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NAO humanoid robot: Analysis of calibration techniques for robot sketch drawing

Avinash Kumar Singh *, G.C. Nandi

Robotics and Artificial Intelligence Laboratory, Indian Institute of Information Technology Allahabad, Allahabad, U.P., India

HIGHLIGHTS

- The paper proposed 3 novel techniques to calibrate humanoid camera plane to its end-effector position. The solution is generalized consider the experimental setup is same.
- Extensively error analysis and time complexity analysis is performed to evaluate each proposed technique.
- Proposed techniques are computationally sound and require only few points (4 points) to calibrate the system. The error involved in calibration is also very less.

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ABSTRACT

The strength of the NAO humanoid robot is discussed with several challenges in the arena of human portrait and sketch drawing. These challenges include extracting feature points from the input image, defining these points with respect to end effector, finding the inverse kinematics solution and designing a visual feedback system. This paper mainly addresses the fundamental issue of defining a relationship between the points of the image plane and NAO end effector position. This relationship enables NAO to perceive points of image plane with respect to its body coordinate system. Three different techniques based on the principles of fundamental matrix, pseudo inverse and Artificial Neural Network based regression analysis are applied to handle the calibration difficulties on NAO robot. A comprehensive study on sample points collected from NAO end effector position and corresponding image points has been made to understand the effectiveness of each technique. The degree of performance ability of each technique has been measured using time complexity, and mean square error metrics.

1. Introduction

Humanoid robots have apparently similar body structure like human beings. Their human like design enables them to share the same workspace with humans [1]. Apart from the appearance similarity they do have similar kind of human like sensors (e.g. they have vision sensors analogous to the human eyes, tactile sensors analogous to human touch sensors and they have speakers and microphones to produce as well as to hear sound, similar like human mouth and ear). The rapid development in the field of humanoid robotics during the last few decades shows the presence of several different kinds of humanoid robots in our society. Although they are coming under the same umbrella (Humanoids) yet their shapes, size and specification vary between manifestation [2–5]. For example ASIMO (Advanced Step in Innovative MObality) [6] from Honda Research Laboratory has 57 degree of freedom (DOF), HRP-4C [2], (Humanoid Robotics Platform-4(Cybernetic human)) from National Institute of Advanced Industrial Science and Technology (NIST) Japan has30 DOF, iCub [3] built by Italian Institute of Technology has 53 DOF while the other two popular robots Humanoid Open Architecture Platform -2 (HOAP2) [7] and NAO [8] developed by fujitsu and Aldebaran Robotics respectively have DOF as 25. One possible reason for these differences could be that they all have designed for different specific purposes and they are still in the development process. We have not yet able to discover the best shape and size of these humanoid robots.

Apart from the physical similarities with human beings, they do also have computation power which helps them to perceive and process different objects, gestures and human commands [6,9]. They can recognize human beings as well can do dialogs with them. WioNA [10](Wikipedia Ontology NAO) can communicate with you in its native Japanese language. It has also built in Japanese

* Corresponding author.
E-mail addresses: rs110@iiita.ac.in (A.K. Singh), gcnandi@iiita.ac.in (G.C. Nandi).

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Wikipedia Ontology and Robot Action Ontology, which gives liberty to NAO to discuss various topics as well as express them in their different gestures. The other humanoid robots ASIMO [11] is inherited with various data analysis (audio/video/sensors) and processing tools which helps it to understand human intentions. The technology is getting transferred from the single standalone systems to these mobile robots, moreover research is also getting popular in the field of their cognitive architecture design [11,12] which facilitate them to learn things by themselves. A brief discussion of humanoid cognition and learning can be found in [13]. These advancements establish their presence in various household applications (cleaning, cooking, washing, etc.) [14,15]. They can play various sports like soccer, golf, etc., keeping their interest in sports a Robocup [16] is being organized every year. Robocup is a soccer game organized between two teams of humanoid robots having 5 members in a team. The objective of Robocup is to beat a Federation of International Football Association (FIFA) world cup winner's team under the rules and protocol of FIFA in 2050. They are also helping in educating by assisting their supervisor [17,18]. They are becoming a good housekeeper specially for assisting physically disabled persons. Their role in fighting against autism is very appreciable [19]. Their specially designed program for Autism Spectrum Disorder (ASD) children helps them in making interaction with them and to find other ways to deal with Autism [19]. They have also been tried in the military field where they can be used to rescue as well as to combat with the enemies [20,21], but there is always a question regarding risk, ethics and design to use these robots in the war field [22]. They are also turning to be a good entertainer [23].

