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Tele-Evaluation based on quality and quantity of hemiplegic children movements

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ABSTRACT Continuation of rehabilitation processes is a key element for success. Home-based therapy has become one of the major therapies' types in terms of continuation. Evaluate patients' progress in home-therapy is critical for therapeutics. This study concerns meanly on simulating human techniques of evaluation by recruiting available mathematics methods in order to make assessment decisions. A haptic device is embedded with virtual reality scenarios in order to build the upper limbs tele-rehabilitation system. Fuzzy logic concept is used in this novel evaluation method to enable us to ensemble both: I) Data related to the quality of movements; and II) Data related to the quantity of those movements. Then, calculate the functional enhancement of concerned affected upper limbs by study the changes of the function motions of those limbs. Finally, provide therapists with objective evaluation to help them judging the rehab process. The evaluation system was used for two children who were used the rehab system.

Keywords: Upper limb rehabilitation, haptics and virtual reality, fuzzy logic, evaluation.

تقييم عن بعد يعتمد على جودة وكمية الحركة للأطفال المصابين بالشلل النصفي

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الملخص استمرار عمليات إعادة التأهيل هو عنصر أساسي للنجاح. أصبح العلاج في المنزل أحد أنواع العلاجات الرئيسية من حيث الاستمرارية. يعد تقييم التقدم ومستوى الشفاء للمرضى في العلاج المنزلي أمراً بالغ الأهمية في العلاجات. تهتم هذه الدراسة بشكل أساسي بمحاكاة التقنيات البشرية للتقييم من خلال توظيف أساليب الرياضيات المتاحة من أجل اتخاذ قرارات التقييم. يتم تضمين جهاز الروبوت اللمسي مع سيناريوهات الواقع الافتراضي من أجل بناء نظام إعادة التأهيل عن بعد للأطراف العليا. يستخدم مفهوم المنطق الغامض في طريقة التقييم الجديدة هذه لتمكيننا من تجميع كل من: (1) البيانات المتعلقة بجودة الحركات؛ و (2) البيانات المتعلقة بكمية هذه الحركات. ثم، القيام بحساب التحسن الوظيفي للأطراف العلوية المتأثرة المعنية من خلال دراسة التغييرات في الحركات الوظيفية لتلك الأطراف. أخيراً، القيام بتزويد المعالجين بتقييم موضوعي لمساعدتهم في الحكم على عملية إعادة التأهيل. تم استخدام نظام التقييم على طفلين ممن قاموا باستخدام نظام إعادة التأهيل.

الكلمات المفتاحية: إعادة تأهيل الطرف العلوي، الروبوتات اللمسية والواقع الافتراضي، المنطق الغامض، التقييم.

I. INTRODUCTION

Hemiplegia is an illness caused by brain damage, it can be defined as disability on one half of the body, and it is a part of Cerebral Palsy (CP) [1, 2, 3]. Several weaknesses in upper limb's abilities have been stated as CP's consequences by many authors [4, 5, 6]. Remarkable upper limbs' (UL) enhancements have been noticed; especially in its functionalities. For example, a reduction of arm dysfunctions has been reported as well as important improvement in its functions because of the applied arm task-oriented training rehabilitation therapy Song, [7, 8, 9]. The judgment of a rehabilitation process is largely based on derived results from functional and impairment evaluation. Therapists usually use these outcomes to make their final decision about the next step in the up going therapy as well as the overall therapy's plan [10, 11]. Those decisions mainly based on the results of used assessment methods. Actually, there are various methods of assessment, that are used by therapists, which can be divided into two categories: self-report measures and performance measures. Self-report measures comprise of Motor Activity Log (MAL) and Stroke Impact Scale. Whereas, performance measures comprise of Action Research Arm Test (ARAT), Box and Block

Test (BBT) Chedoke Arm and Hand Activity Inventory (CAHAI), Jebsen-Taylor Hand Function Test, Nine-Hole Peg Test, and Wolf Motor Function Test (WMFT) [12].

Self-reports measure is an evaluation method where therapists have to prepare a set of questions; these questions are made based on therapist experiences. And then, patients have to answer those questions in order to make a decision on each case individually. Whereas, performance measure is an evaluation method where therapists have to time and rate the performance of affected upper limbs during the therapy process. Both methods are required the presence of concerned qualified therapists in order to make final decisions. However, therapists have frequently asked that they desire a measurement instruments sets. Those sets have to be built based on therapists' experiences; then to be applied automatically with less user intervention, modifications and interruptions [13].

Performance improvements and impairments assessment routines are crucial in decision making circles which are performed by therapists [14, 15]. In fact, there are various rehabilitation systems that use robotics and haptic devices as main rehabilitation devices [16, 17, 18]. However, the majority of those devices are employed to guide patients during patient passive-mode rehabilitation process [19, 20]. Otherwise, they are employed to restrict patients' movements during patient active-mode rehabilitation process [21, 22]. Although these processes have shown interesting results and improvements, most of those process are unable to measure both impairment and enhancement levels of patients' performance. So, therapists use above methods of assessment.

Evaluation methods of the progression of patients in rehabilitation systems like self-report or performance measures are regularly performed by therapists at certain schedules and times. Those evaluations provide therapists with the meanwhile enhancements and impairments; not the overall progression history during all rehabilitation processes. This might make the decision about the patient performance and the level of enhancement such hard work.

