HAPTIC HANDWRITING SYSTEM FOR MOTOR LEARNING IN CHILDREN WITH MOVEMENT DISORDERS

ABSTRACT

Motor learning difficulties affect children's ability to develop fine motor skills such as handwriting, which has a great effect on their academic performance. Occupational therapy and robot-assisted learning are useful in helping develop these skills and minimise the impact of these disorders.

A handwriting robotic platform was developed aimed at measuring current handwriting capabilities in children and assist in learning through a haptic feedback planar 2-degree of freedom (DoF) robotic arm. Through a structured design approach, an intuitive end-effector guide was developed, to replicate normal handwriting ergonomics. The system can assess the child's handwriting capabilities through optical character recognition, based on which a series of tasks are generated with an engaging and interactive user interface.

Validation of the platform showed promising results but shortcomings in developing full haptic feedback capabilities for the system impaired full assessment of its performance. A novel solution has been introduced to inform future work and development.

Keywords — Handwriting, Haptic feedback robotics, Developmental Coordination Disorder

1. INTRODUCTION

1.1 Introduction

Handwriting has for a long time been a key skill that children are expected to master. It is thought most children fully develop their handwriting ability by age 11. Children who suffer from Developmental coordination Disorders (DCD)s are far more likely to struggle with handwriting and this often results in below average academic attainment, despite a normal range of cognitive ability amongst these patients. The predominant cause of bad handwriting in this group is contested, though visual motor integration is thought to be major predictor. Children with DCDs were historically known as having "clumsy child syndrome". Now, it is officially recognised as a motor control disorder by The American Psychiatric Association and the World Health Organisation.

Diagnosis of these disorders is often aided by handwriting scales that assess the quality of handwriting. The Beknopte Beoordelingsmethode voor Kinderhand-schriften (BHK) test created by the University of Leiden is considered the new "gold-standard" [1]. By utilising Dynamic difficulty adjustments (DDAs) [2], the appropriate level of exercise and haptic feedback can be provided at all times. This ensures a child will not feel frustrated or bored whilst providing them with a challenging enough experience to keep them engaged until the end of the exercises. Traditional handwriting exercise books increase in difficulty in a stepwise manner [3]. This often leads to a negative experience as the child will attempt to map a " pre-decided learning curve" [2]. In order to provide a DDA experience and increase the time spent exercising it was decided to incorporate a tablet computer into the project. Tablets are increasingly being recommended by doctors for handwriting practice [4] because they encourage independence, a key part of therapy [5]. Studies have shown that increased autonomy during practice leads to increased retention of motor skills [6].

An increasing amount of research has been conducted on haptic handwriting systems. While some studies have taken different adaptive approaches, which do not replicate handwriting *[7]*, most longitudinal studies conducted thus far relied on adaptations of existing haptic pen systems, such as the Novint Falcon™ and Phantom Omni™, used mostly for computer-aided design (CAD) *[8] [9] [10]*. These studies demonstrated significant handwriting improvements from such systems and increased engagement. Using haptic robots in the learning environment has been shown to be more stimulating while providing personalised feedback to its user.

There are limitations to these systems, however. The adapted devices have a limited range of motion (RoM), restricting the writing to single characters. By having this restriction, a system is impaired in its ability to assist in learning some basic normal handwriting practices such as writing full words or sentences. Also, there is no clear communication about the author's decision-making on angular or vertical motion feedback provided by the device, which could be restricting to a user due to differentiation in each individual's writing style.

Task design is the most common way in which to measure human motor control capability. Typically, being measured by analysing a controlled task, most commonly it will be a visual representation of a task that the user must follow and complete.

The Kinematic Assessment Tool (KAT) [11] framework is applied when recording primary handwriting data to plot the accuracy of the task carried out. This method determines the normalised jerk (time derivative of the acceleration) of the user from the velocity and acceleration data. This jerk data is then used to assess the user's overall handwriting capability. The advantage of this tool is its versatility; it can be implemented into other similar tasks. The key disadvantage to this method is the lack of testing that has been trialed; this could potentially reduce the validity of this method. [11]

1.2 Aims

Design and build a robotic system that can be used to promote “normal” handwriting practice in children through haptic feedback.

