Chapter 6
Planning for Freeform Surface Measurement

In this chapter, we present a sensing strategy for determining the probing points for achieving efficient measurement and reconstruction of freeform surfaces. B-spline is adopted for modeling the freeform surface. In the framework of Bayesian statistics, we develop a model selection strategy to obtain an optimal model structure for the freeform surface. Based on the selected model structure, a set of probing points are then determined where measurements are to be taken. In order to obtain reliable parameter estimation for the B-spline model, we analyze the uncertainty of the model and use the statistical analysis of the Fisher information matrix to optimize the locations of the probing points needed in the measurements. Using a “data cloud” of a surface acquired by a 3D vision system, we implemented the proposed method for reconstructing freeform surfaces. The experimental results show that the method is effective and promises useful applications in multi-sensor measurements including vision-guided CMM for reverse engineering.

6.1 The Problem

Reconstructing the freeform surface from a set of discrete measurement data points is a problem important to many areas including reverse engineering, metrology, inspection by machine vision, computer-aided design (Song and Kim 1997, Thompson and Owen 1999, Wolovich et al. 2002, Weir et al. 2000). The first task in the reconstruction of a freeform surface is to obtain the measurement data. Among the various sensing techniques available, mechanical contact probes such as CMM (Coordinate Measuring Machine)’s touch probe, and 3D topography measuring systems using structured light or fringe illumination are widely used in practical applications. CMM with touch-triggered probes can provide high measurement accuracy at sub-micron level. However, the measurement speed is much lower than that of a 3D vision system. A vision system can acquire thousands of data points over a large spatial range in a snapshot (Li and Chen 2003). However, the achievable resolution is relatively low, at around 100–200 μm. Therefore, in practical applications, using one of the techniques means that the user has to suffer from its limitations, e.g. the low speed with CMM.

A way to overcome the limitations of individual sensing techniques lies in integrating multiple sensors in the measurement as conceptualized in Fig. 6.1. Research efforts have been made to achieve this. For example, Nashman et al.
Chen and Lin (1997) presented a vision-aided reverse engineering approach (VAREA) to reconstruct free-form surface models from physical models, with a CMM equipped with a touch-triggered probe and a vision system. The VAREA integrated computer vision, surface data digitization and surface modeling into a single process. The initial vision-driven surface triangulation process (IVSTP) generated a triangular patch by using stereo image detection and a constrained Delaunay triangulation method. The adaptive model-based digitization process then refined the surface reconstruction using measurements from the CMM’s touch probe. Since the vision system in VAREA used a 3D stereo algorithm to detect 3D surface boundaries, only 3D surface boundaries were reconstructed and geometrical information about the freeform surface could not be retrieved. Recently, Shen et al. (2000, 2001) presented a multiple-sensor coordinate measuring system for automated part localization and rapid surface digitization. The multiple-sensor system consists of a high-precision CMM equipped with a touch probe and a 3D active vision system. Their research focused on setting up a multiple-sensor system and processing the geometrical information from the vision system. In these systems, the CMM’s touch probe plays the role of accurately digitizing a surface, especially when high-precision is desired. The question of how to determine the set of measurement data, including the needed number of the measurement data points and their locations, for accurate reconstruction of freeform surfaces, remains untouched.

Using a CMM for 3D measurements, only a finite number of discrete measurement data can be taken for a surface. From the statistical viewpoint, each measurement data point contains a certain amount of geometrical information about the surface, and the quantity of information contained in the set of measurement data points depends on the number and locations of the measurement points.

Fig. 6.1. Multiple-sensor coordinate measuring system