THREE-DIMENSIONAL ROBOT POSITIONING SYSTEMS WITH VISION GUIDANCE

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Motivation

Development of a versatile robot positioning system equipped with stereo cameras suitable for picking parts deviated in six degrees of freedom (6DOF).

Industrial robots are used traditionally as "blind" machines. The manipulators always rely on a predictable pose of an object (position and orientation in 6DOF) to perform gripping tasks of parts located for instance in palettes or on assembly lines. In practice though, the part can deviate from its ideal nominal location. If this is the case, the robot can miss or worse yet crash into the part causing damages and downtime. In response to rising demands for safe, cost-effective, versatile, precise and automated gripping of rigid objects deviated in 6DOF an analytical 3-point robot positioning system guided by stereo vision has been developed.

Industry

- automotive
- food
- pharmaceutical
- glass
- every-day-products

Application

- depalletizing
- picking from assembly lines
- racking and unracking
- picking from bins
- tracking systems

Accomplishments

- creation of an analytical system measuring 3D points (object features) based on stereo images (for small parts)
- creation of a numeric system measuring 3D points based on two non-stereo images (for large parts) – 'separate images' method
- derivation of an analytical system for adjusting the manipulator to grip the object in 6 DOF based on measured 3D points
- elaboration of the calibration method including hand-eye calibration
- correction of the hand-eye calibration parameters using a genetic algorithm ensuring the system's repeatability of ±1 *mm* and ±1 *deg*
- establishment of Ethernet based communication exchanging XML strings between a Kuka robot (client) and a Siemens camera (server) without integrating any PC unit
- successful implementation of stereo system in the Siemens camera and the Kuka robot proving feasibility of the system

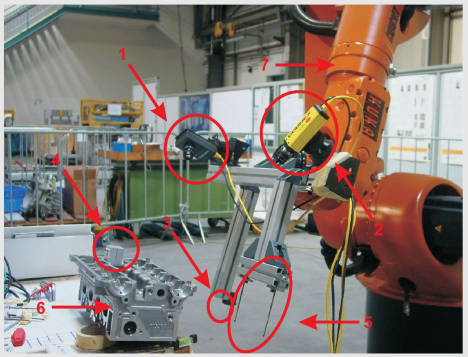
Mathematical tools

- Transformations between coordinate systems
- Linear and nonlinear least squares method
- Gröbner basis and Buchberger algorithm
- Laguerre algorithm
- Genetic algorithm
- Lie algebra

Software

- Kuka Robot Language
- Kuka Ethernet package
- Siemens SIMATIC language
- Matlab
- Mathematica

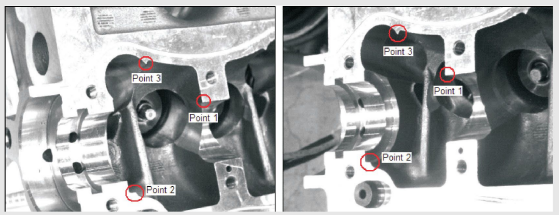
Test setup of the robot positioning system



1. Siemens CCD camera VS 723 (with Fujinon TV lens 16 *mm*)
2. Cognex CCD camera In-Sight 1100 (with PENTAX TV lens 16 *mm*)
3. Measuring needle
4. Calibration needle
5. Gripper (simulated by two nails)
6. Object (tilted in this picture)
7. Kuka robot KR 60-3 with 6 axes

Detection of object features

The process of 3D object gripping is divided into two stages, i.e. measurement of 3D coordinates of at least three features and then estimation of the object pose (exterior orientation) or the camera motion (relative orientation). In order to compute 3D points it is necessary to find their corresponding pixel coordinates in the images. Hence, an image processing application (IPA) has to be developed for retrieving object features during the automatic mode of the entire plant. Since the objects are manufactured differently, their surface/texture differs and thus specific source of lighting (e.g. white, red, green, IR) has to be utilized to help the IPA retrieve the features. Creating an effective IPA is thus far one of the most challenging aspects in vision guided robotic systems.



Calibration of the positioning system

Calibration of the system is the most crucial stage because it strongly influences the precision of the measurements of the features as well as the performance of the whole gripping process. The robot is taught the gripping motion as follows: if you 'see' the object in this way, then grip it in that way. The most significant part comprises hand-eye calibration, i.e. derivation of geometrical relation between the robot (hand) and the cameras (eye) based on which 3D points can be measured. The calibration process of the system takes about two hours and is done manually.

Commercial applications

- **Braintech Inc.** developed the system **SC3D**™ for positioning the robot based on single image – technology bought by ABB in 2005
- **Shafi Inc.** developed the vision package **RELIABOT® PC** for positioning the robot based on multi images – technology bought by Adept, Stäubli, Motoman in 2005
- **FANUC** developed the package of vision systems **V-500*i*ATM** based on multi images for picking small and large parts – year 2006

Future development of the project

- optimization of mathematical equations for robot positioning to increase robustness of the analytical/numerical system
- further research on 'separate images' method
- implementation of other methods for computing the relative and exterior camera orientation based on single or multi images
- implementation of other hand-eye calibration methods based on pose or structure-from-motion algorithms and development of an algorithm for an automatic hand-eye calibration compatible with leading robot brands
- creation of a versatile image processing software for retrieving arbitrary object features (e.g. edges, holes, corners) including robust pattern finding algorithms
- development of software using a CAD model of the object to simulate how the object, lighting, and CCD cameras interact with each other to determine the optimal camera-lighting configuration and potential object features
- creation of an intelligent system for bin-picking applications (avoiding walls and choosing one particular object)
- development of tracking algorithms and visual servoing applications