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Procedia Manufacturing 3 (2015) 1442 – 1449

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Analysis of human grip strength in physical Human Robot Interaction

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Abstract

The purpose of this paper is to explore how an operator's grip plays a role in physical Human Robot Interaction (pHRI). By considering how the operator reacts to or initiates changes in control, it is possible to study the operator's grip pattern. By analyzingthe grip pattern, it is possible to incorporate their natural response in order to create safer and more intuitive interfaces. An experiment where an exoskeleton and human collaborate in order to complete a path following task has been chosen to measure the forces applied by the user at the handle to observethe interaction between the operator and robot. AThruMode Matrix Arraysensor has been wrapped around the robot'shandle to measure the applied pressure. By introducing the sensor it not only enables the measurement of applied forces and how theyare applied but also a measure of how tight the user is gripping the handle. Previous studies show that the natural response of a human to an unexpected event is to tighten their grip, indicating that howan operator grasps the handle canbe related to the operator's intention. In order to investigate how the operator's grip of the handle changes, the experiments presented in this paper examine two different scenarios which might occur during an interaction, the first where the robot attempts to deviate from the path and the second where the operator wishes to deviate to a new path.The results of the experimentsshow that whether the operator or the robot initiates the transition, a measurable change in how the operator grasps the handle.The information in this paper can lead to new applications in pHRI by exploring the possible uses of an operator's grasping strength.

Peer-review under responsibility of AHFE Conference

*Keywords:*Exoskeleton; Grasping strength; Physical Human Robot Interaction

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Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.320

1. Introduction

Theintegration of robots into the industrial and hospitality sectors has greatly benefited humans by providing assistance while performing physically demanding tasks [1]. When used by human operators, robots can improve the productivity of a task while simultaneously reducing the required effort of the operator. In recent years, the intelligence of robots has increased substantially, diversifying the roles which a robot can take, ranging from simple machines to fully autonomous robots. The proposed taxonomy of autonomy found in[2],categorizes a robot's Level of Autonomy (LoA) based on the contributions of the operator and robot in sensing, planning, and actuation. In modern industrial applications, a robot's LoAis usually found betweenassisted tele-operation where operator is in full control of the task and the robot is able to intervene in emergencies, and supervisory control where the robot performs all aspects of the task but the operator has override capabilities.Depending on the complexity of the task and the risks involved, a robot may be required to switch between more than one LoAduring its operation,and it is the nature of this role change which plays a major factor in Human Robot Interaction (HRI). If the robot is not fully autonomous, then determining whether the operator or robot has control over the system and how control is passed back and forth between the two plays an important role in the interaction.

In physical Human Robot interaction (pHRI) where the operator is in physical contact with the robot at all times, being able to correctly determine who should be in control has a direct influence on the safety of the operator. Previous literature dictatethat when an operator collaborates with a robot, the operator should always be in control, however, they should also be able to experience or initiate shifts between the different LoA[3].Over the years researchers have created a variety of methods to shift the LoA of a robot, from a simple switch to more complicated models like H-Mode which is a style of control inspired by the loose and tight rein control of horse riding[4]. The ability to take control of the robot in the event where it acts against the operator’s intention can reduce risks and assist in reducing injuries.

This paper aims to explore new ways to determine which agent is in control or determine when it would be safe to change the robot’s LoA. The majority of the existing methods would compare the applied force of the operator to a virtual force generated by the robot representing its intentions and then shift the LoA based on the difference between the two. The research in this paper will look at a new method of determining the operator's intentions by investigating how an operator holds the end effector of the robot. Previous research has shown that a human will instinctively tighten their grip when an object is unexpectedly pulled from between their fingers [5, 6].This work is to find out whether a similar instinctual response can be observed in pHRI when the robot acts undesirably. Experiments were performed with human subjects utilizing an upper limb exoskeleton to perform simulated grit blasting tasks. A sensor is used to measure the grip strength of the human operator during the task execution.

2. Experimental study

The aim of the experiment is to observe the grasping force of the operator in reaction to unexpected actions of a robot.The experiment will be based on the practical application of human robot collaborative grit blasting. Grit blasting is a physically demanding task where human operators are required to support the blasting nozzle’s reaction loads of up to 100N for prolonged periods of time [7], it is made more challenging by the operator’s poor visibility as a result of the dusty environment and the personal protective equipment that are required to be worn. The assistance of a robotic exoskeleton can reduce the forces transferred to the operator’s body, reducing the risk of physical injury.