Assessment specialists (medical doctors and/ or therapists) build their evaluation of patients' performance based on both quality and quantity of desired movements. They notice the movement's accuracy of targeted upper limbs during performing tasks to make their decision about the movement's quality; and also, they notice the movement's speed and velocity of targeted upper limbs during performing tasks to make their decision about the movement's quantity. Their final decision is built on both notices with certain priorities based on their experiences. In this work, an intelligent evaluation system which simulates assessment specialists' steps of decision making process is developed. This evaluation system uses the collected data, which represent the quality and the quantity of a certain movement, from the system itself to build the desired decision about each movement. The number of collisions with virtual obstacles in virtual reality scenes represents the quality of the movement; whereas, the needed time to complete a proposed task represents the quantity of the movement. This developed evaluation method has used the fuzzy logic concept in order to provide therapists with final decision about each movement. in fact, fuzzy logic concept has been used in perceptual image quality assessment [23]. And also, it has been used to provide an assessment about the behavior of a machine system [24]. Both approaches have illustrated the usability of using fuzzy logic concept in assessment field.

The application of this evaluation method will be a novel approach in terms of an aggregation of possible objective judgments, based on specialists and therapists' experience in assessment field, and provide them with the history of the performance based on the quality and the quantity of movements.

II. METHODOLOGY

In this method, techniques of assessment specialists, when they judge a performance, will be simulated. In other words, each movement has its related parameters to the quality and the quantity of that movement. Specialists use those parameters to make the decision about the performance. But they do not use those parameters individually; instead, they combine them under a certain mechanism, which will respect the priority of each parameter over others, to reach appropriate area for the performance decision as can be seen in Fig 1. For example, if they make their decision based on the quality of the movement (Accurate) the result will be inappropriate, because they built their decision based just on the quality of that movement. Also, the result will be different if they based their decision on the quantity of the movement (Speed) and so on…

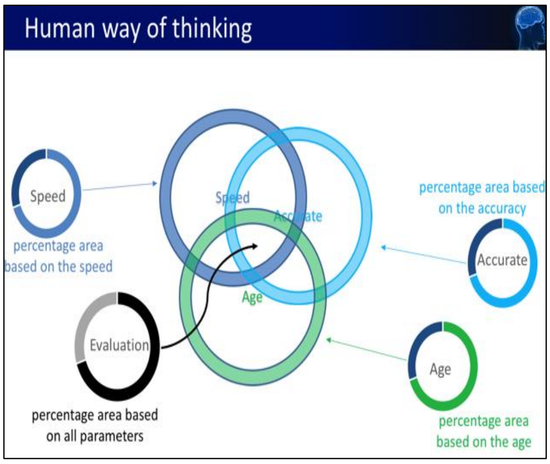


Figure 1: decision making process

In Fig 1 we have represent the human way of thinking when they judging a performance in order to create an algorithm which will simulate this way of thinking.

In this section, we will present the experimental procedure which contains the participants, the protocol and the procedure.

a. Participants

Two children, 5/7 years old, 114/129 cm, 22/27 kg, boys (S1, S2) respectively, were participated in

2018 at Polytechnic University of Hauts-de-France. They were chosen to test the feasibility of the system and its usability for the therapists. Children were chosen based on their ability to practice all proposed joints' recruitments and see if these movements have been correctly transformed to decisions.

***b.* Protocol**

Subjects have used the novint falcon haptic device along with VR scenarios for five days, two times a day, and for five minutes in each attempt, in order to practice all possible normal joints' recruitments that are needed to perform relative ADLs in the future. Each subject has played the three proposed scenarios in each session. In fact, subjects have experienced Shoulder and Elbow Flexion-Extension movements in the first scenario, Shoulder-Lift Elbow-Extension movements in the second scenario and Elbow Pronation-Supination movements in the third scenario.

c. Setup

Cinematic schemas were developed by using a 3D Virtual Reality (VR) application to control the behavior of the novint falcon haptic device which was used as the therapy hardware. This 3 degree of freedom (DOF) haptic device was used to determine the actual position of the impaired UL in the proposed scenario as well as the consumed time to perform one or more actions as can be seen in Fig. 2, the hand of the impaired limb applies an external force on the handle of the falcon to move the blue ball which represents the movement of the device in the VR scenarios, thus the external PC registers the position and the needed time to reach that final position or goal position, as well as the number of the connection between the hand and the force feed-back exerted by the falcon to redirect the hand in the proposed trajectory. And then, it uses these parameters to find out the diverse enhancement of different possible categories (time, position, accuracy…).

