Hand-eye calibration for 3D reconstruction

Frederik Hagelskjær, Rudi Hansen, Kent Stark Olsen and Leon Bonde Larsen
Group number: 4. Supervisor: Unknown.

Introduction

Models are necessary in most applications of robotics. Often the models are build in advance and used by the robot as a priori knowledge, but this approach limits the application of robots in dynamic environments. Furthermore modelling complex environments can be a tedious and time consuming task, making automatic modelling desirable.

One way of recording such 3D models is by mounting a stereo camera on the end effector of a robot arm and let the robot move the camera to the views needed to generate the model. The precision of such systems is dependent on robust calibration with respect to both camera and kinematics.

The camera can be calibrated using a marker plate in different poses thus calculating intrinsic parameters and camera disparity (Zhang1999, Zhang2000). The process of generating a 3D model involves calculating a disparity image from the stereo camera input. From the disparity a point cloud can be generated and point clouds from different views can be stitched together. The combined point cloud can then be filtered and used for surface- or volume reconstruction. The stitching process is dependent on the robot pose, since each point cloud must be transformed to the same frame.

The robot pose can be calibrated in a process called hand-eye calibration solving for the unknown spatial relationships in the kinematic chain. This calibration thus influences the quality of the combined point cloud.

It is hypothesised that a hand-eye calibrated system can generate significantly more precise models than the same system without calibration.

Evaluation of the 3D model is based on a known object, where the combined point cloud can be compared to the 3D model of the object. This introduces a pose estimation problem, since the model must be aligned to the point cloud.

Calibration of robot systems has received considerable attention and continues to be an active field of research. A solution for the unknown transforms from camera to end effector and from maker to robot base can be obtained relatively easy by solving a homogeneous transform (Shiu1989). Several algorithms for more or less autonomous calibration has been proposed (Tsai1988, Tsai1989) often simultaneously calibrating camera and hand-eye (Malm2003, Zhao2008, Jordt2009).

This work is a manipulative study investigating the effect of hand-eye calibration measured on the quality of the produced point cloud. The novelty of the study is the practical implementations of hand-eye calibration and model evaluation as well as calibration routines for the robot kinematics.

Materials and methods

To test the hypothesis a closed loop system based on the Good Old Fashion Artificial Intelligence (GOFAI) environment interaction model (Pfeifer2007) was developed (Figure 1). In the following each block will be described with respect to functionality and interfaces.

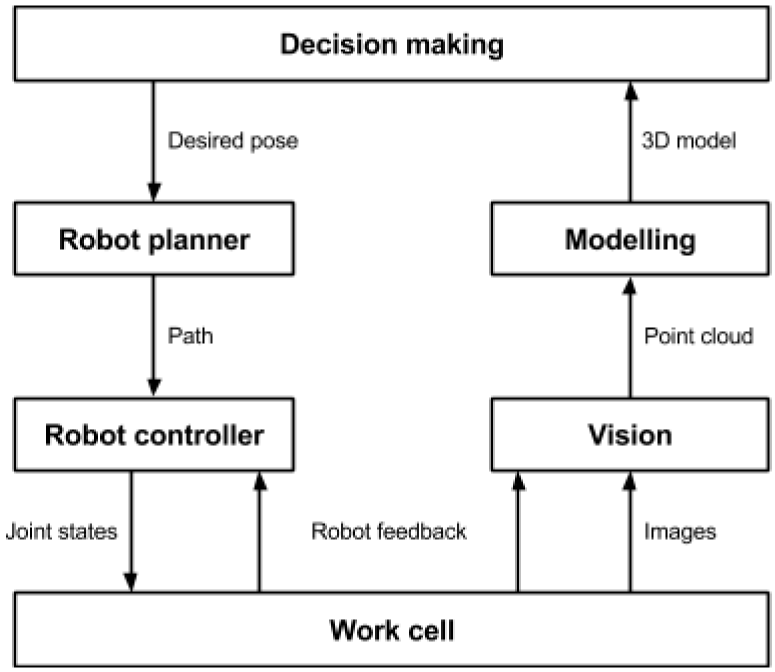

Figure 1 - Block diagram of the eye-in-hand 3D reconstruction system

Decision maker

The desired pose is ‘hard-coded’ into the decision maker to capture the object from for example 24 discrete locations on a sphere. The captions are uniformly distributed to cover the entire object. When the robot is at rest in the desired pose a signal is sent to the vision block to capture the current view.

