# Investigation of Opto-Mechanical Scanning Systems with the use of a Ray-Tracing Tool

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**Abstract**

Optical beam scanners are used in a wide range of applications, from data storage to nanometrology and, when combined with an autofocus procedure, an optical probe system is achieved. Such systems are commonly used in precision engineering. They allow the measurement of 3D surfaces with high resolution and accuracy and in each of its applications, especially in the field of nanometrology, the correct project and design of those scanning units is of great importance for system performance.

This article presents a systematic evaluation of different possible arrangements and combinations of simple optical components to achieve such probing systems.

Concluding the article a selection diagram is proposed in order to assist engineers in the choice of the most appropriate arrangement for each situation based on the advantages and disadvantages of each presented configuration.

## 1 Introduction

Optical scanning can be seen as the convolution of a point spread function over an information bearing surface, and the device responsible for this relative motion is the optical scanner. Such scanners are used in a wide range of applications [1, 4].

Besides the lateral scanning, in order to achieve a 3D measuring system, a depth scanning must also be implemented. There are numerous techniques for that purpose such as triangulation, interferometry, auto-focus and many others [2]. In each of those systems it is of extreme importance to be able to steer the light beam into a specific position, and for that task the coupling between mechanical and optical systems plays an important role.

In Fig. 1 five simple scanning configurations are presented. In each of those assemblies both lateral and depth scanning are achieved through the relative mechanical movement between the optical elements.

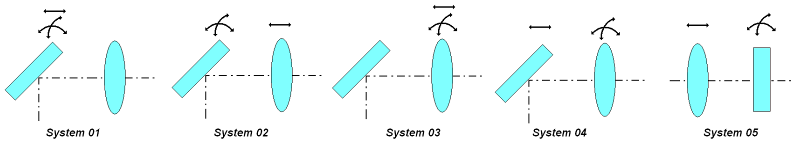


Figure 1: Analysed configurations

In order to compare these architectures, they were analyzed in the 2D paraxial region and simulated in the 3D space with a specially developed ray-tracing software [3].

## 2 System Analysis

The first step for system analysis is the mathematical modelling in the paraxial region, where optical aberrations are neglected and a simple geometrical analysis can be carried out. Figure 2 shows this analysis for System 02.

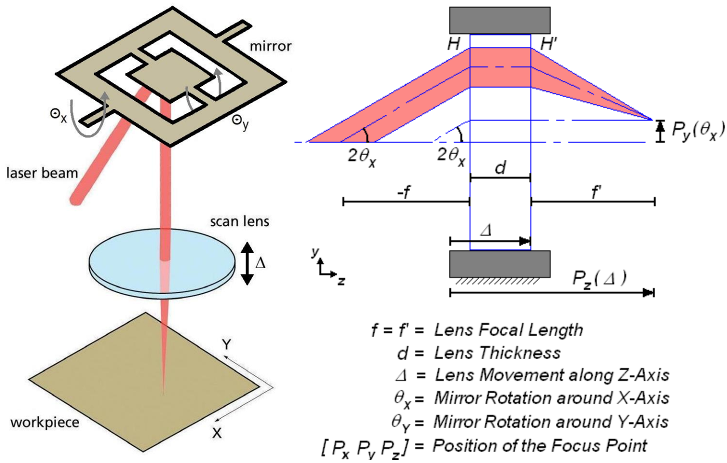


Figure 2: Paraxial Model

Deriving the equations for the above illustrated configuration (Eq. 1), the linear behaviour of the achieved depth scanning can be observed. This linearity is one of the reasons why this optical scanning configuration is one of the most widely used in laser engraving and confocal laser microscopy.

$$\begin{cases} P_y(\theta_x) = f'\tan(2\theta_x) \\ P_z(\Delta) = f' + \Delta \end{cases} \qquad \text{Equation 1}$$

But, when analyzing the system out of the paraxial region (Fig. 3), the influence of the optical aberrations, especially field curvature, appears.

