PriMera Scientific Engineering
Volume 1 Issue 1 September 2022

Mini-Review

Neural Networks for Robot Collision Estimation and Detection

Citation: Abdel-Nasser Sharkawy. "Neural Networks for Robot Collision Estimation and Detection". PriMera Scientific Engineering 1.1 (2022): 12-15.

Received: August 11, 2022

Published: August 30, 2022

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Abstract

This paper presents a mini-review on our previous work presented in ref. [1-6] in which the neural networks (NNs) were used for estimating and then detecting the robot's collisions with the human operator during the cooperation task. This review investigates and compares the designed NN architectures, their application, the resulted mean squared error (MSE) from training, and their effectiveness (%) in detecting the robot's collisions. This review reveals that the NN is an effective method in estimating and detecting the human-robot collisions.

Introduction

Human-robot interaction aims to perform a complementary combination between the robot abilities and the human skills [7, 8]. Robot abilities include the speed, the force, and the precision. Human skills include the experience, the knowledge of performing the tasks, easy learning, and understanding of the strategies of the control. Safety is the most necessary stage during human-robot collaboration because the proximity of the operator to the robotic manipulator may lead to possibility of injuries [9]. In this article, a mini review is presented for the human-robot collision estimation and detection methods which were based on NNs and presented in ref. [1-6]. A collision occurs between the robot and the human operator is presented in Fig. 1.

NNs for Collision Estimation and Detection

NNs were used for estimating and then detecting the robot's collisions with the human operator, as presented in our previous work [1-6]. In these papers, the NN was designed taking into consideration the manipulator dynamics and trained, using data containing collisions and data free of collisions, by the algorithm of Levenberg-Marquardt for detecting the collisions that occur between the human operator and the robotic manipulator. The priori knowledge to the dynamic model was not required. Four NN structures were investigated, as presented in Table 1.

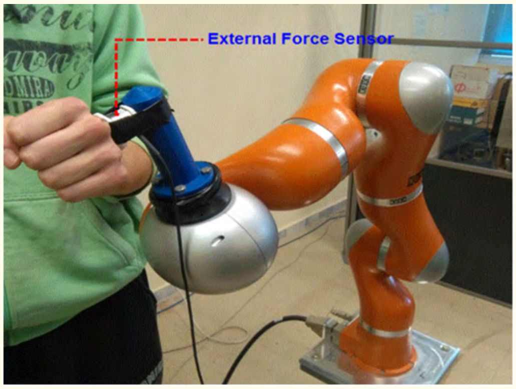

Figure 1: A collision occurs by the human hand on the force sensor that fixed on the robot end-effector [4].

Architecture	***Hidden Layers***	***Used Signals in Implementation***	***Application***	***Experimental Investigation***
Multilayer Feed forward NN, MFFNN-1	1	Position and torque sensors	Collaborative Robots that contain the torque sensors	1-DOF, 2-DOF, and 3-DOF manipulators
Multilayer Feed forward NN, MFFNN-2	2	Position sensors	Any conventional robot	1-DOF and 2-DOF manipulators
Cascaded forward NN, CFNN	1	Position sensors	Any conventional robot	1-DOF manipulator
Recurrent NN, RNN	1	Position sensors	Any conventional robot	1-DOF manipulator

Table 1: The four NN architectures used to estimate and detect the robot's collisions [1-6].

All these architectures could be applied with all robot joints. The experimental work was executed by the use of KUKA LWR IV Robot. The collision was detected based on a defined collision threshold. The threshold was calculated as the maximum value of the absolute approximation error. This error was the difference between the external joint torque obtained by KUKA robot controller (KRC), which was used for NN training, and the estimated one by the NN, of the contact-free motion. ISO standards were considered for confirming that the detection of the collisions using the introduced method was in the safe area of human-robot collaboration.

Results' Discussion and Comparison

The experimental results showed that the designed NNs were trained very well, and the resulted mean squared error (MSE) is very small and satisfactory, as presented in Table 2. This means that the training error is very small and the trained NN is able to estimate the collision correctly. The effectiveness of the trained NN was investigated by performing many different and random robot's collisions by the human hand. The results proved that the developed system could estimate and detect the collisions effectively. In addition, the trained NN had the generalization ability under different conditions. The results were presented in terms of the trained NN's effectiveness for collisions' detection, the number of the collisions that are not discovered by the trained NN which are the false negatives (FN) collisions, and the FP collisions which are the collisions' alerts given by the trained NN, if there is no actual collision. The results are showed in Table 3. The results presented in Table 3 show that the NNs are efficient and desirable method in detecting the human-robot collisions. The effectiveness (%) is high and the FP collisions are low.

Manipulator	Structure	MSE
1-DOF	MFFNN-1	0.040644
	MFFNN-2	0.21682
	CFNN	0.39200
	RNN	0.43078
2-DOF	MFFNN-1	0.018244
	MFFNN-2	0.036427
3-DOF	MFFNN-1	0.034677

Table 2: The resulted MSE from training the four NN structures.

Manipulator	*Structure*	*Effectiveness (%)*	*FN collisions (%)*	*FP collisions (%)*
1-DOF	MFFNN-1	76	16	8
	MFFNN-2	80	16	4
	CFNN	84	16	0
	RNN	80	20	0
2-DOF	MFFNN-1	82.52	1.136	16
	MFFNN-2	85.73	7.95	6.82
3-DOF	MFFNN-1	86.6	4.7	8.7

Table 3: The experimental results of using the four NN structures in robot collision detection.

Conclusion and Recommendation

This article presents a mini review on our previous work which used the artificial NNs for estimating and detecting the robot collisions with the human operator. The designed NNs architectures, their application, the resulted MSE from training, and their effectiveness (%) are discussed and compared. This review reveals that the NN is an efficient technique in human-robot collision estimation and detection. The good results presented in this review motivate to implement and investigate other different types of NNs for the human-robot collisions' detections. Furthermore, Super Vector Machine (SVM) and deep learning can be considered.

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