# Robust automatic coarse registration of specular free-form surfaces

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Many industrial applications of optical 3D sensors require the alignment (so-called “registration”) of different 3D data sets into one common coordinate system. This is necessary e. g. for variance analysis or to combine several partial measurements of an object into a complete 3D view. Smooth specular surfaces, however, have no prominent features like edges or corners. That makes registration difficult. We present a promising registration method based on Hough transformation. It is robust against small shape deviations, outliers, and noise, and it does not require user interaction.

## 1 Introduction

Recently developed 3D sensors like *Phase-measuring Deflectometry* (PMD) allow the measurement of a wide range of different specular surfaces [1]. In many industrial applications, however, the surfaces are too large or too curved to be measured with one single measurement. Instead, several views have to be “stitched” together to obtain one complete range image. This “stitching” requires the alignment of partial views.

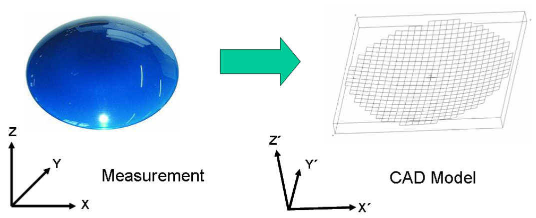


***Fig. 1*** *Variance analysis: We seek a rigid coordinate transformation (rotation and translation) to align the measured surface with its model.*

The problem also arises in industrial inspection, when a measured surface needs to be compared to its CAD model. In both cases, the task is to find a rigid 3D coordinate transformation, consisting of a rotation and a translation, to match the coordinate systems of the involved data sets (see Fig. 1).

As an example, we consider the variance analysis of *progressive addition lenses* (PALs). Currently, the alignment is done using laser engravings as reference markers. These engravings, while being invisible to the human eye, are easily detectable with PMD and hence provide a good registration accuracy.

In the general case, however, there are no markers on the measured object. Furthermore, the detection of markers still needs some user interaction. This leads to the demand for a robust and automatic registration method for specular surfaces.

## 2 Pose estimation

It turns out that for smooth, specular surfaces registration is a difficult task. Common algorithms for automatic coarse registration rely on the detection of high-frequency features like edges or corners. These features, when detected in both images to be registered, can then be used as “intrinsic” reference markers [2]. On smooth surfaces, however, there are apparently no such features.

Instead, for estimating the pose of the measured object in 3D space, one needs to apply higher-order geometric surface properties: In each point of an aspheric, twice differentiable surface it is possible to calculate a *local, orthonormal frame* consisting of the normal vector and the two principle curvature directions. This is called a *Darboux frame* (see Fig. 2).

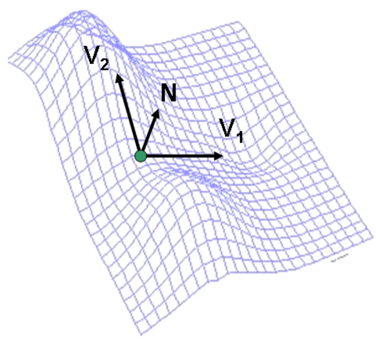


***Fig. 2*** *Darboux frame on a smooth surface with normal vector N and principal curvature directions* $V_1$ *and* $V_2$.

It is now sufficient to find two corresponding Darboux frames in the two range images to calculate a unique coordinate transformation.

## 3 Hough transformation

In principle, the registration problem can be solved using an exhaustive search: Each frame of one 3D data set has to be paired with each one from the other data set. After applying the resulting coordinate transformation to one of the two data sets, the registration error can be evaluated. Then, one only needs to pick the transformation that yields the minimal error.

It turns out, however, that the explicit calculation of the registration error is not necessary. It can be avoided by employing a technique known as *Hough transformation* [3].

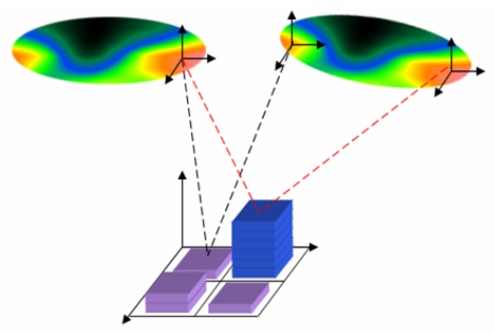

***Fig. 3*** *Registration by Hough transformation: Pick the most frequent transformation in parameter space.*

This method exploits the fact that the potential coordinate transformations have different *frequencies of occurence*. All correct pairings of frames have the correct coordinate transformation in common, while the wrong pairings spread over a wide range of possibilities. Therefore, the correct coordinate transformation can be found by picking the most frequent transformation in parameter space (see Fig. 3).

The method is implement by *geometric hashing*: For each possible pairing of frames, the resulting coordinate transformation is used to index a six-dimensional table (one dimension for each degree of freedom), increasing a counter at this table entry. The entry containing the maximal value then indicates the correct transformation.

The advantage of this approach is that it is possible to register partially overlapping views of an object. Further, it is quite robust against noise due to the discretization of the Hough table. On the other hand, this discretization limits the localization accuracy.

The implementation has also to take into account that for real-world applications the cost of time and memory explode with the data size. Therefore, one has to devise strategies to reduce the amount of data to feasible sizes. One possibility is to consider only pairings where the corresponding points have similar mean curvature. Since the Darboux frames exist only at non-spherical points, it is advantageous to compute them only where the principal curvatures are sufficiently separated [4].

## 4 Results

We tested this method by a numerical simulation: The measured range image of a PAL was moved by a known translation and rotation. After adding realistic noise, the Hough transformation method was applied to register it to its original, unmodified copy. Using a Hough table discretiziation of 0.1° for rotation angles and 1 mm for lateral translation, it was possible to align the two data sets with an accuracy of 0.6 µm (rms), averaging the transformations contributing to the peak entry in the Hough table [4].

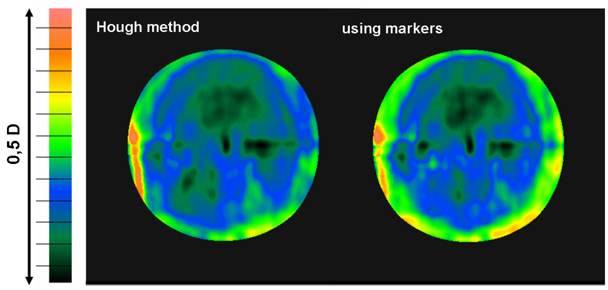


***Fig. 4*** *Difference of mean curvature maps of a PAL (variance analysis), using Hough transformation method (left) compared with using laser engravings as reference markers (right).*

With real data, however, the evaluation of the method is difficult. For a real variance analysis of progressive addition lenses, the two data sets are *a priori* known to be different. Furthermore, the expected registration error has an order of magnitude similar to the calibration error of the sensor.

Therefore, we compared the variance analysis of a PAL using the Hough transformation method to a variance analysis of the same lens using reference markers (see Fig. 4). There are no apparent registration artifacts; the maximum difference is even smaller when using the Hough transformation method.

### References

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