Discovering the Structure of a Planar Mirror System from Multiple Observations of a Single Point

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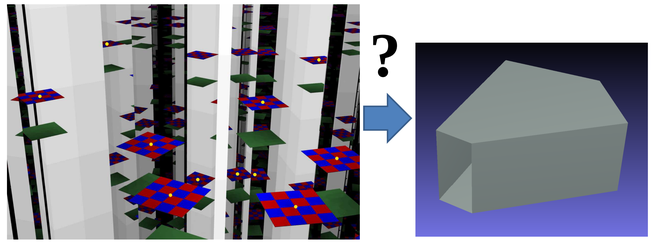
Problem formulation

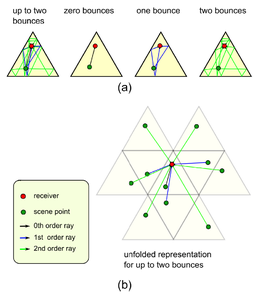
What is the room geometry given 3d coordinates of different reflections of a single point?



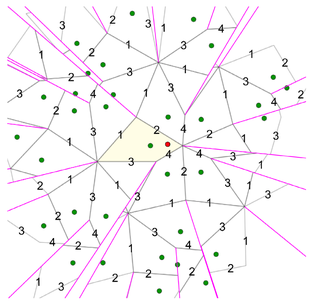
A yellow point on the checkerboard is observed by the camera through different reflections in a mirror room. Original checkerboard is not visible here.

The mirror room geometry.

2D interpretation

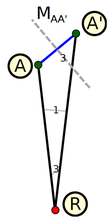


(a) A point is visible to an omni-directional receiver via multiple specular reflections; (b) To the receiver, the situation appears as if there are multiple points at different distances from its own position.

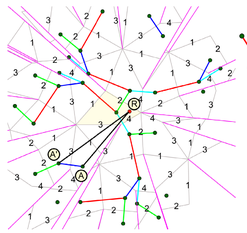


Unfolding example for a general polygon (yellow), a camera position (red) and an observed point position (green dot inside the yellow polygon).

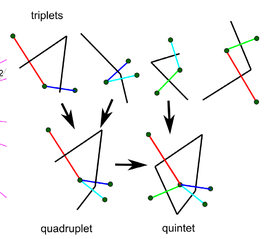
Reconstruction principle



AA' – doublet,
R – receiver,
$M_{AA'}$ – virtual mirror

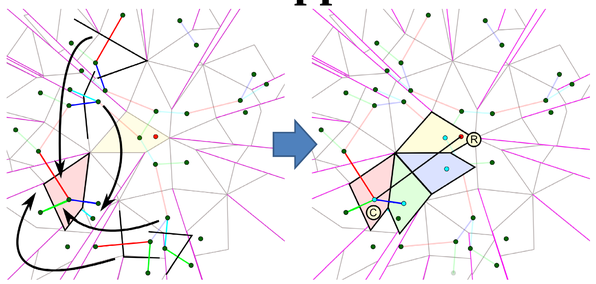


The doublet AA' together with other doublets in an unfolding example



Assembling the geometry by combining doublets into triplets, quadruplets, quintets etc.

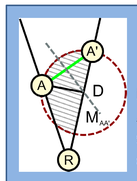
Basic approach



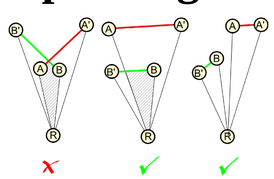
Joining doublets into triplets (represents room corners). Then triplets with common doublets can be joined together in an iterative process. This way, a candidate room geometry can be recovered in some virtual location.

Configuration verification procedure by reflecting the reconstructed geometry along a line of sight (black) until it contains the receiver. Then unfolding of this geometry enables to compare predicted and recorded points.

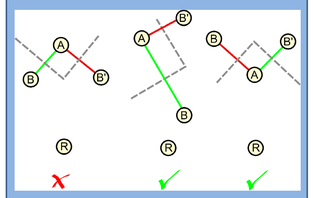
Search space pruning



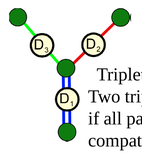
Potential doublets filtering.
AA' - doublet => shaded area must be empty.



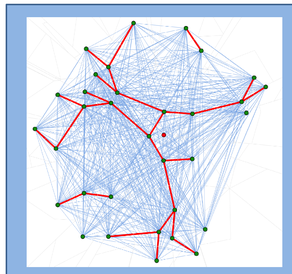
Doublet compatibility test.



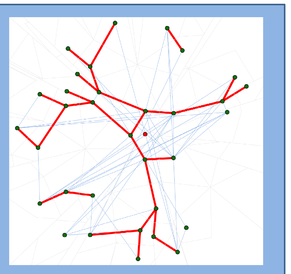
Potential triplets filtering.



Triplet compatibility test. Two triplets can be joined if all pairs of doublets are compatible. D_1, D_2, D_3 are doublets, representing two different triplets.



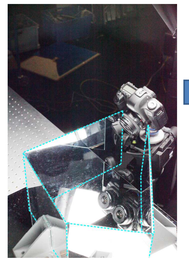
In the case of unknown doublets (red) and triplets all possible pairs of points have to be considered (blue segments).



