SIMULATED KALMAN FILTER (SKF) BASED IMAGE TEMPLATE MATCHING FOR DISTANCE MEASUREMENT BY USING STEREO VISION SYSTEM

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science in Electronics Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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LIST OF SYMBOLS

c_1	Learning factor 1
c_2	Learning factor 2
G_{best}	Updated best in the program
P(0)	Initial value of error covariance estimation
P_{best}	Best fitness value of each iteration
Q	Process noise value
R	Measurement noise value
w_{max}	Maximum weight
w_{min}	Minimum weight
$X_{best}(x)$	Best fitness value of each iteration
X_{true}	Updated best in the program

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
ABC	Artificial Bee Colony
ACO	Ant Colony Optimization
ANN	Artificial Neural Network
BA	Bat Algorithm
BAM	Bat Algorithm with Mutation
CA	Cooperative Algorithm
EKF	Extended Kalman Filter
emCGA	Elitism and Mutation Operator on Compact Genetic Algorithm
FFO	Fruit Fly Optimization
GA	Genetic Algorithm
GPU	Graphics Processing Unit
HSAD	Hybrid of Sum of Absolute Differences
ICP	Iterative Closest Points
IMP	Image Matching Problem
IOLD	Interleaved Order based Local Descriptor
IR	Infrared
ITMP	Image Matching Template Problem
LRF	Laser Range Finder
NCC	Normalized Cross-Correlation
OFC	Occlusion Free Correlation
PIM	Performance Index Method
PSNR	Peak Signal to Noise Ratio
PSO	Particle Swarm Optimization
RANSAC	Random Simple Consensus
SAD	Sum of Absolute Differences
SCC	Strongly-Connected Components
SEA	Schoof-Elkies Atkin
SIFT	Scale-Invariant Feature Transform
SKF	Simulated Kalman Filter
SLAM	Simultaneous Localization and Mapping

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ABSTRAK

Sensor pengukuran jarak seperti Kinect dan laser jarak jauh (LRF) sudah lama digunakan dalam industri. Salah datu daripada isu penting berkaitan sensor ialah ketepatan dalam mengukur jarak. Tesis ini menerangkan tentang pembangunan satu algoritma baru untuk pengukuran jarak dengan menggunakan sensor penglihatan stereo. Sistem penglihatan stereo terdiri daripada dua buah kamera stereo yang dipasang secara selari untuk mendapatkan kedudukan yang tetap. Sensor ini boleh memberi data untuk warna dan tekstur untuk memudahkan proses pengambilan ciri-ciri bagi satu imej. Berdasarkan hal tersebut, jarak antara ukuran asal dan analisis daripada sistem penglihatan stereo adalah tidak tepat. Algoritma stereo juga telah digunakan untuk menyelesaikan masalah pengukuran jarak ini seperti yang telah dinyatakan dalam sorotan literatur. Algoritma stereo terdiri daripada penentukuran kamera, pemetaan stereo (peta ketaksamaan) dan titik awan tiga dimensi (3D). Terdapat banyak algoritma untuk peta ketaksamaan seperti algoritma blok separa global mempunyai masalah ketepatan dan agak rumit untuk dilaksanakan. Penyelidikan ini telah memperkenalkan satu pendekatan baru untuk mengukur jarak menggunakan sistem penglihatan stereo. Pendekatan ini menggunakan aplikasi penyamaan templat imej yang mana dengan mencari imej yang paling sesuai, dan seterusnya, mengira jarak antara dua piksel dengan menggunakan persamaan kedalaman stereo. Berdasarkan pendekatan ini, pencarian piksel yang terbaik adalah sangat mencabar. Hal ini kerana proses ini memerlukan penyimpanan data yang tinggi dan masa pengiraan yang sangat lama apabila terlibat dengan piksel imej. Berdasarkan sorotan literatur, algoritma konvensional untuk padanan imej templat seperti korelasi antara dua imej memakan masa pengiraan yang terlalu lama. Oleh itu, masalah tersebut telah dipertimbangkan sebagai masalah pengoptimuman. Dengan hal tersebut, ia boleh mengurangkan masa pengiraan dan boleh diaplikasikan untuk penyelesaikan masalah sebenar. Dalam kajian ini, Simulasi Penapis Kalman (SKF) dipilih untuk digunakan dalam padanan imej ini sebagai algoritma pengoptimuman. Perbandingan antara SKF dengan algoritma konvensional untuk padanan templat imej iaitu algoritma nilai indeks prestasi (PIM) dan korelasi menggunakan komponen DC dari imej (TMC) dan menggunakan kuasa sesuatu imeg (TMP). Dapatan kajian menunjukkan bahawa masa pemprosesan untuk SKF lebih rendah berbanding kaedah yang lain iaitu 1.5 saat dalam 25 percubaan. Manakala, untuk PIM, TMC dan TMP adalah 2.0, 2.2 dan 3.3 saat. Selepas itu, SKF juga diuji untuk mencari ketepatan dalam padanan imej dengan Pengoptimuman Rombongan Zarah (PSO) dan Algoritma Kelawar dengan Mutasi (BAM). Hasilnya mendapati 40% padanan imej yang Berjaya berbanding 12% untuk PSO dan 20% untuk BAM. Tambahan pula, untuk memastikan algoritma SKF ini kuat dan sesuai digunakan untuk keadaan yang berbeza, algoritma ini telah diuji berdasarkan masalah penglihatan, oklusi dan pembezaan pencahayaan. Untuk kedua-dua masalah, SKF menunjukkan prestasi yang baik dalam penyamaan imej berbanding PSO dan BAM yang mana purata untuk ketepatan penyamaan imej untuk oklusi ialah 33.33% dan perbezaan cahaya ialah 15.2%. Seterusnya ialah eksperimen berkaitan aplikasi penyamaan imej untuk pengukuran jarak dengan menggunakan sistem penglihatan stereo. SKF dibandingkan dengan PSO, BAM, algoritma stereo dari sistem penglihatan stereo, model ralat anggaran dan ukuran asal untuk pengukuran jarak dengan menggunakan kamera stereo telah diuji untuk 24 kes yang berbeza. Setiap kes yang terlibat mempunyai ukuran jarak yang berbeza dari kamera dengan objek dalam imej. Keputusan menunjukkan ketepatan untuk model ralat anggaran, SKF, PSO dan BAM adalah 83.50%, 87.36%, 61.31% and 34.00%. untuk kes ini, kadar ketepatan tertinggi ialah dengan menggunakan SKF berbanding kaedah lain. Oleh itu,

