https://doi.org/10.22306/atec.v10i2.203 *Received: 12 June 2024; Revised: 21 June 2024; Accepted: 27 June 2024*

Development of a robotic handwriting assistant for children with movement disorder

Ismael Breton
Université Laval, Department of Mechanical Engineering, 1065 Av. De la Médecine, Quebec City, QC, Canada, G1V 0A6, ismael.breton.1@ulaval.ca (corresponding author)
Alexandre Campeau-Lecours
Université Laval, Department of Mechanical Engineering, 1065 Av. De la Médecine, Quebec City, QC, Canada, G1V 0A6, alexandre.campeau-lecours@gmc.ulaval.ca

Keywords: mechatronics, developmental coordination disorder, assistive technologies, robotics, handwriting.

Abstract: Developmental coordination disorder (DCD) impairs motor skills in children, particularly handwriting, which is a significant part of school activities and personal development. Current robotic assistants often lack a fully physical interaction or tangible result, thereby limiting their effectiveness in coordination development similar to handwriting. To address this gap, a robotic assistant capable of physical input and output could enhance development. This paper presents the development of a robotic handwriting assistant to aid children with DCD. The prototype is a planar robot controlled via a joystick capable of covering an 8.5" by 11" paper sheet. The paper provides insight into the causal real-world context of the prototype's development and discusses the designs considerations, the conception and the control. It concludes with intial results and the future for the project.

1 Introduction

Developmental Coordination Disorder (DCD) is prevalent among children aged 5 to 11, affecting approximately 8% of Canadian children. This condition, characterized by impaired motor skills, can stem from various neurological and neuromuscular disorders, including cerebral palsy, ataxia and muscular dystrophy [1]. Furthermore, DCD and attention-deficit/hyperactivity disorder (ADHD) comorbidity is quite frequent [2]. Consequentially, children with DCD often struggle to participate in physical activities at the same level as their peers, exhibiting slower task completion [3]. Poor coordination can result in a more sedentary lifestyle and increased fatigue due to inefficient movement, thereby negatively impacting the daily lives of both children and adults living with DCD [4].

Handwriting, a common school skill, poses significant challenges for children with DCD. This graphomotor skill demands various capacities, including hand function, perception, and motor control, which individuals diagnosed with DCD often lack [5]. Consequently, it becomes a source of frustration as it hampers their ability to express their creativity, limits their learning potential and diminishes their interest in handwriting. In a common scenario at school, such as a math class, handwriting is mostly required to complete problems. Children with DCD use more time and energy just to concentrate on the writing. Therefore, it leaves them with less time to complete the problem. It creates a severe imbalance between the time used to concentrate on the step and the times used to concentrate on writing.

Using computers and tablets for writing and drawing is a contemporary approach that offers accessibility and simplicity to compensate for the effects of DCD. However, research indicates that the sensory information inherent in handwriting fosters stronger memory retention compared to computer typing [6]. Moreover, students tend to reframe their notes in their personal language when handwriting, whereas computer typing tends to enforce a more rigid note-taking approach [7, 8]. In summary, for the purposes of adaptation and coordination enhancement, a physical input and output system is superior to computers, considering the benefits of memory improvement and the freedom afforded in notetaking.

Two types of devices can be considered for children with. Firstly, there are mechanical aids to support the correct way of grasping the pen [9,10]. They allow greater handling while writing. Secondly, there are devices that facilitate handwriting tasks for those living with stiffness and mitigate unwanted motion [11]. This project is in the later category.

Previous studies have explored the integration of robotic devices in enhancing children's handwriting skills [12]. One such trial utilized a haptic 6 degrees of freedom (DOFs) robotic system known as the "PHANTOM Omni" [13]. A comparison was made between the performance of children who had prior exposure to the robotic device and those who had not, revealing promising results in motor skill development. However, the substantial cost associated with these tools was noted. As of 2024, the "PHANTOM Omni," now rebranded as the "Geomagic Touch", has a price tag of $3400 USD [14]. Alternatives like the AxiDraw SE/A3 from *Evil Mad Scientist* are available, boasting excellent drawing quality [15]. However, its main use is as a drawing plotter, relying on virtual inputs rather than manual writing, makes it less suitable. for coordination development. Furthermore, with a price of 1160 euros ($1260 USD), it remains expensive [16].

