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Calibration and Registration Framework for Multisensor Panoramic Color Scanning

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Abstract

The focus of this work is 'Modeling the Reality'. The goal is the reconstruction of scenes with accurate geometry and real radiometric textures. Thereby, a common problem is to acquire colored panoramic 3D data, which is highly accurate with sufficiently high resolution. We present a novel, multi-sensor calibration and registration framework that fuses highly accurate and robust colored panoramic 3D data. To achieve this, we use a panoramic 2.5D laser scanner in combination with a 2D matrix camera and an electronic spirit-level.

The spatial resolution of the scanner is very dense and requires high precision for sensor calibration and for the registration of data streams. We introduce a novel sensor model for the scanner and describe it in a general context for calibrating polar measurement systems.

For covering the same visual field for the digital camera, it is mounted on a vertical tilt-unit. Overlapping color images are acquired by rotating the entire system horizontally and the tilt-unit vertically by predefined angle increments. The calibration of the camera and the registration between both sensors can be enormously simplified by using these increments as fixed input parameters.

To yield complete 3D data, we acquire scans from multiple viewpoints. For stabilizing the registration between these viewpoints, we use an electronic spirit-level to compensate the vertical tilt of the system. This increases the automation of the approach in various field scenarios.

The registration and calibration of the camera as well as the registration of multiple scans is based on corresponding points between the data streams. We present automated feature-based matching methods, which focus on the multi-modal characteristics of our data streams.

The methods are verified in a broad variety of different indoor scenarios demonstrating their performance and applicability.

In summary, we present a highly accurate multi sensor system including robust methods for the calibration and registration of the local data streams and its fusion to a dense global 3D point cloud.

Zusammenfassung

Die vorliegende Arbeit beschäftigt sich mit 'Modeling the Reality', d.h. der wirklichkeitsgetreuen, dreidimensionalen Rekonstruktion der erfassten Umgebung. Das Ziel ist, Geometrieinformation in einer sehr hohen Auflösung und Genauigkeit zu gewinnen und diese mit farbiger Textur zu kombinieren. Dazu wurde ein neues, multimodales Sensorkonzept bestehend aus einem Panorama-Laserscanner, einer Farbkamera und einer elektronischen Libelle entwickelt.

Die Ortsauflösung des verwendeten Scanners ist sehr hoch und erfordert folglich eine hohe Genauigkeit bei der Kalibrierung. In der vorliegenden Arbeit wird ein neues Sensormodel zur Scannerkalibrierung vorgestellt und dies im Kontext einer allgemeinen Theorie zur Kalibrierung von polaren Messsystemen beschrieben.

Um Texturen in demselben Sichtbereich wie des Scanners aufnehmen zu können, ist die Kamera an einen in vertikaler Richtung drehbaren Motor justiert. Die Aufnahme der Bilder erfolgt in vordefinierten Winkelschritten durch horizontale Drehung des Gesamtsystems, sowie vertikaler Drehung des Kameramotors. Wie in der Arbeit gezeigt wird, lässt sich die Kalibrierung und Registrierung der Kamera durch die Einberechnung dieser Winkelschritte als feste Eingabegrössen beträchtlich vereinfachen und stabilisieren.

Um vollständige 3D Punktwolken zu generieren, werden üblicherweise Daten von mehreren Standpunkten aus aufgenommen. Um die Registrierung zwischen diesen Standpunkten zu vereinfachen, ist am System zusätzlich eine elektronische Libelle angebracht, mit Hilfe derer die Horizontalneigung jedes Standpunktes berechnet werden kann. Wie gezeigt wird, kann dadurch die Registrierung vereinfacht und somit stabilisiert und besser automatisiert werden.

Die Kalibrierung des Scanners und der Kamera, sowie die Registrierung mehrerer Scanstandpunkte zueinander, basiert auf korrespondierenden Punktepaaren zwischen den Sensordaten. Um dies zu automatisieren, wurden in einem weiteren Schwerpunkt der Arbeit Methoden zur Merkmalsextraktion und deren

paarweiser Zuordnung entwickelt. Dabei wurde auch der Aspekt der multimodalen Charakteristik der Sensordaten berücksichtigt.

Um die Alltagstauglichkeit des Systems zu demonstrieren, wurde exemplarisch ein breites Spektrum an Projekten mit typischen Anwendungen durchgeführt und die Ergebnisse dieser Feldstudien gegen existierende Methoden validiert.