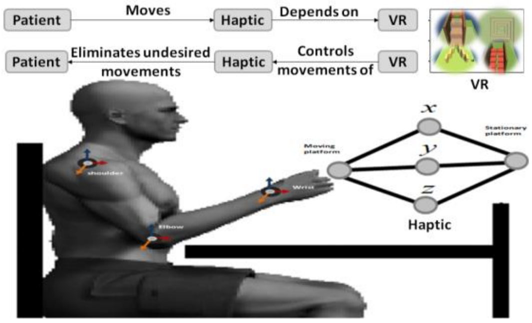


Figure 2: Subject with VR scenarios (Fig.3, Fig.4 and Fig.5)

***d.* Procedure**

1) Initial position

- For Shoulder-Elbow Flexion-Extension movements: The subjects were seated comfortably at a height-adjustable table in order to have their shoulder flexion at ≈ 45^{0}, elbow flexion at ≈ 135^{0} with the hips and knees flexed 90^{0} and both feet flat on the ground. Both elbows were rested on the table so that the shoulder was in the neutral position, the forearm was pronated, and the wrist was also held in neutral with the palms hold the handle of the falcon which was placed at certain height for each child in order to end up with 90^{0} of shoulder extension at their maximum reach. They have used a comfortable seat belt to reduce the trunk compensation, knowing that small amount of this type of compensation in this period of age is normal.
- Shoulder-Abduction Elbow-Extension movements: The subjects were also seated at a height-adjustable table in order to have their shoulder abduction at ≈ 45^{0}, and elbow flexion at ≈ 90^{0} with the hips and knees flexed 90^{0} and both feet flat on the ground. The haptic device was positioned in the right-hand side of the body to enable the children to perform the desired movements. They have also used a comfortable seat belt to reduce the trunk compensation.
- Elbow Pronation-Supination movements: The subjects were seated at a height-adjustable table in order to have their shoulder flexion at ≈ 0^{0}, and elbow flexion at ≈ 90^{0} with the hips and knees flexed 90^{0} and both feet flat on the ground. The haptic device was positioned in front of the affected side of the body to enable the children to perform the desired movements. They have also used a comfortable seat belt to reduce trunk and shoulder compensation.

2) Flexion-Extension movement

The purpose of multiple goals reach simulation is to improve bilateral shoulder and elbow movements, as well as reaching accuracy. The VR scenario shows a three-dimensional floor and roads with different spaces. Although Z axis will be fixed at a certain value and remains constant during performing this task, but different values of Z axis can be identified by producing several scenes with different degrees of Zs. However, X axis and Y axis of the novint falcon allow joints to perform shoulder and elbow flexion- extension movements. In addition, virtual obstacles impose the haptic device and then the UL to remain within the proposed trajectory, and make the trajectory towards the goal object more constricted by the time, so joints will be constrained to coordinate in certain normal mechanism in order to reach the goal object and enhance reaching accuracy as can be seen in Fig. 3.

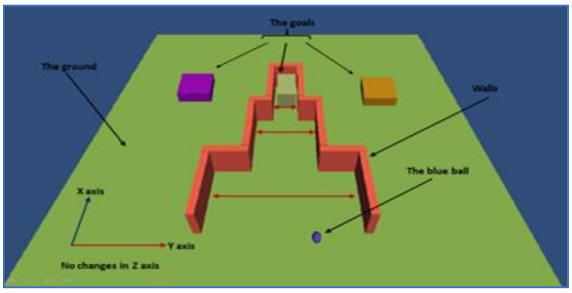


Figure 3: Multiple goals reach scenario

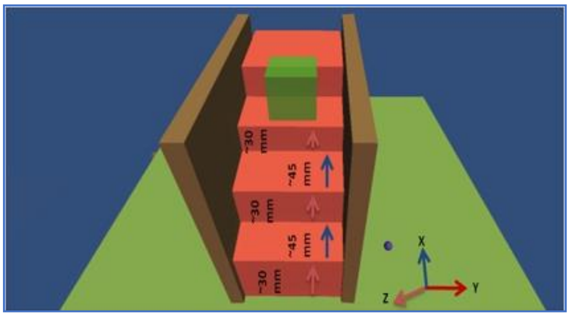


Figure 4: stairs climb scenario

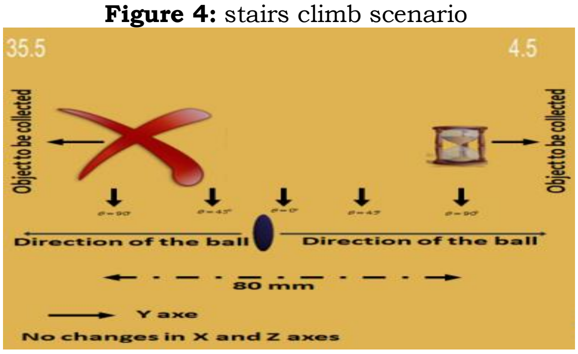


Figure 5: Collect moving objects scenario

3) Abduction-Adduction movement

The main interest of stairs climb simulation is to improve shoulder lift and elbow extension joints' coordinate. As can be seen in Fig 4, subjects were practiced shoulder lift and elbow extension by trying to move the blue ball to the goal object. However, all unwanted movements (abnormal joint recruitment) would be prevented by determining certain trajectory to reach the goal. This trajectory allows changes in (X, Y, and Z) axis of UL's joints. Virtual obstacles (stairs, walls, floor, and hidden sky) are developed to enable joints to move certain axis in each level of this scenario. Furthermore, climb a stair requires a successful shoulder/ elbow coordinate to move the blue ball to the next level, this coordinate was required each climb attempt with different Z axis.