Handwriting is important for the development of children and robotic systems can play a significant role in providing a writing tool for those living with DCD. In observation of the current technologies in this sector, or lack thereof, there is a potential need for and assistive tool to develop the coordination and the motors skills of children with DCD.

In previous studies, the robotics systems had either virtual input or output, thereby diminishing the benefits in development from an entirely physical system. To maximise the benefits, the robotic assistant should integrate both physical input and output capabilities.

This paper presents the development of a prototype of a robotic handwriting assistant for children with DCD. It begins with the modeling of the robot and the selection of hardware components to ensure the design of a user-friendly system. Subsequently, the focus is on the design and programming steps aimed at maximizing the robot's performance while keeping the system as simple as possible. Finally, the paper addresses the current capabilities of the robot and its future work.

2 Goal and Objective

The project has the following goal: To provide children with movement disorder the ability to perform writing tasks in a way to develop motor skills and express their creativity.

The main objective of this project is to develop a low-cost robot able to move a pen to draw and write. This robot must be directly controlled by the user via a controller and must have a usable workspace big enough to cover an 8.5” by 11” sheet of paper.

3 Methodology

The robotic handwriting assistant is a parallel robot with two degrees of freedom (DoFs). Its design is shown in Figure 1. It is driven by two stepper motor in a coaxial configuration (one atop the other). The end effector is a servomotor actuated mechanism to raise and lower the pen.

The user can control the robot with a single joystick equipped with a button. An 8.5” by 11” sheet of paper can be set up on the ABS (plastic) plate. When powered, the user can control the cartesian speed of the pen with the joystick. All the electronics, apart from the motors and the joystick, are enclosed in a box beside the motors. The system is installed on a veneer base.

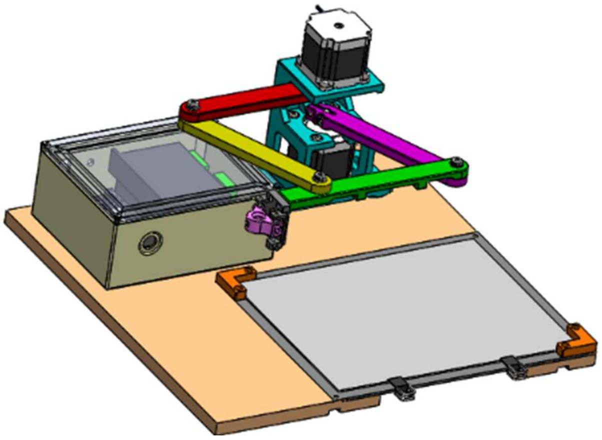
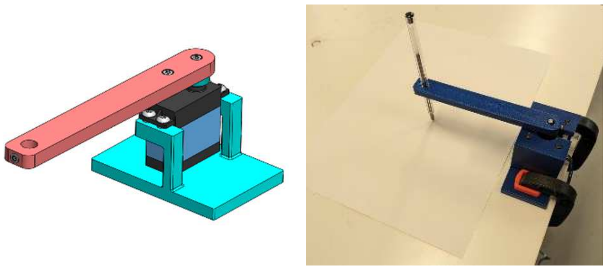


Figure 1 CAD model of the robotic handwriting assistant

The development of the prototype is divided into four iterative parts: I) Selecting the right motor technology for the actuation, II) Selecting a geometrical architecture that suffice the workspace requirements, III) Conception and assembly and IV) Control of the robot.

3.1 Motor technology

To ensure a good pen line quality, which is defined as a uniform line, two motor technologies have been compared: the servomotor and the stepper motor. The test is as followed: Draw five back and fort lines in an arc pattern and compare the quality of the line. The setup of both motors' testing are shown in Figure 2:



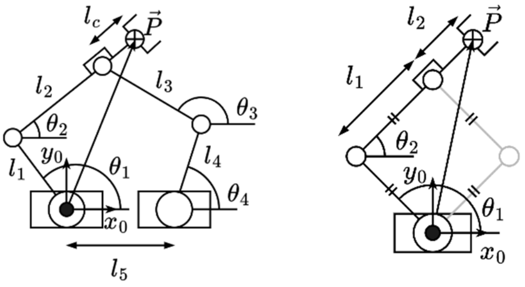
(a) (b)

Figure 2 Assembly of the servomotor (a) and stepper motor (b) test bench to compare the line quality

