# Quantification of Upper-limb Target Acquisition within Various Impedance Fields Using Force Reflecting Joysticks

Xin Feng, Jack M. Winters
Department of Biomedical Engineering, Marquette University, Milwaukee, WI 53233

## ABSTRACT

Robotic devices, especially those that are motivating, have shown a great deal of potential for use in upper-extremity stroke rehabilitation. In this pilot study, we used an interactive home rehabilitation system called UniTherapy in conjunction with commercial force reflecting joysticks to study assessment and therapeutic tasks, as well as usability of the system. The focus of this paper is on target acquisition tasks made by able-bodied subjects under various impedance fields. Key observations are that a resistance impedance field significantly decreases tracking accuracy and a spring assistance impedance field will significantly improve such performance metrics.

**KEYWORDS:** upper-extremity assessment, neurorehabilitation, impedance field, robotics

## INTRODUCTION

Recent research has shown that upper extremity robotic manipulators can provide significant therapeutic benefit, specifically to individuals with stroke-induced arm impairment [1]. Impedance control as used here provides dynamic force fields for resistance and assistance during tracking tasks [2]. While it has been widely used in the rehabilitation robotics research for intervention (e.g. for path channel assistance during tracking tasks) or research (e.g. after-effects of applied fields on subsequent movements), there are fewer studies made to compare the performance metrics under various impedance field. This paper reports on the analysis of a subset of data obtained during a human subjects study of goal-directed tasks performed by able-bodied subjects and stroke-induced functional arm impairment subjects, in this case for tracking of "cross" spatial patterns with 3 point and 5 point in each line by able-bodied subjects.

## METHOD

### A. Experiment System

The UniTherapy system [3], together with various joystick manipulators, was used in this pilot study. Input devices compliant with the Microsoft Windows/DirectX platform (e.g. joystick, driving wheel, mouse, trackball, and keyboard) can be used within UniTherapy. The user has access to a diverse menu of assessment tasks with the available toolboxes, and can use these together with other services that include a protocol manager, a data analysis tool, and a telerehabilitation link. The focus of this paper is on use of a commercial force reflecting joystick (Microsoft Sidewinder), which has two degrees of freedom and can be programmed a series of force effects such as constant, spring and damper at 33Hz.

### B. Subjects Protocol

Eight normal subjects participate in this pilot study, four male and four female with ages ranging from 21 to 43. All participants were experienced computer users, with 10-40 hours of personal computer use per week, which ensures that their performance would not be affected by their previous experiences with using computer programs. Half of the subjects were physical therapists and occupational therapists who also held faculty appointments, and the other half were engineers or engineering students.

As shown in Fig. 1, the subject was first oriented with a force reflecting joystick fixed to a cart (optional arm support) at a position of comfort, generally located lateral and anterior to the shoulder joint. Instructions were given as to how the device worked, and practice time was provided until the participant

felt comfortable making accurate goal-directed movements.

<< *Insert Fig. 1: Subjects using the conventional joystick..* >>

Subjects then completed a suite of goal-directed tasks by their non-dominant limb, which in all cases was their left. For the target acquisition tasks that will be discussed here, participants viewed square targets displayed on the computer screen, and were instructed to make movements to the target as quickly and accurately as they can. Once the subjects get into a target region ("target window"), they receive positive visual feedback by a change in color, and are then instructed to stay as stable as possible for a threshold of success time (defined as "dwell window," DW); DW used in this study is set to 1 second. After successful completion of DW, the target jumps to the next predefined position. The target acquisition tasks presented here consisted of cross patterns with three (3PC) or five points (5PC) in each line, as three point cross pattern shown in Fig. 2. Each of these patterns was repeated three times.

<< *Insert Fig. 2: Three point cross pattern task* >>

The three point cross task was repeated with each of anti-spring (3PC_SR) and damper (3PC_DR) resistance force fields, with the force algorithm being:

$$\text{For 3PC\_SR,} \quad F_{x,y} = -k*(Subject_{x,y} - T\arg et_{x,y}) \qquad (1)$$

$$\text{For 3PC\_DR,} \quad F_{x,y} = -b*(Subject_{x,y}{}' - T\arg et_{x,y}{}') \qquad (2)$$

where $k$ represents the spring coefficient, $b$ represents the damper coefficient, $Subject_{x,y}$ represents the subject position at x and y axis, $Target_{x,y}$ represents the target position at x and y axis.

The five point cross task was repeated with each of spring assistance (5PC_SA) and experimenter dependent spring assistance (5PC_EA) force fields, with the force algorithm being:

$$\text{For 5PC\_SA,} \quad F_{x,y} = k*(Subject_{x,y} - T\arg et_{x,y}) \qquad (3)$$

$$\text{For 5PC\_EA,} \quad F_{x,y} = k*(Subject_{x,y} - Experimenter_{x,y}) \qquad (4)$$

The experimental setting of 5PC_EA is unique in that the experimenter uses the second force reflecting joystick to "assist" the subject to get into the target, where the assistance field is dependent on the experimenter's position.

