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UNIVERSITÀ DEGLI STUDI DI PADOVA

Freeform optics for space instruments

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Overview

- Freeform optics description:
  - Design;
  - Manufacturing;
  - Performance;
- PRISMA mission
- Description of the integration of freeform to PRISMA II
- Application of freeform to small satellite and to CubeSat
- PhD thesis timeline description

Freeform optics

Freeform optics is a new kind of technology that in the last few years, has started to be highly used for imaging and non-imaging system enabling high performance and compactness even if requiring expertise in bringing together cross-disciplinary design, fabrication, and testing fields.

This emerging technology has already been applied on different areas such as:

- **Lighting** and **illumination**
- **Manufacturing**
- **Remote sensing**
- **Infrared** and **military instruments**

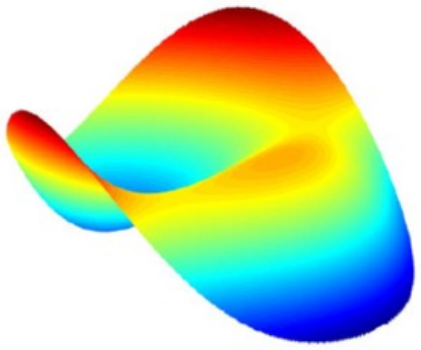
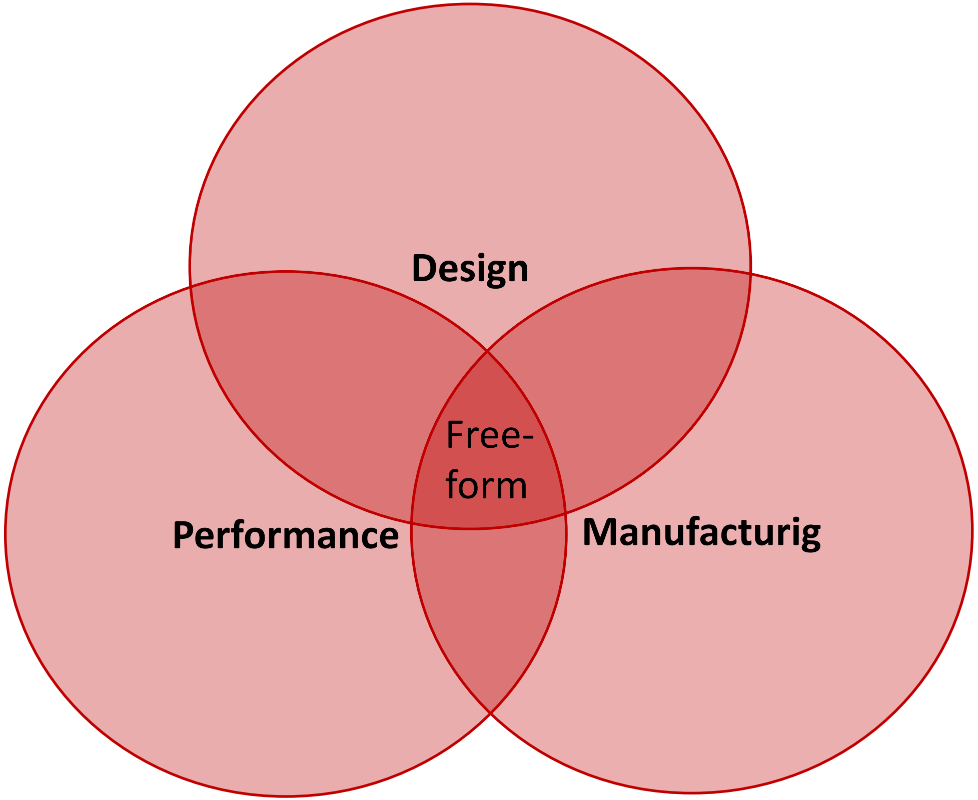


Fig. 3D plot of a Freeform surface.

Freeform optics

- Freeform optics are characterized by **the absence of an axis of rotational symmetry**, thus allowing many more degrees of freedom with respect to standard (also aspherical) optics.

- Studies show that there are significant advantages in using these optics, both in terms of **improved optical performance** and in terms of **instrument compactness**.



Mathematical design of Freeform

There are emerging methodologies for the design of freeform optics; we can underline that the **mathematical description** can be either:

- **Local**, such as radial basis functions;
- **Global**, such as orthogonal polynomials.
- For a freeform surface with large slope variation in local areas or large global gradient, hybrid or combined representation methods should be considered for characterizing the fine local features of the surface.

Optimization constraints may then be used in design to break the degeneracies and yield more optimal designs from a manufacturing viewpoint.