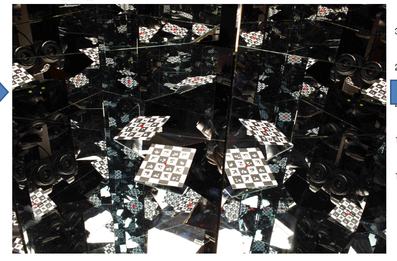
Our geometric constraints are able to remove most of the false connections

Results:

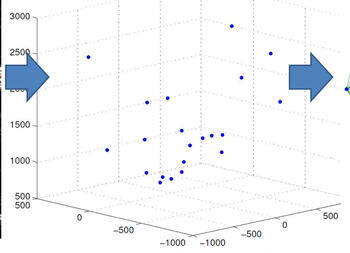
1. The reconstruction pipeline on a real world example



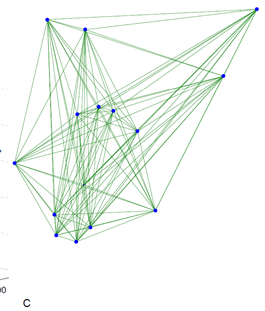
Our setup: mirrors are indicated and the top mirror is removed to show the inside.



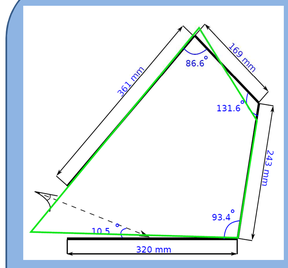
Observed by the camera multiple reflections of the center of the checkerboard (red dot). Note: the real checkerboard is not visible here.



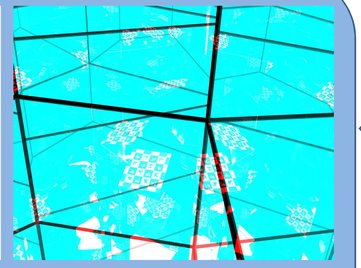
3D positions of the selected image points.



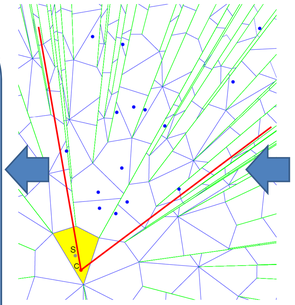
Full graph of all potential doublets.



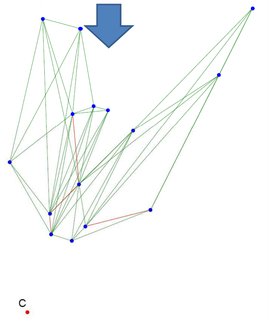
A comparison sketch of the original (black) and reconstructed (green) ground plans.



The reconstructed mirrors are super-imposed on the original image.

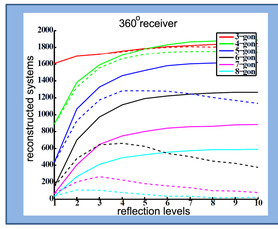


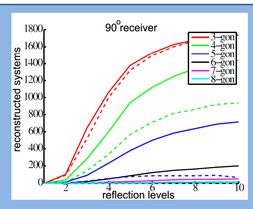
Reconstructed base chamber (yellow), with camera frustrum (red angle), and checkerboard center (S), and selected 2D points (blue dots).



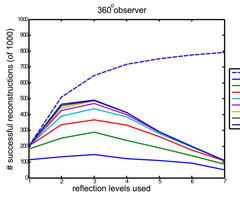
Filtered doublet graph. Red segments - valid doublets found after randomized forward search.

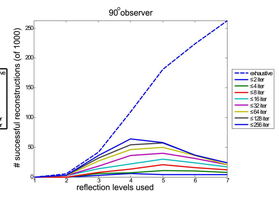
2. Benchmark of the approach on the polygonal rooms (2D)



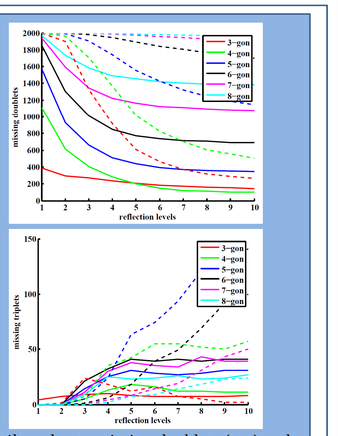


The number of reconstructable systems versus the number of reflections considered for the reconstruction task. The exhaustive search – solid lines, the randomized search – dashed lines.





The number of iterations until recovery of the geometry using the randomized search. The dashed line - the exhaustive search performance (on the clean doublet graph). The randomized algorithm runs on the imperfectly filtered doublet graph.



Failure due to missing doublets (top) and triplets (bottom) for 2000 random n-gons statistics. Solid lines – 360° receiver, dashed – 90° receiver.

Generalized Image Acquisition and Analysis Group

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UNIVERSITÄT DES SAARLANDES

INVENTEURS DU MONDE NUMÉRIQUE

Massachusetts Institute of Technology

max planck institut informatik