# Phase- shifting Strobo-Stereoscopic 3D Imaging of Rotating Milling/Drilling tools

**Xiangyu Guo[1] and ChaBum Lee[1]**
[1]J. Mike Walker' 66 Department of Mechanical Engineering
Texas A & M University
College Station, Texas, USA

## INSTRODUCTION

Drilling and milling operations are material removal processes involved in everyday conventional productions, especially in the high-speed metal cutting industry. The proper monitoring of tool information (wear, chattering, deformation, etc.) is essential to guarantee the success of product fabrication. Many methods have been applied to monitor the cutting tool conditions from the information of cutting force, spindle motor current, vibration, as well as acoustic emission originated from the spindle and/or tool [1]. However, those methods are indirect and sensitive to environmental noises.

Here, the in-process imaging technique that can capture the cutting tool information while cutting the metal was investigated. As machinists judge whether a tool is worn-out by the naked eye, utilizing the vision system can directly present the performance of the machine tools. We proposed a phase-shifting strobe-stereoscopic method for three-dimensional (3D) imaging. The schematic illustration is shown in Figure 1. While the stereoscopy algorithm can provide 3D image at specific measurement position, the phase-shifting of the strobe-light allow the whole-view reconstruction of the machine tool.

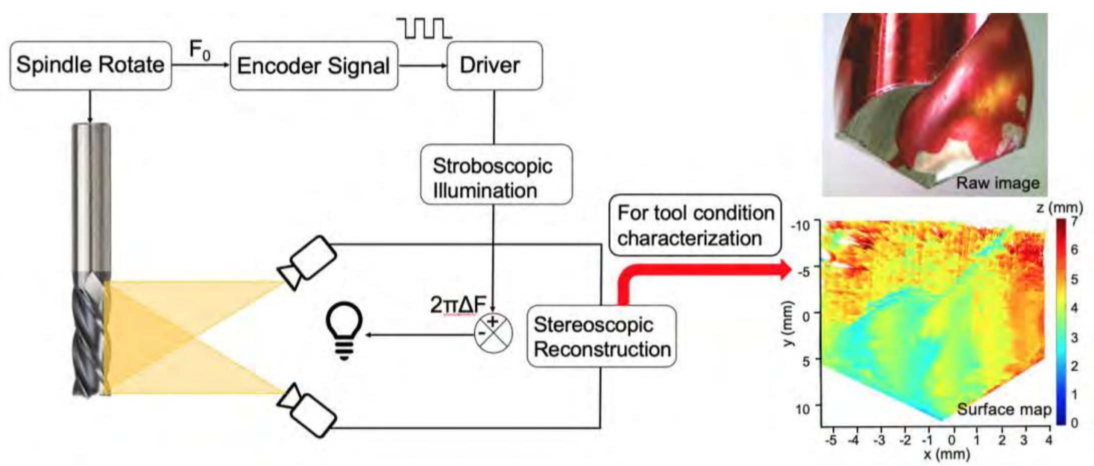


*FIGURE 1. Methodology schematic of strobe-stereoscopy 3D imaging for Drilling/Milling tools metrology and inspection.*

The illumination system and camera system are synchronized with the spindle motion, the measurement operations are automated and digitalized. The strobo-stereoscopy algorithm can provide 3D image at each location along the circumference of the machine tool. The measurement location is depended on the stroboscopic illumination, so that the phase-shifting of the illumination enables the whole 3D surface characterization around the machine tools. Thus, this proposed method provides the in-process metrology for whole-view 3D reconstruction of the drilling/milling tools for tool condition examination and characterization.

## STROBO-STEREOSCOPY SYSTEM

The stroboscopic instrument is typically applied for the measurement of fast-moving objects. The operation principle is as follows: In general, if a changing phenomenon is periodic in time, when synchronizing the frequency of the light source illumination and the motion of object, the resulting successive identical images are integrated by the eye and (if they occur sufficiently rapidly) merge to show the state of the system frozen or to be stationary [2]. If small differences are added to the frequency, the object appears to be slowly moving or rotating. This slow motion can be working as the source for the phase-shifting; with this phase information, the target can be whole-view 3D reconstructed by 360 degrees. The stereoscopic technique is embedded with two CCD cameras equipped capturing images that are located bilateral symmetrically in regard to the target. The 3D scene is reconstructed by the location information of the same object points from both the left and right images.

