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A STAR TRACKER INSENSITIVE TO STRAY LIGHT GENERATED BY RADIATION SOURCES CLOSE TO THE FIELD OF VIEW

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ABSTRACT

Aim of this work is to propose an innovative star tracker, practically insensitive to the radiation coming from the sun or from other strong planetary sources out of (but near) the Field of View. These sources need to be stopped in some way. The classical solution to reject the unwanted radiation is to place a shadow (or baffle) before the star tracker objective. The shadow size depends on the Field of View and on the minimum angle subtended by the source (i.e. the sun) with respect to the optical axis of the star tracker. The lower is this angle the larger is the shadow. Requests for star trackers able to work with the sun as close as possible to the Field of View are increasing, due to the need of maximum mission flexibility.

The innovation of this proposed star tracker is conceived by using spatial filtering with a concept complementary to that of coronagraph for sun corona observation, allowing to drastically reduce the size of the shadow. It can also work close to antennas and other part of the platform, which, when illuminated by the sun, become secondary sources capable to blind the star tracker.

This kind of accommodation offers three main advantages: no cumbersome shadows (baffle), maximum flexibility in terms of mission profile, less platform location constraints.

This new star sensor concept, dated 2007, is now patent pending. Galileo Avionica (now Selex Galileo) is the owner of the patent.

Key words*:* Star Tracker; Star Sensor; Stray light; Baffle

1. INTRODUCTION

The request of attitude sensors for spacecrafts based on star tracker is in continue evolution. The requirement of systems, able to operate with strong radiation sources near the Field of View (FOV), is increasing. In particular, these sources can be the sun, planetary bodies or parts of the spacecraft itself, as for instance antennas or solar panels. Therefore, star sensors, capable to remain operative with such sources very close to its FOV, are objects of particular interest for many space missions, allowing to reduce also problems of installation on board of the platform.

Indeed, this new kind of star tracker increases the mission profiles by reducing the constraints, and at the same time it offers more freedom for the star sensor location on board the spacecraft.

This star tracker concept, almost insensitive to the stray light generated by strong sources, has been patented and the property rights are entitled to Selex Galileo; its patent will be published on 10.10.2008 [1].

The basic idea consists in a spatial filtering of the primary image of objects surrounding the effective FOV in such a way to obscure them, and to re-image the so spatially filtered primary image on the detector, by means of an optical relay. This concept has been applied in the Lightning Imager [2,3].

Aim of this paper is to describe the theoretical aspects of this idea and a possible application of the patent to a typical navigation camera, as reported in last section.

2. THE STRAYLIGHT THEORY

The theoretical concepts on which is based the stray light suppression of this new kind of star tracker will be explained in following steps.

Let consider the first order ray tracing layout representing a classical star sensor objective and its axial and marginal beams, with the detector located on its focal plane, as Fig.1 (a) shows. The sensitive area of the detector is represented as a bold line. The beams inside the effective FOV fall on the detector sensitive area. Let consider the ray r, which enters the lens with a field angle greater than the effective FOV: this ray cannot reach the detector directly. Let assume the surrounding insensitive area of the detector to be flat and reflective. Ray r shall be reflected outwards with respect to the optical axis, and it can come back towards the detector only after one or more interferences with some optical or mechanical surface of the lens system itself. The ray will be scattered or reflected by these surfaces, according to their roughness and polishing [4,5,6].

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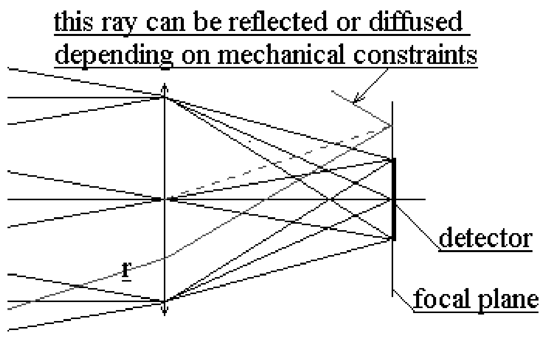

Fig. 1(a). First order ray tracing layout of the spatial filtering concept. The skew ray r is reflected by a flat focal plane.

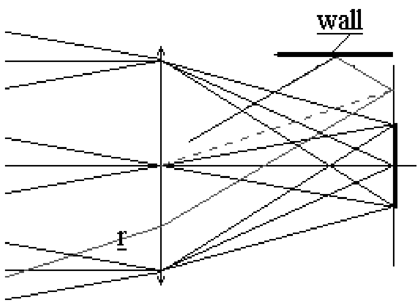

Fig. 1(b). First order ray tracing layout of the ray r reflected by a lateral wall after reflection on the insensitive area of the detector.

