AN LSTM MODEL TO PREDICT THE SUBJECTIVE PREFERENCE FOR ROBOT TRAJECTORIES IN A CONTEXT OF HUMAN-ROBOT COLLABORATION

[1]KUO-HAO TANG, [2]WEI-JU LIAO

[1,2]Department of Industrial Engineering and System Management, Feng Chia University, Taichung 40724, Taiwan, ROC
E-mail: [1]kuohaotang@gmail.com, [2]ruby92019@gmail.com

Abstract - In the process of human-machine cooperation, the acceptance of the path and submission method of the robot arm can be improved, and the robot arm can meet the expected effect of the human when it moves, which can improve the efficiency and fluency of the human operation, and meet the human The posture of psychological expectations can also improve safety and reduce fatigue during the operation. This study will focus on the subject's path planning and submission postures randomly generated in different locations as factors, and in the experiment, use different submission postures and random movement paths in different gripping objects as the entire submission process The subject provides subjective data on the movement path or posture of the robot arm after the experiment. After data collection, the deep learning calculation is used to extract each part of the path to extract the most suitable movement trajectory and delivery method for different delivery objects and positions. In addition, the objective data is analyzed, and the range and posture of the moving path are effectively analyzed and summarized.

Keywords - Hand-Over Task, Human-Robot Collaboration, LSTM, Predictive Models

I. INTRODUCTION

In recent years, Industry 4.0 and "Intelligent Manufacturing" has become a well-known term for everyone. Intelligent Manufacturing combines the Internet of Things (IoT), Digital factory (DF), cloud services, communications and other technologies to create a virtual and real integrated manufacturing industry and change the factory production. Manufacturing thinking enables machines to communicate with machines and people to communicate with machines. And transform the traditional production method into a highly customized, intelligent, and service-oriented business model, which can quickly manufacture a small number of diverse products to respond to the rapidly changing market. In addition to the intelligent manufacturing, the factory records various data in the process of producing and manufacturing products and gathers various data into a database. The technology of big data analysis is used to optimize the manufacturing and service processes to help companies create greater competitiveness. For example, Internet leader such as Google and Amazon are good at using big data analysis to provide consumers with a better service experience, and even cross-disciplinary integration with professional intelligent technology companies such as Siemens to create a leading trend of Industry 4.0.

In addition to Intelligent Manufacturing, robotics can now be seen in various fields. Recent research on robotics is spreading in various fields. Even in life, robotics also can be seen. It seems that humans and robotics have developed to the point where they cannot be easily separated. Although the fully automated production mode is the ultimate goal of the production line, in order to successfully achieve this goal, the human-robot collaboration mode is the first step toward this goal. Therefore, the human-robot collaboration mode plays an important role in smart manufacturing. The role will also be the future trend. How to make full use of the robot's repeatable precision operations and the advantages of humans with more planning flexibility to optimize the manufacturing process will be the key to the successful transformation of traditional factories from automation.

In human-robot collaboration assembly operation, the most common interaction element in collaborative work is hand-over (Edsinger & Kemp, 2007; Johannsmeier & Haddadin, 2017). During a hand-over task, there are several major points, contains the timey of hand-over task and the path of the robot's arm and the final delivering pose should be friendly and not generate unnecessary tension to operators due to factors such as inappropriate speed, sudden movement change, threatening path, to ensure operators' satisfaction (Bauer et al., 2016).

This research attempt is cut from the point of view of human factors engineering. Using the UR3 robot with human-robot collaboration function as a test platform, various types of sensing devices and other equipment are used to capture images and physiological information to obtain operator information in the HRC collaborative assembly system. The AI algorithm of LSTM is used to discuss the key factors of human factors in the collaborative assembly operation between human and robot. Based on the submitted tools or parts, the robot can generate a friendly

movement path that meets the operator's expectations, and a gripper submission pose that meets the operator's ergonomic requirements. This study investigates the potential of using deep learning methods to predict the satisfaction rate of a given robot path during handover tasks. First, a series of "waypoints" defined in UR3 are systematically generated, as shown in 0 and 0.

