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Accuracy improvement of 3D position estimation of mobile robots based on IMU measurements and NNs

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Abstract: This paper proposes a novel approach of fusing inertial measurement unit (IMU) data and neural network (NN) models with the aim to provide IMU-based position/velocity estimation results with enhanced accuracy for mobile robots. First, a comprehensive database of random dynamic motions is generated based on low-cost quadcopter motions, where both raw IMU measurements and ground truth data of system states are recorded. This process is performed with a six degrees of freedom (6-DOF) test environment, which alters both the position and orientation (6D pose) of an IMU model and simultaneously builds the database. Then, a cascade forward NN is developed and trained to estimate the true acceleration of the dynamical system. Different input combinations of IMU measurements are evaluated in the training of the NN, moreover extended Kalman- (EKF) and gradient descent (GRD) orientation filters are also incorporated in the training process to further enhance the effectiveness of the NN model. It is shown that the NN-based external acceleration estimate significantly enhances the rotation matrix-based acceleration vector calculation accuracy, therefore it enables the obtainment of reliable velocity and position results in shorter time windows.

Keywords: pose estimation, inertial measurement unit, neural network, Kalman filter, gradient filter

1. Introduction

The 3D position estimation based on the double integration of acceleration signals is a challenging problem since the uncertainty of the IMU sensor measurements is significant due to both the noisy environment and limitations of the employed measurement system [1]-[3]. This paper investigates the sufficiently accurate IMU-based acceleration determination performance, which can be used to obtain reliable velocity and position estimates for shorter time windows. For this purpose, the true acceleration is estimated with a trained cascade forward NN from solely the IMU sensor readings.

2. Results and Discussion

The first part of Table 1 is the reference-baseline group, which shows the baseline method estimations without the application of NN. In the evaluated cases the orientation was estimated with EKF or GRD based on the raw IMU measurements. The second part is the applicable NN group, which represents the feasible solutions that can be applied in pose estimation problems of mobile robots. The third part is the reference NN group, which employs the ground truth instead of the estimated orientation, i.e., these results highlight the theoretical maximum performance in case of perfect orientation estimation. The achieved performances are shown with correlation measures between the true and estimated accelerations, where various NN models have been evaluated.

Table 1. The performance comparison of NN models on different input channels

Group	Estimated Acceleration		NN correlation with true acceleration			
	Model Channels	Inputs	X	Y	Z	All
Reference - baseline	Sensor acceleration (Acc)	3	0.42	0.20	0.89	0.264
	GRD on Acc+Gyr+Mag	9	0.18	0.35	0.78	0.491
	EKF on Acc+Gyr+Mag	9	**0.55**	**0.48**	**0.93**	**0.725**
Applicable NN with estimated angles (Ekf or Grd)	NN on Acc	3	0.65	0.40	0.94	0.674
	NN on Acc+Gyr	6	0.69	0.68	0.95	0.758
	NN on Acc+Ekf	6	0.75	0.71	0.96	0.783
	NN on Acc+Grd	6	0.68	0.54	0.95	0.721
	NN on Acc+Gyr+Ekf	9	0.77	0.77	0.96	0.808
	NN on Acc+Gyr+Grd	9	0.71	0.73	0.96	0.772
	NN on Acc+Mag	6	0.78	0.71	0.96	0.803
	NN on Acc+Gyr+Mag	9	0.80	0.78	**0.97**	0.830
	NN on Acc+Gyr+Mag+Ekf	12	0.82	0.80	**0.97**	0.836
	NN on Acc+Gyr+Mag+Grd	12	**0.84**	**0.82**	**0.97**	**0.848**
Reference NN with truth angles (Ang)	NN on Acc+Ang	6	0.98	0.98	0.97	0.957
	NN on Acc+Gyr+Ang	9	**0.993**	**0.993**	0.9767	**0.9643**
	NN on Acc+Gyr+Mag+Ang	12	**0.993**	**0.993**	**0.9768**	0.9642

It is found that EKF gives the highest correlation results from the baseline groups (*r=0.725*). The best reference NN becomes the Acc+Gyr+Ang combination (*r=0.965*), however the version with an additional magnetometer is very similar. The best applicable NN is the Acc+Gyr+Mag+Grd combination (*r=0.848*), which is halfway between the baseline and theoretical perfect solution. The results prove that the most important factor is the accuracy of the estimated orientation for the NN-based acceleration estimation. NN, as a supervised method, is a powerful model for both aggregating the available measurements and estimating the external accelerations of mobile robots. Fig. 1 depicts an example of the estimated position and velocity values. This outcome was obtained by simple double integration of the obtained acceleration. NN-based accelerations yield reliable data for 10 seconds.

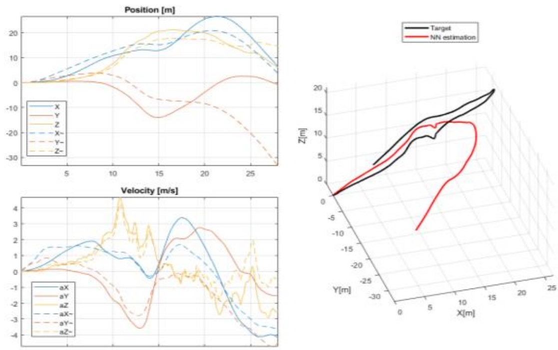

Fig. 1. Position and velocity estimation results based on the estimated acceleration by the best NN model.

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