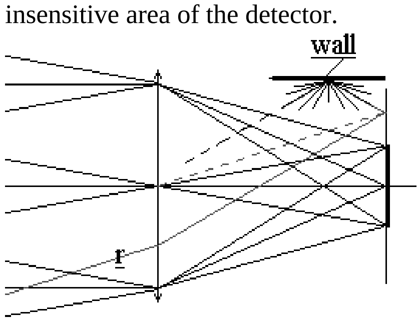

Fig. 1(c). r is scattered by the lateral wall.

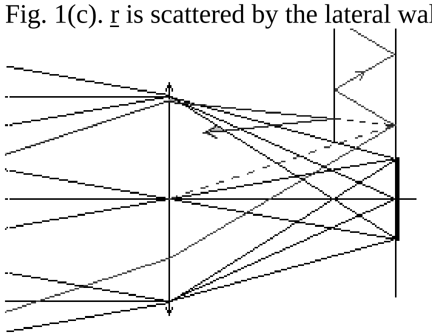

Fig. 1(d). Trapping of r and rejection of a ray entering parallel to r (on the top)

Of course, when a ray r impinges on a well polished reflective surface S the emerging direction can be determined by means of Snell law. It is then possible to redirect the ray in whatever direction by changing the orientation of S with respect to the optical axis, thus avoiding the encountering of r with the sensitive area of the detector, as, for instance, Fig. 1(b) shows.

If the surface S is not polished, the ray r will be scattered, as Fig.1(c) schematically shows. An unwanted portion of the scattered light could impinge on the sensitive area of the detector, with a lower intensity with respect to the ray r, because of the material absorption coefficient of surface S and the distance between the reflecting point and the detector. Indeed the intensity decreases with the inverse square of the distance. So, the stray light hitting the detector could be reduced by using only polished and highly absorbing surfaces on mechanical walls.

But aside from the complexity and the technological difficulties of such an approach, there are two important weak points in the above illustrated model of star sensor. The first is that the real focal plane can not be as simple as represented in Fig.1(a), because of complex structures of detectors, entrance window, proximity electronics, etc. So the detector itself concurs to increase the stray light.

Secondly, the described model does not involve the external baffles, which paradoxically results the main source of residual stray light in star trackers. Indeed, when the stray light source is located in the half space in front of the star sensor entrance pupil, at least one of the internal edges of the baffle stops (also called "rings") is intensely illuminated. The number of the directly illuminated rings increases as the stray light source comes closer to the optical axis. Fig.2 shows a typical structure of a baffle.

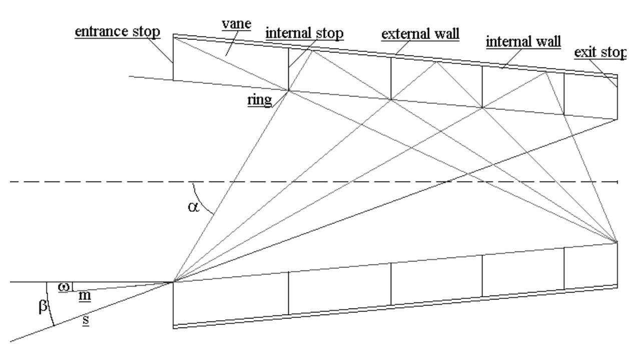

Fig. 2. A typical baffle design

The positioning of rings allows to shadow the internal walls which can be seen through the exit stop aperture. The envelope of the rings is close but external to the marginal ray m, which limits the maximum FOV (half angle is ω). The rejection angle β is the minimum angle which a stray light source forms with the optical axis, indicated with a dashed line, without passing directly through the exit stop.

Let consider the angle α of the line joining two points of the first and second ring, on opposite sides with respect to the optical axis. When the stray light source direction angle σ, with respect to the optical axis, is greater than α, only the entrance stop is illuminated. As the angle σ decreases, the number of illuminated rings increases.

The rings are always visible through the exit stop, and decreasing σ, the total illuminated section increases. Therefore, the light scattered by the edges of the stop enters the exit stop with increasing intensity for the more internal stops. These phenomena are unavoidable. Clearly the radiation coming from the rings is out of the effective FOV and increasingly out of focus. So the rings images fall always outside the FOV.

