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Vision-Based Control of Robotic Manipulator

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Abstract—*This paper provides a brief review of the technologies used in the vision based control of the robotic arm or robotic manipulator. Robotic arm is the most widely used robotic technology. It is used in many industrial applications, but majority of these applications are single purpose. Robotic arms of these applications work in a strictly defined domain on strictly defined parts. There is no or very little change in such systems. Vision based control allows such systems to be dynamic. It allows the system to incorporate more changes and recover from errors. In such systems, visual servoing is used. Visual servoing, as discussed in this paper has two approaches-position-based (PBVS) and Image-based (IBVS). The concepts of Robotic Vision are also discussed. The camera is the main sensing equipment in such systems and has two main configurations eye-in-hand and eye-to-hand, as discussed. The specifications needed for the camera in such applications are also discussed. Other important requirements of most robotic vision systems are also discussed in this paper, which include the light; the equipment required like films, storage media etc.; and the processing capabilities required to interpret the feed. Implementing vision in robotic manipulators also has its challenges like working conditions, the speed of data transfer and handling such data. All these and more are also discussed in this paper.*

1. INTRODUCTION

Robotic manipulator is the most widely used robotic technology in many industrial applications including spot welding, spray painting, pick and place, material handling and much more. The controlling of these robotic arms is usually done by predefined programs which have a little room for error. They lack the intelligence to make decisions and handle errors without the intervention of the operator. This restricts the range of their applications. Also, sometimes, robotic arms use basic level sensors such as limit switches to ensure accuracy. This is a closed loop engagement but it still is limited to a predefined set of parts the arm can handle. Moreover, the changes in posture, orientation and position of the workpiece cannot be handled by such systems.

Vision-based control of robotic arm allows for intelligent control of the arm. It allows the manipulator to work with objects of different orientations, whose position is not known beforehand. It allows the system to identify the part and decide the path the arm should take to reach it. Vision-based control of robots is useful in many fields including underwater robotics [7], planar cable robots [32], and teaching robots [14] and even in human-robot interaction fields [30]. The visual control of the manipulator is however a technologically intensive task and many techniques are employed in this regard. These techniques are discussed in the following sections. This technique employs a different variety of sensors coupled with a camera setup [10, 31].

Robotic vision systems have some common requirements such as robustness, cost-effectiveness, responsiveness, part recognition capability etc. which are discussed in the following section.

2. REQUIREMENTS OF ROBOTIC VISION

The robotic vision system can have varied requirements based on their configuration, layout, approach algorithm and application. However, some requirements are common for all robotic vision systems. Some of these requirements are discussed in the following text.

As discussed in section one, the majority of robotic vision applications are in the industry. In the industrial environment, robots are used for tasks which are unsuitable for humans. These tasks may be repetitive, heavy load carrying or hazardous for humans such as spot welding, etc. Thus, the robustness of the system becomes a major requirement. It involves the ability to deal with incomplete data input. Current setups have many limitations. They require the objects to not be touching each other along with proper lighting, limited field-of –view etc. A desirable attribute would be that a general robotic system would be able to "guess" at least partial data.

Cost is another very important requirement [17]. Industry requires the setup costs and operating cost to be as low as possible for all machines. Cost-effectiveness is also a very important quality of the robotic vision setup. Often a reduction in costs comes from a trade-off with quality. This reduces the capabilities of the system. Currently available robotic vision setups are capital intensive and require high capital investment in the beginning. This is a hindrance in the mass application of such systems.

Research oriented robotic vision systems require high speed, the richness of architecture, and flexibility. These systems must be capable of supporting powerful, high-level programming languages [17, 23].

Another requirement is part recognition [17, 28]. It is one of the key requirements. This capability is usually dependent on the ability of the system to detect features and colour. The features may include holes, surface features, ridges, edges etc. However, as the part family increases, this becomes a computationally intensive task. Also, if the parts are very familiar, the system may fail to differentiate between them. This is one problem that is a continued source of research.

