传感器/多传感器标定融合

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相关综述

1. A Review of Data Fusion Techniques
2. A COMPREHENSIVE REVIEW OF THE MULTI-SENSOR
3. Multisensor data fusion：A review of the state-of-the-art

单相机标定方法

在理想相机成像模型(针孔成像模型)中,涉及到如下四个常用坐标系:

- 像素坐标系
- 图像坐标系
- 相机坐标系
- 世界坐标系

其中像素坐标系与图像坐标系由于坐标原点和单位的不同呈现出线性相关性(平移和缩放),图像坐标系与相机坐标系为比例关系(缩放),世界坐标系与相机坐标系则需要通过刚体变换(三维旋转和平移).

相机畸变:

- 径向畸变
  - 枕型畸变(由内向外凸出)
  - 桶型畸变(由外向内凹陷)
- 切向畸变

径向畸变 在相机制造过程中,很难保证镜头的厚度完全均匀,由于制造工艺的原因,通常为这种情况为中间厚、边缘薄,因而光线在远离透镜中心的地方,会发生更大程度的扭曲,这种现象在鱼眼相机(桶形畸变)中尤为明显.

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \left(1 + k_1 r^2 + k_2 r^4 + k_3 r^6\right) \begin{bmatrix} x \\ y \end{bmatrix}$$

这里 x, y, x', y' 均为归一化平面下的坐标(焦距 f 为1,即图像坐标系和相机坐标系相同)

- r为曲率半径,有$r^2 = x^2 + y^2$
- k_1, k_2, k_3 为径向畸变系数,并且随着阶数的增加,k矫正的区域向外扩散
- x, y, x', y' 分别为矫正前和矫正后的像素点坐标

切向畸变 切向畸变产生的原因在于相机在制造过程中,成像平面与透镜平面不平行,产生了透视变换,这里直接给出矫正公式

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 2p_1 xy + p_2\left(r^2 + 2x^2\right) \\ 2p_2 xy + p_1\left(r^2 + 2y^2\right) \end{bmatrix}$$

p_1, p_2 为切向畸变矫正系数

两者联合矫正的公式为直接相加即可

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \underbrace{\left(1 + k_1 r^2 + k_2 r^4 + k_3 r^6\right) \begin{bmatrix} x \\ y \end{bmatrix}}_{\text{径向畸变}} + \underbrace{\begin{bmatrix} 2p_1 xy + p_2\left(r^2 + 2x^2\right) \\ 2p_2 xy + p_1\left(r^2 + 2y^2\right) \end{bmatrix}}_{\text{切向畸变}}$$

张正友标定法

具体流程

- 把被取的十个点的世界坐标(齐次坐标)进行转置
- 对单应性矩阵求解并优化
- 把六幅图的单应矩阵求解出来后求解出6向量(B矩阵).因为每个单应矩阵可以得到两个方程,通过循环对矩阵y赋值后,再对y进行正交分解即可得到6向量.进而得到相机的内参矩阵
- 先求解出相机的外参,然后对畸变系数进行求解,得到相机坐标(Xc, Yc, Zc)
- 调用函数对内参和畸变系数进行优化,并显示优化后的结果.然后根据优化后的结果求解外参矩阵
- 从旋转矩阵中分解出独立变量(三个坐标的转角),再得到平移矩阵,最后把它们和内参、畸变系数一起优化进行最终优化

单相机在线标定

1. A New Technique of Camera Calibration: A Geometric Approach Based on Principal Lines
2. Traffic Surveillance Camera Calibration by 3D Model Bounding Box Alignment for Accurate Vehicle Speed Measurement
3. Autocamera Calibration for traffic surveillance cameras with wide angle lenses

多相机标定

1. 相关paper 1、Calibration of Asynchronous Camera Networks: CALICO

   2、Infrastructure-based Multi-Camera Calibration using Radial Projections

   3、 Infrastructure-Based Calibration of a Multi-Camera Rig

   4、Leveraging Image-based Localization for Infrastructure-based Calibration of a Multi-camera Rig

2. 开源代码 https://github.com/idiap/multicamera-calibration https://github.com/strawlab/MultiCamSelfCal https://github.com/seed93/Calibration

鱼眼相机标定

1. 相关paper Calibration of fisheye camera using entrance pupil
2. 开源工程 https://github.com/sourishg/fisheye-stereo-calibration

Lidar 和 Camera标定

1. Spatiotemporal Camera-LiDAR Calibration: A Targetless and Structureless Approach
2. An Extrinsic Calibration Tool for Radar, Camera and Lidar，项目地址：github.com/tudelft-iv/multi_sensor_calibration
3. LiDAR-Camera Calibration using 3D-3D Point correspondences
4. Online Camera-LiDAR Calibration with Sensor Semantic Information（在线标定）
5. Improvements to Target-Based 3D LiDAR to Camera Calibration
6. LiDAR and Camera Calibration using Motion Estimated by Sensor Fusion Odometry
7. Automatic extrinsic calibration between a camera and a 3D Lidar using 3D point and plane correspondences
8. A Novel Calibration Method between a Camera and a 3D LiDAR with Infrared Images（ICRA2020）
9. Unified Intrinsic and Extrinsic Camera and LiDAR Calibration under Uncertainties（ICRA2020）
10. Analytic Plane Covariances Construction for Precise Planarity-Based Extrinsic Calibration of Camera and LiDAR（ICRA2020）
11. 开源工程： https://github.com/ankitdhall/lidar_camera_calibration https://github.com/mfxox/ILCC https://github.com/beltransen/velo2cam_calibration https://github.com/swyphcosmo/ros-camera-lidar-calibration https://github.com/heethesh/lidar_camera_calibration https://git

hub.com/TurtleZhong/camera_lidar_calibration https://github.com/XidianLemon/camera_lidar

Lidar 和 Lidar标定

Lidar和双目相机标定融合

1. Intersection Safety using Lidar and Stereo sensors

Lidar和Radar标定

1. Extrinsic and Temporal Calibration of Automotive Radar and 3D LiDAR

Lidar和事件相机标定

1. Calibration of Event-based Camera and 3D LiDAR

Camera和Radar

1. Radar and vision sensors calibration for outdoor 3D reconstruction
2. Targetless Rotational Auto-Calibration of Radar and Camera for Intelligent Transportation Systems

激光雷达、Camera、毫米波雷达融合

1. Multiple Sensor Fusion and Classification for Moving Object Detection and Tracking.
2. An Extrinsic Calibration Tool for Radar, Camera and Lidar
3. Extrinsic 6DoF Calibration of a Radar – LiDAR – Camera System Enhanced by Radar Cross Section Estimates Evaluation

IMU标定

IMU与Camera标定

1. https://github.com/ethz-asl/kalibr/wiki/calibrating-the-vi-sensor

IMU与Lidar标定

1. https://github.com/ethz-asl/lidar_align

深度相机、双目相机与激光雷达联合标定

具体流程:

- 通过计算相机和雷达对同一个标定板来确定两者的相对位姿,其中相机的位姿估计可以通过ArUco二维码来计算
- 将双目相机的点云和雷达点云通过上一步生成的相对位姿进行KD-tree匹配，通过ICP算法计算平移,Kabsch算法计算旋转

论文：LiDAR-Camera Calibration using 3D-3D Point correspondences 论文：[Automatic Extrinsic Calibration Method for LiDAR and Camera Sensor Setups](

传感器时间同步

传感器空间同步