3. THE STRAYLIGHT SPATIAL FILTERING

The new approach, which allows to remove also the spurious stray light introduced by rings, is to place a field stop precisely matching the effective FOV on image plane. So a diaphragm in the focal plane on the detector stops the primary image of the rings, eliminating a great part of residual light.

In order to obtain an image of the useful part of the object (image delimited by the field stop), a relay lens is needed and the field stop with the relay lens acts as a spatial filter.

The system acts also as an angular filter, allowing the radiation coming from the FOV to reach the detector without disturbance, while the skew rays from outside the FOV can be easily filtered and stopped by suitable set of stops put inside the relay objective.

Therefore, the new concept of star tracker consists mainly of an optical system, a field stop matching the effective FOV and a relay lens which conjugates the field stop on the detector.

This kind of layout offers a further advantage: it allows eliminating the baffle rings images and the need of the baffle itself at the same time.

4. EXAMPLE OF NAVIGATION CAMERA

An application of new star sensor concept is a navigation camera with characteristics similar to Rosetta camera. This optical system consists in a dioptric or catadioptric system allowing to observe a narrow FOV (usually employed for navigation cameras).

Using the spatial filter in image plane, the straylight due to high intensity sources in FOV can be reduced and at the same time the external baffles can be removed.

Figs. 3 and Fig. 4 show an example of a navigation camera.

The configuration is a Maksutov primary objective (Fig. 3) followed by a relay (Fig. 4, on the right, which is shown at first order). The Maksutov camera covers a circular FOV, 2° of diameter, with a clear entrance pupil of 70 mm and an effective focal length of 350 mm. The 1.43 x relay lens increases the overall effective focal length to 500 mm, with a relative aperture f/7; the resulting camera overall length is about 180 mm.

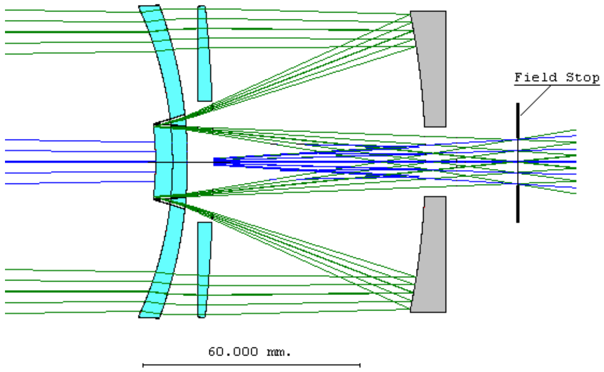

Fig. 3. Maksutov objective and field stop for a navigation camera.

The relay consists of two lenses interfaced in parallel beam, which render the system perfectly telecentric, with a pupil stop in the middle. This stop offers a further advantage in blocking stray light, because it represents an angular filter able to reject the most part of the few residual scattered radiation.

Indeed, assuming this pupil stop as highly absorbing and weakly reflecting, a ray falling outside its aperture is back reflected; if it passes through the first part of the relay it will cross the field stop. Then, if it passes through the aperture of the field stop it will be rejected towards the object space, else it is outside of the FOV and shall be not imaged directly onto the detector.

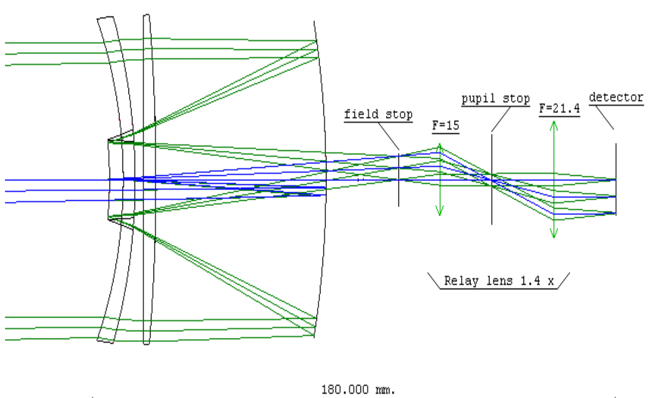

Fig. 4. Overall layout with a first order relay.

5. CONCLUSIONS

This paper summarizes the concept of a new start tracker that allows reducing the stray light without need of cumbersome baffles and allowing to remain operative also when the stray light sources are close to the edge of the FOV. An application to a navigation camera has been described.
The evolution of the process leading to the invention object of the patent was also outlined.

6. AKNOWLEDGEMENT

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