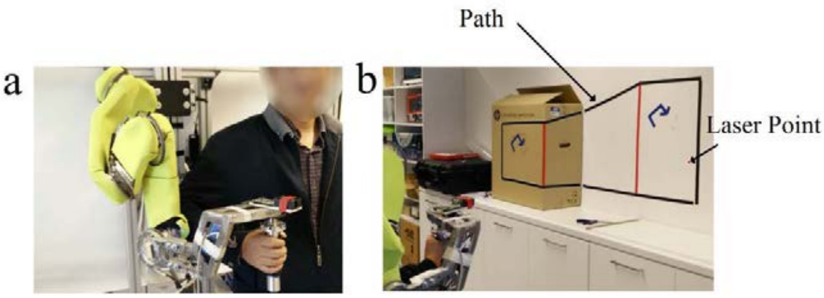

Fig. 1.(a) Upper body exoskeleton; (b) Planned path.

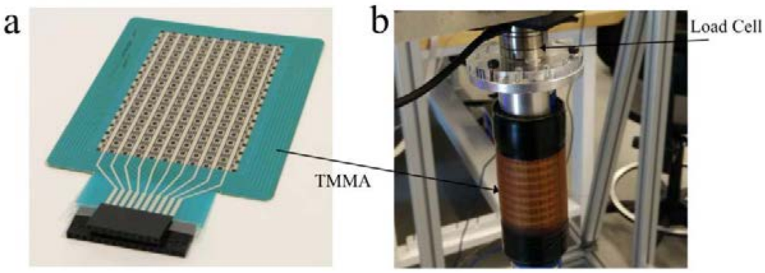

Fig. 2.(a) TMMA sensor; (b) TMMA on the end effector.

The upper limb exoskeleton shown in Fig. 1(a)is used in this experiment. The exoskeleton was specially developed for research on physical assistance applications and is controlled by applying forces to a handheld end effector [8]. For the purposes of this experiment, the exoskeleton has been equipped with a laser range finder which emits a visible light to simulate the blasting point and provides the operator with a visual representation of where the nozzle is currently pointing. The path which the operator and the exoskeleton will be following can be seen in Fig. 1(b). During the experiments a grit blasting scenario is performed with the operator controlling the movement of the laser range finder by applying forces to the end effector with the objective of following a path with the projected laser point.

A ThruMode Matrix Array (TMMA) sensor from Sensitronicsshown in Fig. 2(a) is used in this experiment to measure the grasping force of the operator. The flexibility of the sensor allows it to be wrapped around the cylindrical handlebaras shown inFig. 2(b). The TMMA sensor was previously used in [9] in a similar configuration together with a load cell in order to determine the direction and magnitude of the operator's applied force. In this experimentthe sensor has been covered with a rubber compound of shore hardness 20A to distribute the forces applied by the operator across the matrix array. Since the TMMA sensor is designed to be applied on a flat surface, wrapping the sensor onto the handlebar introduces noise into the system which is not present when the TMMA is laid flat. The recorded valuefor the TMMA sensor isthe sum of all the cell values.The readings of the TMMA sensor tend to oscillate, to condition the sensor readings the values are passed through a moving average filter and a minimum value threshold is established.

Two experiments are proposed to simulate events which may arise in the collaboration between the operator and the exoskeleton when performing a path following task. There are three values of interest, which are:

- F_H - the force the user applies at the end effector measured by the load cell in N
- F_G - the virtual guidance force generated by the exoskeleton at the end effector in N
- P_T - the sum of the pressure readings measured by the TMMA sensor in mV

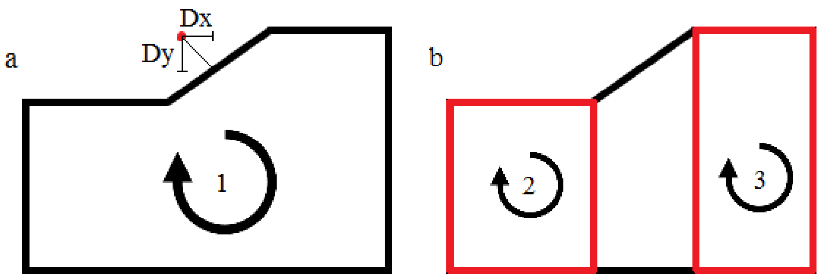

Fig. 3.(a) Path for Experiment 1; (b) Path for Experiment 2.