1.3 Objectives

1. Research handwriting, motor learning difficulties, and the current landscape on relevant robotic systems.
2. Follow a structured design process and establish design requirements.
3. Design a system to replicate the feeling of writing with a regular pen and provide haptic feedback for assisting learning.
4. Develop software with an interactive user interface to assess handwriting ability and provide appropriate feedback.
5. Evaluate the platform against design requirements.

2. MOTION CAPTURE

A rudimentary motion capture system was set up at home using technology that was readily available to acquire primary data on pen tip velocity and acceleration during handwriting tasks. A video camera was set directly above a page of squared paper. The resulting video footage was analysed manually. Pen-tip displacement was measured against time, allowing velocity and acceleration to be calculated.

Upon receiving the Mobile Expandable ePaper Notebook (MeeNote) a study was conducted on 4 participants. Dominant and non-dominant handwriting samples were collected with 3 of the participants being right-hand dominant, whilst the fourth was left-handed. Participants were asked to complete a series of exercises, designed to capture the full range of upper and lowercase of the Latin alphabet and an additional 4 tracing exercises.

2.1 Results

Kinematic data was measured by logging a JavaScript Date object for every pixel along a trace. By calculating the Euclidean distance between a set of pixels, the velocity and velocity derivatives can be calculated. Lifts from the page were recorded. The time and distance data from the end of one stroke to the beginning of another were removed (an example is the letter “t” or “j”). This reduces overfitting when comparing performance between participants because there are fewer dependent variables.

Table 1: *Mean Velocity values for participants*

Participants:	1	2*	3	4
Dominant hand mean velocity [mm/s]	12.1	9.14	9.70	8.62
Non-Dominant hand mean velocity [mm/s]	13.1	8.14	9.50	8.59

*Left-handed participant

The data is available in public repository (https://github.com/tabpier/helping_hand/tree/main/handwriting_data) or upon request.

3. SYSTEM DESIGN

A haptic handwriting system for motor learning in children with movement disorders was developed using a structured formal process. Using this methodology, a set of design requirements were established, and a final prototype was manufactured.

3.1 Design Methodology

The design methodology adopted during this project is the six-phase process for product design and development as described by Karl T. Ulrich and Steven D. Eppinger [12]. The six phases proposed are planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up.

As part of the planning phase, all subsequent phases were adapted to fit the scope of this project. An extensive search of relevant systems was performed, and all design requirements were established along with the project timeline.

During concept development, all team members presented their ideas from which two concept designs were compared, to establish the final solution. A variety of modifications were explored to create an optimal solution based on all team member’s input.

During System-level and Detailed design phases, mechanical, electrical, and software design took place. All aspects were put through a repetitive process of testing and refinement to inform the final design and any future work.

3.2.1 Design Requirements

- Factor of safety 2-3
- Suitable visibility of workspace
- Provide haptic feedback
- Assess handwriting
- Read and write to an accuracy of 0.1 mm
- Low friction and low inertia in the system.
- Suitable for individual handwriting habits
- Suitable for left and right-handed children
- Suitable RoM to replicate normal handwriting scenarios
- Aesthetically pleasing design
- Low cost (under £300)
- Maximum Size (500mm*700mm*200mm)
- Simple assembly
- Suitable for additive manufacturing
- Minimal system complexity

3.3 Concept Development

After all team members presented their ideas, two solutions were selected to be compared and are seen in figures 1 and 2 below.

Figure 1: *2-Point Control Robot*

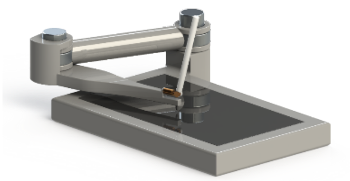

Figure 2: *Planar 2-DoF Robotic Arm*

The planar 2-joint 2-degree of freedom (DoF) arm design was chosen as it better satisfied the requirements. Its main advantage was its ability to reach the full workspace in its RoM as a compact device while not obstructing the writer's hand. The device utilises two motors, two encoders, and a touchscreen tablet to collect information and provide haptic feedback. The tablet provides the benefit of streamlining the teaching process by introducing a variety of engaging interfaces.