4) Pronation-Supination movement

The main interest of collect moving objects is to improve elbow Pronation-Supination movements. As can be seen in Fig 5, subjects were practiced elbow pronation, supination, and pronation-supination movements by trying to move the blue ball in order to collect the moving objects which were presented in the VR scenarios. However, all unwanted movements (abnormal joint recruitment) would be prevented by determining certain trajectory to reach the goal. This trajectory allows changes in Y axis of the haptic device. The translate device, which responsible to transmit the rotation movement of the elbow to a straight movement in Y axis of the haptic device, enables the targeted elbow joint to perform Pronation-Supination movements. This scenario was developed to enable rotations with different angles such as 0^0, 45^0 and 90^0 in pronation movement, or 0^0, 45^0 and 90^0 in supination movement.

This movement can be performed by two joints to enable two different types of movements. First, Elbow Pronation-Supination, if the elbow flexion is at 90^0. Second, Shoulder Internal-External rotation, if the elbow extension is at 180^0.

III. DATA ANALYSIS

In all scenarios, the needed time to complete a task represents the speed of the UL during movements. So, as less the needed time as fast the movement of the UL. In fact, if the movement of the UL is fast then it can collect more objects. Thus, we consider this data for the needed time as quantity of the movement.

The collision with virtual obstacles imposes the contact between the UL and the force feed-back of the haptic device to redirect that UL to stay within the proposed trajectory. Thus, the number of collisions with virtual obstacles increases when a child attempt to make other movements or attempts to make a compensation movement to reach the goal point. In other words, the number of collisions represents the accuracy and smooth of the movement of the UL. So, as less the number of collisions as better the quantity of the movement is.

Each assessment category such as time, and number of collisions, needs to be analyzed, based on the proposed fuzzy approach, in order to determine its affiliation to that category level as following:

1) Patient enhancements: fuzzy approach

Zadeh has defined the fuzzy set as a generalization of crisp set [25]. Each individual in a fuzzy set has a certain degree of membership, which illustrates the level of compatibility of that individual with the concept of that fuzzy set. Each fuzzy set, F, is defined by the set of elements, X, which contains of each element (x) that verify the function F(x), in the closed interval [0, 1]. So, the degree of membership of x in F can be defined as: $\mu F(x): x \rightarrow [0, 1]$. The fuzzy set F is normal if $\sup_x \mu F(x) = 1$, so we distinguish two kinds of membership functions depend on the degree of membership, triangular form, and trapezoidal form to represent our assessment categories as follows:

2) Fuzzification

Inputs for the fuzzification are the time needed to complete a task (T), and the number of contact with the force feed-back or the number of collisions with virtual obstacles (N) which comes from the haptic device. T shows the movement progression in respect of time, for example as much the time is small as much the ability of that UL is increased in terms of the quantity. Whereas N shows the accuracy of that movement, because as much the patient performs the movement without the aid of the haptic device (less number of N) as much the accuracy is. In this section, we have used 5 fuzzy sets for each input: very small VS, small S, medium M, big B, and very big VB to include all possibilities for evaluating the movements. We choose triangular form and trapezoidal form to represent the different fuzzy sets as following:

For the triangular fuzzy member:

$$\mu F(x) = \begin{cases} 0 & \text{if } x < a \text{ or } x > c \\ \frac{x-a}{b-a} & \text{if } a \leq x \leq b \\ \frac{x-c}{b-c} & \text{if } b \leq x \leq c \end{cases} \qquad (1)$$

For example, as can be seen from Fig 6. The fuzzy set, S, which represents the small values for the time, contains the following parameters: a=5, b=10, c=15. So, the relation would be as follows:

$$\mu F(x) = \begin{cases} 0 & \text{if } x < 5 \text{ or } x > 15 \\ \frac{x-5}{10-5} & \text{if } 5 \le x \le 10 \\ \frac{x-15}{10-15} & \text{if } 10 \le x \le 15 \end{cases} \quad (2)$$

In our case, if the needed time to complete a task was a number between 5 and 15 seconds, so this particular time is judged as small. Then, we calculate its affiliation to that small area based on the calculation shown in (2).

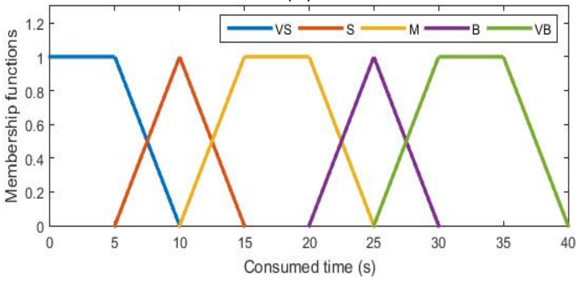


Figure 6: Overall expected levels of the proposals calculated when the maximum time is 40

For the trapezoidal fuzzy member:

$$\mu F(x) = \begin{cases} 0 & \text{if } x < a \text{ or } x > d \\ \frac{x-a}{b-a} & \text{if } a \le x \le b \\ 1 & \text{if } b \le x \le c \\ \frac{x-d}{c-d} & \text{if } c \le x \le d \end{cases} \quad (3)$$

For example, as can be also seen from Fig 6. The fuzzy set, M, which represents the medium values for the time, contains the following parameters: a=10, b=15, c=20, d=25. So, the relation would be as follows:

$$\mu F(x) = \begin{cases} 0 & \text{if } x < 10 \text{ or } x > 25 \\ \frac{x-10}{15-10} & \text{if } 10 \le x \le 15 \\ 1 & \text{if } 15 \le x \le 20 \\ \frac{x-25}{20-25} & \text{if } 20 \le x \le 25 \end{cases} \quad (4)$$

In our case, if the needed time to complete a task was a number between 10 and 25 seconds, so this particular time is judged as medium. Then, we calculate its affiliation to that medium area based on the calculation shown in (4).

