Design Study of a Fringe Projection System

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Introduction

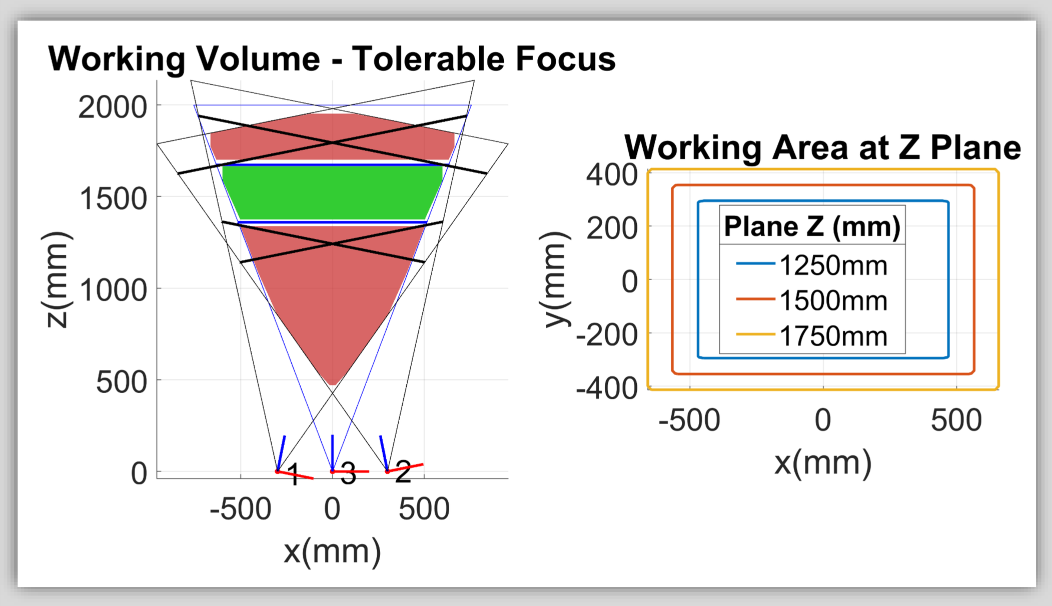
A design study has been carried out for the construction of a modular, re-configurable fringe projection 3D scanner, intended for use in the emerging area of concrete additive manufacturing in the Dept. of Civil and Building Engineering, Loughborough University. The scanner must operate in highly **variable thermal conditions**, **be cost effective**, **reconfigurable for highly variable part sizes** and achieve **sub-mm accuracy**. The design volume for this study is 1x1x1 m. Summarised here is the hardware selection process, tools for geometry configuration and performance verification study.

Hardware Selection

Projector – CASIO XJ-F100W Selected for its relatively small aperture (f2.5) for a projector, high brightness (3500 lm) and illumination technology (Laser &LED). It has a large off the shelf depth of focus and the LED/laser illuminant is robust to vibration.
Cameras – Basler L acA4096-30um. Large format sensor (1.1") with a large pixel size (3.45um) and high resolution (12MP), allowing high point density and FOV with a 16mm lens.
Baseline – Ø50mm carbon fibre tube. Selected for both excellent torsional and bending stiffness, as well as low coefficient of thermal expansion.
Software – HP Scan Pro v5 provides straightforward calibration and scanning.

Working Volume Simulation

Simulations of the working volume are conducted to estimate the coverage for a given hardware (camera, lens focal length, aperture) and geometry (baseline, target depth) combination. The circle of confusion is calculated at each point in the volume to determine the zone of tolerable focus.