3.4 Final Design

3.4.1 Structural Optimisation

To minimise material in the system, for cost and inertia reduction, the main structural components of the design underwent a topology study to optimise their respective geometry. For this study, all parts were built to occupy the maximum allowable space they could and were simulated using the Topology Optimisation tool in SOLIDWORKS® Simulation [13] to use an iterative material removal process. The final parts were based on their respective constraints and force inputs, based on the expected system forces.

As part of this study, the proximal, and distal arms were tested. All forces on the parts were based on an external application of 1N on the pen grip vertically at full extension of the arm. The internal forces in the system were based on a representation of the arm and attachments as a system of cantilever beams.

An overall reduction of 0.3763 kg (41.64%) was achieved in relation to the maximum-occupied-volume parts.

3.4.2 Pen Design

The pen design was a crucial component in achieving the most natural replication of normal handwriting. The grip of the pen can rotate about a vertical and horizontal axis on its fixation point, allowing it to rotate naturally during handwriting while keeping the tip fixed to the distal arm as an end-effector. It was also set on an offset axis from that passing through its rotational centre to alight it with the writing tip as seen in figure 3 below.

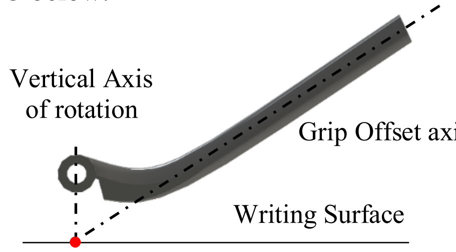

Figure 3: *Pen Grip Design*

For expected angles during handwriting, the axis' projection point on the screen deviates by a maximum of 11.55 mm from the writing tip. In comparison, if no offset axis were utilised, the deviation of the projected point on the screen by the grip's central axis would have been approximately 35mm on average making it less intuitive.

3.4.3 Final design Assembly

The final components and assembly of the design can be seen in figure 4 below.

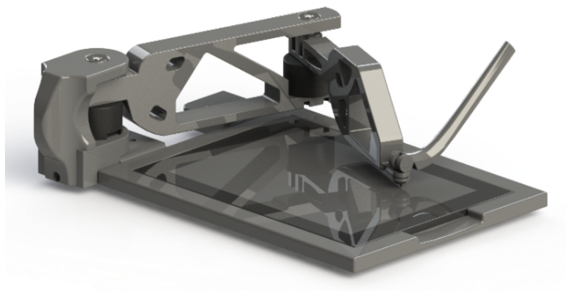

Figure 4: *Final Design Assembly*

The final design components, as seen in figure 7 above, were adapted to suit additive manufacturing, simple assembly, and to fit all other components to the design. The design utilises a ball bearing with a central axle to facilitate attachment to each motor, minimising any friction in the system not caused by the motor. A clearance of 5 mm was created between the writing tip and the screen and based on the mechanical properties of the parts from the structural optimisation, vertical movement is achievable to engage and disengage the pen.

$$Weighted\ Mean\ Score = \frac{\sum(Weighting\ Factor * \ Relative\ Score)}{\sum Weighting\ Factor} \quad (\boldsymbol{Eq.1})$$

3.5 Prototyping

Prototyping was done using additive manufacturing (AM) on the Ultimaker® 2+. The prototype was based on a previous iteration of the design and was used to inform decisions on the final design. It was also used to validate the design.

3.5.1 Additive Manufacturing

Table 2 below displays the printer settings for all parts of the assembly excluding the pen assembly which was done with 0.06mm layer height and 80% infill density to minimise flexibility and increase the accuracy of the print.

Table 2: *Printer Settings*

Printer Setting	**Value**
Wall Thickness	1 mm
Infill Density	30%
Infill Pattern	Triangles
Layer Height	0.15 mm
Print Speed	60 mm/s

The settings displayed in table 2 above were chosen to decrease print time. Material properties in the structural optimisation were based on a 30% infill density. A triangular infill pattern was chosen to increase stiffness in the print's direction.