The tested motors where the model FT6335M from *Feetech* for the servomotor and the model 17HS13 from *StepperOnline* for the stepper motor. The servomotor is position controlled with a discretized trajectory, whereas the stepper motor is speed controlled using a trapezoidal speed profile. During the tests, we observed that the pen line had noticeable vibration with the servomotor. The consensus was that backlash in the motor's gearbox was too great using the standard servo library of *Arduino*. In comparison, the stepper motor proved superior in terms of line quality. In addition, stepper motors have the capability of instant velocity changes at speeds lower than 600RPM, only limited by the maximum speed and torque specified. Therefore, it was decided to use stepper motors for the prototype.

3.2 Architecture and mechanism

The robotic assistant requires an architecture that enables the pen to cover an 8.5” by 11” sheet of paper. The initially proposed architecture shown in Figure 3 (a) is a five-bar linkage mechanism with both motors at different positions. The second architecture shown in Figure 3 (b) is also a five-bar linkage mechanism. However, both motors are now coaxial and all bars, with the exception of the offset length l_2, have the same length l_1. An advantage of this architecture is its modeling. Indeed, due to the equal length of the bars, the system can be kinematically simplified to a two DoFs planar serial robot. Consequently, the control of the system is simpler. As shown in Figure 3 (b), the greyed out bars are redundant in the kinematics. But, they are necessary to transfer the motion of the second motor.



(a) (b)

Figure 3 Standard eccentric five-bar linkage (a) and the chosen five-bar linkage (b). All main bars have the same length of l_1 *and the motors are concentric*

The parallel architecture is chosen instead of the serial RR (two revolute joints in series) architecture for two reasons. First of all, if the motors were directly connected at the joints, the motor at the second joint would add a significant mass on the arms and cause sagging. Second of all, using a belt system for the second joint would have added multiple mechanical parts and increase the cost of the system. The origin $[x_0, y_0]$ is positioned at the concentric axis of the motors and the cartesian position of the pen is represented as $\vec{P}$. The angle θ_1 is controlled by motor #1 and θ_2 is controlled by the motor #2. As seen in figure Figure 3 (b), the angle θ_2 is also the angle for the second link of the simplified robot geometric (in black).

The system's geometry and a sheet of paper are modeled as shown in Figure 4. Then, using an iterative method, the dimensions of the bars and the position of the sheet in respect of the motors position are selected. Following the analysis, he length l_1 is set at 0.15m and the length l_2 is set at 0.065m.

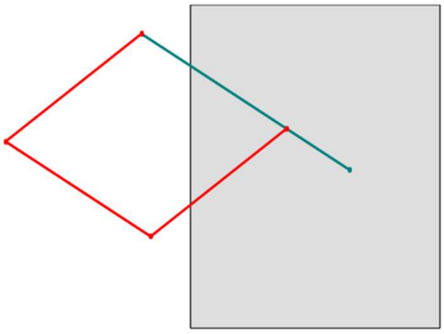


Figure 4 Selection of the bar's dimensions using Solidworks, The red bars all have the same length l_1 *and the teal bar has a length* $l_1 + l_2$

3.3 Design

3.3.1 Mechanical Hardware

The main mechanical components of the mechanism, be the motor support, bars and pen holder, are 3d printed in PLA. PLA, and fused deposit modeling (FDM) printing, have the advantage of being low cost and quick to manufacture new parts. PLA has sufficient mechanical properties for the robot’s requirement. For the joints, shoulder screws are used. They slide in plastic bushings and are screwed in heat inserts. The proximal bars are directly connected to the shaft of both motors.

The pen holder uses a cam, shown in Figure 5 in red, directly connected to a servomotor to move the pen support, shown in purple, vertically. The motion is guided with two pins side-by-side of the cam and springs help to counter the friction and, subsequently, lower the pen.