3. ROBOTIC VISION CONCEPTS

Vision is the sense of which many species, humans included, perceive the world. Visual sensing is one of the most sophisticated and intricate systems of the human body [17, 25]. The visual process extracts important data and descriptions of the scenes. These scenes are majorly ambiguous. We recognise not only the object but we do this despite the change of other factors such as lighting, orientation, postures, and placements. We also identify objects from two-dimensional drawings and sketches [17]. In computerised vision systems we try to emulate this process of identification of the object using artificial systems such as cameras, image processing systems and algorithms. This is a huge task for a computer based vision system.

Computer vision has come a long way from just binary image processing to highly complex feature based systems [28]. Computer vision or Machine Vision is an important technology for making intelligent robotic systems. It allows robustness and flexibility in the systems which are the key aspects of intelligent systems [28]. Most of these approaches employ model-driven techniques where the common methodology is to match the model of parts to image data in order to recognise these parts [28].

The combination of vision systems with robotic manipulators is being done for a long time now [2, 3]. Robotic vision, in essence, is recognition of the object and its properties. These properties include its position, pose, orientation along with the workspace environment [17, 22]. It also includes uncertainty reduction and error handling [2, 17]. These are tasks which are categorised as high interaction tasks, in the sense that they require greater association among workpieces and the manipulator in the three-dimensional workspace.

The main areas of application of robotic vision in the industry are assembly operations and material handling [11-15]. It must also keep the orientation of the part as required. Assembly operations generally require fastening of finished parts to make a complete product. Hence, it requires greater coordination among robotic arm and vision system. Other sensors, such as limit switches, might also be used. Material handling operations are those in which workpieces are transferred to the plant or work cell. For this application, the system should be capable of differentiating between different parts which might be very similar. Their orientation and position are also of key importance and the image acquisition must be monitored with the delivery being verified.

Implementation of visual control in real-time robotic systems is a very daunting task. In these systems, the visual systems convert the three-dimensional workspace into a two-dimensional image. This results in loss of data of one dimension i.e., the depth data [34]. This coupled with the nonlinearities involved with image projection introduce difficulties in integrating robots with visual systems. The solution to this is presented in the form of Visual Servoing.

4. VISUAL SERVOING

In traditional systems, robotic manipulators were used as point-to-point devices. In these systems, the visual sensing and the robotic manipulators were combined in an open loop fashion. They followed the methodology of “looking” then “moving” [3, 5]. However, the accuracy of such systems depends directly on the accuracy of the visual sensing system. It also depends on the accuracy of the manipulator and its controller. To overcome this problem and to increase the accuracy, a visual feedback loop of control was introduced.

Visual Servoing, as a term, was introduced by Hill and Park in 1979 [3]. Visual servo control is, basically, the use of data acquired from computer vision system to control the path or motion of the robotic manipulator [5]. The task in visual servoing is to control the pose of the robot’s end-effector, relative to the target, using visual features extracted from the image [2]. The camera may be fixed in the workspace or mounted on the robotic manipulator. The configuration in which the camera is fixed in the workspace is known as end-point open-loop. In this configuration, the camera observes both the workspace and the robot’s end-effector. The second configuration, in which the camera is mounted on the robot’s end-effector, is also known as end-point closed loop or eye-in-hand [6]. In this configuration, the camera monitors only the workspace with respect to the robot’s end-effector.

Robotic and visual servoing are today vital and stimulating fields of research. Experimentation plays a crucial role, as in any other applied science, giving to new ideas the opportunity to have a confrontation with a real environment and bringing them close to a future application [16].

4.1 Approaches to Visual Servoing

Fundamentally, there are two approaches to visual servo control: Position-Based Visual Servo (PBVS) and Image-Based Visual Servo (IBVS). There is also another approach which combines the benefits of both of these called as Hybrid Visual Servo control.

In Position-Based Visual Servo Control, a calibrated camera is used for determining the pose of the object in the workspace. This is done with respect to the said camera. A geometric model of the object in the workspace is created for this method. The robotic manipulator then moves according to the path developed by the algorithm using the geometric model created [2, 5]. The algorithm is designed for pose estimation as well as path generation. The algorithms used for this purpose are computationally expensive [3, 26-29]. It is also referred to as three-dimensional visual servoing [24]. PVBS approach uses the three-dimensional information in the joint space to design the algorithm for control [8].