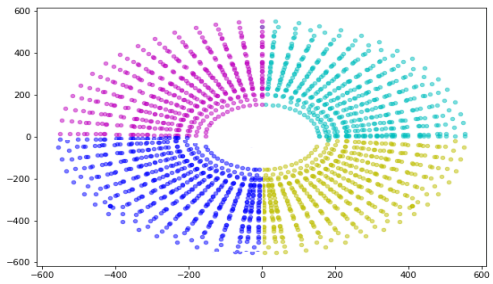


Fig1. Locations of predefined waypoint(top view)

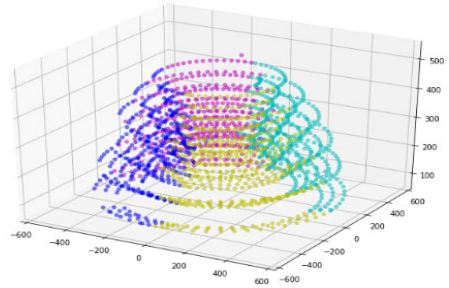
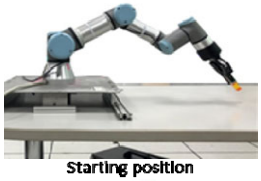


Fig2. Locations of predefined waypoint (3D view)

Next, a Python program was written to generate random paths by using these waypoints and control the UR3 to move accordingly as shown on 0. During the experiment, an operator stood about 75 cm away from the center of the robot arm, UR3 robot would execute a series of randomly generated paths and then this subject gave a preference between 1 to 7 after each movement. One is negative feeling related to the least favorite, uncomfortable, dangerous, and not easy to operate; seven are positive feelings related to the smoothest, feel safe, the most convenient. Finally, when the collaborative robot submits different tools or parts, it can generate a friendly path that meets the operator's expectations through the LSTM, increasing the operator's subjective acceptance



Starting position



Moving through waypoints



Delivering point

Fig3. A movement path generated by starting point, waypoints, and delivering point

This study will be divided into four chapters. Chapter 1 is an introduction, mainly about the research background, motivation and research purpose. Chapter 2 is the literature discussion, which discusses the literature related to this research, which includes the parts of human-robot collaboration, hand-over task and deep learning. Chapter 3 is experimental equipment and methods; Chapter 4 is the conclusions and future work, based on the results of the experimental analysis to draw conclusions, and give suggestions for future research.

II. LITERATURE REVIEW

A. Human-Robot Collaboration

In Intelligent Manufacturing, the division of labor between humans and robots does not mean the cooperation between humans and robots. The division of labor between humans and robots means that people and machines do their own things, and they do not communicate with each other. For example, fully automated factories and light-out factories are all aimed at 100% automation. Human-Robot Collaboration (HRC) refers to the process of continuous improvement of work processes between people and machines through experience and work exchanges; that is, machines can perform operations based on information and processes imported by humans, and humans can then output according to machines. The results are adjusted to form a collaborative model. If the human-machine collaboration mode is applied to the production line, it usually refers to the operator and the robot being merged together in a common work area to perform operations or processing, removing the strict distinction between the manual work of the operator and the automated work of the robot. The work areas of the operator and the robot overlap, creating a common work area.

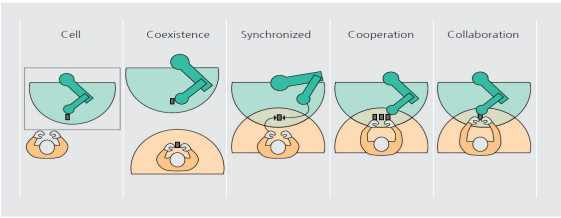


Fig4. Different levels of human- robot collaboration(Bauer et al. , 2016)

B. Hand-Over Task

In the environment of human-robot collaboration, operators and robots generally need to transfer tools, parts, and semi-finished products. This transfer action called hand-over. However, the hand-over job contains a wide range of aspects, such as motion control and planning, grasping motion planning, grasping force control during the hand-over process, and other posture changes before and after robot hand-over. During the submission process, the moving speed and posture of the robot arm are the key factors that affect the operator's preference.