Stereo imaging is one of the powerful methods used for measurements of 3D structures and volumes [3]. The basic principle of the stereo method is that when a 3D scene is photographed by a pair of cameras, range information can be recovered from the pair of stereo images. The pair of images is known as a stereoscopic image pair. A range image is one where the matrix of gray levels represents the distances of the points of objects in the scene from the camera [4]. From the computation point of view, if a 3D scene is represented by two different views, the recapture of the depth information is possible when the information therein is combined with knowledge of the sensor geometry (eye or camera location); this process is called stereovision. In addition, stereoscopic displays always convey a very compelling sense of 3D depth, and the most important aspect is providing 3D information, such as orientations and distances, of the objects in the scene [5].

## PHASE-SHIFTING PROCESS

The flow chart of the stroboscopic light system for phase shifting process is presented in Figure 2. The stroboscopic control algorithm synchronizes the rotational speed RPM (revolution per minute) with the light blinking frequency and shifts the phase of the light signal from 0 to 360 degree. This phase-shifting scan method by stroboscopic control algorithm is programmed in the LabVIEW environment.

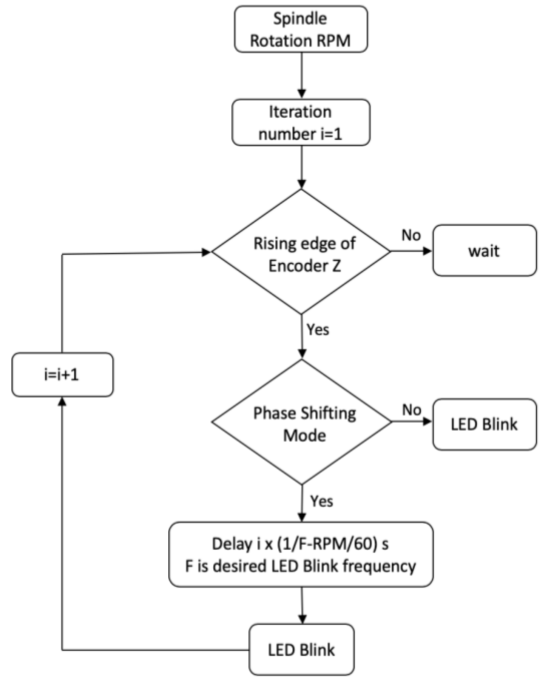


*FIGURE 2. Flow chart of stroboscopic motion and light control algorithms.*

The rising edge of Encoder Z is used as the signal that whole cycle of rotation is finished. This signal is related to the rotary speed, F is the desired LED blink frequency, the delayed time for the LED blink can be calculated. When F is equal to the spindle rotary frequency, both CCDs gather pictures at the single location of the machine tool, this is also called as phase-locking mode. When F is different from the spindle rotary frequency, a sequence of images was gathered under the phase-shifting process for a whole-view 3D reconstruction, this is called as phase-shifting mode.

## EXPERIMENT SETUP

In the proposed system, an air spindle was applied to secure the motion accuracy and drilling/milling speed. As shown in Figure 3, Two CCDs with 10X objective lenses were installed on two linear rails (x and z-direction) with rotary stages to capture the raw picture of a cutting tool bit for further 3D reconstruction. Cross lasers on top of each CCD camera are added to guarantee both cameras focus at the same location of the measurement target.