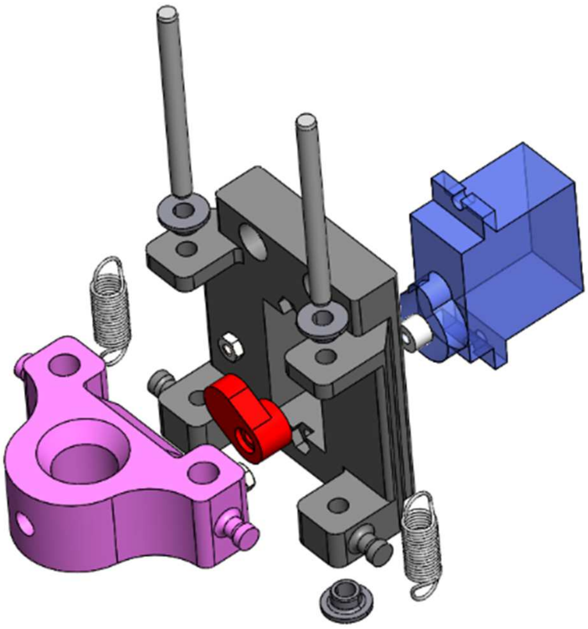


Figure 5 Exploded view of the pen holder

The platform is a veneer base which has been CNC machined, whereas the base for the paper is made of ABS which has been manually machined.

3.3.2 Electrical hardware

The selected motors are the NEMA 23HS56 driven by DM556T motor drives both from *StepperOnline*. These drives offer multiple settings of microstepping, which helps to increase the resolution of the motion. The value for microstepping has been set at 2000 µsteps/rotation.

The model of the servomotor for the pen is the SG90. Its small dimensions and low weight are perfect for the actuator.

The µcontroller is an Arduino Mega 2560. To power all three motors, at least three different fast pulse width modulation (PWM) timers are required. The Arduino Mega 2560 has four 16-bits timers and a good amount of general purpose input/output (GPIO), which makes it suitable for the prototype.

The joystick is a simple dual-axis joystick with spring loaded potentiometers and a single button. These three inputs are sufficient to move the pen and raise/lower it.

3.4 Programming

3.4.1 Model

The mathematic model of the robot arm, using the vector loop method, is represented in scalar values by the equations (1) and (2):

$$x = l_1 \cos\theta_1 + (l_1 + l_2)\cos\theta_2 \tag{1}$$

$$y = l_1 \sin\theta_1 + (l_1 + l_2)\sin\theta_2 \tag{2}$$

These equations are the direct kinematic of the robot. When the equations (1) and (2) are derived in respect to time, it is possible to determine the relationship between cartesian speed and angular speed. This relation is shown in the equation (3):

$$\dot{\vec{P}} = \boldsymbol{J}\dot{\vec{\theta}} \tag{3}$$

where $\boldsymbol{J}$, defined as the Jacobian matrix, has these values:

$$\boldsymbol{J} = \begin{bmatrix} -l_1 \sin\theta_1 & -(l_1 + l_2)\sin\theta_2 \\ l_1 \cos\theta_1 & (l_1 + l_2)\cos\theta_2 \end{bmatrix} \tag{4}$$

3.4.2 Control

The handwriting assistant uses speed control illustrated in the Figure 6. First and foremost, the joystick inputs are read and transformed into a speed value in cartesian space. Subsequently, the inverse Jacobian is used to output the motor's desired angular speed from the cartesian speed. The last step is to transform the angular speed into PWM frequencies. As the speed increases, the frequency is higher. This relationship is linear and based on the motor stepping. At each pulse, the drivers commute. Then, the motors achieve a new step and the angle gets updated in the µcontroller. These angles are used in the inverse Jacobian and the direct kinematic.

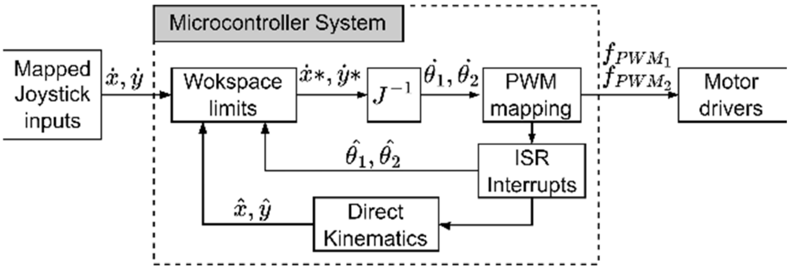


Figure 6 Schematic of the simplified kinematic control

A challenge in the motion control is the change of direction of any motors. The motor drivers require a PWM input and a direction (DIR) input. To assure a stable direction update, the PWM timers are turned off during the change in direction states. Beforehand, a delay of 10 microseconds is added, which is shown in Figure 7. Following the updates, a second delay of 300 microseconds is added. Finally, the PWM timers are turned back on.