The number of collisions levels and the level of enhancement are presented in Fig 7 and Fig. 8 respectively.

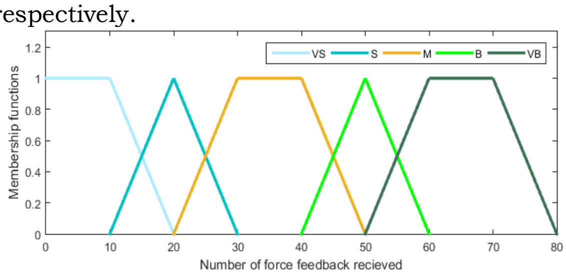


Figure 7: Overall expected levels of the proposals calculated when the maximum number of force feedback is 80

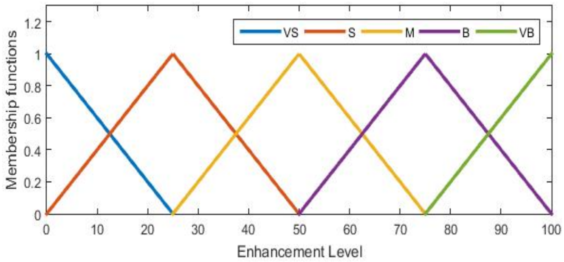


Figure 8: Overall expected levels of enhancement

3) Inference

In this section, we have used Mamdani method depend on the rules shown in table 1. And based on the schema general for fuzzy system which presented in Fig. 9. \

Figure 9: Schema general for fuzzy system

From Table 1, T is the needed time to complete a task, and N is the number of contact with the force feed-back during that task. This table is created based on the experience of the medical doctors who have the ability of judging movements. For example: If the time (T) is very small (VS) and the number of force feed-back (N) is very small (VS) then the decision (enhancement) is very big (VB), also If the time (T) is very big (VB) and the number of force feedback (N) is very big (VB) then the decision (enhancement) is very small (VS), and so on. Each field, for example VS, has limits form start point to end point. This period gives the possibility to determine the degree of affiliation of certain movement to that field as can be seen in section 5.

Table 1: Fuzzy rule table

N	VS	S	M	B	VB
VS	VB	VB	M	S	S
S	VB	B	S	S	VS
M	B	M	S	VS	VS
B	M	M	S	VS	VS
VB	M	M	VS	VS	VS

4) Defuzzification

Fuzzy outputs are combined into discrete values needed to drive the decision mechanism. And by applying the centroid method, we can find out the percentage of enhancement, this percentage helps the therapists to make their final decision as following:

$$E^* = \frac{\int \mu(E).EdE}{\int \mu(E).dE} \quad (5)$$

Whereas E^*, $\mu(E)$ are the enhancement level and the output of the inference rule respectively, for a given consumed time and number of force feed-back received during a movement.

In our case, we combine the two areas of assessment which are T and N. Then we calculate the center of that new area to find the percentage of the level of enhancement of each movement.

IV. EXPERIMENTAL RESULTS

• ***For the multiple goals reach:***

Both children were performing the suggested multiple goals reach scenario. By the time, the related data, such as the time needed to complete the task and the number of contact with the force feed-back, were collected by the system. Those collected data are used as inputs to the Fuzzification. And then we have applied the proposed fuzzy logic strategy to have the final decision. This decision depends on inputs parameters presented in Fig. 10.b. After several attempts of this particular movement a line chart, that illustrates the comparison between the quality and the quantity of this movement in the different attempts, was drawn to help the therapists to make their choice about the following stage in the therapy process as can be seen in Fig. 10.c.

The different positions of the handle of the novint falcon, from the start point to the end point, were collected to draw the trajectory that represents the movement as can be seen in Fig. 10.a. An ideal trajectory was drawn for each type of movement. This ideal trajectory represents the correct joint recruitment from the start point to the end point without collisions with the virtual walls or haptic feed-back. The ideal trajectory was drawn by the developers to be compared with other trajectories of children when performing the same scenario.

Achieved trajectories from different attempts by children were compared with the ideal trajectory drawn in green, to see the level of movement accuracy at each attempt. At each trail, the drawn trajectory was compared with the relevant decision, which was come from the fuzzy strategy, to see the harmony between these two methods of assessment.

