IMPROVING ROBOTIC GRASPING SYSTEM USING DEEP LEARNING APPROACH

MOHANNAD K. H. FARAG

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis, and in my opinion, this thesis is adequate in terms of scope and quality for the award of Doctor of Philosophy.

____

(Supervisor's Signature)

Full Name : ABDUL NASIR ABD GHAFAR

Position : SENIOR LECTURER

Date : 21/8/2020

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.

____

(Student's Signature)

Full Name : MOHANNAD K. H. FARAG

ID Number : PET17003

Date : 21/8/2020

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MOHANNAD K. H. FARAG

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ABSTRAK

Pergerakan robot tradisional bergantung kepada modul pergerakan yang telah diprogramkan, menyebabkan keterbasan fungsi dan operasi robot. Genggaman sistem penglihatan komputer atau visi komputer (computer vision) bagi tujuan pengesanan genggaman robot (grasp detection) telah terbukti sebagai bidang penyelidikan yang aktif dan menjadi tumpuan para penyelidik. Seiring dengan kajian semasa, penghasilan konfigurasi genggaman penuh objek sasaran merupakan dikenalpasti sebagai cabaran utama bagi penghasilan operasi robot di tahap optimum. Pengintegrasian teknologi penglihatan komputer (computer vision) dan penderian taktil (tactile sensing) dijangka menjadi inisiatif yang mampu untuk mengoptimumkan fungsi robot. Walau bagaimanapun, kajian terkini telah menggunakan penderian taktil (tactile sensing) berdasarkan model pengesanan genggaman bagi meningkatkan ketepatan pengesanan, tetapi tidak melaporkan kejayaan genggaman fizikal. Oleh itu, kajian ini mengetengahkan isu gelinciran genggaman (genlincir event) yang berpunca daripada faktor-faktor tertentu. Kajian ini dijalankan bertujuan untuk membangunkan model pengesanan genggaman Deep Learning dan algoritma pengesanan gelinciran, seterusnya menghasilkan satu sistem genggaman robot yang inovatif. Menerusi teknik empat langkah augmentasi data (four-step data augmentation), ketepatan genggaman yang dicapai adalah 98.2%, melebihi ouput data terbaik yang dilaporkan di mana 625 contoh baru dihasilkan bagi setiap gambar asal dengan label genggaman yang berbeza. Selain itu, teknik dua langkah pemindahan pembelajaran (two-step transfer learning) telah Berjaya meningkatkan output yang diperolehi bagi fasa kedua kajian sebanyak 0.3% berbanding dengan fasa pertama. Manakala bagi genggaman fizikal robot, kaedah perwakilan genggaman tujuh dimensi (seven-dimensional grasp representation) yang dicadangkan membolehkan pengesanan kendiri bagi saiz dan kedalaman genggaman dilakukan. Model yang dibangunkan mencatat 74.8 milisaat sebagai masa pengesanan. Ketepatan pengesanan yang tinggi memungkinkan genggaman model tersebut dilakukan untuk aplikasi robot yang bersifat masa nyata (real-time). Berdasarkan pemerhatian terhadap maklum balas masa nyata (real-time) dari sensor perintang pengesan daya (force sensing resistor sensor), algoritma pengesanan gelinciran yang dicadangkan menunjukkan tindak balas pantas dalam dengan catatan masa sepantas 86 milisaat. Penemuan ini membolehkan sistem untuk terus menahan objek sasaran dengan peningkatan kekuatan genggaman dengan kadar segera. Pengintegrasian model Deep Learning dan pengesanan gelinciran telah menunjukkan peningkatan yang signifikan sebanyak 18.4% menerusi hasil penyelidikan genggaman yang dilakukan pada robot SCARA. Selain itu, alat pengesan tepi (edge detector) Zerocross-Canny yang digunakan telah meningkatkan ralat kedudukan robot sebanyak 0.27 mm berbanding dengan kajian terdahulu, seterusnya memperkenalkan sistem genggaman robot yang inovatif dengan menggunapakai skema Grasp-NoDrop-Place.