3.5.2 Final Assembly

Figure 5 below displays the final assembly of the prototype.

Figure 5: *Final Prototype Assembly*

4.6 Design Validation

Based on the design requirements in section 3.2, the mechanical design was evaluated. The prototype seen in figure 5 was utilised to assess the device's RoM, interchangeability between left-and right-handed configurations, overall manufacturing success, and ease of assembly. Table 3 below displays the scoring matrix of the overall device in relation to the user needs, based on how well it aligns with the relevant design requirement. By using the weighted mean score equation, given by equation 1 below, the final score design was scored.

Table 3: *Design Scoring*

User Need	**W.F.**	**R.S.**
Safe use	5	5
Visible writing workspace	4	3
Provides Haptic feedback	5	1
Back drivable	3	4
Ergonomic Design	4	4
Suitable RoM	5	5
Engaging Workspace	1	4
Measuring	5	4
Precise	4	1
Cost	3	5
Fits within a student's workspace	4	5
Ease of assembly	2	5
Ease of Manufacturing	3	4
Ease of design	5	3
Weighted mean score		**3.679**

4. EVALUATION SOFTWARE AND TASK DESIGN

4.1 Graphical user interface (GUI)

Initially, the Tk interface (tkinter) package was used to create the Graphical User Interface (GUI) because it contains a library of basic GUI widgets and was it was available on Windows and Unix platforms and. It was decided to switch to a web-based GUI to allow kinematic data collection from any web-based device (primarily Android or iOS devices). Additionally, Web Applications remove potential installation issues and allow for improvements to be made to the software without having to push the updated files to users. The python web framework Flask was chosen over Django because it allows for greater control, it is simpler to develop with, and has a smaller number of automatically included dependencies. PythonAnywhere was chosen as a web hosting service because it can provide browser access to server-based Python code, has an integrated development environment, and is free of charge given the number of users.

The front page of the website is minimalist, containing a list of hyperlinked user profiles and their assessed abilities. Users are given a choice of the background colour for the website. This was based on studies demonstrating that providing participants with choices can enhance motor learning even when the choice is unrelated to the task *[14]*.

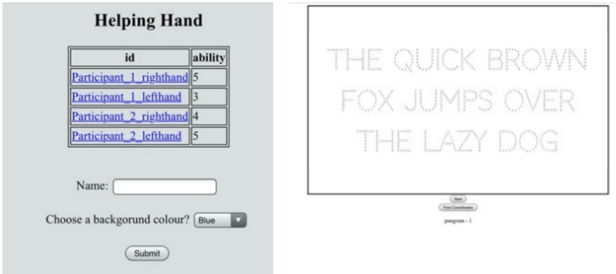

Figure 6: *Web application for evaluating handwriting (domain: http://pierret.pythonanywhere.com/)*

Once a user has created a profile, they are asked to complete a pangram exercise. No haptic feedback would be provided during this stage in order to form a baseline evaluation of their ability and to compare against future pangrams as a measure of progress. Once a user's ability is determined, a series of exercises are provided designed to challenging but not frustrating. When a user posts their coordinates to the sever, it is confirmed with a pop-up message. The metadata includes an array of x and y coordinates, the time taken between each position array, the number of lifts from the page a user made, their id name and the exercise number.

4.2 Task Requirements

Before the development of a task had begun it was important to identify requirements the design should have

- Identify patterns within handwriting
- Identify letters within the alphabet in lower and uppercase
- Provide a system to assess handwriting ability
- Must provide quantifiable data for analysis
- Must aid and improve users handwriting capability

The identified methodology that was settled upon was the KAT Framework.

4.3 KAT Framework

The chosen methodology for implementation was the KAT framework, use of this framework was suitable as we could accomplish all the set-out requirements for data collection and analysis alongside the methodology being flexible enough to implement various task designs within.

4.4 Evaluative task design

The design of the initial evaluative task used pangrams, which are sentences that possess every letter within the alphabet. This task collects handwriting information about the user. A complete set of data covering the whole alphabet is acquired, which can be used for analysis later.