The control of the exoskeleton utilizes the measured interaction force F_H to implement an admittance control loop similar to that in [10]. The virtual force F_G is added into the admittance control loop to assist the operator, guiding the laser point to follow the desired path. The guidance force of the exoskeleton is given by:

$$F_{GX} = K_N \cdot D_X + K_T \cdot L_X \quad (1)$$

$$F_{GY} = K_N \cdot D_Y + K_T \cdot L_Y \quad (2)$$

$$F_{GZ} = K_P \cdot D_Z \quad (3)$$

Where D_X, D_Y is the distance between where the laser is currently pointing and the path and D_Z is the distance recorded by the laser rangefinder to the surface, L_X, L_Y is the distance from the laser pointer to the next point of interest, in this case corners, and K_N, K_T, K_P are constants.

Before the experiment begins, the operator will manually follow the paths seen in Fig. 3 with the exoskeleton in order to familiarize themselves with the operation of the exoskeleton. The goal of this step is to ensure that the subjects of the experiment are comfortable with the control of the exoskeleton regardless of their prior experience. Following this, the exoskeleton will be put into supervisory control mode for the experiments.

In the first experiment, the exoskeleton and the operator will follow path 1 shown in Fig. 3(a). The goal of this experiment is to observe the changes in force and pressure at the handlebar when the exoskeleton acts in an unexpected manner. The exoskeleton will provide the guidance force F_G required to follow the path and the operator will be asked to ensure that the laser pointer remains on the path. The operator will complete three loops of path 1, during which at certain time intervals the value of F_G will increase dramatically in a direction away from the path. This will result in the laser pointmoving away from path 1 until the operator manages to return it at which point the exoskeleton will once again continue along the desired path until the next disturbance. While moving along the path the forces and pressures will be recorded.

The second experiment will look at the situation where the operator is the one who wishes to diverge from the path. In this experiment the paths 2 and 3 shown in Fig. 3(b) can be followed by the exoskeleton, the exoskeleton will continually follow its current path until the operator decides to switch to the other one. Initially, the operator will feel resistance from the exoskeleton as it continues its guidance along the original path, however, when the magnitude of F_H exceeds F_G the exoskeleton will lock onto and switch to the closest path. In the second experiment because the operator decides when to initiate the change in path, the forces and pressures will be recorded over the course of three minutes during which the operator is able to freely follow and move between the paths.

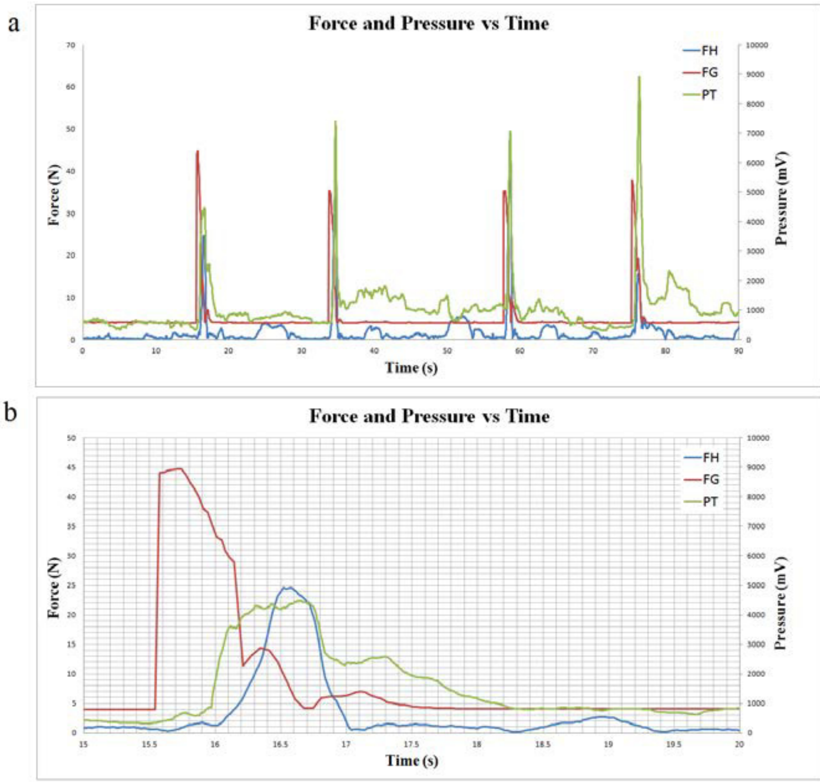

Fig. 4. (a) Experiment 1 Sample Result; (b) Close up of the disturbance from t=15s to t=20s.

