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Estimating the Ladder Angle and the Camera Position From a 2D Photograph Based on Applications of Projective Geometry and Matrix Analysis

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Abstract : In forensic investigations, it is often the case that the most potentially useful recorded evidence derives from coincidental imagery, recorded immediately before or during an incident, and that during the incident (e.g. a 'failure' or fire event), the evidence is changed or destroyed. To an image analysis expert involved in photogrammetric analysis for Civil or Criminal Proceedings, traditional computer vision methods involving calibrated cameras is often not appropriate because image metadata cannot be relied upon. This paper presents an approach for resolving this problem, considering in particular and by way of a case study, the angle of a simple ladder shown in a photograph. The UK Health and Safety Executive (HSE) guidance document published in 2014 (INDG455) advises that a leaning ladder should be erected at 75 degrees to the horizontal axis. Personal injury cases can arise in the construction industry because a ladder is too steep or too shallow. Ad-hoc photographs of such ladders in their incident position provide a basis for analysis of their angle. This paper presents a direct approach for ascertaining the position of the camera and the angle of the ladder simultaneously from the photograph(s) by way of a workflow that encompasses a novel application of projective geometry and matrix analysis. Mathematical analysis shows that for a given pixel ratio of directly measured collinear points (i.e. features that lie on the same line segment) from the 2D digital photograph with respect to a given viewing point, we can constrain the 3D camera position to a surface of a sphere in the scene. Depending on what we know about the ladder, we can enforce another independent constraint on the possible camera positions which enables us to constrain the possible positions even further. Experiments were conducted using synthetic and real-world data. The synthetic data modeled a vertical plane with a ladder on a horizontally flat plane resting against a vertical wall. The real-world data was captured using an Apple iPhone 13 Pro and 3D laser scan survey data whereby a ladder was placed in a known location and angle to the vertical axis. For each case, we calculated camera positions and the ladder angles using this method and cross-compared them against their respective 'true' values.

Keywords : image analysis, projective geometry, homography, photogrammetry, ladders, Forensics, Mathematical modeling, planar geometry, matrix analysis, collinear, cameras, photographs
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