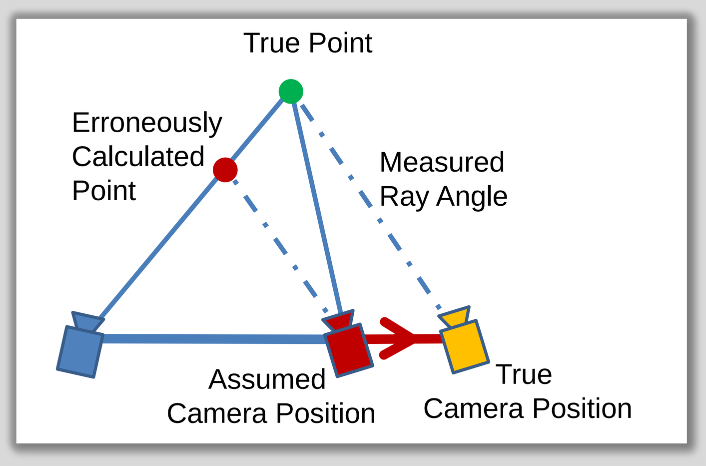


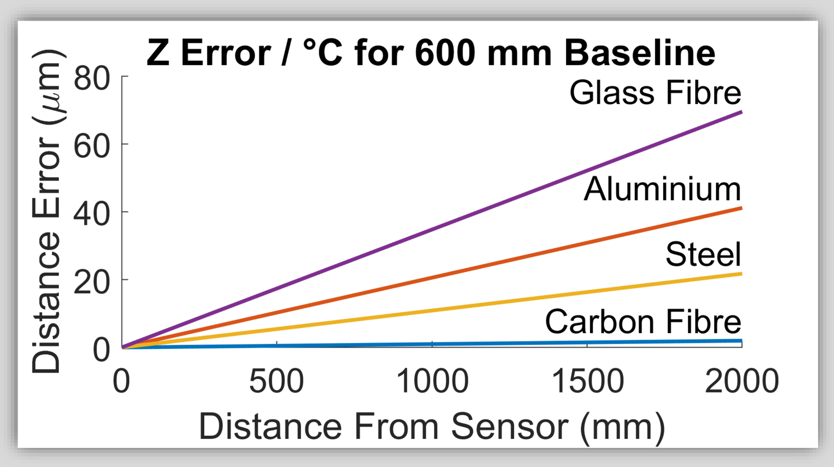
The camera and lens were chosen from a shortlist of appropriate cameras by running the simulation for each combination and selecting based on the compromise of field of view and point spacing. Below is a sub set of results with the selected hardware highlighted.

				Properties at Z = 1500 mm					
				Horizontal Field of View (mm)			Point Spacing (mm)		
			Lens focal length (mm)	12	16	25	12	16	25
Camera	MP	resolution	pix size (um)						
acA2440	5	2448 x 2048	3.45	1015	751	470	0.43	0.32	0.21
acA3800	10	3840 x 2748	1.67	784	575	366	0.21	0.16	0.10
acA4096	9	4096 x 2160	3.45	1109	1126	813	0.43	0.32	0.21
acA4112	12	4096 x 3000	3.45	1109	1126	813	0.43	0.32	0.21

Effect of Thermal Expansion

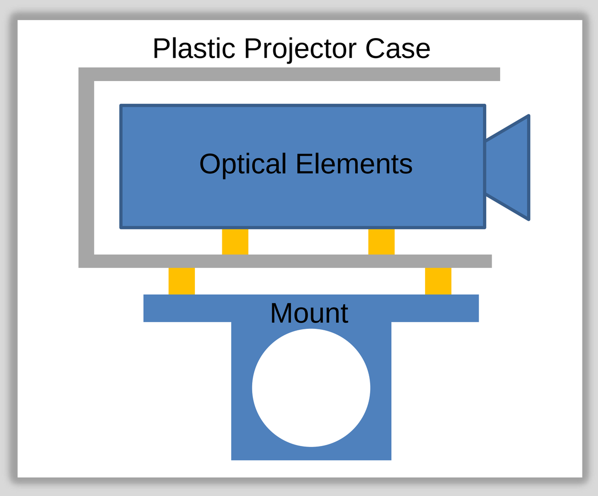
Thermal expansion of the camera baseline causes significant errors in the reconstructed point cloud if the cameras are mounted to a poorly selected material. Carbon fibre is ideally suited due to its stiffness and low coefficient of thermal expansion.



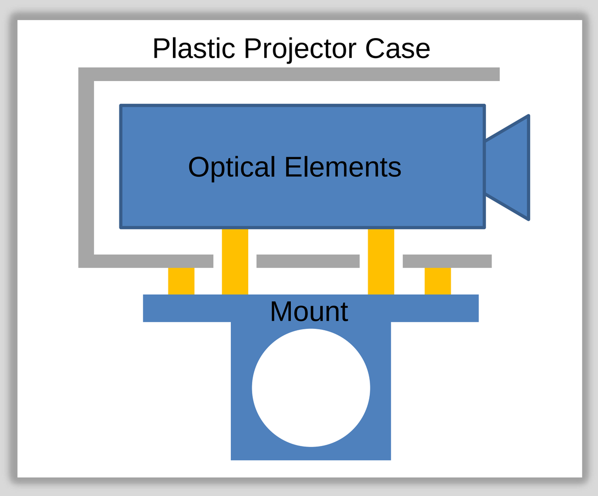


Projector Modifications

Optical rigidity is essential. The projector was modified to affix the optical elements directly to the mounting plate, rather then via the factory projector mounts which coupled to the optics via the plastic casing.