C. Performance Metrics

Table 1 presents a subset of the performance metrics that were used in the data analysis. These metrics aim at assessing quickness, accuracy, smoothness and stability of goal-directed tracking movements.

<< *Insert Table I: The performance metrics used within the data analysis* >>

## RESULTS AND DISCUSSION

The mean and standard deviation value of performance metrics discussed in the above section are shown in Fig. 3. These data shows that:

- The reaction time (RT) of 5 point cross with spring assistance (5PC_SA) task is significantly lower than other tasks, which can be well explained in that instead of the normal sensorimotor latency, with the spring assistance force-field there is a mild force that starts to pull the subject towards the new target location immediately, but must first overcome inertia. Notice that the RT for the others was not a function of impedance settings, which is as could be expected.
- The movement speed (MS) of 3 point cross with spring resistance (3PC_SR) task is lower than other tasks – this makes sense since the subjects had to overcome the anti-spring resistance field.

- The peak number (PN) is considerably higher for spring resistance (3PC_SR) and damper resistance (3PC_DR) tasks than four other tasks, which suggests that subjects broke the whole movement into several subcomponents. Also, the PN of 5PC_SA is lower than others, which indicates that subjects make smoother movements under spring assistance force field.
- The average error (AE) of resistance tasks (3PC_SR, 3PC_DR) is higher than four other tasks, which indicates that accuracy or time to target is worse than for other tasks. Also, the AE of 5PC_SA task is considerably lower than others, which indicates that accuracy is improved due to the spring assistance force field.
- The distance ratio (DR) of resistance tasks (3PC_SR, 3PC_DR) is considerably higher than four other tasks, which indicates that subjects had more path curvature in these tasks.
- The stay percentage in dwell window (SPDW) of the 3PC_SR task is lower than the expected value near 1.0 that is seen for the other tasks, which indicates that even when subjects had moved into the target, the anti-spring resistance field could still potentially make the subjects stay unstably.

<< *Insert Fig. 3: The mean and standard deviation value of performance metrics in selected target acquisition tasks* >>

In summary, we found that the resistance impedance field, especially anti-spring field, considerably diminished the tracking smoothness (PN), accuracy (AE, DR) and stability (SPDW), and that the spring assistance field considerably improved the tracking smoothness (PN) and accuracy (AE, DR). These results clearly show the influence of impedance field on the tracking movement performance of normal subjects. Without presenting the results here, we found the similar trends within the stroke subjects group.

## REFERENCES


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## ACKNOWLEDGMENTS


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## Author Contact Information:


Xin Feng, MS, Marquette University, Biomedical Eng. Dept, 1515W, Wisconsin Ave, WI, 53233
EMAIL: xinfeng@mu.edu

## GAPHICS PAGE

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Fig. 1: Subjects using the conventional joystick

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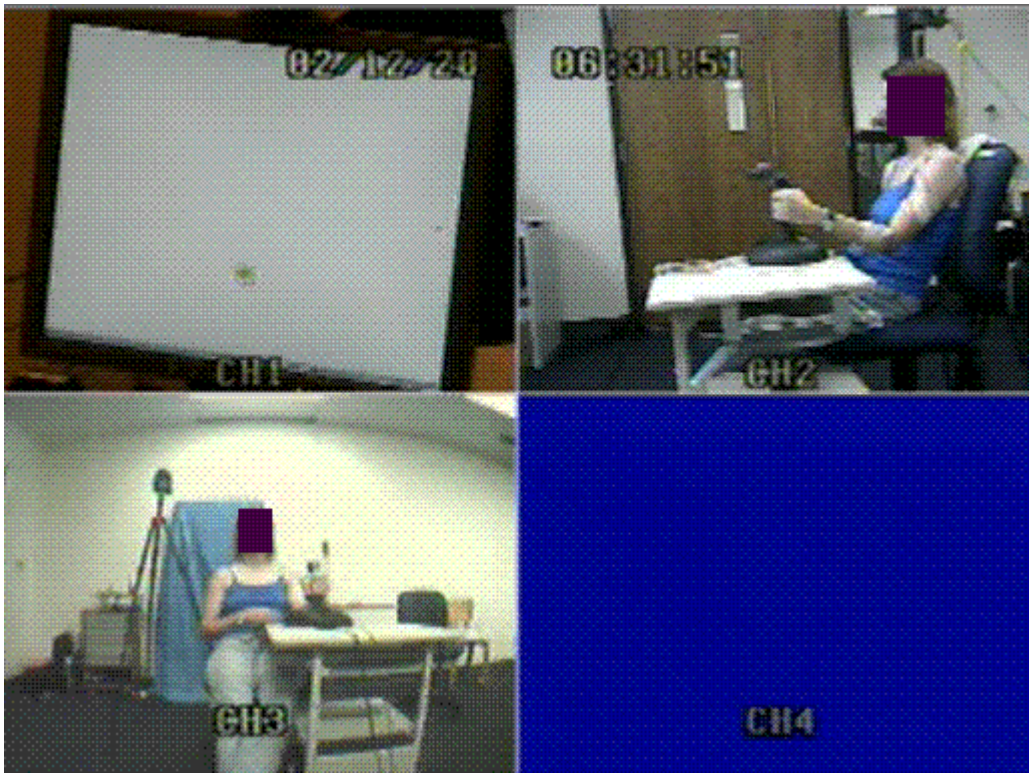