C. Deep Learning

In recent years, artificial intelligence has been a hot topic, the field of application is also quite extensive. The definition of artificial intelligence is actually to design and write computer programs to simulate human "wisdom" behaviors. These include behaviors such as "listening to reading and visual recognition" that simulate human senses, "inference decision-making, understanding and learning" of the brain, and "movement and motion control" of actions. But apart from artificial intelligence, machine learning (ML) and deep learning (DL) are believed to be familiar to everyone. But in fact, machine learning belongs to a branch of artificial intelligence, and deep learning belongs to a branch of machine learning.

The concept of deep learning is to establish and simulate the human brain for analysis and learning. Use it to mimic the mechanisms of the human brain to interpret data, such as images, sounds, and text. The human brain weighs more than a kilogram and its structure is very complicated There are about 86 billion neurons and more than 100 trillion nerves connected, forming a network larger than the most advanced supercomputer. Because of human neural networks are too complicated, in order to facilitate computer simulation, neurons are divided into multiple layers to simulate neural networks.

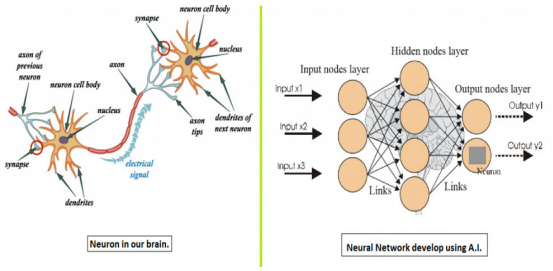


Fig5. Neuron and neural network comparison (Ajinkya Kulkarni , 2016)

There are many kinds of deep learning algorithms. Common ones are Deep Neural Network (DNN), Convolution Neural Networks (CNN), Recurrent Neural Network (RNN) and Long short-term memory (LSTM).

1) Deep Neural Network

The concept of a neural network originated from the nervous system of the human brain, that is, the interconnection between all neurons, and became the inspiration for the development of neural networks. The earliest developed algorithm is Artificial Neural Network (ANN), referred to as Neural Network (NN), also known as neural network. In the beginning, the structure of the neural network was very simple. There was only one input layer (x), one hidden layer (h), and one output layer (y). The biggest difference between Deep Neural Network (DNN) and Neural Network (NN) is the "depth" of deep neural networks. The so-called deep neural network refers to the entire neural network must be large enough and deep enough. Thus, the structure will naturally increase the number of hidden layers. Generally speaking, if it is greater than three layers, it can be called Deep Neural Network.

2) Convolution Neural Networks

Convolution Neural Networks (CNN), is one of the most well-known and popular technology in deep learning and is often used for image recognition. The architecture of CNN is derived from the model architecture of LeNet-5. At the time, LeNet-5 was mainly used for text recognition, and the CNN architecture that we widely use today is the LeNet-5 model that has been continuously optimized. It can be divided into three parts, including convolutional layer, pooling layer or subsampling layer, and fully-connected layer. Through multi-layer convolution and pooling, the extracted features are regarded as Input, and then connected to one or more fully connected layers for classification, which is the typical practice of CNN. After through this a process, it embodies the powerful advantages of CNN in image recognition, including reducing the number of weights in the calculation process, being free from slight distortion or deformation in recognition, having automatic learning and feature induction properties, identification of objects is not affected by changes in the position of the object in the picture.

