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A UNIFYING "ANYCENTRIC" PINHOLE CAMERA MODEL FOR CALIBRATING ENTO-, TELE- AND HYPERCENTRIC LENSES

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In an image, objects further away are smaller… Or are they?

At least that is how our eyes work, or how practically all (conventional) cameras work, as they are usually equipped with so-called *entocentric* lenses. However, it is possible to build other lenses that seem quite unintuitive to us: *Telecentric* lenses image an object always *at the same size*, regardless of the distance from the camera – this comes in very handy for quantitative measurement purposes. Even weirder, so-called *hypercentric* lenses image an object actually *larger* the further away it is – using this sort of imaging, receding objects seem to *grow* rather than shrink. These lenses literally facilitate new perspectives, allowing otherwise complex imaging and metrology tasks to be tackled with ease. As indicated, telecentric lenses are ideal for size measurement tasks and are therefore widely used in industrial applications, while hypercentric lenses can simultaneously image the top as well as the surrounding sides of an object in one single shot (see Figure 1).

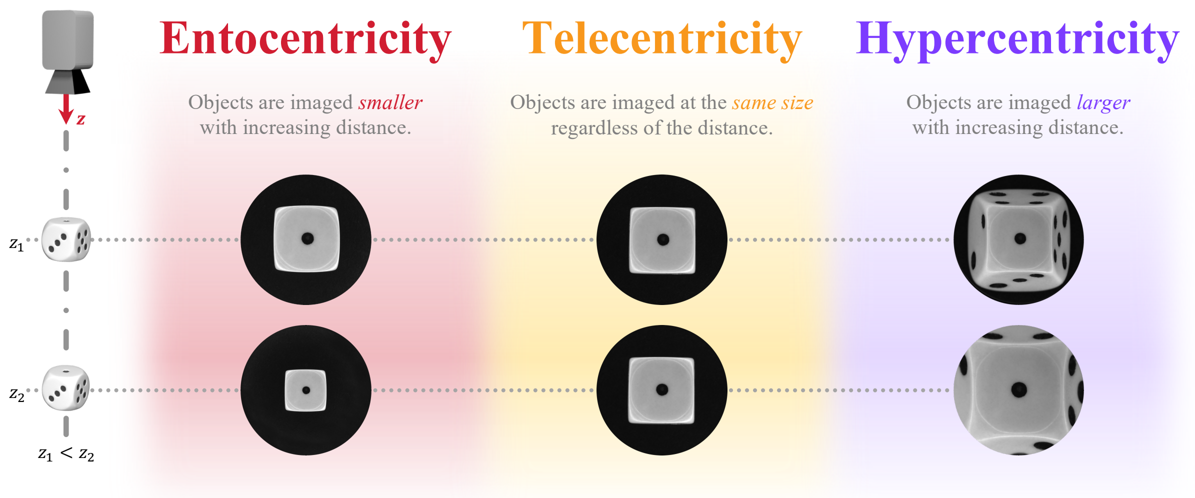

Figure 1: Exemplary images of a dice at different distances from the camera with entocentric, telecentric and hypercentric lenses.

To make this work, these lenses differ fundamentally in their (object-sided) chief ray path. But here lies the crux of the matter, which makes non-entocentric lenses, despite their usefulness, rather cumbersome to work with – especially in metrology applications: For the crucial task of photogrammetric calibration, these lenses *cannot be described* by the famous and widely used *pinhole camera model* – until now!

This contribution shows how the pinhole model can be generalized for ento-, tele- and hypercentric lenses using the elegance and projective geometry of *Plane-based Geometric Algebra* $\mathbb{R}^*_{n,0,1}$. The resulting new "*anycentric*" pinhole model features a smooth transition between perspective projection and orthographic projection, making it well suited for the mathematical optimization process used during camera calibration, and resulting in a more complete and more general camera model without increasing its complexity.

Furthermore, due to the smooth transition between the perspectives, this camera model inherently provides a highly practical way to directly *describe and calibrate telecentricity errors* of telecentric lenses (as those lenses, despite claiming to be telecentric, usually comport themselves a teeny bit ento- or hypercentric in practice).

To show you how this can be achieved, we would love to welcome you to our poster!

If you're unfamiliar with optics, don't worry –
the issue is itself "hypercentric" and quickly appears smaller the closer you approach!