First of all, we are going to apply the fuzzy approach on the attempt number five as an example. As can be seen from Fig. 10. b, and c, T=21.7s, and N=33. First of all, fuzzification needs to be performed as following: For the given T, and from the Fig. 6, we find that this particular time is related to two memberships Medium (M), and Big (B). The next step is to find the degree of affiliation of this time T to each membership as following:

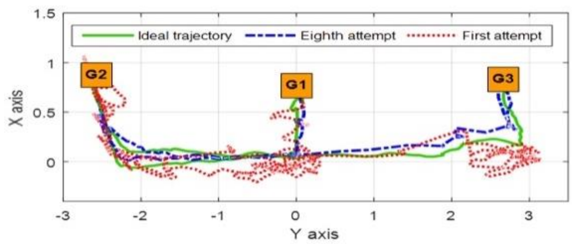
For T: With medium, we are going to use trapezoidal fuzzy member because Medium membership is trapezoidal

$$\mu_M(21.7) = \frac{21.7-25}{20-25} = 0.66$$

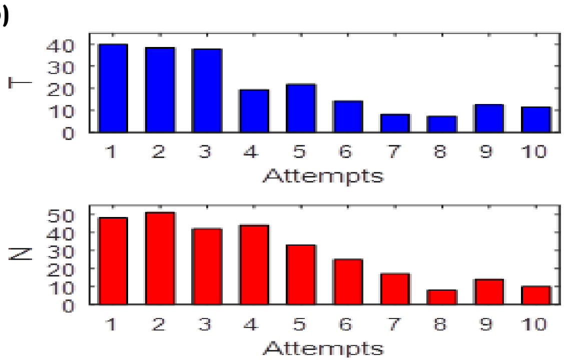
And use the triangular fuzzy member for the Big membership because of that the Big membership is triangular

$$\mu_B(21.7) = \frac{21.7-20}{25-20} = 0.34$$

a)



b)



c)

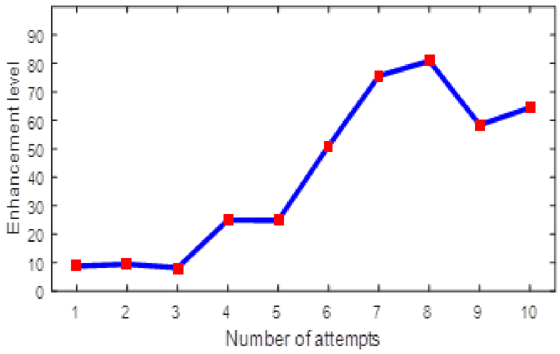


Figure 10: (a) Different trajectories for VR scenario shown in Fig.3. (b) Time and number of contacts with the force feedback. (c) The line of enhancement for all attempts

From the concept of our fuzzy approach, we found that the other fuzzy members are equal to zero for this time T.

$$\mu_{VS}(21.7) = \mu_S(21.7) = \mu_{VB}(21.7) = 0$$

In other words, this time T is not related to Very small (VS), Small (S), or Very big (VB) memberships.

For N: This related just to Medium (M) membership which needs to be counted by using trapezoidal fuzzy member as the Medium membership is trapezoidal

$$\mu_M(33) = 1$$

N for the other memberships VS, S, B, and VB is zero. So, this number for collision relates completely to the Medium membership.

Secondly, we are going to perform the inference which will give us the exact area of all related memberships to this movement as following:

Rule1: T is medium (M) and N is medium (M) then the enhancement E is small (S). This results (S) has come from Table 1, and depend on the medical doctors' experience.

OR

Rule2: T is big (B) and N is medium (M) then the enhancement E is very small (VS).

By now, we have combined the relations between: 1) The degree of affiliation of T to (M) membership with the degree of affiliation of N to (M) membership. And, 2) The degree of affiliation of T to (B) membership with the degree of affiliation of N to (M) membership.

By applying the results on these rules, we found:

Rule1: 0.66 * 1 which has been changed from the general case shown in Fig.11, for the Small membership in the enhancement level presented in Fig. 8. To the special case related to rule 1 when $\mu_M(21.7) = 0.66$ as shown in Fig.12.

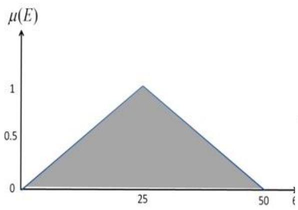


Figure 11: The normal member

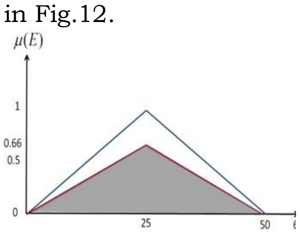


Figure 12: The related member

OR
Rule2: 0.34 * 1 which has been changed from the general case shown in Fig.13, for the Very small (VS) membership in the enhancement level presented in Fig. 8 in the enhancement level. To the special case related to rule 2 when $\mu_B(21.7) = 0.34$ as shown in Fig.14.

