CUDA accelerated bin-picking with a 3D-camera

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We present a fast random bin-picking system: using an Asus Xtion 3D-camera for point cloud acquisition and RANSAM for object localization in the point cloud, processing times < 1s are achieved. We present an automated approach for hand-eye calibration and investigate the properties of our RANSAM implementation and its potential for parallelization on GPUs using CUDA.

Introduction

A major task for industrial robots is the insertion of parts into the production process: the robot has to mount the part within the cycle time and on the other hand the parts have to be delivered to the robot with the same frequency. An elegant but demanding solution is *random bin-picking*, i.e., to enable the robot to pick randomly oriented parts directly from their transport bins. After more than three decades of research on bin-picking, e.g. [Bois81], it was only recently that first commercial random bin-picking systems became available for selected applications, e.g., SHAPESCAN3D from ISRA VISION. Nevertheless random-bin-picking is far from being solved completely and in many industrial applications there is a great demand for faster systems with respect to both sensors and localization algorithms.
The aim of our research is to devolop a fast bin-picking system, which is „robot limited", i.e., the speed of the system is determined by robots maximum speed and not image processing. As a first step, in this poster we present a fully operational bin-picking system using an Asus Xtion 3D camera for point cloud acquisition and the RANSAM-algorithm of Buchholz et. al. [Buch10] and investigate its properties with respect to processing time, accuracy and its potential for parallelization on a graphics hardware (GPU).

Experimental setup

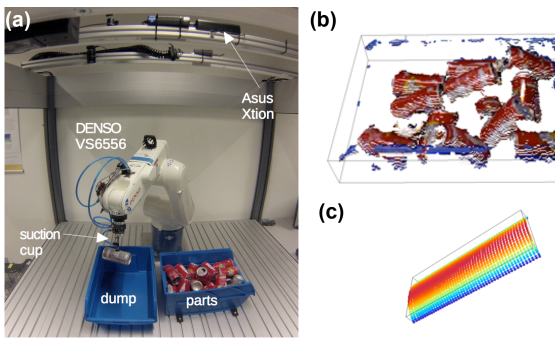

Fig. 1 (a) Robot cell **(b)** Typical point cloud of bin as imaged by Xtion **(c)** Synthetic point cloud of a quarter cylinder used as search template for RANSAM

- DENSO VS6556 (600 mm arm length)
- End effector: 16 mm suction cup, spring loaded
- Bins: 435 mm x 305 mm x 180 mm
- Parts: empty soft drink cans (d = 55 mm, l = 125 mm)
- Xeon E5-2609 quad-core CPU, 6 GB RAM, NVIDIA Tesla C2075, Windows 7
- Software: MILAN, Qt, PCL, OpenCV 2.3, CUDA 5.0.
- Camera: Asus Xtion (Kinect clone), approx. 1000 mm above bin, RGB-D 640x480, 30 Hz, depth resolution $\Delta d \approx \pm 3.5$ mm

Random Sample Matching (RANSAM)

RANSAM, introduced by [Wink06], is a very efficient algorithm to match point clouds utilizing a birthday attack to find corresponding point pairs in two point clouds (Fig. 2). For our experiments we implemented RANSAM as outlined for bin-picking in [Buch10]. Details of our implementation are:

- Statistical forecast using 25 points to minimize time for deep quality estimation of contact ratio
- Nearest neighbour search using k-d tree (PCL)
- Fast calculation of contact ratio on GPU

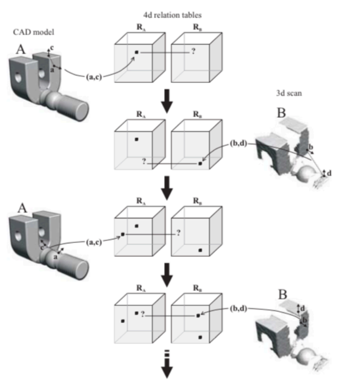

Fig. 2 The main principle of RANSAM - rapid generation of likely pose hypotheses (from [Buch10])

Hand-Eye-Calibration

- Sampling of work volume with grid of n^3 points, defined by corner points and no. of subdivisions n.
- Sphere is located in point cloud using HSI color segmentation, centers obtained with RANSAC (PCL)
- Point correspondences of Tool Center Point (TCP)-positions and sphere centers from point clouds allow mean square fit for hand eye calibration matrix ${}^{W}T_c$