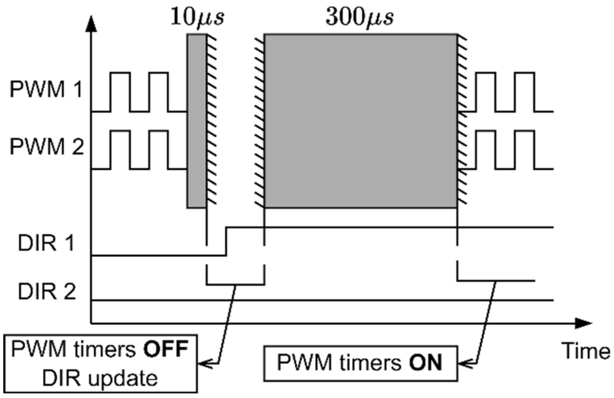


Figure 7 Functioning of the directions' update (named DIR), and control of the PWM timers during this update

3.4.3 Workspace limits

To assure a safe usage of the robot without any collision between the bars and the motor mount and without reaching the geometric limits of the robot, defined as singularity, software limits have been added. The workspace limits are shown in the figure Figure 8. The defined angular limits are a maximum angle of 180° for the first motor ($\theta_{1,MAX}$) and a minimum angle of 0° for the second motor ($\theta_{2,MIN}$). By intuition and physical measurements of the pen position at critical positions of the robots, The minimum radius R_{min} is set at 0.15 meters and the maximum radius R_{max} is set at 0.36 meters.

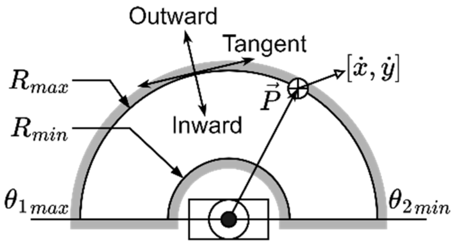


Figure 8 Software limits represented in the physical workspace in front of the actuators

When the robot reaches the radius limits, calculated using the direct kinematic, the orientation of the desired motion ($\dot{x}$ and $\dot{y}$) is compared to the vector comprised of the position ($\hat{x}$ and $\hat{y}$) using the scalar product (SP), which is (5):

$$SP = \hat{x}\dot{x} + \hat{y}\dot{y} \tag{5}$$

The Table 1 explains the program's behaviour based on the scenario:

Table 1 Programmed behavior of the robot based on the workspace limits and desired motion. A desired motion that is allowed (Inward, Outward or Tangent) is represented as "Yes" and a motion that is denied is represented as "No"

Radius Reached	Inward	Outward	Tangent
R_{min}	No	Yes	Yes
R_{max}	Yes	No	Yes

4 Results and discussion

This paper has presented the cycle of development of the prototype robotic handwriting assistant. The first prototype is shown in the Figure 9.

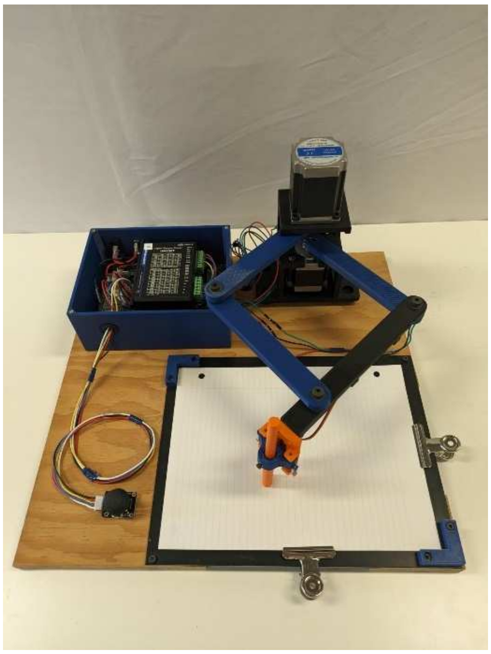


Figure 9 Prototype of the robotic handwriting assistant

4.1 *Drawing performance*

The performance was evaluated with multiple passes horizontally, vertically and diagonally. Additionally, a circular pattern was tested.