Robot planner

The robot planner executes the desired pose based on the PRM algorithm subject to the constraint that the camera always points to the center of the object being modelled. The robot planner is based on the Open Motion Planning Library (OMPL) which is integrated into the moveIt stack in ROS and collision checking is based on the a priori model of the work cell.

Robot controller

The robot controller further processes the path adding kinematics and time tessellation to meet velocity and acceleration constraints. The controller interpolates the joint states and handles closed loop control with feedback from the workcell. The robot controller is based on the ros_control stack in ROS.

Work cell
The workcell contains a six degrees of freedom RX60 robot arm with a stereo camera mounted on the end effector. The work cell interface is based on a ROS node communicating with the robot and a node broadcasting data from the camera.

Vision
The vision module takes input from the stereo camera mounted on the end effector of the robot. The images are undistorted and rectified using calibration parameters obtained independently using the ROS calibration node. A disparity image is generated using the semiglobal block matching (Hirschmuller2008), and by using the obtained projective parameters the point cloud is obtained. The vision part will be implemented with a combination of built-in ROS nodes and homemade ROS nodes using the OpenCV library for image processing.

Modelling
The point clouds from the vision block are transformed to a common frame based on the robot pose and are then cropped, filtered and combined into one point cloud representing the sum of information about the object. Methods from Point Cloud Library (PCL) will be used for point cloud cropping, filtering and the assembly process. A wavelet based algorithm will be implemented for surface reconstruction according to Manson *et al.* (2008).

Evaluation
Even though the system is capable of reconstructing models of unknown objects, a known object is used for evaluation.

There are two possible ways of comparing the models. 1) comparing the reconstructed model with the known model or 2) comparing the assembled point cloud to a point cloud sampled from the known model (Figure 2). Both approaches introduce the problem of aligning, but the proposed solutions are different. In the first case the two models are aligned by hand and visually evaluated and in the second case a pose estimation algorithm is used to align them (Fischler1981, Torr2000).

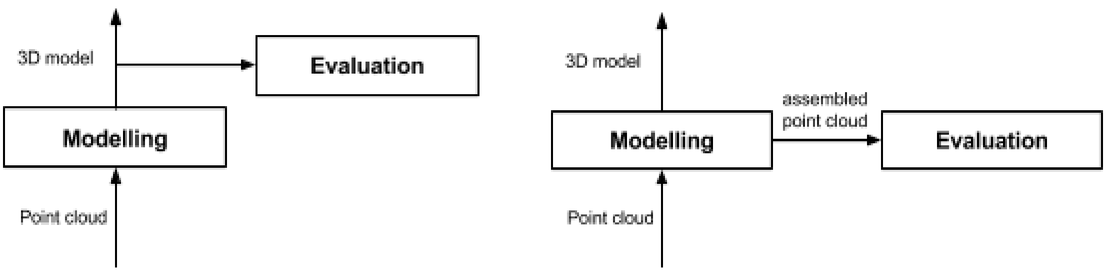

Figure 2 - The evaluation methods. Comparing the reconstructed model with the known model (left) or comparing the assembled point cloud to a point cloud sampled from the known model (right)

The system is evaluated using three different known objects (Figure 2) chosen for different levels of detail. The trials are performed by mounting the object, executing the caption sequence, calibrating the system, re-executing the caption sequence and offline evaluating and comparing the quality of the generated point clouds. The robot is then reset and the process is repeated for each of the objects. The result are evaluated using relevant statistical comparisons.

Figure 2 - The three objects used for evaluation. (We know that the third is missing...)

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