4.5 Developmental task design

The first task design aimed to test the user's ability to make connections from dot to dot to identify the path that the user would take. This initial task is to start to developing the users handwriting capability, this methodology was based around development of handwriting starting from learning to draw simple shapes such as circles, squares, and triangles [15].

The design for task two allowed identification of any deviations that the user makes from the desired path. This deviation would be a key marker of user capability and development using this task would increase the user's ability to create controlled lines.

The theory behind the design for task three was to understand the user's ability to replicate identified patterns without the ability to follow a traced path. This task would develop the user's ability to draw free-handed without the guidance of a dotted line.

The aim of task four was to develop the user's ability to control the pen on sharp corners. The development of this skill is key when designing for DCD, since it has been shown that this is one of the key weaknesses for children with DCD [16]. Repetition of this type of control would develop user's ability to control their handwriting along curves.

4.6 Gamification task design

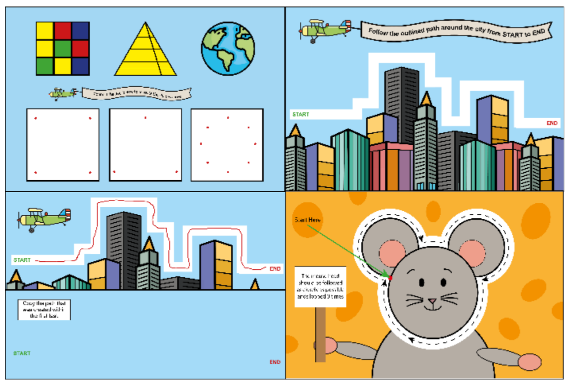

Figure 7: *Final Task Designs*

All of the evaluative and developmental tasks have been designed to have a gamified aspect to them; the style, pattern, and path of the tasks have been made to look like video game design. This methodology allows for a more visually stimulating aesthetic designs for the end user, the reasons for this are that it has been demonstrated through multiple case studies that the use of gamification greatly increases the engagement of the user. [17], alongside this gamification has illustrated over time that it will increase the users over performance [18].

4.7 Handwriting Evaluation

During pangram exercises on-line and off-line data was collected in order to update the record of a user's ability. Updates occur at the end of each exercise allowing us to provide a dynamic difficulty adjusted (DDA) experience, moderating the level of haptic feedback provided and the type of exercise provided. Three different types of measurements would be used to evaluate a user ability to handwrite letters.

4.7.1 Time derived data

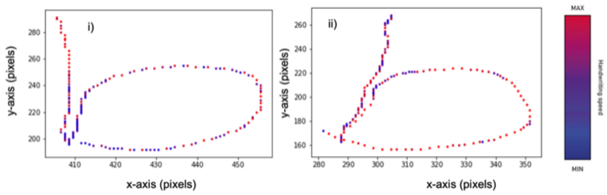

Figure 8: Speed comparison between dominant and non-dominant handwriting

Figure 8 shows an example of the dominant (i) and non-dominant (ii) handwriting of a participant. Where the colour represents the speed at that point in space. The handwriting score is adjusted by comparing the number of saccades present in each sample.This is an improvement over the BHK test which only measures the number of characters written in 5 minutes.

4.7.2 Bandwidth of Tremor Frequencies

This feature quantifies the number of tremors in a handwriting sample. A high value represents an inability to write smoothly and is computed by taking the cross product between vectors of adjacent points ("local vectors") and vectors between points or an arbitrary number of points apart ("global vectors"). By setting the global vector to be 9 points apart it was possible to distinguish between dominant and non-dominant handwriting 84.6% of the time. This was on the assumption that handwriting performed with the dominant hand is always smoother. This is not an accurate comparison to being able to detect normal handwriting from dysgraphic handwriting.

