit form. In [25], Huo proposed a work in which kinematic optimisation is done based on joint parameterization and the self-optimizing method. Kinematic simulations are performed after optimisation of kinematic solutions.

## VIII. KEY ELEMENTS OF CAMERA CALIBRATION AND KINEMATICS DETERMINATION

Robot manipulator or robot should be present for performing the hand eye coordination and also for kinematic determination. Cameras should be present which can be either inbuilt in the robot or externally mounted. Simulation software MATLAB should be present for camera calibration and kinematics determination. A system should be present which can run the simulation and also for interfacing the robot.

### A. ROBOT MANIPULATOR OR ROBOT

In Nao, robot is used for performing hand eye coordination. Many works on hand eye coordination have used different types of robotic manipulators. SCORBOT-ER VII have been used in [9]. A PR2 robot is used in one of the work which involves camera control to project object on image plane [12]. COERSU robot has been used by Jafari for performing hand eye coordination using hybrid method [18]. Son has used a 3 link industrial robot manipulator for identifying inverse kinematics. Schmerling has used Nao robot for hand eye coordination [21]. Huo has used 7R humanoid arms in which kinematic optimization is proposed [25]. Kuo proposed a work to calculate the pose of end effector in which SCORBOT robot is used [23].

### B. CAMERAS

Various works on hand eye coordination have been used in which cameras are either mounted or inbuilt. In Nao, camera is inbuilt. In [5], two high resolution cameras are used. In most of the works Charge Coupled Device (CCD) cameras are used.

### C. SIMULATION

The simulations are done in MATLAB using neuro-fuzzy algorithms or neural network. Camera calibration and inverse kinematics identification can be done. Algorithms used may vary.

## IX. CONCLUSION

This paper dealt with the review of hand eye coordination on Nao robot and other robots. Kumaresan fuzzy logic algorithm gives less accumulative error than linear interpolation method [4]. Ghadirzadeh work's most important feature is real time learning. It requires robot to have only few interactions with environment [7]. Gaskett's work provides robust and accurate control without calibration [8]. Beale's Bayesian approach method is robust to noisy data when estimating position of object [10]. Kuo's work accuracy depends on camera resolution [18]. Crenganis proposed a model which is effective, accurate and easy to implement.

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Vol. 6, Issue 1, January 2017

Table 1.Comparison of Different Methods Used

Paper	Feature	Method
[1]	Suitable	Real time operation Tracking-Learning-Detection
[3]	Suitable	Fuzzy rules and rule based expert systems
[4]	Suitable	Dynamic gain of robot feedback through neural network
[5]	Suitable	Denavit-Hartenberg method
[6]	Suitable	Intelligent vision localization system
[7]	Suitable	Newton-Euler method
[8]	Suitable	Arm control algorithm
[11]	Suitable	Neural network
[12]	Suitable	Sensorimotor contingencies
[14]	Suitable	Hybrid neural control scheme
[15]	Suitable	Statistical method using Bayesian Robust to noisy data
[17]	Suitable	Reinforcement learning and neural network
[19]	Suitable	Adaptive Neuro Fuzzy Inference System
[21]	Suitable	Differential evolution and back propagation algorithm

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Vol. 6, Issue 1, January 2017

[25]		Self optimizing	Efficient
[28] and measurement errors	Suitable	Homogeneous matrix equation	Stable with respect to noise
[30] effectiveness		Recursive Newton-Euler formula	Improved performance,

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Vol. 6, Issue 1, January 2017

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