Robust Optical Measurement of Dust Thickness on a Flexible Filter Surface

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ABSTRACT

A stereo computer vision system as a thickness measurement device is introduced. The challenging task is to measure the thickness of dust deposits over the surface of a flexible cloth filter with a target resolution of $0.5mm^2$ per measurement in the filter plane and a depth resolution of up to $50\mu m$. The total area to be measured is $100mm \times 2500mm$. There is practically no texture present on the dusty filter surface. Analyzing dust deposition over the whole filter length during operation has not been possible so far and promises to give insight to air flow in the filter chamber, behaviour of different filter materials and design flaws of filter chambers. Our approach is to first create dense 3D-reconstructions of surface patches. This is done using a calibrated stereo setup and a standard slide projector that provides texture by projecting a random pattern onto the filter surface. The thus obtained surface patches are registered against each other using an ICP algorithm to get a complete 3D model of the filter surface. This step is done twice, for the clean filter surface and for the surface including dust deposits. We finally retrieve the actual depth information by registering the clean and dusty models using markers applied to the filter surface and calculating the difference. In this paper we present the measurement device as well as the underlying vision system and show that it is possible to meet the given requirements under industrial conditions.

Keywords

Computer Vision, Stereo Reconstruction, Rigid Registration, ICP

1 INTRODUCTION - SYSTEM OVERVIEW

The given setup consists of several cylindrical filter bags (height $= 2500mm$, diameter $\sim 120mm$) enclosed in a chamber with a glass window. Air mixed with chalk dust is blown into the chamber and sucked through the filter bags. The dust particles remain on the filter surface and form a layer of $\sim 3mm$ thickness, called filter cake.

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The goal is to measure cake thickness over the visible surface area of the filter bag, through the window at a distance of $\sim 500mm$. Reconstruction of patches of dense 3D models of the filter surface is done using a stereo vision setup. For alignment the popular Iterative Closest Points algorithm ([Besl92]) is applied.

Getting from the surface model to cake thickness one needs to reconstruct the filter surface in two states, clean and dirty. Since the surface is flexible and may change its position during operation, special Teflon markers are attached to the filter bag that remain clean during the filter process. Their exact position can be extracted in both states and are used as a landmark for another rigid registration step using a linear least squares approach.

2 RECONSTRUCTION

The camera setup is calibrated, so the two camera matrices P and P' are known, as well as the

fundamental matrix F and a set of homologous points, $\mathbf{u}_i, \mathbf{u}'_i$, from the calibration target.
So in our application the reconstruction of the 3D-points is composed of four steps: Projective rectification, matching, subpixel refinement and triangulation.

3 REGISTRATION

With the given hardware setup several small surface patches with an overlap of $\sim 5mm$ are reconstructed and registered against each other to form a continuous model. The registration of two of these patches is done using the ICP (iterative closest points) algorithm from [Besl92].
The final registration matrix is a combination of all matrices calculated in the iteration loops.
For fast results of the registration only the overlapping parts of the images are considered.

4 EXPERIMENTS

4.1 Reconstruction Results

For reconstruction accuracy the goals were to reach a resolution of 2 measurements per mm^2 over the filter surface. Until now tests were conducted using the laboratory setup only (i.e. without the looking glass in the optical path).
Since there was no highly accurate calibration target available, relative accuracy and depth resolution were evaluated by reconstructing two parallel planar surfaces with a height difference of $\sim 75\mu m$. The used target consists of a small plate with adhesive tape attached to the surface. The target was reconstructed in two different orientations and the average normal distance of the measured points from the best fit plane and the average height difference were evaluated. The interesting question was how much deviation from an ideal plane one would encounter in the planar regions and if the height of the tape could still be resolved. A height difference of about $75\mu m$ could not be measured exactly but was still clearly resolved. The resolution of $0.5mm^2$ in x/y direction could be easily reached in the average case, although larger areas may occur where no reliable matches can be found.

4.2 Registration Results

In our experiment the difference of two overlapping image parts is composed of a translation less than $1mm$ and a rotation less than 3°.
The reconstructed 3D-models contain ~ 223000 points from which, for registration, 5000 points were regularly sampled. Several tests with Gaussian noise levels ($0mm \leq noise \leq 0.5mm$) were done. The rotation was fixed to an angle of 2° around the y-axis and for translation a vector of length $1.67mm$ with an arbitrary direction was used. At all tested noise levels the ICP algorithm achieved satisfactory results with an average Euclidean error less than $4mm$.
In addition we tested the ICP algorithm at a fixed noise level of $0.02mm$ and a fixed translation vector of length $1.67mm$. A stepwise rotation around the y-axis was calculated for different angles. A robust registration is possible for angles up to 10°.
Finally we examined the behavior of the registration for a noise level of $0.02mm$ and a 2° rotation around the y-axis. The initial point set is translated along each coordinate-axis and the length of the translation vector is continuously increased. As long as the translation vector is less than $1mm$ (as given in our experiments) the average Euclidean error is less than $0.1mm$ afterwards the error increases noticeable.

5 CONCLUSION

This work shows that it is possible to conduct dense and accurate depth measurements using a stereo setup on practically untextured surfaces. The advantage over standard structured light approaches using coded light is that the target can be reconstructed in a single step and there is no need for expensive calibrated lighting equipment. The accuracy requirements can be reached under laboratory conditions. Ongoing work includes porting of the setup to the deployment stage and incorporating more sophisticated algorithms in the registration stage.

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