7: Optical MEMS Scanners

7.1 Introduction to MEMS Scanners

Using mirrors to deflect and position optical beams is a trick that is as old as it is important. Light houses might have been the first “killer app” (or more appropriately “savior app” for someone growing up on the treacherous coast of Norway). With the invention and development of laser, this age-old technology has become ubiquitous! Optical scanners are the enabling components in systems covering an astonishing range of applications, including such important areas as imaging, microscopy, communications, printing, displays, retail, light shows, fiber switches, security, remote sensing, metrology, surveillance, laser machining, and laser surgery.

This variety of uses has of course led to a similarly large variety of implementations. We will limit ourselves to systems using miniaturized scanners based on MEMS technology, but even with this restriction, the field is way too large for a comprehensive description of the different technologies that are in use. Instead we will focus on the fundamental characteristics of optical scanners, and, since we are interested in miniaturized systems, on their scaling.

One consequence of our focus on miniaturization is that we will exclusively consider spatially coherent light, which allows the scanning optics to be significantly smaller than the systems needed to scan spatially incoherent light. Spatial coherence will often, but not always, mean light from single-spatial-mode lasers. The important exception for Optical MEMS is large arrays of microscanner that can be illuminated by a collimated beam from a traditional light sources of small area such that the angular spread of the illumination is small compared to the diffraction angle from each microscanner in the array. Each microscanner is then effectively illuminated by spatially coherent light, even though the light source itself is spatially incoherent\(^a\). This is the typical illumination scheme for TI’s DLP tech-

\(^a\) In this case, spatial coherence is established by spatial filtering the light from the traditional light source. In most cases this is an inefficient process involving sending the light through a pin hole, but the magnification of the beam, which
nology. Our focus on spatially-coherent light simplifies our treatment, because it allows us to use the Gaussian beam theory developed in Chapter 4 to model the performance of scanners.

In the first part of the chapter, we describe the resolution of optical scanners. The resolution can be quantified as the number of pixels, or number of resolvable spots, that the scanner can support. The number of resolvable spots is a fundamental property of a scanner [1]. The optical system can reduce the number of resolvable spot by introducing loss, but no linear, lossless optical system can increase the number of resolvable spots established by the scanner. This insight is very useful when designing scanning systems. By casting the application requirements in terms of a number of resolvable spots, the scanner can be specified, and then the optical system can be designed to fit the scanner. Some iteration might be necessary, but nevertheless, starting with the number-of-resolvable-spots greatly simplifies the design process.

In the second part of the Chapter, we consider effects that can limit or reduce scanner resolution. These include mirror aperture, surface roughness, and static and dynamic mirror curvature. MEMS mirrors are typically coated with a thin metal film to enhance reflectivity. We use the formulae for Fresnel reflections, derived in Chapter 3, to clarify material choices and film thicknesses needed to achieve good mirror performance.

The focus of this book is optical design, but mechanical design is so important for scanners that we devote a section to highlight the most significant issues. The mechanical design is due to the high frequency operation, the low available forces, and the under-damped characteristics typically encountered in most MEMS designs. It is further complicated by the desire to keep fabrication simple and compatible with MEMS parallel processing. We discuss these issues and how they influence the implementations of single-axis and dual-axes scanners.

The last section of the Chapter is devoted to several examples of successful MEMS scanner designs. The examples are chosen to illustrate a range of mechanical designs, including gimbals and universal joints used to implement high-resolution, 2-axes scanners. A wide variety of actuators have been used to implement MEMS scanners, but our focus is on electrostatic actuation due to its prevalence and its material compatibility and relative simplicity of integration with IC manufacturing processes. An important adjunct to this Chapter is therefore Appendix B on Electrostatic actuators.

reduces its angular content, combined with the small size of the microscanner, allows the spatial filtering to be efficient.