pendekatan baru untuk mengukur jarak dengan munggunakan SKF berdasarkan penyamaan templat imej untuk sistem penglihatan stereo adalah tepat, efisyen dan kuat.

ABSTRACT

Distance measurement sensor such as Kinect and Laser Range Finder (LRF) are already been implemented in industrial applications. One of the important issues for sensors is the accuracy of distance measurement. This thesis explains the development of new algorithm for distance measurement using stereo vision sensor. Stereo vision sensor consists of two stereo cameras, mounted parallel in stationary position. Stereo vision sensor can provide color and texture information for easy data and feature extraction. Based on literature, stereo algorithm is already being implemented to solve the distance measurement problem. Stereo algorithm consists of camera calibration, stereo mapping (or disparity mapping) and 3D point cloud data. From the algorithm, disparity mapping algorithm such as Semi-global block algorithm is found out to be inaccurate and complex. This research introduces a new approach to measure distance by using stereo vision systems. The new approach is by using image template matching application which is by finding one best matching pixel from stereo images, and then, calculate the distance between two pixels using stereo depth equation. Based on this approach, searching the best pixel in the images is a challenging task. It is because the process need high memory and expensive computational time when dealing with image pixels. As reported in literature, conventional algorithm for image template matching such as correlation between two images took very long processing time. That is why, image template matching problem is now considered as an optimization problem. By implementing optimization algorithm in image template matching, it is expected that the computation time can be reduced. In addition, it is expected that it can be applied in real-time application. In this study, Simulated Kalman Filter (SKF) is applied to image template matching application as the optimization algorithm. SKF is compared with conventional algorithms for image template matching which are performance index value (PIM) and correlation by using DC components of image (TMC) and by using power of images (TMP) methods. The findings showed that computational time for SKF is lower than others, which is 1.5 seconds within 25 runs. Meanwhile, the computational time for PIM, TMC and TMP methods are 2.0, 2.2 and 3.3 seconds respectively. After that, SKF is tested to find the most accurate image template matching and compared with Particle Swarm Optimization (PSO) and Bat Algorithm with Mutation (BAM). The result obtained is 40% successful image matching for SKF compared with PSO and BAM which are only 12% and 20% respectively. In addition, to ensure the robustness of SKF algorithm, the algorithm is tested under vision problems, occlusion and illumination-invariant. For both problems, SKF showed the good performance in correct image matching compared to PSO and BAM with the average successful image matching result of all cases for SKF is 15.2% for illumination-invariant problem and 33.33% for occlusion. The next experiment is the application of image template matching for distance measurement using stereo vision system. SKF is compared with PSO, BAM, stereo algorithm for stereo vision system and ground truth data for distance measurement of 24 different cases. Each case involved different distance between stereo camera and interested object in the image. The result shows that the accuracy of estimate error model, SKF, PSO and BAM are 83.50%, 87.36%, 61.31% and 34.00%, respectively respect to the ground truth value. The highest accuracy is by using SKF compared to other methods. Therefore, the new approach for distance measurement by using SKF based image template matching on stereo vision system is accurate, efficient and robust.

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