Conventional microscopes with high magnification are limited by the size of the field of view. For precision assembly tasks in a large work volume, a common solution is to move either the camera or the platform, which typically has limited bandwidth. This paper presents an alternate approach of combining high speed scanners and a high speed camera to create a mosaic view over a large field of view at high refresh rates. We state the design problem of the optical, motion, and image processing subsystems and discuss the initial experimental setup and results.

1 Introduction

For micro-assembly and micro-manipulation, a microscope is an indispensable tool [1]. However, conventional microscopes suffer from the limitation that high magnification reduces the size of the field of view. As a result, many micro-assembly tasks that requires micron to sub-microns precision over millimeter work volume are beyond the capability of fixed optical microscopes. A common solution is to move the platform supporting the sample or move the microscope itself. The bandwidth of the motion is limited by the inertia of the platform or microscope, and the vibration resulting from the motion can blur the image or even modify the scene. This paper introduces a new approach to optical microscopy, which we call scanning optical mosaic scope (SOMS), that addresses the limitation of the field of vision. The key idea is to use high-speed scanners and a high-speed camera to scan the workspace, and combine the individual frames together to create an effective enlarged view. Since scanners can be precisely controlled and have superior dynamic characteristics, it is conceivable that a large field of view may be achieved at high refresh rates. In addition, if timing is less critical, the scanner motion can also be chosen to produce a higher effective resolution than the CCD array.

Forming a larger image through mosaicking is an old idea, from NASA planetary flybys to the photo-stitching software in some consumer digital cameras. The challenge here is to attain high enough refresh rate to allow dynamic tasks in assembly and manipulation to be performed with real-time vision guidance. Confocal microscopes also employ high speed scanning to form images but only a single pixel data is obtained at each scan [2]. Since our approach acquires a complete image in each scan, we are faced with a large amount of data as well as intensive computation to merge the images. To be specific, the following technical issues need to be addressed in order to realize the stated objective:

- The optical system needs to be carefully designed so the images are focused and undistorted over the full range of the scanner motion.

- Image processing needs to be performed to stitch the individually scanned images together on the fly. The amount of image processing depends on the scanner position sensor resolution.
• The scanner motion needs to be coordinated with image capture to enable precise image stitching and avoid blurring (high speed electronic shutter may also be needed).

• Lighting needs to be controlled to allow fast image capture but not too much as to damage the sample.

• The scanning pattern should be adapted to the regions of interests (likely time varying) in order to obtain the highest overall refresh rate.

• For objects with significant depth variations, focusing and zooming will need to be coordinated with scanning and image capture.

For the initial proof-of-concept experiment, we have used mainly low-cost off-the-shelf components to demonstrate the optical scanning and image mosaic capability. We estimate that by using currently available technology, a 25Hz refresh rate will be attainable with the proposed system.

2 Conceptual Design and Design Specifications

The scanning optical mosaic scope operates by scanning over the specimen in a prescribed pattern. At each sample point, the scanning mirrors come to rest and a complete image is acquired with a high speed camera. The multiple images are then stitched together to form a single mosaic image which can be displayed or used to guide the tasks under the scope.

Figure 1 shows an example of the optical setup of SOMS. Many other variations on this design are possible, for example, using a two-axis single mirror scanner [3, 4]. The optical system can be divided into two main blocks:

• Block for scanning: In its simplest form, this block should include the objective lens, the scanning mirrors and the iris. In the example shown in Figure 1, the object is placed at the focal plane of an achromat lens (L1) such that each ray reflecting off the object is collimated at the scanning mirrors. An iris is placed just after the lens to enhance the image contrast.

• Block for image capture: The second block conditions the image according to the required performance such as the desired magnification and the CCD size. In our example, a Galilean-like optical system (5 times ratio) is used, which consists of a converging lens (L2) and a diverging lens (L3). Rays exit parallel to the Galilean expander and form an image on the CCD by means of a fourth lens (L4).

Other optical systems such as a laser beam [4] can be added between the two optical blocks to perform different functions like machining or fluorescent stimulation.

Figure 1 also shows the key design parameters of SOMS. On the optical side, the size, shape and distance from the mirror of the lens L1, will directly affect the size of the field of vision as well as the image quality (such as optical aberrations, image distortions, etc.) as the system is working off the optical axis. On the mechanical side, the settling time of the scanner will define the refreshing rate. Many of these parameters are closely related. For example, a larger mirror will allow, among others, a larger field of vision but at the cost of a longer settling time and therefore a lower refreshing rate. A larger CCD array provides
higher image resolution but requires more data transfer and image processing time. We intend to approach the design problem systematically as a multi objective optimization problem that takes into account the interaction between the optical, mechanical and vision subsystems [5].

With the target refresh rate of 25Hz, the timing budget for a complete image is 40ms. The main contributors to the time consumption are scanner motion (including motion profile generation and physical movement from one scan area to the next), and image acquisition and processing. These two operations can be executed in parallel since they involve different processors. Based on the commercially available technologies for galvanometer and its controller, high speed camera and frame grabber, and computer, the bottleneck of the system appears to be the scanner settling time. This will be the focus of the next phase of our development.

3 Initial Experimental Setup and Results

We have constructed a low-cost proof-of-concept testbed to demonstrate the optical scanning principle and image mosaicking capability. The components used for this system are shown in Figure 1. A moving mirror $\theta_x, \theta_y$ galvanometer system is placed in the optical path to achieve optical scanning. Such galvanometers have been used extensively in laser machining and drilling applications and can achieve millisecond settling time over small motion ranges.

For this initial setup, the scanner operates at a low speed to allow ample time to settle, the optical system has only minimal complexity, and image acquisition is based on freely available software. For the ease of development, we use MATLAB to coordinate the motion control with the image acquisition and image processing. As a result, the bulk of the operation time at the present is spent on image acquisition and processing. An example 4×4 mosaic image is shown in Figure 2. The dimension of each imaged area is 2mm×1.5mm and the overall field of view is 8mm×6mm. For this example, the resolution is $6.25 \times 6.25 \, \mu \text{m}^2/\text{pixel}$ which is currently only limited by the frame grabber (resolution: 320×240).
4 Conclusion

This paper has introduced the concept of an optical scanning mosaic scope which has the potential of achieving a large field of view with high refresh rate and large magnification. The initial experiment has demonstrated the basic scanning and mosaic capability. Our current focus is on increasing the overall image refresh rate.

References