3) Recurrent Neural Network

Recurrent neural network (RNN) is suitable for projects that need to be identified, and there is a type of sequence. For example, like language recognition, language recognition needs to consider the preface and sequel, in order to avoid out of context, you need to use RNN. So far, RNN seems to be a good algorithm for predicting sequential tasks, because it can link previous messages to the current task. But whether RNN is good or not depends on the situation, because sometimes, we only need to see the latest information to complete the current task, but sometimes, we need more information. When the distance between the relevant information and the location where the information is needed is very large,

the RNN becomes unable to connect to the relevant information. This problem is called the long-distance dependence problem. Therefore, in practice, the long short-term memory network (LSTM) is commonly used.

4) Long short-term memory Networks

From the previous section, we can know that the advantage of RNN is that it can solve the problems related to the order, but it cannot solve the problem of long-distance dependence. Hochreiter & Schmidhuber (1997) proposed Long short-term memory Network (LSTM) to effectively solve the problem of long-range dependence of RNN. In fact, LSTM is a special type of RNN that structurally removes or adds information through the gate structure. Can be divided into forget gate, input gate and output gate, each gate has its own task. The forget gate is responsible for deciding what messages to discard, the input gate is deciding what new messages should be stored in the sequence, and the output gate is responsible for deciding what value to output.

III. EXPERIMENTAL EQUIPMENT AND METHODS

A. Experiment Equipment (Collaborative Robot, UR3)

The UR3 collaborative robot produced by Universal Robots in Denmark. The 3 of UR3 indicates that the rated load of this type of collaborative robot reaches 3 kg. There are other types of collaborative robots in this series, such as UR5, UR10, and UR16. It can be seen that UR3 is the cooperative robot with the lightest load in this series. In addition, in terms of use, UR3 also has many advantages, such as easy programming, fast setup, flexible deployment, and collaborative security, etc., and his biggest advantage is that he has endless joints that can rotate infinitely, effectively assisting in optimizing production Process, ensure the consistency of product quality. In terms of application, in addition to general assembly operations, locking screws, welding, polishing, mold making and other operations can also be done, the application level is very wide.

B. Experimental Method

The movement path and hand-over position of the robot arm are mainly based on python coding to control the activities of UR3 during the collaboration process. In addition to designing the movement path and delivery position of the robot arm, the movement speed and acceleration are also designed to make the movement of the robot arm smoother and more natural. This anthropomorphic design not only makes the movement of the robot arm feel elegant and natural, it also makes the subject feel comfortable and safe. Next, the experimental design content will be described in detail below, including the planning of the waypoint of the robot arm, the setting of the starting point, midpoint and final delivery position of the moving path, as well as the setting of the moving speed and acceleration of the robot arm and the setting of the mixing radius.

1. Waypoint and moving path planning

In order to simulate the environment space of human-machine cooperation, the experiment needs to set the movement range of the robot arm programmatically, which is close to the real human-machine collaboration working space. In this experiment, the collaboration position of the robot arm is obtained through the conversion between Cartesian coordinate system and spherical coordinate system, as shown in 0.

Assuming that the position of the robot arm is at point P in three-dimensional space, the position of point P is expressed in rectangular coordinates (x, y, z), and the distance between point P and the origin is calculated as r, and then the line OP and the Z axis are calculated. The polar angle and the azimuth angle between the projection line of the line OP on the XY plane and the X axis, which can be obtained by spherical coordinates P(r, θ, φ).

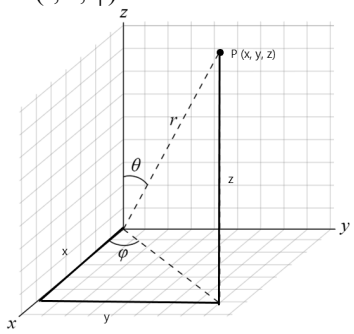


Fig6. Collaboration position

In this experiment, the waypoint is set to bring the azimuth angle into the rotation angle of UR3, and the origin and point P are applied to the lowest and highest points of UR3. After converting the spherical coordinates to Cartesian coordinates, you can get a mark as (x, y, z). The setting of Waypoint includes the point passed by the submission path and the submission point, with UR3 as the central point, and the space specification from UR3 to the submission point is set to 180°, and the related parameter settings refer to 0.