ABSTRACT

Traditional robots can only move according to a pre-planned trajectory which limits the range of applications that they could be engaged in. Despite their long history, the use of computer vision technology for grasp prediction and object detection is still an active research area. However, the generating of a full grasp configuration of a target object is the main challenge to plan a successful robotic operation of the physical robotic grasp. Integrating computer vision technology with tactile sensing feedback has given rise to a new capability of robots that can accomplish various robotic tasks. However, the recently conducted studies had used tactile sensing with grasp detection models to improve prediction accuracy, not physical grasp success. Thus, the problem of detecting the slip event of the grasped objects that have different weights is addressed in this research. This research aimed to develop a Deep Learning grasp detection model and a slip detection algorithm and integrating them into one innovative robotic grasping system. By proposing a four-step data augmentation technique, the achieved grasping accuracy was 98.2 % exceeding the best-reported results by almost 0.5 % where 625 new instances were generated per original image with different grasp labels. Besides, using the two-stage-transfer-learning technique improved the obtained results in the second stage by 0.3 % compared to the first stage results. For the physical robot grasp, the proposed seven-dimensional grasp representations method allows the autonomous prediction of the grasp size and depth. The developed model achieved 74.8 milliseconds as prediction time, which makes it possible to use the model in real-time robotic applications. By observing the real-time feedback of a force sensing resistor sensor, the proposed slip detection algorithm indicated a quick response within 86 milliseconds. These results allowed the system to maintain holding the target objects by an immediate increase of the grasping force. The integration of the Deep Learning and slip detection models has shown a significant improvement of 18.4% in the results of the experimental grasps conducted on a SCARA robot. Besides, the utilized Zerocross-Canny edge detector has improved the robot positioning error by 0.27 mm compared to the related studies. The achieved results introduced an innovative robotic grasping system with a Grasp-NoDrop-Place scheme.

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LIST OF SYMBOLS

B_{eff}	effective viscous friction factor (Ns/m)
P_m	actual muscle pressure (MPa)
C_1 & C_2	adaptive backstepping control parameters (second^{-1})
e_{av}	average of the positioning error
$u(t)$	control input of adaptive backstepping controller
Fc	coulomb friction force (N)
k	current experiment attempt
F_d	drop prevention force (N)
F_1	FSR sensor feedback (N)
z_{gr}	grasp depth (mm)
F_g	grasp force (N)
$\left(x_{gr}, y_{gr}\right)$	grasp position (mm)
h_{gr}	grasp size (mm)
F_i	initial grasp force (N)
a & b	modelling coefficients of robot finger
N_{act}	number of actuators
N_{dof}	number of degrees of freedom
P_a	object's actual position
P_d	object's detected position
z_1	PAM mechanical displacement error
z_2	PAM velocity error
z_{pr}	place depth (mm)
$\left(x_{pr}, y_{pr}\right)$	place position (mm)
$e(k)$	positioning error of the k^{th} experiment,
R	pulley radius (m)
t_s	response time (ms)
$\left(x_r, y_r\right)$	robot coordinate system (mm)
l	robot finger length (mm)
K	slip detector coefficient
S	slip detector sensitivity

k_1	spring coefficient (N/m)
n	total experiment attempts
I	total moment of inertia of the finger ($Kg.m^2$)
x_1	translational position of PAM actuator (m)
(x_w, y_w)	world coordinate system (mm)
μ	friction coefficient
F_t	tangential force
F_n	normal force
θ	orientation of the rectangle
(x, y)	the center of grasp rectangle
h	the height of gripper parallel plates
w	the maximum distance between gripper parallel plates

LIST OF ABBREVIATIONS

μ-LDV	Doppler Velocimeter
AI	Artificial Intelligence
BLDC	Brushless Direct Current
CMC	Carbon Micro-Coil
CNN	Convolutional Neural Network
DAG	Directed Acyclic Graph
DAQ	Data Acquisition
DBM	Deep Boltzmann Machines
DBN	Deep Belief Networks
DL	Deep Learning
DNN	Deep neural networks
DOF	Degree of Freedom
FN	False Negative
FP	False Positive
FSR	Force Sensing Resistor
KSS	Korea Standard SCARA
LC	Inductor and Capacitor
ML	Machine Learning
PAM	Pneumatic Artificial Muscle
RBM	Restricted Boltzmann Machines
RMSE	Root Mean Square Error
RNN	Recurrent Neural Network
RPN	Region Proposal Network
SAE	Stacked Autoencoders
Sparse AE	Sparse Auto-Encoder
SCARA	Selective Compliant Assembly Robot Arm
SCTM	Soft Compliant Tactile Microsensor
SGD	Stochastic Gradient Descent
SGDM	Stochastic Gradient Descent with Momentum
TP	True Positive

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