**Alternative Text Description for Fig. 1: Subjects using the conventional joystick:**
Sample video frame with the subject using the conventional joystick; the views are the computer screen (top left quadrant), lateral or sagittal view (top right quadrant) and anterior or frontal view (bottom left quadrant).

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Fig. 2: Three point cross pattern task
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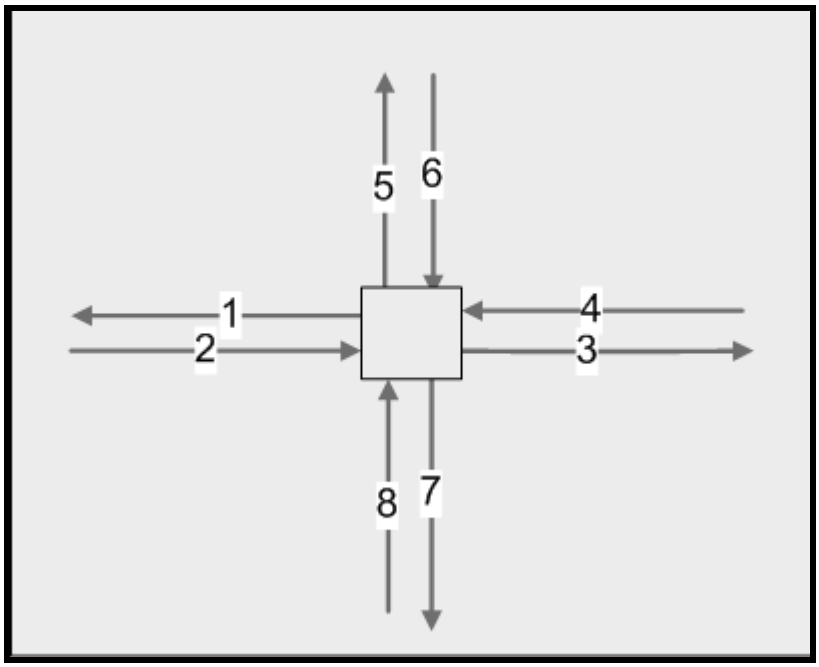


**Alternative Text Description for Fig. 2: Three point cross tasks:**
3 Point Cross pattern was screen centered encompassing close to the full horizontal and vertical range of device with the target starting at the center of the screen, and jump to left, right, up and down position, after each go back to the center position once. There are 9 targets per cross pattern.

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Table 1 the performance metrics used within the data analysis

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| Performance Metric | Definition | Remarks |
|---|---|---|
| ***Reaction Time (RT)*** | The time from the movement of the target to the first significant movement made by the user detected by an algorithm based on either three quick movements or five positive movements towards the target. | Reflects the human-machine system response capability. |
| ***Movement Speed (MS*** | Derived from the Movement Time (the time between the end of the reaction time to the time after which the user has stayed within the target window for 4 consecutive samples); to make comparison easier. *MS*, which is the average speed within the movement time window is used here instead. | Reflects the effective quickness of the movement performance. |
| ***Peaks number (PN)*** | The number of peaks in a low-pass filtered speed profile has been used to quantify smoothness in healthy subjects. | Fewer *PN* represent fewer periods of acceleration and deceleration, making a smoother movement. |
| ***Average error (AE)*** | $Error_{Avg} = \sum_{1}^{n} \sqrt{(x_{t_i} - x_{s_i})^2 + (y_{t_i} - y_{s_i})^2)} / n$ (5) where $t_i$ and $s_i$ represents to the x or y coordinate of the target (t) and subject (s) positions at measurement sample I, n represents to the number of samples. | *AE* provided an indication of overall performance accuracy and quickness. |
| ***Distance ratio (DR)*** | Defined as the ratio of subject movement distance over the target distance. | The higher DR indicates more curvature in the overall movement. Ideally this value should be close to 1. |
| ***Stay percentage in Dwell window (SPDW))*** | Defined as the percentage of time subject staying in the target during the dwell window period. *SPDW* is in the range [0, 1], | The higher value indicates a better performance to stay stably. Ideally this value should be close to 1. |

**Alternative Text Description for Table 1 the performance metrics used within the data analysis:**
These metrics aim at assessing quickness (reaction time, movement speed), accuracy (average error, distance ratio), smoothness (peak number) and stability (stay percentage in dwell window) of goal-directed tracking movements.