	First quadrant	Second quadrant	Third quadrant	Fourth quadrant
φ	1°~90°	1°~90°	1°~90°	1°~90°
r	310~560	310~560	310~560	310~560
θ	30°~80°	30°~80°	30°~80°	30°~80°

Table1. Waypoint parameter settings

The path traveled by UR3 is set within the range, and the route formed by any waypoint in the range between UR3 and the delivery point is the travel path.

Considering the additional problems caused by the limitation of its own rotation angle during the movement of UR3, this experiment moves the orientation of UR3 to the delivery point in a counterclockwise and clockwise manner, and moves the same coordinate position at two different angles to set the angle at which the UR3 joint moves.
The waypoint setting is divided into four quadrants. Taking UR3 as the center point, the first quadrant is the submission point in human-machine collaboration, the third quadrant is the starting point of the UR3 movement path, the second and fourth quadrants are the midpoints of the UR3 movement path, and the moving direction during the movement is Randomly set to move counterclockwise or clockwise. The complete UR3 movement path is from the starting point through the midpoint to the delivery point.

Further, the 90° range of the first quadrant is set to five delivery points, which are five positions of -45°, -22.5°, 0°, 22.5°, and 45°, respectively. The position of these five submission points is the position of the subject's experiment.

During the experiment, the subjects will use the sitting position and the standing position respectively to perform the submission tasks in human-machine collaboration. In order to ensure that the subject can complete the submission operation within a reasonable delivery range, the delivery range setting in the horizontal plane, that is, the setting of the azimuth angle is 180° to 270°, and the setting of the delivery vertical plane is the setting of the polar angle. It is in the range of 30° to 80°. To put it simply, UR3 is the mainstay. The delivery distance and delivery height of UR3 are divided into three levels. The delivery distance is divided into near, medium and far, and the delivery height is divided into low, medium and high.

2. Moving speed and acceleration

In the process of man-machine collaboration, in addition to the movement path will affect the mental state of the operator, the speed of UR3 movement will also be affected, which may easily cause anxiety at the psychological level of the operator or increase the cooperation between man and machine. Risk, which in turn reduces the subjective feelings of the subject.

3. LSTM model

The construction of the prediction model is based on the initial data, including the starting point position, the midpoint position, and the position of the robot arm joint rotation angle base to wrist3 and X, Y, Z, Rx, Ry, Rz; speed, acceleration; The location of the subject; the height of the subject, a total of 40 characteristics. Convert the data obtained by the experiment into a csv file and read it into the python program. Random 70% of all the data in the csv file is used as the training subset and 30% as the prediction subset, using LSTM as the model training, the input layer unit is 128; the hidden layer is set to four layers unit: 64, 32, 16, 8, and batch size is set to 80, total training epochs is 500 times.

IV. RESULTS

All the information regarding movement path (starting point, waypoints, delivering point, speed, acceleration) and subjects (height, standing location, preference) were recorded in database. A total of 2080 valid data were recorded, and two-thirds of data were used as training subset and the rest were testing subset. We used Recurrent Neural Network (RNN) and Long Short-Term Memory (LSTM) to build the prediction model and implemented the model using Keras in Python. The batch size was set to 500, and the dropout rate for the 4th and 5th hidden layers were set to 50%. The results show that the accuracy reaches to 40% for the training subset at 500th epoch while the loss function is 10% as shown on 0 and 0. During validation, the testing subset shows accuracy of 36% around 200th epoch and becomes stable while loss function does not converge maybe due to overfitting.