In PVBS system, pose estimation is the key task. It is estimated with respect to the camera [2]. The knowledge of the intrinsic parameters of the calibrated camera and the features of the observed image plane is required. Errors are computed based on the difference between the actual output position and the desired position. Same computations are done for pose and orientation. The controller then generates a controlling signal to counteract these errors [10, 21]. However, achieving this control is not an easy endeavour. Robustness of the system along with the responsiveness, accuracy and computing ability remain the main challenges [2, 8, 13]. Moreover, while using PBVS, the object might escape from the camera's field of view, thereby resulting in loss of control over the image trajectory [35].

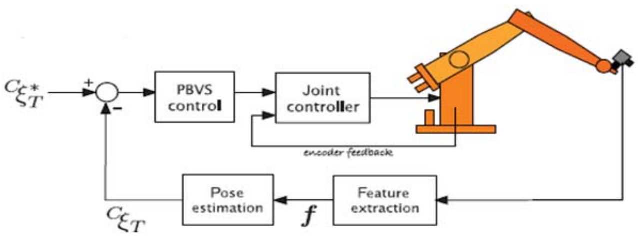

Fig. 1: Position Based Visual Servo Control Loop [2]

Unlike PBVS, IBVS does not estimate the pose of the target object. The relative pose is implicit in the values of the image features. In IBVS, the controller uses the location of features on the image plane directly for feedback [2]. Elements of the task are specified in image space, not in world space. IBVS controller controls the joint angles directly, and no specific joint controller is required. Image feature data is directly used for the calculation of control commands by algorithms. The difference between the desired features and the current features gives the error. Image features usually used in this approach could be the position of points, size of a region, centre of a region, length of a line, segment and rotation angle of line and etc. [37].

IBVS has several advantages over PBVS. Computation cost of this approach is considerably lower than PBVS as there is no image interpolation and three-dimensional image reconstruction. It is more robust to errors in robot calibration and camera calibration. IBVS controller eliminates the effects of calibration errors [37]. This method does not require object modelling [5, 6]

Almost straight line trajectory control is possible with IBVS controller; however, the uncontrolled Cartesian trajectory may violate the robot's joint limit. This particularly happens in the case of large translational and rotational displacements. Also, image singularities and occurrences of local minima are other drawbacks of this method [31, 35].

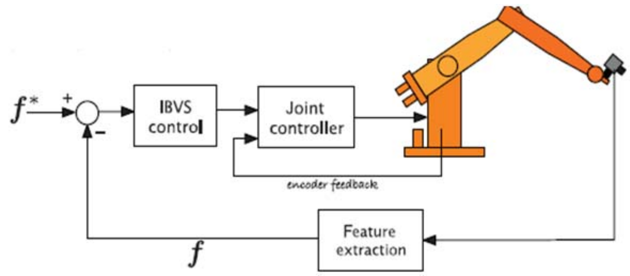

Fig. 2: Image Based Visual Servo Control Loop [2]

Reviewing the main visual servoing strategies, one can conclude that the overall benefits of IBVS strategy are greater than those of the other two methods. This is due to the less computation that it requires and higher robustness that it provides.

4.2 Visual Servoing Controller

Visual servoing systems use controlling algorithms for guidance and feature extraction. In the beginning controllers used were proportional, PI and PID type [32]. Proportional controllers were most commonly used as they reduce the errors exponentially [35-37]. Adaptive control was introduced for estimation of unknown parameters such as object depth etc. It was even used for estimation of calibration parameters [24]. Robust visual servoing was proposed in order to perform more reliable visual servoing tasks in presence of big camera or robot calibration errors which provide more stability to the system [24, 28]. Model predictive controllers have also been developed for visual servoing systems in order to consider the system constraints such as image boundaries and robot's joint limitation during the motion of the robot [33]. Furthermore, other non-linear controllers have been practised on visual servoing systems such as sliding mode control to increase the robustness of the task in feature trajectory tracking [37-39].