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Fig. 3: The mean and standard deviation value of performance metrics in selected target acquisition tasks

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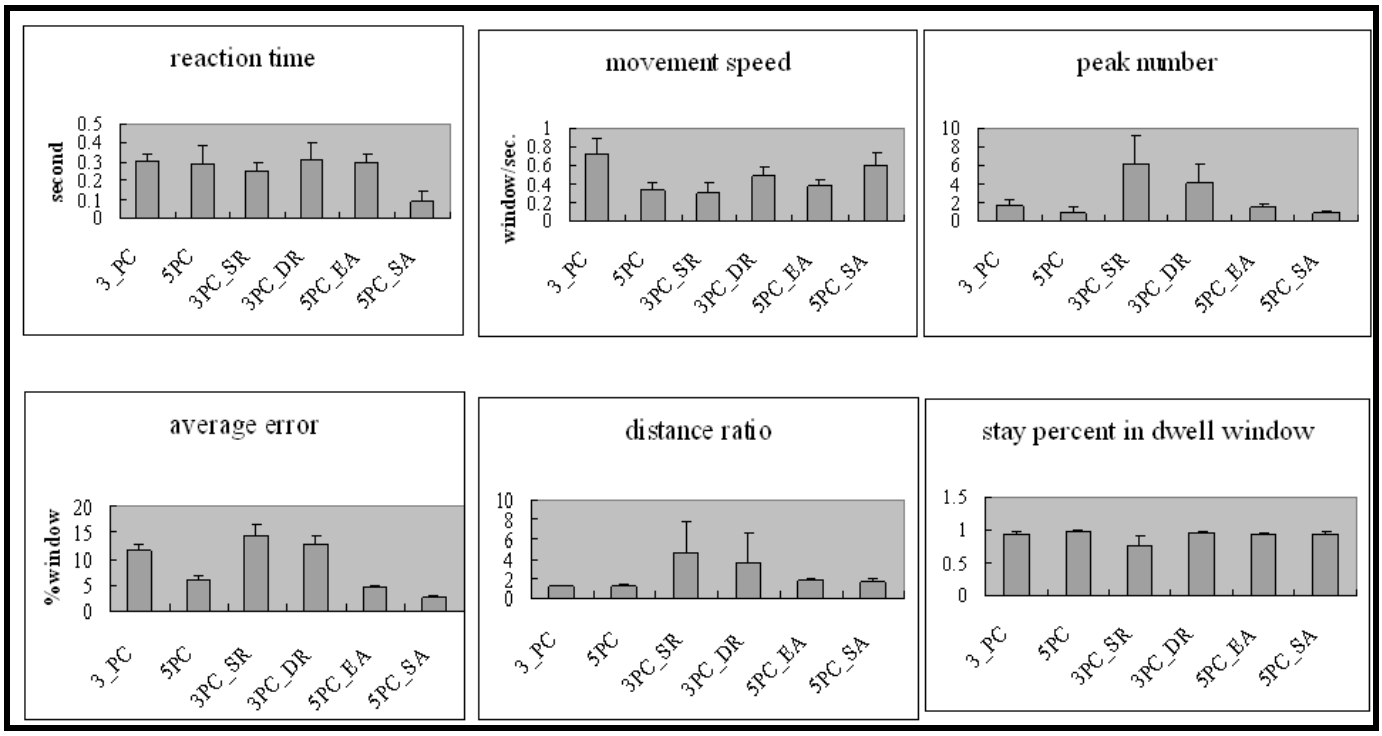


**Alternative Text Description for Fig. 3: The mean and standard deviation value of performance metrics in selected target acquisition tasks**

Top left is reaction time, with most values around 0.2 or 0.3 second, except 5PC_SA, which is under 0.1 second. Top middle is movement speed. Top right is peak number, with most values around 1 or 2, except 3PC_SR and 3PC_DR considerably higher. Bottom left is average error, with 3PC_SR and 3PC_DR considerably higher and 5PC_SA considerably lower. Bottom middle is distance ratio, with most values under 2, except 3PC_SR and 3PC_DR considerably higher. Bottom right is stay percent in dwell window, with most values close to 1, except 3PC_SR is considerably lower. Abbreviations: *3PC*: 3 point cross; *5PC*: 5 point cross; *SR*: spring resistance; *DR*: damper resistance; *EA*: experimenter dependent assistance; *SA*: spring assistance.