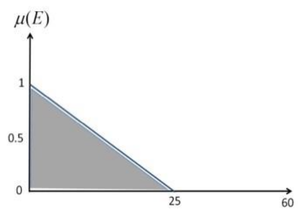


Figure 13: The normal member

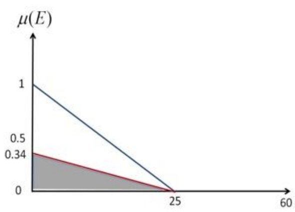


Figure 14: The related member

Now, we need to determine the related area to both rules in order to build the final decision about the enhancement level. This final related area ensures that the upcoming final decision is built on all related memberships to this movement. In order to achieve this goal, the max of the results between rule1 and rule2 needs to be calculated as following:

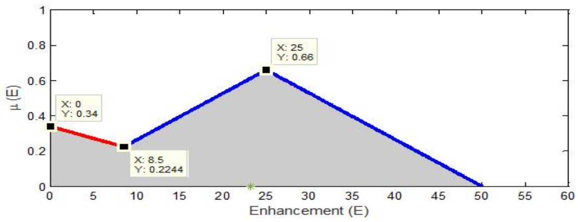


Figure 15: The complete related member

Finally, the deffuzzification needs to be applied to obtain the decision of enhancement for this attempt. In our case, the deffuzzification gives us the center point of this final area of memberships.

$$E^* = \frac{\int \mu(E).EdE}{\int \mu(E).dE} = \frac{A}{B}$$

From Fig. 15 we will start with A= $\int \mu(E).EdE = 416.5942$

Which was calculated by:

$$\int_0^{8.5} (\frac{-0.34}{25} * E^2 + 0.34 * E)dE + \int_{8.5}^{25} (\frac{0.66}{25} * E^2)dE + \int_{25}^{50} (\frac{-0.66}{25} * E^2 + 1.32 * E)dE$$

And then find the other equation B= $\int \mu(E).dE = 17.945$

Which was calculated by:

$$\int_0^{8.5} (\frac{-0.34}{25} * E + 0.34)dE + \int_{8.5}^{25} (\frac{0.66}{25} * E)dE + \int_{25}^{50} (\frac{-0.66}{25} * E + 1.32)dE$$

This finally gives us the decision about the percentage of the level of enhancement for this attempt as following:

$$E^* = \frac{416.5942}{17.945} = 23.215\%$$

This percentage comes from the application of the fuzzy approach to the obtained data from the system T, and N during performing the fifth attempt of Flexion-Extension movement.

• ***For stairs climb:***

Fig. 16 presents the collected data of stairs climb scenario. Those data consist of the needed time to complete the task and number of contact with the force feed-back. The collected data were used to make the final decision about the combined quantity and quality of this movement, based on the inputs to the proposed fuzzy strategy as can be seen in Fig. 16.b and c. Also, the drawn trajectories in this type of movement have been collected as can be seen in Fig. 16.a.

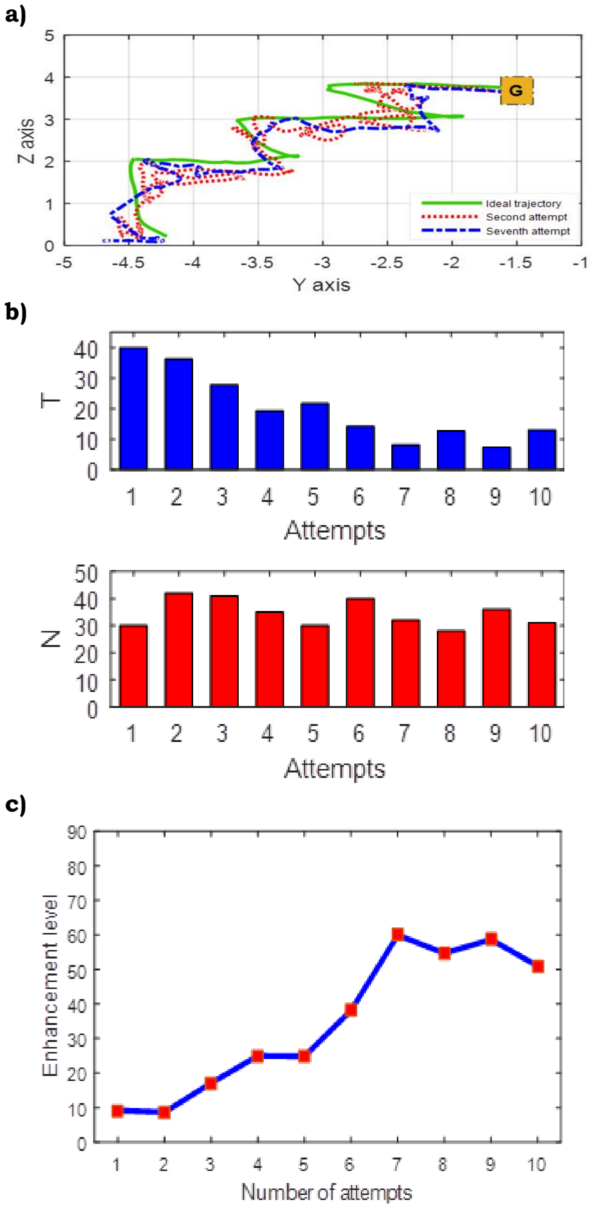


Figure 16: (a) Different trajectories for VR scenario shown in Fig.4. (b) Time and number of contacts with the force feedback. (c) The line of enhancement for all attempts

• ***For collect moving objects:***

Fig. 17 presents the collected data of collecting moving objects scenario. Those data consist of the number of collected objects during the specified time and number of contact with the force feed-back. The collected data were used to make the final decision about the combined quantity and quality of this movement, based on the inputs to the proposed fuzzy strategy.

