Human adaptation towards a Force Augmenting Device: Experimental results

S. K. Gadi*[, a], A. Osorio-Cordero[b], Rogelio Lozano[b, c], R. Garrido[d]
[a]*FIME, Universidad Autónoma de Coahuila, Torreón, México*
[b]*UMI-LAFMIA, CINVESTAV-CNRS, Av. IPN 2508., Mexico City, Mexico*
[c]*Sorbonne Universités, UTC, Heudiasyc UMR 7253, Paris, France*
[d]*DCA, CINVESTAV, Av. IPN 2508., Mexico City, Mexico*

Abstract

This short communication article presents the experimental results showing the interaction between a human arm (HA) and a force augmenting device (FAD). Through these experiments, it is observed that the person adapts itself to achieve stability of the HA-FAD interaction after few trails. It provides recommendations for the designers and testers of FADs.

Keywords: *Force augmenting device, adapting human, ergonomics, human factor.*

1. Introduction

Humanity has employed machines since very long back in time to ease the performance of their tasks. The importance of their usage increases day by day. Before World War II, the machines were designed for a particular purpose, and the human operators had to learn to operate them i.e. human beings had to adapt to the machine. Nowadays, machines are designed to fit the operator characteristics giving birth to the science of ergonomics [1].

The avoidance of accidents in the human machine interaction (HMI) process is an important concern nowadays. HMI Safety can be improved giving importance to the human factor, e.g. it is observed that the reduction of the stress in the human operator contributes significantly to the reduction of accidents [2], [3].

Humans and machines have different abilities. Human beings have a great variety and a large number of sensors like 3D vision, hearing, touching, etc. These, help humans to perform high precision tasks even in the presence of uncertainties. On the other hand, machines are powerful, can perform repetitive tasks with high precision, without getting tired, can be connected to other machinery to transfer information [4], etc. Exoskeletons and force augmenting devices (FAD) are employed when humans require performing precise tasks that require power that they do not possess. Exoskeletons enhance the abilities of human beings, but the human being is the one who has the control of the man-machine process. There is a growing interest nowadays in the development of machines worn by humans to enhance their force [5], [6].

A FAD amplifies the human strength and lets the human operator handle heavy loads while still feeling a part of the load [7]. The human-machine interaction has been extensively studied [8]–[14].

* Corresponding author. Tel. & fax: (+52 1) 871 757 0239
E-mail address: research@skgadi.com

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This article extends the work presented in [14] by providing experimental results showing that humans indeed adopt themselves to manipulate the objects.

The next section presents the closed-loop system considered for this experiment. Simulation results and experimental results are presented in Section 3. Concluding remarks are given in the final section.

2. Experimental setup

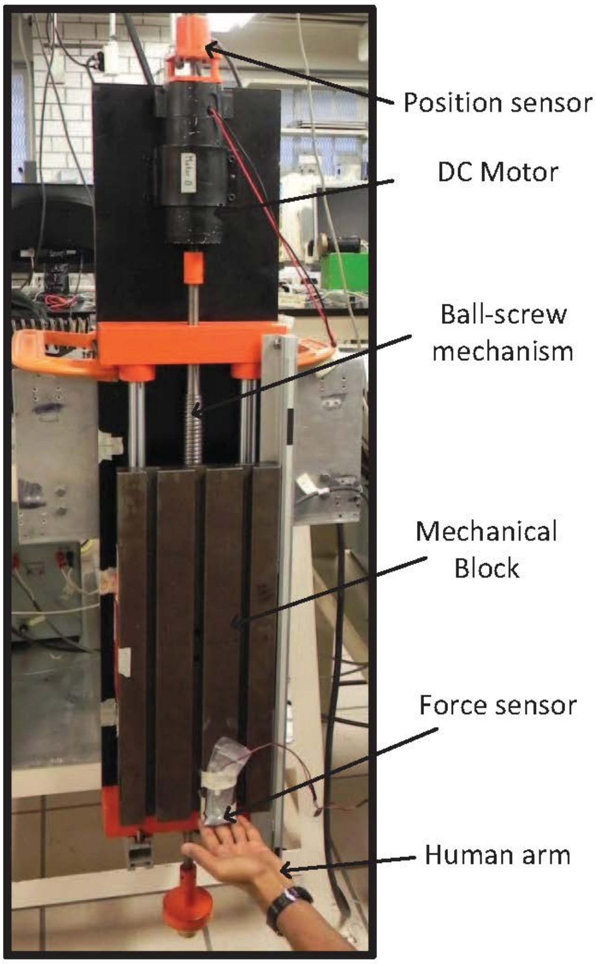

Figure 1. A Human operator is handing the force augmenting device (FAD).

Figure 1 shows a human operator handling the force augmenting device (FAD). The FAD is made of the following elements.