4.3 Image Features

Image feature is a piece of information defined in the image. Image features are used in visual servoing to define the system error by comparing it to the desired values. The desired features information is gathered from an image taken at the place where the camera is in its desired position relative to the target object. Initially, geometric features such as points, segments or straight lines are usually used as image features in visual servoing [9]. Although these features are very easy to be detected for various kinds of objects, they are also prone to get lost by being occluded by another object or a human hand, during operation. This leads to a visual servoing failure. Recently, in order to apply the visual servoing technology to track the complicated objects and enhance the robustness, several novel features were adopted such as laser points [38] and image moments [6]. In [38], laser point is also used as an instrument to estimate the object's depth. Image moments have widely been used in computer vision for a very long time in applications such as pattern recognition [6].

5. CAMERA FOR ROBOTIC VISION

Video cameras are the most widely used robot vision sensors. The camera captured images are analysed by the on-board robot processors and the detected features are used to direct robot movements [31, 32]. Camera used for robotic vision applications are usually CCD Cameras. These are robust and relatively cheaper, thus a perfect tool for industrial applications.

For the majority of applications, eye-in-hand configuration is preferred. This is similar to a human looking at the workpiece. It is used in space applications [12, 19], underwater [7, 32] applications and mining applications to name a few. The major advantage of this configuration is that it allows the camera to focus on the object, thereby reducing the computation requirements.

Eye-to-hand configuration is used where the view of the entire workspace is required. In this, the image of the workpiece may be occluded during the motion by the manipulator itself or other obstacles. It gives a steady view of the workspace and the wider field of view. This is majorly applied in operations which include moving targets.

Regardless of camera configuration, camera calibration must be performed in order to obtain the camera intrinsic parameters such as focal length, resolution and the principle point [34].

Calibrating the camera and the robot is both time and money consuming. In order to overcome such problem, some un-calibrated visual servoing methods have been introduced. Malis proposed a visual servoing method invariant to camera parameters [5, 6]. He proved the stability of the controller in presence of large calibration errors. Other un-calibrated and automatic calibration visual servoing techniques are introduced in [16, 17]. It is shown that position based visual servoing does not have good precision using the un-calibrated camera and manipulators.

Visual servoing can be performed using a different number of cameras; single camera (Monocular), two cameras (Stereo Vision or Binocular) and multiple cameras. In each of these categories, the camera(s) could be installed in an eye-in-hand or eye-to-hand configuration. Kragic and Christensen [18] reported a comprehensive survey on each category. Among all categories, the single camera needs less processing time to extract the visual information. Due to the fact that, every point in the 2D image plane corresponds to a line [17] in 3D space, a single camera cannot provide a good estimation of the distance between the camera and the object. The solution to obtain more precise position and depth of the object is to use a stereo camera vision system. Depth computation is done by comparing the small differences between multiple views of the same scene.

The stereo vision system is rarely used in an eye-in-hand configuration. Stereo vision systems usually have a smaller field of view than monovision. This is because stereo vision systems only work with the shared part of the field of view of each camera. This also limits the camera baseline distance, which affects the accuracy of depth estimation. In contrast, stand-alone stereo vision configuration has fewer limitations and hence is very common in visual servoing systems. Kragic addressed some eye-in-hand and stand-alone stereo vision configuration applications in [18].

6. CHALLENGES AHEAD

A lot of research has been done in the field of robotic vision based control of the robotic arm but there are still some challenges remaining. These challenges are described as below.

6.1 Video Standards [3]

Video standards conformity is an important issue. The earlier low-quality video was a challenge to work on but as technology has progressed, high-quality video is becoming cheaper. However, even then the quality required for precision tasks is still expensive for the large scale industrial application. This restricts the spread of the technology.

6.2 Cameras [3]

Solid state cameras such as CCD, NMOS are used widely in robotic vision application. However, the application of robotic arm control requires small cameras which are robust and provide good quality images. Colour plays a major role in robotic vision applications and good cameras with high resolution are required. This becomes more important when the part families are big, as minute features also decide the difference in parts [33, 35]. Also certain applications such space and underwater require a special type of cameras.

6.3 Lenses [3]

Lenses can cause a lot of problems such as distortion of the image. Most important of this is radial distortion especially near the edges. To overcome this algorithm have to be made more robust. Also, as the work environments of these robots are hazardous, they have detrimental effects on the surface of the lens. This calls for a frequent replacement which in turn increases the cost.

