博士論文要旨

論文題名:コンピュータビジョンに基づく 産業用組立プラットフォームの傾斜測定手法

立命館大学大学院理工学研究科
電子システム専攻博士課程後期課程
メン ゼリン
MENG Zelin

製造工場では産業用ロボット等を用いた組立工程の自動化が進んでいる。組立の際には、ロボットのアームに取り付けられたカメラの映像を用いて、アームの姿勢を高い精度で制御する必要がある。本研究では、コンピュータビジョンの基本原理、SLAM（Simultaneous Localization and Mapping）技術、AI（Artificial Intelligence）アルゴリズムを組み合わせることにより、産業用組立プラットフォームの傾斜測定手法を開発する。本論文の主な貢献は以下の 4 点である。

1 点目は、カメラの歪みの補正、カメラのピクセル座標系からワールド座標系への変換など、組立プラットフォームの姿勢推定や傾斜測定に必要となる幾何学を体系的に整理したことである。

2 点目は、カメラ画像の特徴点を選択する手法の提案である。カメラ画像から 3 次元の画像を生成するためには、複数のカメラ画像間の特徴点のマッチングを見つける必要がある。しかし特徴点の数が多すぎると、特徴点のマッチングを見つけることが困難となる。そこで、マッチングの精度低下を抑制しつつ、特徴点の数を削減する手法を開発した。提案した手法は非最大抑制法に基づいている。実験により、提案手法は 6.7%の特徴点を削減し、これによりマッチングの精度を 80%から 92%に向上することを示した。

3 点目は、SLAM ベースの傾斜測定手法の提案である。提案手法は、PnP（Perspective-n-Point）アルゴリズムに基づいている。数多くの試行実験を通じ、傾斜測定に適したパラメタを取得した。実験により、既存のエピポーラ制約ベースの手法と比較して、時間効率が 7.3%高く、また、測定誤差を 90%削減することを示した。

4 点目は、機械学習ベースの傾斜測定手法の提案である。提案手法は、多層パーセプトロンに基づくニューラルネットワークモデルに基づいており、広範な実験を通じてモデルの最適な構造とパラメタを決定した。 実験により、提案手法の精度は最大 98%となり、他の機械学習ベースの手法と比較して優れていることを示した。

Abstract of Doctoral Dissertation

Title: Inclination Measurement for Industrial Assembly Platforms Based on Computer Vision

Doctoral Program in Advanced Electrical, Electronic and Computer Systems
Graduate School of Science and Engineering
Ritsumeikan University
メン ゼリン
MENG Zelin

The research and application of computer vision and artificial intelligence (AI) in the direction of industrial automation is a hot topic in the current scientific and technological circles. Because it is of great theoretical and practical significance to flexibly apply this technology to further improve the intelligence of manufacturing automation. Based on the basic principles of computer vision, combined with simultaneous localization and mapping (SLAM) technologies and AI algorithms, this study implements the methods for the inclination angle measurement of the bearing assembly platforms in manufacturing industry. The main works of this study are as follows.

For the motion estimation of the assembly platform, we illustrated and determined the mathematic expression of motion, that is, the motion of the camera coordinate system relative to the world coordinate system is expressed from the two dimensions of rotation and translation. Then, we demonstrated the coordinate transformation model from the pixel coordinate system to the world coordinate system. Afterward, considering that the camera will introduce distortions and influence the performance of the vision algorithms, we calibrated the industrial camera, and then obtained the camera's intrinsic parameter matrix.

Considering that the current project has high requirements on the accuracy and processing speed of the algorithm, as well as the computing power of the computing platform, we conducted many comparative experiments and selected the algorithm combinations of image features and feature matching approaches which are suitable for the project. To further reduce the false matching rate of feature point pairs, we applied a screening strategy based on the non-maximal suppression method. By adding the screening conditions, only a certain number of best matching point pairs are retained, which saves the computing resources and shortens the overall running time of the algorithm, and at the same time improves the accuracy of the algorithm towards motion estimation. In specific, in the evaluation experiments, 6.7% of the total matched point pairs have been eliminated when applying the screening strategy. Under the circumstance that without adding the screening conditions, the maximum good

match ratio could only reach 80%, while the evaluation experiments show that the ratio of the good match reaches 92% in the case of applying the non-maximal suppression strategy with the tuned parameters.

For the SLAM-based motion estimation algorithm, we compared several mainstream motion estimation algorithms including feature matching-based, and feature tracking-based methods, etc. In specific, we implemented the perspective-n-point (PnP) method to realize the inclination measurement. In addition, we have tuned the parameters of the optimization algorithm and obtained the optimal parameters through a large number of experiments, making it more suitable for the current research project. The optimized PnP algorithm minimizes the estimation error of the inclination measurements. Evaluation results show that the time efficiency of the proposed system achieves 7.3% higher than the conventional epipolar-constraints-based ones. On the other hand, the implemented system significantly reduces the measurement error by 90% compared with the conventional epipolar constraints-based methods.

Regarding the machine learning-based algorithms for inclination angle classification, we designed a shallow neural network model based on a multilayer perceptron and determined the optimal structure of the model through extensive experiments. In addition, we have also implemented and verified the performance of other machine learning algorithms and deep learning algorithms as the baseline for this project. Through many comparative experiments, we verified the effectiveness and reliability of the designed lightweight neural network, as well as its advantages in the field of industrial automation, especially in this research project. In contrast to those traditional methods, validation experiments certificate that the proposed method achieves the best performance while reducing computational complexity by 45.31%. In addition, the validation accuracy of the designed neural network with tuned parameters reaches up to 98%, which outperforms other baseline models.