4.7.3 Optical character recognition

Optical character recognition (OCR) comprises many different types of technology with the aim of recognising text. Characters are classified using a common set of features which is why the use of neural networks is suitable. A Machine Learning (ML) model has previously been used to detect dysgraphia an accuracy of almost 80% *[19]*. The model was fed the spatiotemporal and kinematic aspects of handwriting which was beyond the scope for this project. Instead given that all participants for this report do not have dysgraphia it was decided to train a convolutional neural network (ConvNet) to classify the different characters from the EMNIST Dataset (CITE). An accuracy of 96% was achieved. Because of this high accuracy, the confidence of classifications could be used to evaluate handwriting quality. This was verified by distinguishing dominant and non-dominant handwriting without having been trained to do so.

5. ACTUATION AND CONTROL

5.1 Electro-mechanical construction and function

Once the design requirements for the device were established, electro-mechanical components were selected that would meet these requirements. A microprocessor, actuators, actuator drivers, and encoders all required selecting. The main requirements that were needed to be met were that the robotic arm's end effector, with 2 degrees of freedom (DOF), would be as a guidance of the hand by the smooth position change of the end-effector using impedance control to alter the position and with the use of the encoders to provide varying levels of feedback along the desired path for each handwriting exercise.

Selection of hardware, construction of the circuit , and coding of the control approach were chosen according to the design requirements.

5.1.1 Calculating Force Required for actuation.

Values for maximum force in the x-y plane, necessary for the actuator specification were calculated by reviewing the literature.

Initially, a crude estimate for the maximum planar force required from the actuation system was found by calculating the force required to drag a human arm across a page. Using the typical mass for a child's arm, [20], along with derived values for the friction coefficient between skin and paper [21], an upper bound for the maximum force required to move a child's arm was estimated to be 16.19N. In reality, during handwriting, the arm is mainly stationary, and it is mainly the fingers that move. With this is in mind, the mean pinch and tripod grip strength for children with DCD was used as the new working value for the maximum force required from the actuators. According to a 2020 clinical study [22]these are 25.2 N and 34.1 N respectively. This is an even greater assumed maximum force than before. However, as the study points out, grip strength does not accurately predict handwriting ability or reflect the magnitude of force used in handwriting. Basteris et al. showed in

2012 that robot-provided assistance during handwriting exercises resulted in improvements in inter-manual transfer when providing trajectory-based guidance. [23] The maximum force being provided by the robot, in this case, was 4-5 N. A 2008 study fabricated a custom "kinetic pen" that could measure the magnitude of force applied to a pen in 3 dimensions during normal handwriting procedure. The study found that maximum force applied parallel to the page was around 3.5 N. [24]

5.2 Motors

The types of motor under consideration for the device were Stepper Motors, Servo motors, Brushed DC motors, and Brushless DC (BLDC) motors. The type of motor that was chosen for this project was a BLDC motor due to the requirement of the project to have low friction back-drivability and using impedance control approach, the smooth change in the position of the end effector. The selection was a GM3506 brushless motor with AS5048A encoder. The torque range of the motor is 600-1000g/cm with an rpm of 2200. The required torque based on the calculations conducted was met by the product specifications. The weight of the motor was 0.08kg and the voltage required for the motor was 12V and the current required was 1A. [25]

The AS5048A encoder, which was included in the casing of the GM3506, was selected to provide verification of the position of the motor at a specific time, in terms of feedback. Based on the data represented by the datasheet, assuming that the linearization and averaging is performed by an external microcontroller, the maximum accuracy of the system would be 0.05°. [26]

5.2.1 Motor selection

Cogging torque is a form of torque ripple that occurs in BLDCs when the permanent magnets in the rotor are attracted to the outward-facing parts of the stator coils. At low speeds, such as is required for haptic feedback, this torque ripple can dramatically affect speed and overall performance. Usually, a premium is paid for motors with low torque ripple.

In 2016 researchers at Penn robotics lab successfully demonstrated that torque ripple due to cogging could be dramatically reduced (by up to 88%) in a range of low-cost brushless DC motors by implementing an algorithm that estimates a map of cogging torque against the motor position and subtracts the magnitude of cogging torque from the desired torque at that position. The result is that low-cost motors were able to operate at low speeds with the smoothness normally expected of motors with much higher prices. The evidence provided by this study informed the rationale for choosing a motor. The GM3506 motor was chosen for its ability to provide torque in the necessary range laid out in the specification at a price within the budget of the project and operate smoothly by utilizing an anti-cogging algorithm. Open-source anti -cogging algorithms can be found online, for example, "Odrive" provides an anti-cogging algorithm within their development section in github that has been demonstrated to reduce cogging [27].