Moving from the war, sports and household application they are creating their presence in the field of painting and sketch drawing. Every human wants to be drawn either for leaving trails to its successors or to satisfy their own ego. All of the approaches discussed in the following subsections are developed to create human portraits were inspired by this idea however some of them were designed to perform accurate painting for industrial purpose. The first work in this direction of portrait drawing is noticed in 1970s. A program designed by Harold Cohen named as "AARON" [24] to a pictorial representation of visual scenes. AARON has been in the continuous development phase and it has learnt the morphological representation of different objects like plants, animals and persons. There are a small number of robots specified to create drawing in an open loop without having any feedback system. The other advancement in this field is categorized into two wings (a) the first wing discusses the development with respect to manipulators while the (b) second wing focus more on humanoid robot drawing.

1.1. Painting/sketch drawing by manipulators

There are several inspiring as well as successfully running robotic machines which prove that robots can do better drawing and painting if they are trained properly. Haeberli [25] has developed different techniques such as sampling geometry using ray-painting, approximating images by relaxation, etc. to create static and animated images which are the abstract representation of the photograph and synthetic scenes. The type of brush used in the painting has great impact on the quality; therefore Hertzmann [26] varied the brush size to paint rough approximation of given images. The painting process is divided into several layers and for each layer different size of brush is used to keep the gradient of image into consideration. PUMA paint [27,28] was such an online painting project started in late 1998. The PUMA robot was connected to the internet which allows you to draw anything with the help of its Java based interface. The PUMA paint has accurate drawing capability; however it is not a fully automatic tool. The previous semi-automated techniques require human involvement. Later, several fully automated systems came into the picture which can create sketches in a fully automated manner. Collomosse [29] defined an automatic system to control brush stroke and sizes based on the image salience and gradient. The other issue associated with these systems was to accumulate feedback system. Therefore the vision based system has been taken in use. The vision guided system helps in providing the feedback to the system as well as helping in achieving the full automation [30–32]. Rectification of the input image and proper gripping are the two major challenges in sketch drawing/painting. The 3 step solution has been discussed by Shunsuke et al. [33] to discuss these challenges. The first step used to create the 3D model of the object in order to recognize it; the second module used to extract the edge, line, etc. like features from the transformed silhouette images and the third module discuss how multi fingered hand paints the geometry. Paul a robotic hand–eye system designed by Tresset et al. [34,35] does the aesthetic human face sketching more accurate than all the previous approaches. It has 4 degrees of freedom with the camera placed at different body. It has efficient feedback control and facial feature extraction modules. The other kind of robotic manipulator based painting has also been developed in order to paint cars and other objects [36,37].

1.2. Painting/sketch, drawing by humanoids

The first fully automated humanoid system which could be tried as sketch artist is developed at EPFL taking help of HOAP-2 robot [38]. The robot can draw the sketch of any person who is sitting in front of him. The primitive techniques of face detection, boundary and edge extraction with the trajectory planning are used in this application. The other effort has been made by Srikaew et al. [39] to create artistic portraits using the ISAC robot. The beauty of using ISAC as a sketch artist is due to their soft hands who can mitigate the drawing as fine as humans. They have McKibben artificial muscle, which is an excellent actuator while the stereo vision helps it in a 3D representation of the object.

After analyzing the existing literature it has been observed that development in the field of painting/ sketch drawing by manipulators has gained much attention in comparison to humanoids. One of the possible reasons could be the extra and redundant degrees of freedom associated with robotic hands. Moreover reachable work space of humanoid robot and solving the inverse kinematics for at least 5 degrees of freedom also act as an inhibitor. We have provided a solution (calibration) which defines the image plane with respect to an NAO end effector. Once NAO define each point of the image plane with respect to its body coordinate system, the only thing left is to calculate the feasible inverse kinematic solution. This paper restricts itself for estimating the content of the calibration metric only. The workflow of the paper is summarized in Fig. 1. The first step is to extract the boundary point using any boundary extraction technique. This problem can be solved by applying the geometrical feature extraction techniques of image processing. The second problem of representing the image points corresponds to NAO end effector is divided over two sub problems. The first problem is to map the image points with respect to table coordinate (the place where NAO supposed to draw sketches) and the second issue is to represent table coordinate system with respect to an NAO end effector. The first problem is solved by applying the linear transformation while the second problem has been tackled by applying three different approaches. These approaches are derived from the concept of the fundamental matrix, pseudo inverse and regression analysis. Fundamental matrix approach basically used in the stereo vision is to find the popular lines. These epipolar