Manufacturing and testing

- For what concerns the fabrication of freeform optics, we can presently use **numerically controlled machines** for grinding, polishing, and diamond turning.
- Some exciting developments are the recent advances in additive manufacturing that enable the **3D printing** of freeform optics substrates.
- **Mid-spatial frequency error** must be considered and evaluated.

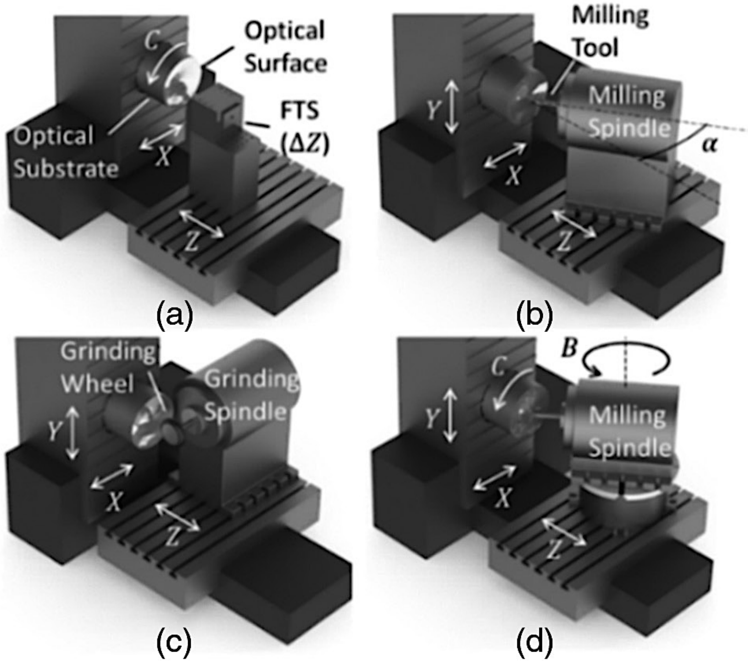


Fig. Ultra-precision machining processes: (a) coordinated-axis diamond turning (X−Z−C), (b) three-axis milling (X−Y−Z), (c) three-axis grinding (X−Y−Z), and (d) five-axis milling(X−Y−Z−B−C) .

PRISMA instrument

PRISMA (PRecursore IperSpettrale della Missione Applicativa) is an instrument designed and realized by Leonardo S.p.A. dedicated to the observation of the Earth surface, of his natural resources and of the relevant natural processes.

The satellite is composed by a hyperspectral sensor that acquires both VNIR (Visible and Near-Infrared) and SWIR (Short-Wave Infra-Red), and a panchromatic camera allowing to capture not only the geometry of the observed object but also the chemical-physical composition of the surface.

PRISMA second generation

PRISMA observes the Earth surface from a LEO orbit at 615 km: its imaging spectrograph has a spatial scale of 30 meter/pixel and the camera 5 meter/pixel.

Leonardo S.p.A. is presently working on the Phase A of an improved version of PRISMA, whose target is to obtain a spatial scale of 10 m/pixel with the spectrometer, over a field of view of 30 km.

Employing **freeform optics** aiming **to** keeping the same swath improving the spatial resolution of a factor 3.

Freeform application to small satellite and Cubesat

Small satellite platforms and Cubesat are playing a major role in planetary observation, and on space satellite in general, due to their lower cost, compressed launch schedule and lower perceived risk as compared to traditional high-cost multi-redundant satellite platforms.

Integrating the freeform new technology to a satellite will allow to get a miniaturization exploiting the main characteristics of freeform optics:

- They allow telescope mirrors to take almost every shape and they have a **strong ability in aberration corrections** thanks to their high number of degrees of freedom.
- They **reduce the number of optical components** and the **mechanical complexity** of the system assembly.

Work timeline description

The work of my PhD thesis will be divided as follows:

- **Ist year:** Is expected the starting of the mathematical approach aiming to find the best polynomial equation for the mirror design; the primary ray tracing tests of the possible layout configurations and data analysis of the PRISMA second new configuration involving freeform mirror.
- **IInd year**: In this second year the data analysis will be concluded. A deeper study on the freeform mirror manufacturing and main constraints will be led. Hoping to have the final optic, a laboratory study on the prototype will be conducted to verify the performance of the model. This second part of the work will be led, in part, at Leonardo's laboratories. Towards the end of the year a new activity focused on the application of freeform optics aiming to miniaturize the satellite will start.
- **IIIrd year**: During the last year the main studies and layout configurations will be conducted. The application of freeform optics will be studied both for the application to medium size satellite and mini satellite.

Thanks for the attention

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