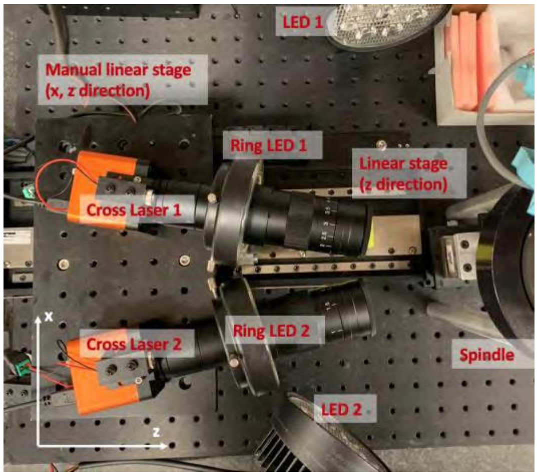


*FIGURE 3. Experiment set-up of the proposed method.*

## WHOLE-VIEW 3D RECONSTRUCTCION

The whole-view 3D image reconstruction process is illustrated in Figure 4. The measurement process in the figure is presented in previous session. Here, we focus on the depth map reconstruction.

The center surface reconstruction is based on the stereoscopic algorithm. Before the depth map is recovered, pre-process for target centering, distortion removal, and brightness adjustment need to be done. Gaussian filter is applied to remove system noises.

For the neighbor surfaces stitching process, we used SIFT (scale-invariant feature transform) to determine the similar characteristics first, as they

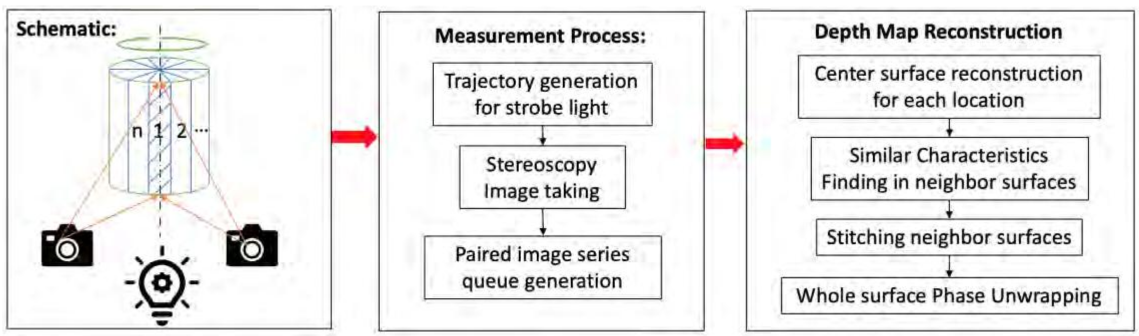


*FIGURE 4. Whole view 3D surface building process.*

provide reference information. Along with the rotating angle, the panorama surface can be generated. After the stitched panorama surface is generated, a surface phase unwrapping process is applied to match the depth information as well as to remove the stitching errors .

Figure 5 shows an example that the target machine tool bit was taken pictures along the rotation every 45 degrees.

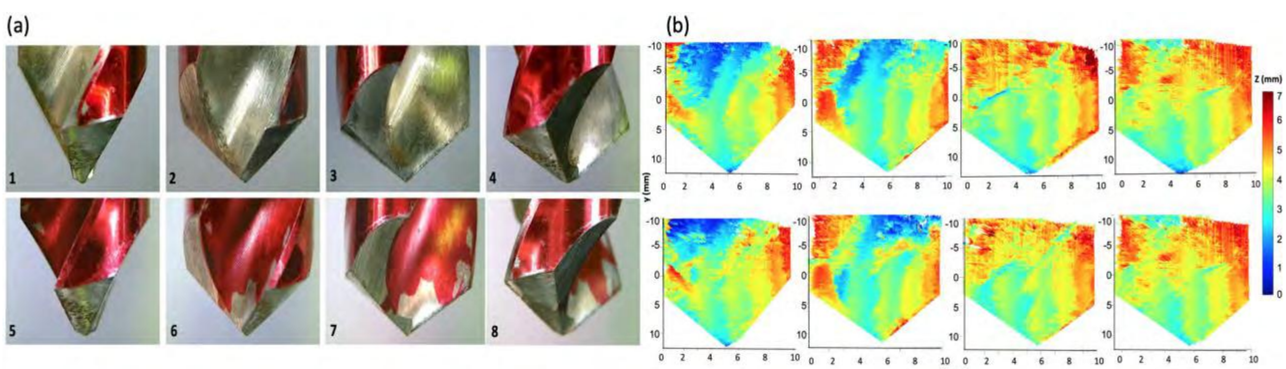


*FIGURE 5. (a) raw image from location 1~8, 45 degree per picture along the cycle, and (b) depth maps for images from location 1~8.*

Towards the results from Figure 5, the stitched panorama surface for the tool body (a) and the tool bit (b) are presented in Figure 6. A circular mask was applied for Figure 6 (a), as the target area here is the tool bit.

