Pemodelan Tiga Dimensi Hasil Kombinasi Laser Scanner SLAM 3D dan Fotogrametri Jarak Dekat (Studi
Kasus: Boulevard Universitas Gadjah Mada)
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INTISARI

Boulevard Universitas Gadjah Mada (UGM) merupakan kawasan dengan karakteristik objek yang beragam dan kompleks, meliputi gapura dengan permukaan reflektif, jaringan jalan, pedestrian, serta vegetasi yang memiliki detail visual yang rumit. *Laser scanner* berbasis *Simultaneous Localization and Mapping* (SLAM) mampu menghasilkan *point cloud* dengan ketelitian geometrik yang baik, tetapi kurang optimal dalam merekam detail visual pada permukaan reflektif dan vegetasi yang kompleks. Sementara itu, fotogrametri jarak dekat mampu menghasilkan detail tekstur dan warna yang kaya, tetapi ketelitian skalanya bersifat relatif dan cenderung menurun seiring bertambahnya jarak objek. Keterbatasan masing-masing metode tersebut menunjukkan perlunya kombinasi data *point cloud* LiDAR-SLAM 3D dan fotogrametri jarak dekat untuk menghasilkan model 3D yang mampu merepresentasikan karakteristik geometrik dan visual objek secara lebih komprehensif. Oleh karena itu, penelitian ini bertujuan untuk mengombinasikan kedua metode tersebut dalam pemodelan 3D objek di kawasan *Boulevard* UGM, mengevaluasi akurasi dimensi dan kualitas visual model, serta menganalisis keunggulan model hasil kombinasi dibandingkan model yang dihasilkan oleh masing-masing metode secara terpisah.

Data diakuisisi menggunakan *laser scanner* Geosun GS-200G untuk memperoleh *point cloud* SLAM 3D yang diolah menggunakan perangkat lunak PointCloudCreater, sedangkan untuk akuisisi foto jarak dekat dengan kamera Canon EOS 200D diolah pada perangkat lunak Agisoft Metashape Professional hingga menghasilkan model 3D dari masing-masing metode. Selanjutnya, kedua *point cloud* dikombinasikan melalui proses registrasi *cloud-to-cloud* pada perangkat lunak CloudCompare menggunakan algoritma *Iterative Closest Point* (ICP) disertai penyesuaian skala dengan *point cloud* SLAM 3D dijadikan referensi geometrik dan skala karena sifatnya yang telah tergeoreferensi dari akuisisi melalui kombinasi GNSS-NTRIP. Kualitas model dievaluasi melalui uji ketelitian dimensi pada 30 titik detail objek serta evaluasi kelengkapan visual pada kedua model.

Hasil penelitian menunjukkan model SLAM 3D memiliki *Root Mean Square Error* (RMSE) dimensi sebesar 0,015 meter dengan rentang selisih ukuran antara 0,001–0,037 meter, jauh lebih kecil dibandingkan model fotogrametri jarak dekat dengan RMSE 0,075 meter dengan rentang selisih 0,001–0,270 meter. Berdasarkan klasifikasi standar *Level of Accuracy* (LoA), model SLAM 3D berada pada level LoA20 hingga LoA50, sedangkan model fotogrametri jarak dekat menunjukkan sebaran ketelitian yang lebih lebar, yaitu LoA10 hingga LoA50. Dalam proses registrasi *cloud-to-cloud, point cloud* SLAM 3D dijadikan sebagai referensi, sehingga model hasil kombinasi memperoleh ketelitian dimensi dan klasifikasi LoA yang sama dengan model SLAM 3D (RMSE 0,015 meter dan LoA20–LoA50), sekaligus tetap menampilkan detail visual dari data fotogrametri jarak dekat. Proses registrasi *cloud-to-cloud* menghasilkan *Final RMS* sebesar 0,077 meter dengan faktor skala 1,029. Kombinasi kedua metode juga terbukti saling melengkapi kekurangan masing-masing, di mana *floating object* pada permukaan reflektif model SLAM 3D dapat dilengkapi oleh *point cloud* fotogrametri, sementara *hole* pada permukaan tanah model fotogrametri dapat dilengkapi oleh *point cloud* SLAM 3D. Dengan demikian, model 3D hasil kombinasi dinilai sebagai representasi paling optimal untuk mendokumentasikan objek di *boulevard* UGM dibandingkan penggunaan salah satu metode secara terpisah.

Kata kunci: pemodelan 3D, LiDAR-SLAM, fotogrametri jarak dekat, kombinasi *point cloud, boulevard UGM*

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ABSTRACT

Boulevard Universitas Gadjah Mada (UGM) is an area characterized by diverse and complex objects, including a gate with reflective surfaces, road networks, pedestrian areas, and vegetation with intricate visual details. A laser scanner based on Simultaneous Localization and Mapping (SLAM) is capable of generating point clouds with good geometric accuracy; however, it is less optimal for capturing visual details on reflective surfaces and complex vegetation. Meanwhile, close-range photogrammetry is capable of producing rich texture and color details, but its scale accuracy is relative and tends to decrease as the distance to the object increases. These limitations of each method indicate the need to combine LiDAR-SLAM 3D and close-range photogrammetry point cloud data to produce a 3D model capable of representing the geometric and visual characteristics of objects more comprehensively. Therefore, this study aims to combine these two methods for 3D modeling of objects in the UGM Boulevard area, evaluate the dimensional accuracy and visual quality of the resulting models, and analyze the advantages of the combined model compared with the models produced by each method separately.

Data were acquired using a Geosun GS-200G laser scanner to obtain a 3D SLAM point cloud, which was processed using PointCloudCreater software. Meanwhile, close-range photographs were acquired using a Canon EOS 200D camera and processed using Agisoft Metashape Professional to generate 3D models from each method. Subsequently, the two point clouds were combined through a cloud-to-cloud registration process in CloudCompare using the Iterative Closest Point (ICP) algorithm, accompanied by scale adjustment. The 3D SLAM point cloud was used as the geometric and scale reference because it was georeferenced through acquisition using GNSS-NTRIP. Model quality was evaluated through dimensional accuracy testing at 30 object detail points and visual completeness evaluation of each model.

The results showed that the 3D SLAM model had a dimensional Root Mean Square Error (RMSE) of 0.015 meters, with differences in measured dimensions ranging from 0.001 to 0.037 meters, which was substantially smaller than that of the close-range photogrammetry model, which had an RMSE of 0.075 meters and differences ranging from 0.001 to 0.270 meters. Based on the Level of Accuracy (LoA) classification standard, the 3D SLAM model was classified within LoA20 to LoA50, whereas the close-range photogrammetry model exhibited a wider accuracy range, from LoA10 to LoA50. During the cloud-to-cloud registration process, the 3D SLAM point cloud was used as the reference; consequently, the combined model obtained the same dimensional accuracy and LoA classification as the 3D SLAM model (RMSE of 0.015 meters and LoA20–LoA50), while retaining the visual details provided by the close-range photogrammetry data. The cloud-to-cloud registration process resulted in a Final RMS of 0.077 meters with a scale factor of 1.029. The combination of the two methods also demonstrated their complementary strengths, whereby floating objects on reflective surfaces in the 3D SLAM model could be supplemented by the photogrammetric point cloud, while holes on the ground surface in the photogrammetry model could be supplemented by the 3D SLAM point cloud. Thus, the combined 3D model provides a more complete representation of the objects in the UGM Boulevard area than either method used separately.

Keywords: 3D modeling, LiDAR-SLAM, close-range photogrammetry, point cloud integration, *boulevard* UGM