5.3 Electrical Hardware

L298N drivers were initially selected as they were already acquired from past projects, but the required function could not be implemented with as required. Therefore, a BLDC shield for Arduino with TLE9879QXA40 was acquired to drive the brushless motor using the 3-phase motor driver chip. Due to the design requirement of two brushless motor for the control of each arm of the 2DOF arm, two BLDC shields were required.

An Arduino Uno Board was chosen as the board, which operates at a 5V logic level. It has 16 digital inputs and outputs where 6 of them can be used as Pulse-Width Modulation (PWM) outputs which were required by the process. Moreover, the Arduino Uno has a relatively low price, compared to other boards found in this category, making it suitable for this project. Its layout makes it compatible with various extension boards or shields such as the one that was chosen. [28]

5.4 Control

The process for the control of system involved the calculations of the 2DOF inverse kinematics to calculate the position of the end-effector (Pen) in terms of the angles of the joint I at the base and the joint II at the point of connection of Arm1 and Arm2. The above data would be used in the system to guide the end-effector in the required pattern without compromising the independent ability of the children to write. Impedance control was chosen for this application based on the robotic manipulation characteristics that can be applied by this control method. Applying position control was a possibility, however on this occasion, the output of this control method would not be as smooth as the output when impedance control was applied. Some basic approaches methods of control were followed that were introduced in other projects where impedance control was used [29] [30]. However, due to the time restraint, and non-physically presented in the University, a fully functional prototype, in terms of the electronics, was not produced; Therefore, this control approach could not be physically tested during the project.

6. DISCUSSION

6.1 Motion capture and Handwriting Evaluation

Overall, the use of the MeeNote was successful in gathering kinematic data, allowing us to make handwriting evaluations. However, a shortcoming of this method was that no z-axis data collected beyond tracking when and how often the stylus was lifted. The Optotrak Certus motion capture allows for the measurement of the stylus angle and azimuth. This information could have been used within the design of the stylus and been shown to be an important aspect within children with DCD *[16]*.

Upon examining the data, it was discovered a significant number of recoded points were 2 or 3 pixels apart. This was not an issue as it was possible to linearly interpolate additional points, which was necessary to increase the classification accuracy of the ConvNet. The gaps were not visible to the user as the linewidth of the user's trace was set to a circle with a circumference of 10 pixels. To further improve the accuracy of the ConvNet improvements in image processing could allow for the data to better match the training data. This includes further adjusting the thresholding and the Gaussian blur. Whilst calculating the number of tremors in a handwriting sample a challenge occurred because the data included the distance travelled whilst not on the page (e.g. writing the letter 't'). This was addresses by removing the cross-product values if they fell outside of 3 standard deviations from the mean.

6.1.1 Primary motion capture analysis

The precision of data from the rudimentary motion capture analysis was determined by the frame rate of the camera used, which was 30 frames per second since velocity for the "L" shapes was calculated for the time in-between frames. Acceleration was calculated from the change in velocity per frame and so had a lower accuracy than velocity. A higher camera frame rate would result in more accurate data.

There was some difficulty gauging by eye when the start of the handwriting process had begun once the pen tip was touching the paper.

As well as the data compiled from this process, certain phenomena could be judged visually. For example, there was consistently a moment lasting for over a frame (0.03s) when the surface of the paper is indented but the pen tip is not moving in the horizontal plane. At this moment, an initiating force is being applied, mainly into the paper, to start the handwriting process. This supports the idea that there is a complex synergy of forces being applied by the hand during handwriting, that varies depending on pen dip direction of movement and angle of pen tip as mentioned by Shim et al *[31]*.

6.2 Mechanical Design

The overall design was able to successfully comply with the design requirements set out in the project. An overall score of 3.679/5 indicates a successful design with some room for improvement. The final design and prototype were able to cover the whole writing surface through their RoM with no noticeable friction, making the device highly back drivable. The pen was highly intuitive, and the vertical motion of the end effector was sufficient, indicating some success in the structural optimization.