Following the results in the Figure 10, we observe a good quality of the straight lines both horizontally and vertically. During the reverse of directions, the robot performs worse with the vertical lines compared to the horizontal lines. More precisely, the pen moves a little horizontally when changing direction.

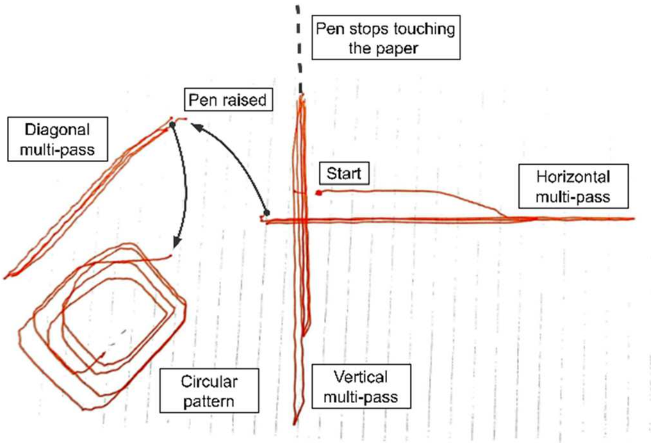


Figure 10 Results of the drawing tests. This includes multiple straight passes in different directions and a circular pattern. The pen is moving at a linear speed of 0.05m/s.

For the diagonal pattern, the pen tends to have regular vibrations caused by the motors. The circular pattern is difficult to perform. It is more orthogonal than circular.

The robot can easily cover most of the 8.5" by 11" sheet of paper. However, when moving the pen closer to the base, the pen stops touching the paper. The workspace limits do perform as presented.

4.2 Analysis and possible improvements

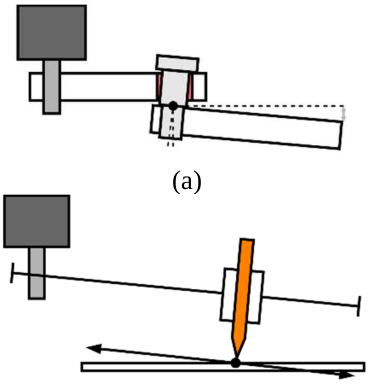
With the results acquired, there are certain points that can be improved.

4.2.1 Line quality

For the line quality, the problem can be divided into two solutions. The first solution is a better PWM management to smooth out the change of direction and the increase of the motor's speed. At slightly higher speed, the behavior of the motors would be more stable and more torque could be had. This can be achieved via the addition of a printed gearbox with a preferable ratio of 1:5 and with the least amount of backlash possible. The microstepping could be lowered at that moment. The second solution is the resolution of the input. With an higher Analog-Digital Converter (ADC) register size, such as the µcontroller stm32 Nucleo-64 with a 16-bit register compared to the Atmel AtMega2560 with a 10-bit register, the modulation of the speed would be more precise. Furthermore, joysticks with a greater electrical angular range could help the user to vary the input speed more easily and gradually.

4.2.2 Sagging

To ensure the biggest workspace with the robot's configuration, the pen's plan of motion must be parallel to the sheet of paper. However, there is possible play in the joints. Its effect, presented in Figure 11 (a), is the sagging of the distal bars. When this sagging is present, the pen is not orthogonal to the sheet of paper, presented in the figure Figure 11 (b). Therefore, the workspace is greatly reduced. Iterative testing of the printed arms is necessary to find and achieve sufficient tolerance to reduce play while keeping the friction to a minimum.


(a)

(b)

Figure 11 Play in the shoudler screw's bore causing sag in the robot (a) and the effect of sag on the pen holder's horizontal alignment

5 Conclusion

This project had the objective of developing a low-cost robot able to move a pen with the direct control of its user via a controller. In this scope, the first prototype proved promising in achieving these goals. The future of this projects will primarily consist of testing with physical medicine and rehabilitation (PM&R) professionals. Following their results and feedback, the system will be improved by the laboratory's team. Moreover, some technical improvements could be done, such as the writing quality, the reduction of the overall system footprint and the optimisation of the components for a reduction of the system's cost. There is needed testing to be done for the implementation of these improvements. It is considered to upgrade the controller and change the motor drivers. Moreover, an added gearbox custom made from 3D printed part could be tested to increase the motion. Overall, there will be subsequent versions of the robotic assistant, following the evaluations from medical professionnals. In conclusion, this project has the capability to provide an affordable assistance in handwriting and clinical studies. There is potential foor this system to be used for other purposes, such as maneuvering a maze or a small parkour.