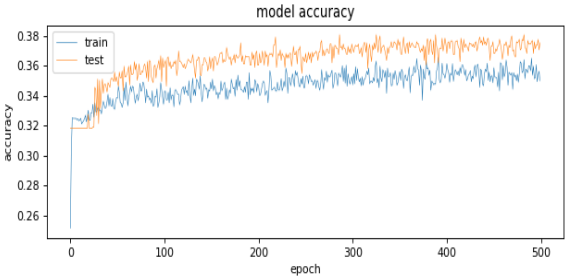


Fig7. Accuracy as a function of epoch

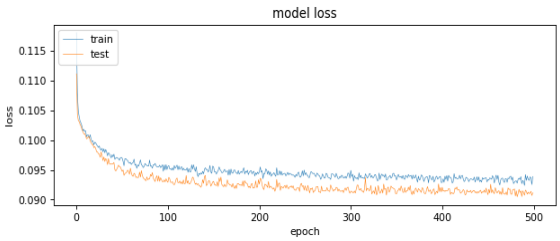


Fig8. Loss as a function of epoch

From the correlation matrix in 0, it can be known that the human preference has a positive correlation with the position of the robot arm when it is delivered, and the remaining items are almost irrelevant. The reason may be that the position of the person is only when the robotic arm is being submitted. As for the position at the beginning of the delivery or the robotic arm is moving, they may not care so much.

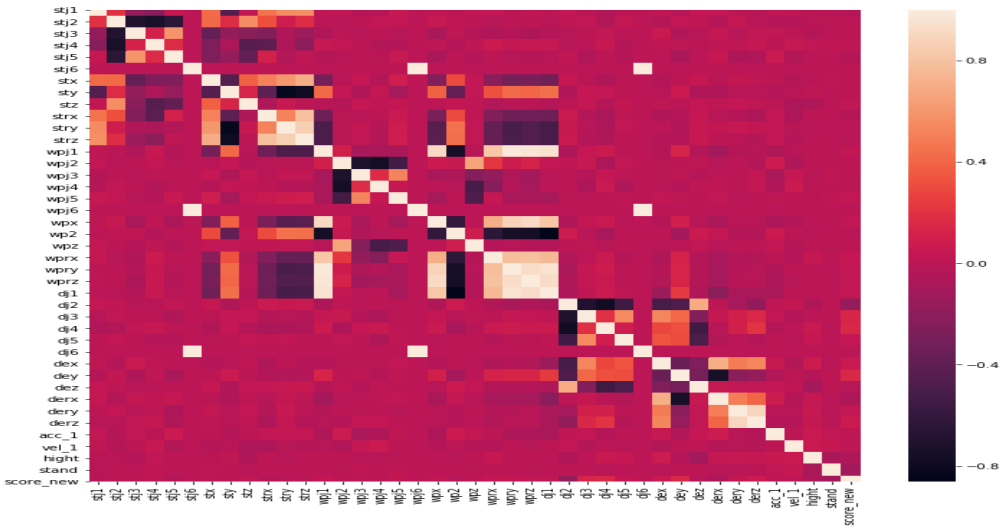


Fig9. Correlation matrix

It can also be seen that the position of the sixth axis of the robotic arm shows a positive correlation no matter whether it is at the beginning, during or after the submission. The reason may be that the sixth axis of the robotic arm belongs to the end of the robotic arm. He will lead the entire robotic arm to move, so the part in the moving direction will be the same. But in general, the subject's preference for the movement path of the robot arm is almost irrelevant in terms of position, speed, and acceleration.

V. CONCLUSION AND FUTURE WORK

The results from this study show that although RNN-LSTM can effectively build a model towards to human preferred paths prediction, some issues remain. Human preferences may be not reliable when compared to labels in other AI applications. For example, if we use CNN to train a set of images containing animals, the quality of labels (animal names, for example) is crucial. If one labels an image containing a dog as cat, such wrong information will result in bad prediction. That is, garbage in garbage out. This bad labeling issue usually does not happen for most AI applications as the labels are usually objective in nature. Human preference, however, is highly subjective. Different individuals may have different opinions and preferences. And even for a single person, the test-retest reliability for the preference to a robot path may still change from time to time. These inconsistency between and within subjects may lead to a less accurate prediction. We would suggest that objective measure such as human response time may be included as dependent variable to increase the prediction accuracy. The main decisive key still depends on personal preference.

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