3. Experimental results

3.1. Experiment 1

A sample result of the first experiment can be seen in Fig. 4(a), the characteristics of all results of the first experiment are similar to the one shown. In this experiment the goal was to observe the reaction of the operator at the handlebar when the exoskeletonmisbehaves. Fig.4(b) is a close up view of one of the disturbances generated throughout the experiment i.e. the force and pressure from 15 to 20 seconds.The results show a sharp increase in the value of F_G followed after a short delay by an increase in $P_T$and F_H. The delay between F_G and the other two readings can be attributed to the operator's reaction time. However the time delay between the TMMA reading and the load cell reading was not expected prior to the experiment but remained consistent over the course of many experiments.

This phenomenon was originally thought to have been caused by the exoskeletons handlebar pressing against the operator's hand the laser point moves off the path.However, if this was the case then the F_H would also increase simultaneouslywhich indicates that the net force was approximately zero. Although the load cell and TMMA sensor poll data at different frequencies, 50Hz and 120Hz respectively, it would still not account for the ~0.2s delay seen in Fig. 4(b). The delay shows that prior to the operatorpushing the exoskeleton's end effector to return to the desired path, the operator had already increased their grasping force on the handlebar.As the handlebar moves in operator's hand, the operator' body will react attempting to prevent the displacement of the handlebar resulting in a stiffening of the hand in the loading direction. In Johansson's work [11] he elaborates on how this automatic grip force response is a result of the body's attempt to prevent slips. If the operator's hand tenses then it makes sense that the grasping force measured by the TMMA sensor will also increase without an increase in F_H as the handlebar is encompassed by the operator's hand.This implies that before the operator consciously took action, their body had already reacted to the exoskeleton's misbehavior.

3.2. Experiment 2

In the second experiment, the applied forces of the operator on the handlebar were observed in the situation where the operator initiates a change. A sample result from the second experimentis shown in Fig. 5(a) reveal that F_H is rising and falling throughout the experiment. It is interesting to note that this pattern is not present in the operator's grasping force P_T.The sample chosen is representative of all the experiment 2 results as they all reveal similar characteristics. This difference in readings indicates that although the force applied to the end effector is fluctuating, the overall change in the grasping force of the operator is negligible, this could have been caused by operator adjusting their grip on the handlebar.

Taking a closer look at one of the instances where the operator decided to change the current path in Fig. 5(b), it appears that there are differences between this experiment and the previous one. The expected results were that as the operator is the one initiating the change in path, F_H and P_T will increase before F_G as the operator will apply forces to the end effector and the system will react to the change by producing a guidance force. While this appears to be the case, the reading from the load cell leads the TMMA reading by ~0.3s. The time delay means that although the operator had already applied force large enough to overcome the guidance force F_G, there was no significant measurable change in the overall pressure applied to the end effector. The time delay between the two readingswhen the operator is changing paths is consistent throughout the collected data for this experiment.

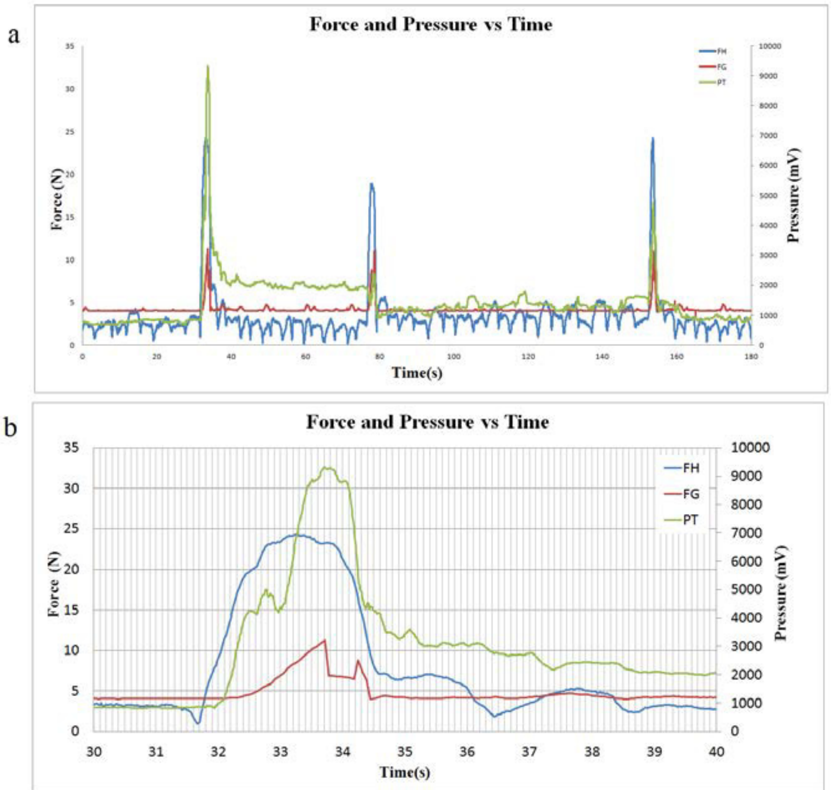

Fig. 5. (a) Experiment 2 Sample Result; (b) Close up of operator initiated change from t=30s to t=40s.