There were some shortcomings in the prototype assembly which were solved, and some post-processing was necessary due to the design. The prototype also showed some unwanted flexion in the first joint support. All these issues were addressed in the final design.

The main shortcomings of the device, as shown on the scoring in table 3 in section 4.6, are visible workspace, providing haptic feedback, precision, and ease of design. Visibility was a slight issue for the left-handed configuration, depending on the seating position of the child, the motor may provide some obstruction of view on the right side of the tablet. Precision was an issue in relation to the high tolerances needed for using additive manufacturing with PLA. This created some unwanted clearances on the pen giving it slight unwanted movement. Lastly, the difficulty proven to successfully implement a control system meant the design difficulty was quite high, impairing the haptic feedback of the device.

For future work, to better validate the design, a finite element analysis (FEA) of the device is suggested. While the topology study ensured a factor of safety of at least 2.5, the final parts for printing were not fully validated. Additionally, manufacturing methods such as CNC machining could prove useful for manufacturing tight tolerance parts such as the pen grip assembly.

6.3 Task design

The task design for this project was sufficient in collecting the required data to identify that was required from a system development perspective, also the design of the task was aimed towards the end users. The way in which the task was laid out visually would have made accessing and operating the system simple for the user of a child aged 5-11 years.

Future developments that would be made to this project would be to further implement more developmental tasks, this would include more simple rudimentary tasks that were design for children that have lower motor control, also for development of tasks for users that their motor control capability higher but still requires improvement.

Another development would be the implementation of customization to the task designs that were designed, for example being able to change aspects of the game such as environment and path choice, the implementation of customization has been demonstrated to improve the user's engagement and performance [14].

6.4 Build and integration

Files were used to post to remove support structures from the printed parts and to ensure the surface was smooth and safe to use. The parts were screwed together using M5 screws. The 4 sections of the base were welded together using a glue welding gun.

This process in full was accomplished within one day without any breakages. However, were this device to be mass–produced, alternative manufacturing techniques would speed up the process, since 3D printing is slow. The 3D printer would need to be large enough to print device bed frame in one piece since the joints of the bed frame are potential areas of structural weakness. Welding them together with glue also adds a process to the assembly, increasing assembly time as well as risk of the screen bed being uneven.

6.5 Electromechanical function and control

Based on the specification required for the project in terms of the arm being back drivable and the torque required to be outputted by the motors, a specific BLDC motor was chosen. Due to already acquiring a specific type of motor driver L298N, an iteration to use the Brushless motor using 3 L298N was conducted which was resulted unattainable. Some limitations appeared could be due to the complexity of the setup, therefore; the problem was harder to be found and resolved. A decision to acquire a BLDC motor shield was obtained in order to be able to have a better control of the system with less noise and less response time. The second iteration using 2 BLDC motor shield with Arduino Uno was offered with higher expectations but the result that could be get out of it wasn't the expected due to limitations of laboratory time as well as the unavailability of physical attendance of people with the required knowledge on this aspect. However, in theory, the project had essential amount of theoretical data to be achievable with the required staff with the acquired knowledge working on it.

7. CONCLUSION

A new handwriting platform was introduced. The design successfully met the user requirements. The software and hardware were designed to maximise in-house design. Handwriting data was collected from five participants using two different types of motion capture. A web application was developed capable of autonomously varying the type of exercises provided based on a user's ability. Handwriting ability was assessed by analysing kinematic data, measuring the number of tremors, and a novel approach using the confidence of a ConvNet's output. Exercises were created to keep children engaged and in accord with the KAT framework. The final design was suitable for additive manufacturing, simple assembly, and to fit actuators appropriate for DCD rehabilitation.

Full evaluation against specifications and objectives was not possible because of shortcomings regarding the actuators, control software, and structural validation. However, individual aspects were met, and future iterations could involve studies with children for assessing handwriting improvements. For future work, further validation of the device is recommended, through simulated studies and physical studies assessing the platform's success in a classroom environment.

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