6.4. Image Processing [3]

The amount of data produced by vision sensors is very large. There are certain technological limitations in processing this data in real time. Also, as we increase the quality of the visual sensors, this data increases manifolds. For the image processing systems to keep up with the increasing quality of images, there need to be significant improvements in this area.

7. CONCLUSION

Hence, we have discussed the in detail the technology used in the visual control of the robotic arm. Research results have been discussed and compared with their historical context. All the research papers used as the basis of this paper are listed in the bibliography of this paper.

Visual servoing is a widely used approach in the visual control of the robotic manipulator. Work in this field has been continuing since the 1960s. A lot of studies is going on in making this more robust. As the part families and application sphere expands the need for more robust control also increases. To handle this adaptive visual servoing and use of neural networks is also increasing.

As the application sphere of the vision based control of robotic arm increases new problems also surface. As in the case of space application, where there can be no human intervention, a lot is at stake. The system has to be very accurate and robust to operate in such environments.

Hence, robotic vision based control of robotic arm can have widespread application in many fields but the technology needs to be more robust, accurate and cost-effective in order for that to happen.

REFERENCES

[1] Edgar G. Munday, Computer Simulation of Compliant Motion Control for a Robotic Arm, IEEE 1998

[2] Peter I. Corke, Robotics, Vision and Control Fundamentals. Springer 2014.

[3] Peter I. Corke, Visual Control of Robot Manipulator, IEEE conference of Robotic Systems, 1993

[4] W.I. Clement and K.A. Knowles, An Instructional Robotics and Machine Vision Laboratory, IEEE transactions on Education, Vol. 37, No. 1994

[5] Chaumette F, Hutchinson S, Visual servo control 1: Basic approaches. IEEE T Robotic Automation 13(4):82–90, 2006

[6] Chaumette F, Hutchinson S, Visual servo control 2: Advanced approaches. IEEE T Robotic Automation 14(1):109–118, 2007

[7] Qingping Lin and Chengi Kuo, "Virtual tele-operation of underwater robots". Robotics *and Automation, 1997. Proceedings., 1997 IEEE International Conference on*, Albuquerque, NM, 1997, pp. 1022-1027 vol.2.

[8] Y. Mezouar and F. Chaumette, “Path planning for robust image based control,” Robotics and Automation, IEEE Transactions on, vol. 18, no. 4, pp. 534–549, Aug. 2002.

[9] K. Hashimoto, “A review on vision based control of robot manipulators,” Advanced Robotics, vol. 17, pp. 969–991, 2003.

[10] Konstantinos Tarabanis, Roger Y. Tsai, and Peter K. Allen(1991), Proceedings of the 1991 IEEE ICRA Sacramento, Califomia - April 1991

[11] R.S. Alhuwalia and L.M. Fogwell, A modular Approach to Visual Servoing. IEEE Internaltional Conference of Robotics and Automation, 1985.

[12] Enric Galceran and Marc Carreras(2013), A survey on coverage path planning for robotics, University of Girona, Underwater Robotics Research Center (CIRS)

[13] Hui Miao, Yu-Chu Tian, Dynamic robot path planning using an enhanced simulated annealing approach, Applied Mathematics and Computation,Volume 222, 1 October 2013, Pages 420–437

[14] W Chamberlain, T Drummond, P Corke, Distributed Robotic Vision as a Service, ACRA 2015 Proceedings, 2015

[15] Vourvoulakis, J, Kalomiros, J, & Lygouras, J. Design Details of a Low Cost and High Performance Robotic Vision Architecture. International Journal of Computing, 14(3), 141-156, 2015

[16] M. Attolico and F. Bernelli-Zazzera, A Visual Servoing Control System for Lightweight Robotic Manipulator, IEEE, International conference on Advanced Intelligent Mechatronics, 2005

[17] Nelson B. Corby, Machine Vision for Robotics, IEEE Transactions of Industrial Electronics, Vol. IE-30, No.3 1983

[18] Zhao-Hui Jiang and Tsuyoshi Eguchi, Vision feedback Based End-effector Motion Control of a Flexible Robot Arm, IEEE, 2007.