- A mechanical block of 24 Kg which serves as the load.
- A ball-screw mechanism which converts the rotational movement into linear movement.
- A DC servomotor to power the ball-screw mechanism. The motor's driver is configured to operate in the torque mode. So, the force applied to the moving block is proportional to the control signal.
- Rotary encoder to measure the motor position which allows calculating the position of the mechanical block.
- A force sensor to measure the force applied by the human arm (HA) over the mechanical block.

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- A PC with Quanser's data acquisition (DAQ) card is used as a controller for implementing the algorithm in Matlab Simulink. The DAQ lets the computer read the position and force sensor and send the control signal from the computer to the DC motor's driver.

The mathematical model for the HA-FAD is given as [14]:

$$F(t) = F_A(t) + F_e(t) - Mg, \tag{1}$$

$$\frac{y_e(s)}{F(s)} = \frac{1}{Ms^2 + K_f s}, \tag{2}$$

$$\tau_h(s) = J\ddot{\theta}_h(s) + B\dot{\theta}_h(s) + K(\theta_h(s) - \theta_v(s)), \tag{3}$$

$$\theta_v(s) = \theta_{vd}(s) + G_p(\theta_{vd}(s) - \theta_h(s)e^{-sd_1}) + sG_v(\theta_{vd}(s) - \theta_h(s)e^{-sd_2}), \tag{4}$$

$$F_e(t) = -F_h(t) = (y_h(t) - y_e(t))E, \tag{5}$$

$$y_h(t) = \theta_h(t)l_a, \tag{6}$$

$$\tau_h(t) = F_h(t)l_a = (y_e(t) - y_h(t))El_a, \tag{7}$$

where F is the total force exerted on the moving block, F_e is the force exerted by the human on the moving block, M is the mass of the moving block, g is the acceleration due to gravity, y_e is the position of the mechanical block, s is the Laplace transform complex variable, K_f is the viscous friction coefficient of FAD, τ_h is the external torque acting on the human joint, J is the human arm moment of inertia, θ_h is the human arm position, B is the viscous friction in the human arm movement, K is the muscle stiffness, θ_v is the output of the spinal cord's reflex action, θ_{vd} is the virtual desired position, G_p and G_v are the control parameters of the spinal cord, d_1 and d_2 are the delays in the position and velocity reflex feedbacks respectively, F_h is the force exerted by the moving block on the human arm, y_h is the human arm displacement at the end of the arm, l_a is the human arm length, and E is the physical compliance of the human flesh.

The control algorithm is given by

$$F_A(t) = (K_A - 1)F_e(t) - K_d\dot{y}_e(t) - K_p y_e(t), \tag{8}$$

where $K_A > 0$ is the augmenting factor that amplifies the force exerted by the human operator, the term $K_d\dot{y}_e(t) > 0$ introduces the required damping into the system, and $K_p > 0$ the is proportional gain [14]. It is proved that the HA-FAD interaction is stable for all the values of K_A provided that $d_1 = d_2 = 0$ [14]. In the case where delays are not zero, there is an upper limit for the augmenting factor K_A. A strategy to calculate the upper limit is also presented in [14].

New experiments are conducted on this FAD to verify that the human adapts to stabilize the system. These experimental results are discussed in the next section.

3. Experimental results and discussions

An experiment is conducted to study the HA-FAD interaction at a very high augmentation factor of $K_A = 100\times10^3$. Figure 1, 2 and 3 shows the experimental results conducted on three healthy individuals of age groups 10, 20 and 30. Individuals are instructed to lift the mechanical block and hold steadily at any position for few seconds and then drop it. Figure 2(a), 3(a) and 4(a) shows the HA-FAD interaction where the users handle the FAD for the first time. It is observed that they were unable to hold the mechanical block at a constant position, which reflects that the HA-FAD interaction is unstable.