Zusammenfassend wird ein hochgenaues, aus mehreren Sensoren bestehendes System vorgestellt, sowie robuste Methoden zum Kalibrieren und Registrieren der Sensordaten und deren Fusion zu farbigen dreidimensionalen Punktwolken.

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Contents

Notation

Miscellaneous

$\langle\ ;\ \rangle$	Euclidean scalar product
$\|\ \|$	Euclidean norm
$\times$	vector product
$\|\{..\}\|$	cardinality, number of elements in $\{..\}$
$E_{n,d}$	Hessian of a plane with dist d to the origin and normal vector n
$G := (g_{ij})_{i \leq N, j \leq M}$	Gray values of an image G, with width N and height M
$S^{(c)}$	Color Scan – Eq. (3.23)
$I^{(d)}$	3D Image – Eq. (3.25)

Coordinate Systems

$K^{(s)}$	Scanner coordinate system – Eq. (2.2)
$K^{(c)}$	Camera coordinate system – Eq. (3.2)
$K^{(h)}$	Horizontal scanner coordinate system – Eq. (4.2)
$K^{(l)}_{r,p,y}$	Level coordinate system – Eq. (4.3)
$K^{(g_0)}_i$	Feature coordinate system at featurepoint g_0 and viewpoint V_i – Eq. (5.39)

Rotation Matrices

id	Unit matrix
Z_α	Rotation around the z-axis and the angle α
X_β	Rotation around the x-axis and the angle β
$R_{x,\alpha}$	Axis-Angle representation of a rotation matrix, with the axis x and the angle α – see reference [100]
$R_{r,p,y}$	Roll-Pitch-Yaw representation of a rotation matrix, with the roll r, the pitch p and the yaw y – see reference [32]

Sensor Models

Φ	The ***ideal sensor model*** – Eq. (2.4)
$\hat{\Phi}$	The ***theodolite sensor*** model – Eq. (2.7)
$\hat{\delta}$	Error characteristic (i) of the theodolite model – Eq. (2.9)
$\hat{\varepsilon}_{\alpha}^{(\delta)}$	azimuth angle of $\hat{\delta}$ of the theodolite sensor model – Eq. (2.18)
$\hat{\varepsilon}_{\beta}^{(\delta)}$	elevation angle of $\hat{\delta}$ of the theodolite sensor model – Eq. (2.19)
$\hat{\xi}$	Error characteristics (ii) of the theodolite model – Eq. (2.10)
$\hat{\varepsilon}_{\alpha}^{(\xi)}$	azimuth angle of $\hat{\xi}$ – Eq. (2.23)
$\hat{\varepsilon}_{\beta}^{(\xi)}$	elevation angle of $\hat{\xi}$ – Eq. (2.24)
$\check{\Phi}$	The ***sensor model of the deflection device*** – Eq. (2.30)
$\check{\delta}$	Error characteristics (i) of the deflection device model – Eq. (2.34)
$\check{\varepsilon}_{\alpha}^{(\delta)}$	azimuth angle of $\check{\delta}$ – Eq. (2.40)
$\check{\varepsilon}_{\beta}^{(\delta)}$	elevation angle of $\check{\delta}$ – Eq. (2.41)
$\check{\xi}$	Error characteristics (ii) of the deflection device model – Eq. (2.35)
$\check{\varepsilon}_{\alpha}^{(\xi)}$	azimuth angle of $\hat{\xi}$ – Eq. (2.45)
$\check{\varepsilon}_{\beta}^{(\xi)}$	elevation angle of $\hat{\xi}$ – Eq. (2.46)
$\tilde{\Phi}$	The ***extended sensor model*** – Eq. (2.54)
$\tilde{\delta}$	Error characteristics (i) of the extended sensor model – Eq. (2.57)
$\tilde{\varepsilon}_{\alpha}^{(\delta)}$	azimuth angle of $\tilde{\delta}$ – Eq. (2.65)
$\tilde{\varepsilon}_{\beta}^{(\delta)}$	elevation angle of $\tilde{\delta}$ – Eq. (2.69)
$\tilde{\xi}$	Error characteristics (ii) of the extended sensor model – Eq. (2.58)
$\tilde{\varepsilon}_{\alpha}^{(\xi)}$	azimuth angle of $\tilde{\xi}$ – Eq. (2.73)
$\tilde{\varepsilon}_{\beta}^{(\xi)}$	elevation angle of $\tilde{\xi}$ – Eq. (2.74)
$\Xi_{\alpha,\beta}$	***Sensor Model of the Camera*** – Eq. (3.4)