[19] Michael E. Stieber, Michael McKay, George Vukovich and Emil Petriu, Vision-based Sensing and Control for Space Robotics Applications. IEEE Transactions on Instrumentation and Measurement, 2000.

[20] Isela Bonilla, Emilio J. Gonz´alez-Galv´an, C´esar, A Vision-based, Impedance Control Strategy for Industrial Robot Manipulators. IEEE Conference on Automation Science and Engineering, 2010

[21] Wong Guan Hao, Yap Yee Leck and Lim Chot Hun, 6-DOF PC-Based Robotic Arm with Efficient Trajectory Planning and Speed Control. International Conference on Mechatronics, 2011.

[22] Y. Shirai and H. Inoue, “Guiding a robot by visual feedback in assembling tasks,” Pattern Recognition, vol. 5, no. 2, pp. 99–108, 1973.

[23] J. Hill and W. T. Park, “Real time control of a robot with a mobile camera,” in 9th ISIR.

[24] Fujie Wang, Zhi Liu, Yun Zhang and C. L. Philip Chen, Adaptive robust image-based visual servoing control of robot with unknown actuator hysteresis, Springer, 2016.

[25] Friedrich Fraundorfer, Lionel Heng, Dominik Honegger, Gim Hee Lee, LorenzMeier, Petri Tanskanen, and Marc Pollefeys, Vision-Based Autonomous Mapping and Exploration Using a Quadrotor MAV, IEEE International conference on Intelligent Robotic Systems, 2016.

[26] Ankit A. Bhurane and Sanjay N. Talbar Vision-based Authenticated Robotic Control using Face and Hand Gesture Recognition, Elsevier, 2015.

[27] Tej Dallej, Marc Gouttefarde, Nicolas Andreff, Mica¨el Michelin and Philippe Martinet, Vision-based Control of Cable-Driven Parallel Robots. IEEE International Conference on Intelligent robots and Systems,2011.

[28] Jim Orrock, Rick Jacobson, John Krumm, Two Dimensional object Modelling for Robotic. International Workshop on Artificial Intelligence for Industrial Applications 1988

[29] R. C. Harrell, D. C. Slaughter, and P. D. Adsit, A fruit-tracking system for robotic harvesting. Machine Vision and Applications, pp 69,80. 1999

[30] Yanxia Zhang and Chaojun Wang, Robot Manipulator Servo Control Based on Force and Vision Sensing. Fifth International Conference on Intelligent Human-Machine, 2013

[31] Soren Zimmermann, Tobias Tiemerding, and Sergej Fatikow, Automated Robotic Manipulation of Individual Colloidal Particles Using Vision-Based Control. IEEE/ASME

[32] Reza Babaghasabha, Mohammad A. Khosravi and Hamid Taghirad, Vision Based PID Control on A Planar Cable Robot. 22nd Iranian Conference on Electrical Engineering

[33] Neerparaj Rai, Bijay Rai, and Pooja Rai, Computer Vision Approach for Controlling Educational Robotic Arm based on Object. IEEE 2014

[34] Shiuh-Jer Huang, and Shian-Shin Wu, Vision-based Robotic Motion Control for Non-autonomous Environment. Proceedings of the European Control Conference 2007

[35] Charan S G, Manjunath M, Niranjana S, Kranthi Kumar G, Monovision based Automated Navigation and Object Detection. International Conference on Robotics, Automation, Control and Embedded Systems ,2015

[36] A. H. Abu-Alola, N. E. Gough, Q. Mehdi and P. B. Musgrove, "Application of a genetic algorithm to an actuation mechanism for robotic vision," Control, 1994. Control '94. International Conference on, Coventry, UK, 1994, vol.2

[37] Mohammad Keshmiri, Image Based Visual Servoing Using Trajectory Planning and Augmented Visual Servoing Controller. PHD Thesis, Concrodia University, Canada, 2016

[38] Chen Gao and Sos Agaian, Robust Template Based Corner Detection Algorithms for Robotic Vision. IEEE ICRA, 2015

[39] Hung-Yi Hsu, Hsing-Yung Hsu and Jung-Shan Lin, Control Design and Implementation of Intelligent Vehicle with Robot Arm and Computer Vision, 2014.