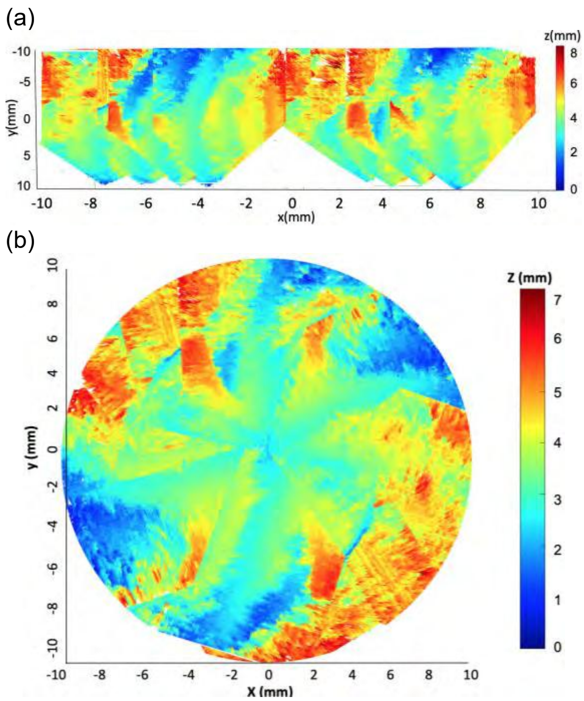

*FIGURE 6. stitched panorama surface for tool body (a) and tool bit (b)*

The results prove the potential of reconstructing the whole-view machine tool bit in the purposed technique.

## FUTURE WORK

For further implementation on this technique, a phase unwrapping technique will be investigated, and a laser scanning process will be added on the system, which can help collect tool edge conditions and dynamic performances. Galvanometer which determine the rotation of the laser source will also be synchronized with spindle motion and illumination system. This combination of strobe-stereoscopy and laser scanning process can improve the 3D image quality, in-process characterization and identification of machine tool dynamic behavior and cutting tool conditions.

## CONCLUSION

This paper presents the novel 3D imaging technique for cutting tool condition monitoring by the phase-shifting strobe-stereoscopy. A hardware set-up is introduced, as well as the 3D imaging algorithm. The reconstructed image analysis under different working speeds is discussed, the reconstruction resolution included. The uncertainty of the imaging process and the built-up system are also analyzed. As the input signal is the working speed, no other information from other sources is required. This proposed method can be implemented into machine tool in on-machine or in-process configuration, enhancing machine tool metrology capabilities. Apart from that, this method can supplement the blank for determining the machine tools' performance status, which further ensures the fabrication process.

## REFERENCES

[1] Wong, S.Y., Chuah, J.H. & Yap, H.J. Technical data-driven tool condition monitoring challenges for CNC milling: a review. International Journal of Advanced Manufacturing Technology. 2020; 107: 4837–4857.

[2] Plows, G.S. and Nixon W.C. Stroboscopic scanning electron microscopy. Journal of Physics E: Scientific Instruments. 1968; 1:595.

[3] Karthik A., Chandra S., Ramamoorthy B., Das S. 3D tool wear measurement and visualisation using stereo imaging. International Journal of Machine Tools and Manufacture. 1997; 37: 1573-1581.

[4] Niranjan K., Ramamoorthy B. Tool wear evaluation by stereo vision and prediction by artificial neural network, Journal of Materials Processing Technology. 2001; 112: 43-52.

[5] Ng, W.B., Zhang, Y. Stereoscopic imaging and reconstruction of the 3D geometry of flame surfaces. Exp Fluids. 2003; 34: 484 - 493.