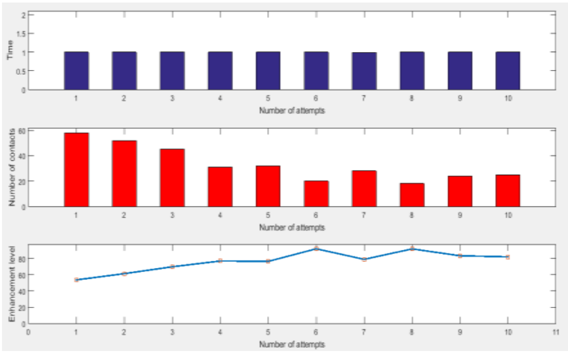


Figure 17: The history of the performance of the VR sceznario showed in Fig.5.

V. DISCUSSION

Both subjects were attracted to different simulations, and the pain level was almost 0/10 which means there was no pain. However, in the upper limb movement, there are many categories need to be considered to make a decision about the level of enhancement of each movement. In this study, the selective movement (quality), the joints coordinate of affected upper limbs to make one movement (quality) and the number of collected objects in certain period of time (quantity), were taking into account to make the enhancement decision.

For the quality of the movements, the system calculates the number of interaction with the force feedback coming from the haptic device, to find out the quality of the movement as can be seen in the red bars in Fig. 10, 16 and 17; knowing that the force feed-back occurs just when the children attempt to make other trajectories which are not specified in VR scenario. In other words, he/ she attempts to make abnormal joint recruitment. For example, in the flexion-extension movements, the child moves the handler of the haptic to reach the next object in the scenario as can be seen in Fig. 3. Then, if the child coordinates their joints to make the correct flexion-extension movement, the blue ball passes through the free trajectory between the two goals in the scenario, and without force feedback. But if he attempts to do an alternative compensation, in order to make these flexion-extension movements, like abduction-adduction movements or shoulder rotation, which results in most cases deviation from the specified trajectory in advance. Then the haptic device provides its force feed-back to impose that upper limb to stay within the pre-defined trajectory. In the meantime, the system calculates the number of the exerted force feed-back as can be seen in the red bars in Fig. 10. As an evidence of how many times that child has attempted to perform other joints coordination or compensation movement to do the desired flexion-extension movement. So, as less the number of interact with the force feed-back as better the quality of the movement is.

For the quantity of all movements, the system also calculates the number of collected and uncollected objects as can be seen from the blue bars in Fig. 10, 16 and 17 knowing that the system counts the number of uncollected objects from the total objects to be collected in certain time in each attempt. For example, in the abduction-adduction movements, the child moves the handler of the haptic to reach the next object in the scenario and from the initial position as can be seen in Fig. 4. Then, if the child coordinates their joints to make the correct abduction-adduction movement, the blue ball passes through the free trajectory between goals in the scenario, and without force feedback. But if he attempts to do an alternative compensation, in order to make these abduction-adduction movements, like shoulder rotation, which results in most cases deviation from the specified trajectory in advance. Then the haptic device provides its force feed-back to impose that upper limb to stay within the pre-defined trajectory. In the meantime, the system calculates the number of the exerted force feed-back. As an evidence of how many times that child has attempted to perform other joints coordination or compensation that unwanted to do the desired abduction-adduction movement. So, as less the number of uncollected objects as better the quantity of the movement is.

From (Only) the quality of the movement (red bars), it is hard to decide about the level of enhancement, because it is not the only category which responsible for that decision. Also for the quantity of the movement, it is not enough to make a decision for the enhancement level. So, a fuzzy logic decision maker strategy was developed and used to make this decision, by calculating the degree of affiliation of each type of movement to above described assessment categories (quality, and quantity) as can be seen in blue line charts in Fig. 10, 16 and 17.

At the end of the study, the children who participated in this study were asked to perform flexion-extension, abduction-adduction and pronation-supination movements without using the system to ensure that they can perform ADLs, and they have made those movements by themselves. They had to re-position a cube from initial position to end position as flexion-extension movements, reach a shelf as abduction-adduction movements, and turned a cube from one side to the other side as pronation-supination movements.

Both children have gained from the visual, audio and tactile feedback to stimulate their brains to choose the correct joints' coordinate in order to perform movements, and they have collected more objects by the time.

VI. CONCLUSIONS & FUTURE WORK

The therapists normally based on the results of the evaluation method to take the critical decisions about the level of enhancement at any type of movement. Use the traditional clinically measurement, or use measurement devices are the most common methods which help the therapists to make those decisions. This implies that the presence of the therapists and/ or use the measurement device which is difficult in home-based rehabilitation. For these reasons, this work suggests a basic fuzzy logic decision making approach. This approach is based on the time needed to complete a task, and the number of force feed-back needed to keep the UL within the proposed trajectory, in order to provide therapists with the percentage of improvement in that particular type of movement to help them make their decision about the suitable next step in the rehabilitation process. The gained results from the case study illustrate the percentage of the level of enhancement at each attempt based on the inputs of those attempts. This also provides the therapists with the history of enhancement for each child, which is not possible when they do the traditional assessment from time to time.

In this work, we have used different methods in order to achieve the fuzzification, inference and defuzzification, which we judge as the most suitable. Investigation of the effect of using the other methods on the accuracy of the final decision needs to be applied.

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