The two experiments demonstrate that the grasping force of the operator plays a role inpHRI between the exoskeleton and the operator. The results of the first experiment shows when an operator is physically collaborating with a robot, if the robot performs an unexpected action the operator will instinctively tighten their grip. In the second experiment in the case where the operator was initiating the change in control, theexperimental results indicated that the pressure readings measured by the TMMA sensor are not always reflected in the load cell readings and vice versa. The load cell measures the net force applied to the handlebar where as the TMMA sensor measures the forces from all directions which is a clear distinction between the two readings which raises the question of what the TMMA sensor can be used for.

4. Discussion and future work

In the experiments, the load cell placed in the end effector was used to determine the forces and torques which the operator was applying to the handlebar.The readings of the TMMA sensor, for the most part followed the trends of readings the load cell which indicates that there may be a potentially quantifiable relationship between the two.Previous works have shown that it is possible to use the TMMA sensor to obtain an idea of the operator’s intention with respect to force and direction. However, it is the differences between the two sensors readings which can lead to interesting research applications. From these experiments we notice that if an operator increases their grasping force but does not push or twist the end effector, what the operator is doing at the end effector is not reflected in the load cell readings. This property means that the grasping force of the operator could possibly be used as an additional system input in pHRI.

If the grasping force of the operator isused as an additional system input then there are hurdles which must be overcome before this can be realized. In pHRI, the operator will communicate their intention using a physical input; in this experiment handle held end effector performed this role. To be able to use the grasping force of the operator as an input, the grasping force must first be differentiated from the forces used to control the robot.The readings from the TMMA sensor are currently a combination of both grasping forces and driving forces. Once the grasping force is derived then it will be possible to look at different applications of the grasping force. From the first experiment it is known that when the exoskeleton performs an unexpected action that the operator’s grasping force increases. Following this train of thought, if the operator’s grip tightens as a result of an unexpected action, this implies that the operator desires additional control over the system as they have noticed that something has gone wrong. In pHRI, when the operator and the robot have shared control over the system, normally the operator must apply greater forces to overcome the robot’s intention, this can be seen in the second experiment where the exoskeleton wishes to continue along the same path but the operator wants to change paths. In our future work we will attempt to explore how the grasping force of the user can be used to shift the LoA of a robot and what effect this could have on the interaction.

In using the TMMA sensor, there have been a number of difficulties which ideally would be fixed in future applications. For the purposes of this experiment, the location of where the operator is applying the forces to the handlebar has been ignored. It is the combined pressure that is being used rather than the individual values of each cell. The TMMA sensor is a 10 x 16 array which is capable of not only determining the applied load but also where the load has been applied. In order to increase the frequency of the response, in this experiment the resolution has been dropped, ideally in future applications having being able to determine the location of the force can assist in determining the user intention. In previous works the acquisition speed of the TMMA sensor was ~10Hz when recording the location of the applied loads. However, in those applications the acquisition speed of the sensor was not a determining factor, but if the sensor is to be used in pHRI then speed of the response must be increased.If the rate can be increased then it would be possible to look at the contact points as well as the pressure applied to obtain more information about the operator’s intention. Aside from this, in the future molding a rubber layer on top of the sensor can improve the reliability of the sensor. By using a vacuum to remove all the air pockets that may be present in the sensor and the noise in the system may be reduced as the handlebar will be one solid piece. There is a lot of work to be done not only on the possible uses of an operator’s grasping force but also on the sensor itself to improve the quality and reliability of the results.

5. Conclusion

The experiments have confirmed the hypothesis that during pHRI an operator will instinctively increase the strength of their grip when the robot acts in an unexpected manner. The results of the experiment indicate that there are a number of differences in the use of a TMMA sensor when compared to a load cell. By considering the differences between the two readings in the future it may be possible to quantify an operator's grasping force by separating it from the forces the operator uses to drive the system. The benefit of the grasping force is that it provides additional information regarding the pHRI which may be used to improve the safety and control of current systems. The technology is in its early stages but it has the potential to be applied in the field ofpHRI.

Acknowledgements

This work is supported by the Australian Research Council (ARC) Linkage Grant (LP140100950), Burwell Technologies, and the Centre for Autonomous Systems (CAS) at the University of Technology Sydney, Australia.

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