Software Error Compensation of Rapid Prototyping

Kun Tong Sanjay Joshi E. Amine Lehtihet
The Harold and Marcus Department of Industrial & Manufacturing Engineering
310 Leonhard Building
The Pennsylvania State University
University Park, PA 16802

Extended Abstract

Inferior dimensional accuracy of Rapid Prototyping (RP) processes is a major obstacle preventing this technology from greater penetration of manufacturing activities. Most studies on RP accuracy improvement to date focus on different aspects of the RP process planning and fall within "Error Avoidance" category. This study presents a method for RP machines accuracy improvement by "Error Compensation" using "virtual" parametric errors, which is inspired by the technique developed over the years for parametric evaluation of Coordinate Measuring Machines (CMM) errors. Error compensation is usually a three-step approach. A mathematical error model is first built for the machine; measurements are then conducted to determine the coefficients in the model; and finally compensation method is developed and applied to the machine control to reduce errors.

In a CMM or machine tool system, the final positioning accuracy of the machine probe or tool tip is dominated by the motion error of its three axes, or the so called 21 parametric errors. Assuming rigid body kinematics, the volumetric error of the machine can be written as a function of its 21 parametric errors. In the RP processes, the error budget is quite large and includes error sources other than axes motion errors, such as material shrinkage during prototyping. However, our approach maps all error sources in the RP machines into 18 "virtual" parametric errors without considering the mechanism of each error source. This will serve a dual purpose: first, it will provide a model with sufficient resolution for compensation; second, it will partition the error budget along meaningful spatial directions and serve as a diagnostic tool for the identification of direction dependent error sources due to other process characteristics. The rigid body kinematics is then used to derive the machine error model of the RP machine.

Since the "virtual" parametric errors cannot be measured directly for RP machines as for CMM or machine tool systems, they will be derived indirectly using the artifact method. An artifact is a specially designed part with known nominal positions (x, y, z) of the key features. It is built using the RP machine to be evaluated and is then measured by a master CMM. The measured positions of the features (X_P, Y_P, Z_P) are written as a function of (x, y, z) in the form of error model to infer the coefficients of parametric error functions.

In RP process, the commands sent to the machine are the part file itself. Software error compensation means to modify these files according to the error model. When going from a CAD design to a final prototype, the same part is represented in several file formats: original CAD model, STL (stereolithography) file and slice file. CAD files are shown only suitable for compensation of discrete feature positions, while STL files and slice files can

be used for entire model compensation. Different compensation targets will provide different resolution. FORTRAN programs are developed for both STL file compensation and slice file compensation.

Experimental study is conducted on a SLA (Stereolithography) 250 machine. Its mathematical error model is derived and 3D artifact is built on it to estimate error functions. Compensation is applied to several test parts. In the test case for feature position accuracy improvement, the volumetric error is reduced to around 35% of its original value on average. This means that, after compensation for errors, the actual data point is much closer to the nominal position. In the study using a part with common features and dimensional constraints, it is shown that (a) overall size of the part and feature positions on the part are considerably improved, (b) cylindrical feature sizes are improved by a smaller amount, and (c) dimensions along the z direction do not show obvious improvement due to "z quantization".

In summary, software error compensation provides a low cost, generic method to improve the accuracy of a RP process and "virtual" parametric error functions can be considered a global measure of RP process accuracy.