Acknowledgement

This work is supported by the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

[1] American Psychiatric Association, *Developmental Coordination Disorder (F82)*, In: *"Neurodevelopmental Disorders," Diagnostic and Statistical Manual of Mental Disorders*, Vol. 5, No. 5, 2022. https://doi.org/10.1176/appi.books.9780890425787.x01_neurodevelopmental_disorders

[2] ZWICKER, J.G, MISSIUNA, C., BOYD, L.A.: Neural Correlates of Developmental Coordination Disorder: A Review of Hypotheses, *Journal of Child Neurology*, Vol. 24, No. 10, pp. 1273-1281, 2009. https://doi.org/10.1177/0883073809333537

[3] MISSIUNA, C., RIVARD, L., POLLOCK, N.: They're Bright but Can't Write: Developmental Coordination Disorder in school aged children, *TEACHING Exceptional Children Plus*, Vol. 1, No. 1, pp. 1-11, 2004.

[4] HANDS, B., LARKIN, D.: *Physical Fitness and Developmental Coordination Disorder*, In: CERMAK, S.A., LARKIN, D. (ed.) *Developmental Coordination Disorder*, Albany, DELMAR, pp. 172-176, 2002.

[5] CASE-SMITH, J., WEINTRAUB, N.: *Hand function and Developmental Coordination Disorder*, In: CERMAK, S.A., LARKIN, D. (ed.) *Developmental Coordination Disorder*, Albany, DELMAR, pp. 163-171, 2002.

[6] SMOKER, T.J., MURPHY, C.E., ROCKWELL, A.K.: Comparing Memory for Handwriting versus Typing,

Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Vol. 53, No. 22, pp. 1744-1747, 2009. https://doi.org/10.1177/154193120905302218

[7] KLASS, P.: Why Handwriting Is Still Essential in the Keyboard Age, Well, [Online], Available: https://archive.nytimes.com/well.blogs.nytimes.com/2016/06/20/why-handwriting-is-still-essential-in-the-keyboard-age [10 Jun 2024], 2016.

[8] MUELLE, P.A., OPPENHEIMER, D.M.: The Pen is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note Taking, *Psychological Science*, Vol. 25, No. 6, pp. 1159-1168, 2014. https://doi.org/10.1177/0956797614524581

[9] Writing Bird, Healthcare Solutions, [Online], Available: https://healthcaresolutions.ca/products/writing-bird [10 Jun 2024], 2024.

[10] Wanchick's Writer 2 - Discontinued, ArthritisSupplies.com, [Online], Available: https://www.arthritissupplies.com/wanchiks-writer-2.html [10 Jun 2024], 2024.

[11] LEMIRE, G.: *Aide à l'écriture pour les enfants vivant aves des incoordinations de mouvement*, M.S. Thesis, Laval University, Quebec City, 2020. (Original in French)

[12] SHIRE, K.A., HILL, L.J.B., SNAPP-CHILDS, W., BINGHAM, G.P., KOUNTOURIOTIS, G.K., BARBER, S., MON-WILLIAMS, M.: Robot Guided 'Pen Skill' Training in Children with Motor Difficulties, *PLOS ONE*, Vol. 11, No. 3, pp. 1-14, 2016. https://doi.org/10.1371/journal.pone.0151354

[13] Phantom Omni – 6 DOF master device, Delft Haptics Lab, [Online], Available: https://delfthapticslab.nl/device/phantom-omni [10 Jun 2024], 2024.

[14] Geomagic Touch Haptic Device, GoMeasure3D, [Online], Available: https://shop.gomeasure3d.com/products/geomagic-touch-haptic-device [10 Jun 2024], 2024.

[15] AxiDraw SE/A3, Evil Mad Scientist, [Online], Available: https://shop.evilmadscientist.com/productsmenu/908 [10 Jun 2024], 2024.

[16] AxiDraw SE/A3 Personal Writing & Drawing Robot (Intl), RobotShop Europe, [Online], Available: https://eu.robotshop.com/products/axidraw-se-a3-personal-writing-drawing-robot-intl [10 Jun 2024], 2024.

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