Laser scanners with rotational Risley prisms: A graphical method to determine and study exact scan patterns [Invited]

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Abstract

We report on a novel, graphical method, using a 3D mechanical design program, CATIA V5R20, to obtain and analyze exact scan patterns or a pair of rotational Risley prisms - in comparison to other scanning modalities, produced by the most common galvanometer laser scanners.

1. Introduction

Optical and laser scanners are built in a variety of solutions. The most important are [1]: galvanometer scanners (GSs)-oscillatory, polygon mirrors (PMs)-rotational, Risley prisms-both oscillatory and rotational, as well as acousto- or electro-optical scanners-both without moving parts (which is an advantage), but with lower resolutions (which is a clear drawback). Scanning applications have a wide range, from commercial to industrial and remote sensing, as well as to high-end biomedical systems such as confocal microscopy and optical coherence tomography (OCT) [2].
The different systems above and their combinations produce several types of scanning modalities with different characteristics which make them appropriate for a certain application. The aim of this paper is to present some of our contributions in optimizing scanners and scanning modalities, from the point of view of their parameters. The focus is on passing from the slower GS-based raster scanning to the faster but non-linear Risley prisms scanning.

2. Scanners and scanning modalities

The main scanning modalities are:
(i) *Raster scanning* is produced with the most common dual axis 2D GSs or Micro-Electro-Mechanical Systems (MEMS). The fast GS produces a laser line which is positioned by the slow GS with a step-by-step or with a continuous movement. For the fast GS, a trade-off must be made between the scan frequency and amplitude, as studied in detail in [3] and optimized with a new mathematical model for 1D GSs in [4], considering the three most common input signals (i.e., sinusoidal, triangular, and sawtooth). For 2D scanning, we demonstrated that, when a GS- or MEMS-based system is used, the step-by-step movement (with certain, *optimized* functions) is better than the continuous movement of the slow GS [5]. The latter is convenient when the slow scan axis is provided by a moving (for example, airborne) platform-as in remote sensing, for which only the issues of the fast scan axis must be solved. Raster scanning has the major advantage of equally-spaced pixels on both axis (when properly optimized), but it is still rather slow. The scan speed can be increased by using a PM for the fast scan axis [6], but with the non-linearity issues of PMs, studied with the novel theory developed in [7]. Because of the above issues of raster scanning, other scanning modalities have been developed, including:
(ii) *Spiral scanning* can be produced with 2D GSs or with MEMS, but with the advantage that both scan axis are faster. The most convenient is to use archimede spiral [8], because resolution can still be constant for such as spot trajectory.
(iii) *Lissajous scanning* is much faster than both of the above, but also highly non-linear, which is a drawback. However, it has been explored lately with interesting advances in high-definition scanning [9]. It also has the disadvantage that it is still produced with oscillatory GSs (or MEMS), therefore it has limitations in both speed and Field-of-View (FOV).
(iv) *Risley prisms scanning* is a much better alternative to Lissajous scanning, because in its most common variant it uses rotational Risley prisms (i.e., usually optical wedges), which do not have to stop-and-turn like oscillatory mirrors – Fig. 1. This is an advantage compared to all scanning modalities presented above.

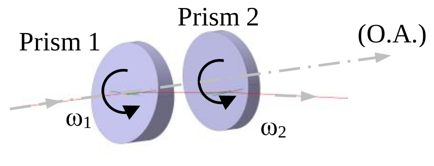
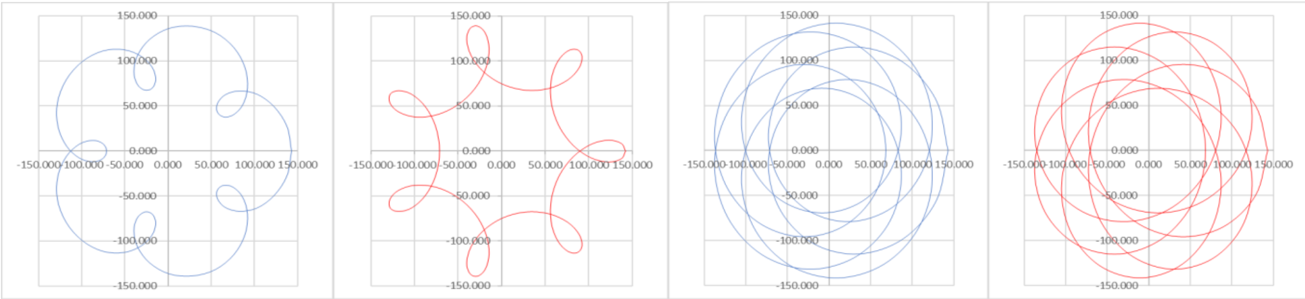


Figure 1: Laser scanner with rotational Risley prisms: modeling with a 3D mechanical design program, CATIA V5R20 to obtain scan patterns (Fig. 2). Configuration *ba-ab* ("a", diopter perpendicular to the optical axis (O.A.); "b", inclined diopter), considered from the four configurations of a pair of prisms.



(a1) (a2) (b1) (b2)

Figure 2: Simulated scan patterns of a pair of rotational Risley prisms, for (a) k=2/6 and (b) k=6/2 and for (1) M=6 and (2) M=-6. The patterns are obtained in a plane perpendicular to the optical axis.

Risley laser scanning systems can be of several types [1]: rotational or translational; with two, three or double prisms. The main applications of these systems are: laser scanning, precision pointing, interferometry, holography, polarimetry, light attenuation and biomedical imaging. The main advantage of the exact scan patterns with the graphical method is that they are accurate, compared to the scan patterns obtained with the analytical method.

3. Graphical simulation of scan patterns of rotational Risley prisms

We have and developed a novel, graphical method to generate and study exact scan patterns of rotational Risley prisms, using only common prisms equations and a mechanical design program, CATIA V5R20 [10]. With regard to approximate method (e.g., using the paraxial domain), our method has the advantage of providing exact scan pattern. With regard to exact, analytical approaches, our method has the advantage of being easy-to-use and fast. A few examples are presented in Fig. 2. A multi-parameter analysis has been carried out with regard to all the possible parameters of a pair of rotational prisms: prisms angles (respectively deviations); distance from the ‘a’ diopter to the screen where patterns are formed; distance between the ‘a’ diopters; Marshall’s parameters, i.e. M, ratio of angular speeds and k, ratio of angles of the prisms [10].

4. Conclusions

We compared the four most common scanning modalities and we reported the graphical method developed to obtain fast exact scan patterns of Risley prisms. The example of a pair of rotational prisms was considered, for different values of the parameter k and for two (equal in module, but one positive and the other one negative) values of the parameter M. Scanning with Riley prisms is nonlinear and complicated, which is a drawback; pixels in a scanned plane are not equally spaced as obtained with raster or (appropriate) spiral scanning. However, the FOV is larger, the speed is much higher, and if fill factors can be limited (for example in remote sensing), such scanners are the appropriate system to use. Current work in our group include applications, as well as studies of other configurations of Risley prisms, as well as comparisons to other scanning systems.

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