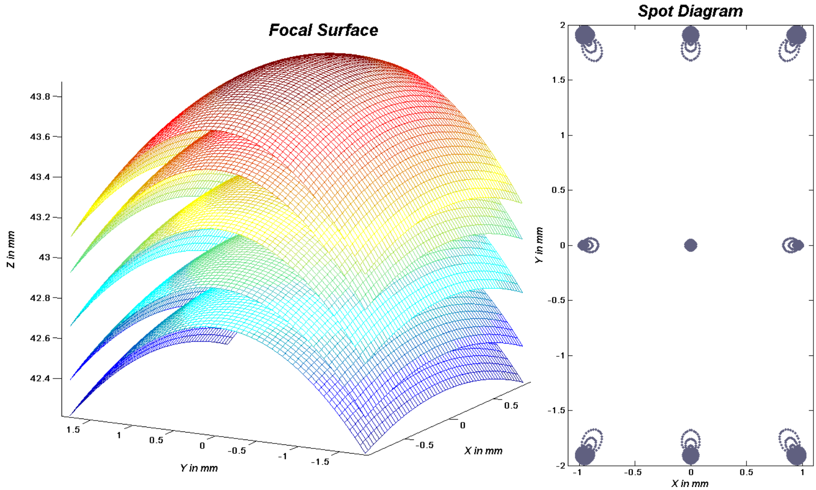


Figure 3: Ray-Tracing Simulation Results

This simple example shows the importance of the ray-tracing simulation, as it makes visible the influence of optical aberrations and offers valuable data that can be used both for compensation or correction of those effects.

## 3 Obtained Results

Each of the studied scanning configurations has its own particular characteristics and present different solutions to the beam positioning requirement. These different approaches reflect directly in how the focusing optic will be utilized. While some systems use most of the lens surface others must move the beam through the lens, so that a smaller beam diameter must be used, affecting optical performance.

Different systems built with the same optical components present different characteristics regarding optical aberrations, theoretical resolution, linearity, scan-axes independency, scanning volume, etc. and different applications lay different requirements on each of those design criteria. For the particular case of an autofocus laser scanning probe for use in nanometrology, system resolution and linearity play an utmost important role [5], while the scanning area stays in background.

In Fig. 4 a relative comparison between the systems illustrated in Fig. 1 is shown.

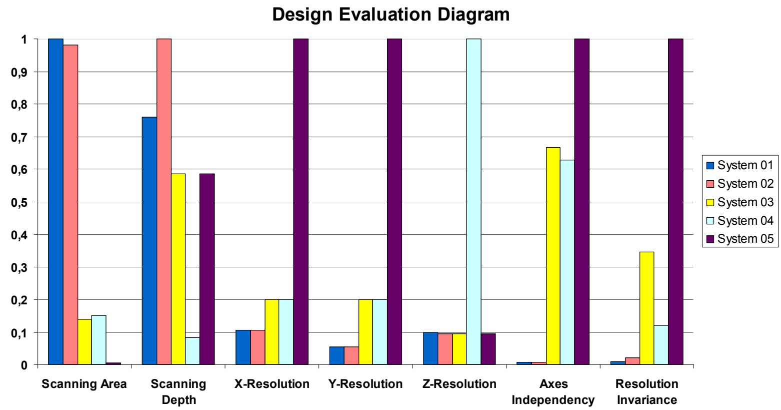


Figure 4: System Comparison Diagram

## 4 Conclusion

In this paper a series of different scanning architectures were analyzed using a ray-tracing tool and the obtained results were discussed with focus on particular features for the elaboration of a design evaluation diagram (Fig. 4).

With support of the proposed diagram, it is possible to determine the best fitted solution for each particular requirement, so that the most suitable configuration for each optical scanning task can be chosen.

Even though the use of more complex lenses can improve system performance, Fig. 4 is still a good starting point for the project of scanning systems. For the case of a nano-scanning probe, the best fitted configuration, according to Fig. 4, is System 05.

**References:**

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