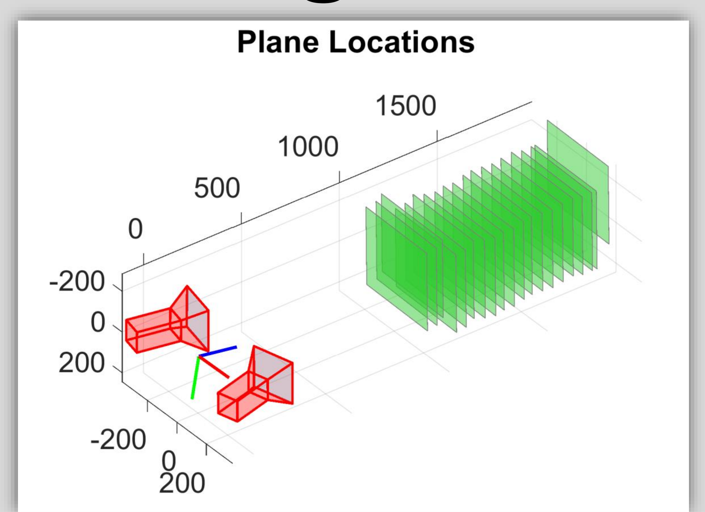


Stock projector mounts

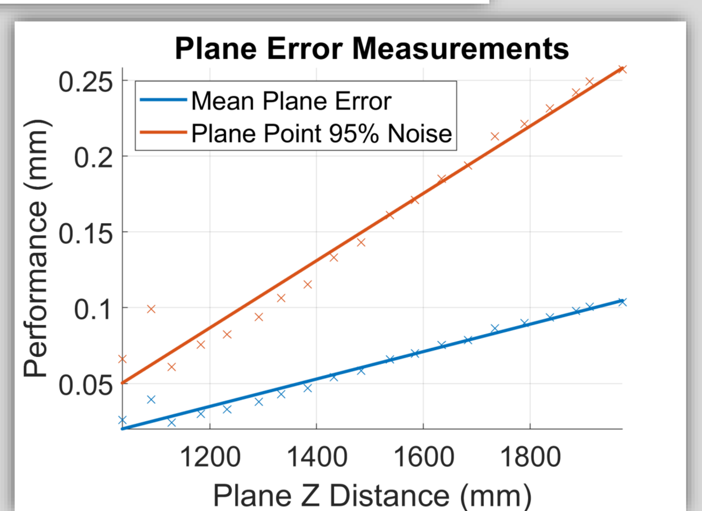


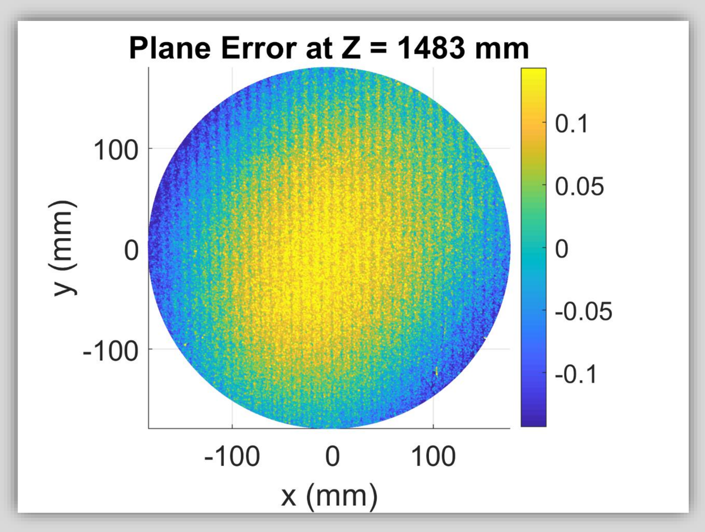
Modified with metal through posts

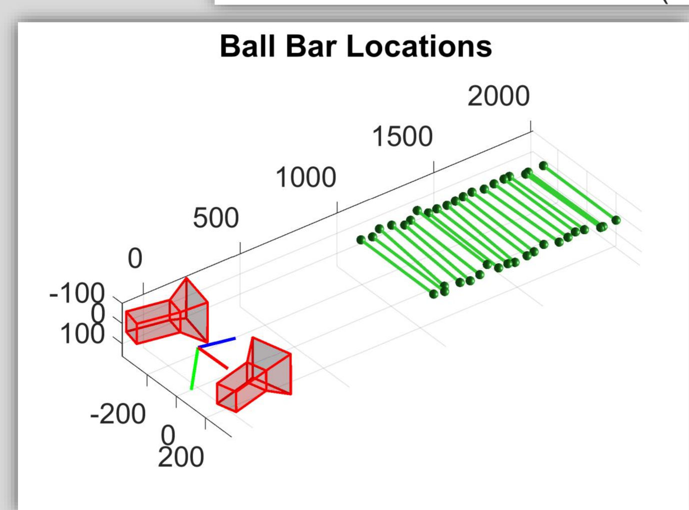
Testing



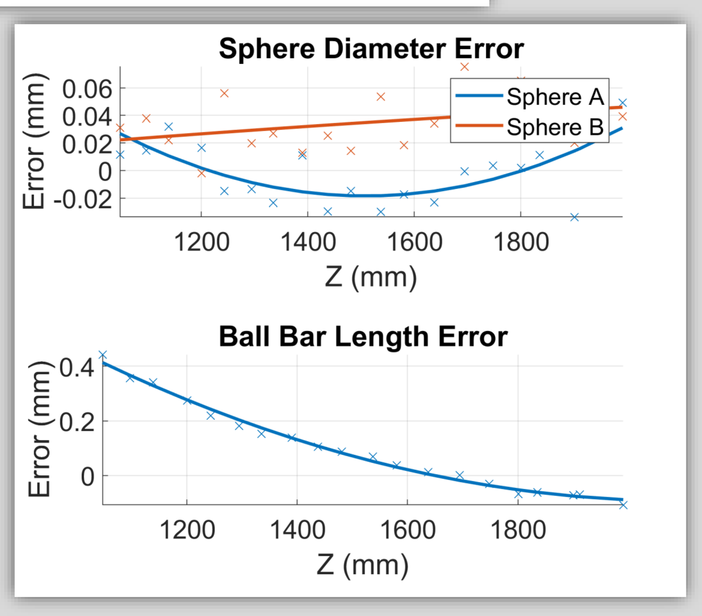
A sandblasted, machined flat aluminium plane is scanned at a set of Z distances to verify scanner measurement noise. Noise is calculated using the distances from measured points to the fitted plane. The point noise remains below 0.25mm over a 1m deep working volume. The plane fit indicates a slight 'cupping' of space relative to the fitted plane.

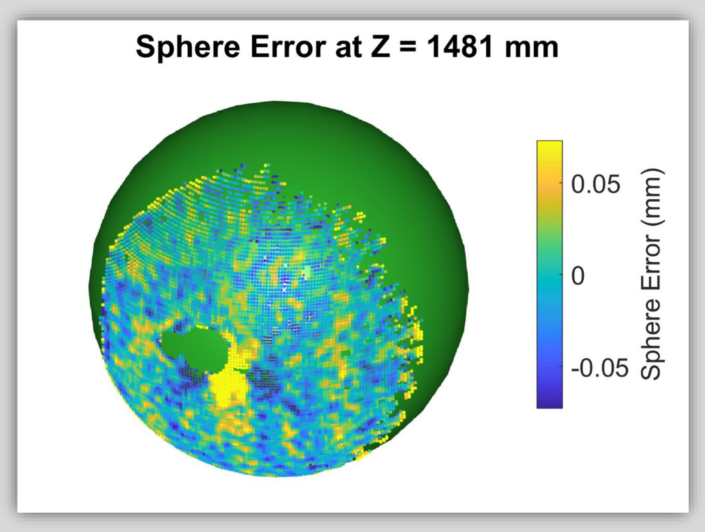






A ball bar artefact, traceable to an uncertainty of 2um with 38mm diameter balls and 500mm separation is measured at the locations shown. Sphere diameters are least squares fitted with an uncertainty of 0.056mm. Bar length has a standard deviation of 0.16mm and mean error of 0.1mm over the measurement depth, with a maximum error of 0.4mm.





Conclusion

A modular fringe projection system using commercially available imaging software is designed and verified to have point uncertainties of less than 0.25mm and scale errors less than 0.4mm over the measurement volume, which easily meets the design criteria for 3D concrete printing.

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