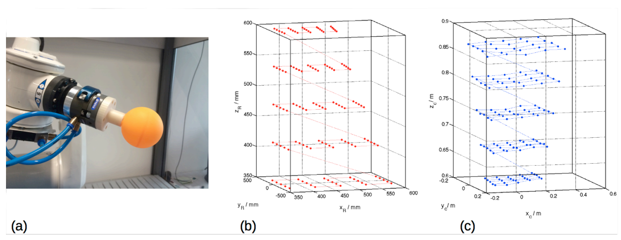

Fig. 3 (a) Calibration tool consisting of a sphere (d = 55 mm) centered at the TCP **(b)** TCP-Positions of a test run with 125 positions (n = 5). **(c)** Corresponding sphere centers extracted from the point cloud.

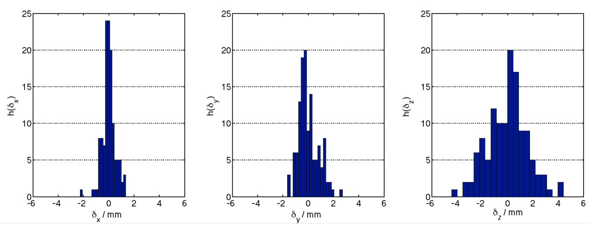

Fig 4. Distribution of x-, y-, and z-components of reprojection errors ($<\mathbf{p}_w - {}^{W}T_c\, \mathbf{p}_c>$) for calibration run from Fig. 3 (b) and (c)

Path Planning and Collision Detection

- Inverse kinematics using geometric approach
- Cylinder model for robot and end effector
- Plane model for boxes
- Multiple gripping vectors on model allow selection of optimum gripping pose for a given object location

Estimation of Alignment Errors

To estimate alignment errors samples were matched to rotated and translated copies. Four situations were tested

- Synthetic quarter cylinders (Syn.)
- Synthetic quarter cylinders with noise (Quasi-Real)
- Real data from the bin-picking scenario (Real)
- Real data from an asymmetrical surface (Asym.)

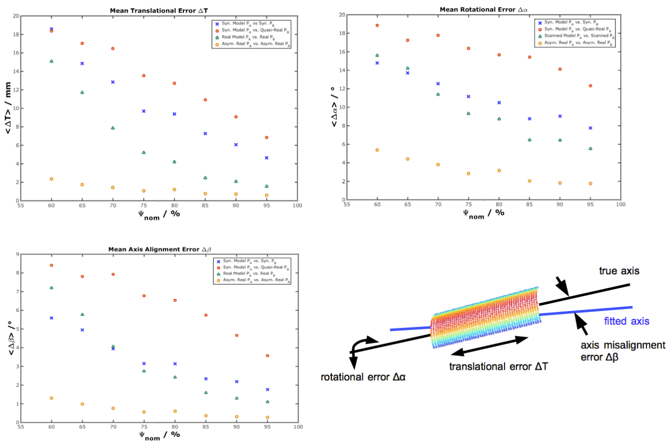

Fig. 5 Alignment estimation

Timing Measurements

- Timing measurements are performed on a fixed set of 100 pointclouds taken from experiment
- Search time for the first pose hypothesis satisfying the required contact ratio Ψ_{nom} is measured

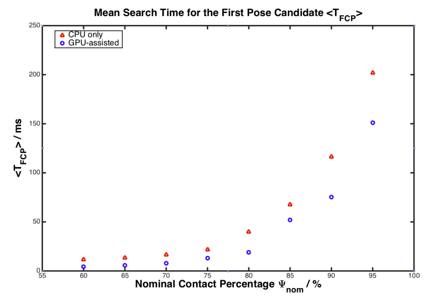

Fig. 6 Timing measurements

Conclusions and Outlook

Bin-picking with RANSAM works stable and gives good results, if a sufficiently high nominal contact ratio Ψ_{nom} is chosen, e.g., 90%. For such contact ratios we achieve search times in the order of 100 ms. For the total time, the acquisition and the initialization of RANSAM (i.e. the creation of the k-d tree) add about 500 ms, resulting in a total analysis time of approx. 600 ms. However, worst case times might be larger, because poses might be rejected if they are not pickable, e.g., due to arm collision. The GPU implementation gains an – albeit small – reduction in computing time. The reason is the very efficient statistical forecast of RANSAM which avoids most costly deep quality estimations and which does not scale well to the GPU, since only 25 points are used in calculation. Currently we speed up the k-d tree creation, which is at the moment the limiting factor in calculation time.
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References

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