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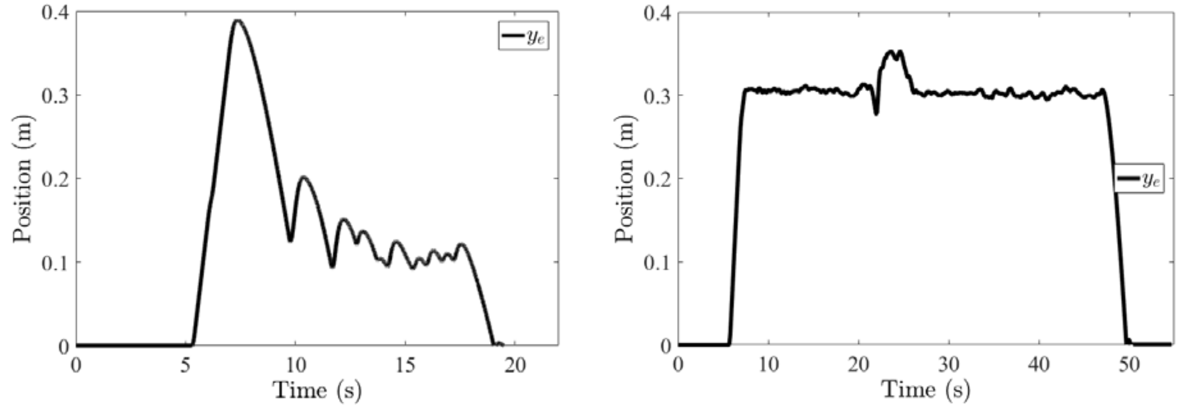
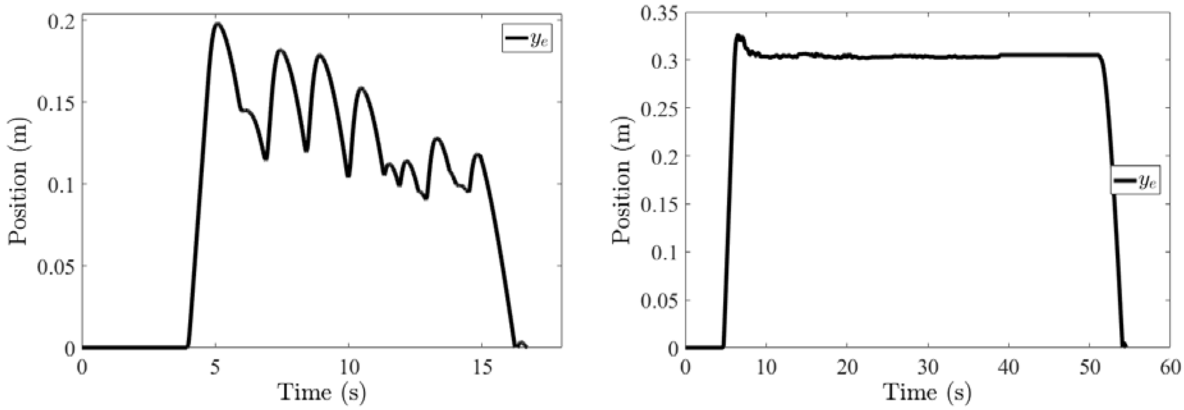
The individuals are asked to repeat the task for few more times. The third time HA-FAD interactions are recorded and displayed in Figure 2(b), 3(b) and 4(b). The graphs show that the interaction is stable.



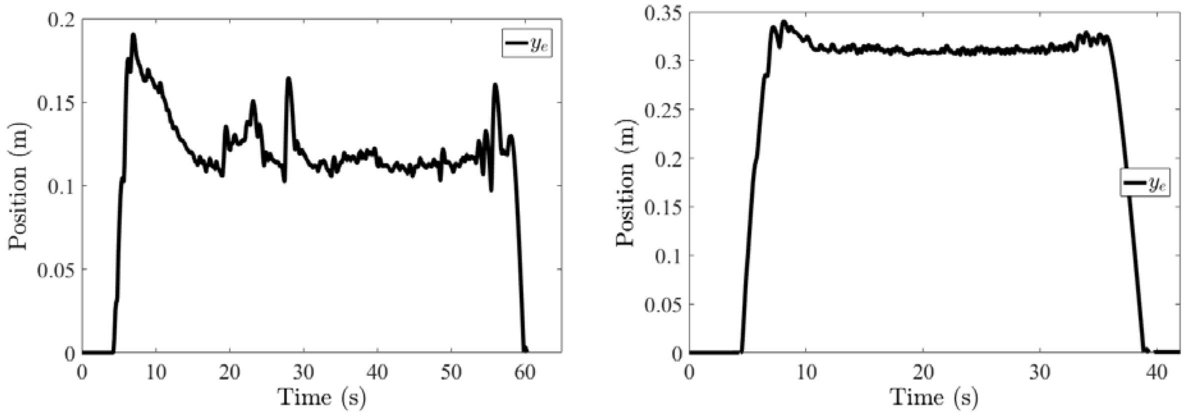
(a) Handling the FAD for the first time (b) Handling the FAD for the third time

Figure 2 A 10-year-old individual handing the FAD with $K_A = 100 \times 10^3$



(a) Handling the FAD for the first time (b) Handling the FAD for the third time

Figure 3 A 20-year-old individual handing the FAD with $K_A = 100 \times 10^3$



(a) Handling the FAD for the first time (b) Handling the FAD for the third time

Figure 4 A 30-year-old individual handing the FAD with $K_A = 100 \times 10^3$

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4. Conclusions

This work extends [14] to investigate the adapting capability of the human operator. In the light of the experimental results presented in the previous section, it can be concluded that the human operator adapts to stabilize the interaction. Since the parameters d_1 and d_2 cannot be changed, the parameters G_p and G_v associated with the human operator's reflex action are capable of adapting. The simulation results presented in [14] also suggest that by selecting the parameters G_p and G_v an unstable interaction can be converted to a stable one.

These results confirm the importance of considering human factor into the FAD's design to reduce the stress on the human operator. Also, it recommends using new test subjects for the testing of FADs with high augmentation factor.

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