A Smart Parametric 3D Printing Hand Assistive Device with A Practical Physically Intervention Feedback Based on The Embedded IMU Sensor

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ABSTRACT Assistive devices are one of the crucial medical instruments for rehabilitation. Customized designs are required to match the geometry and dimensions of the affected sites of human bodies. The existing practice of assistive device development remains mostly a manual process, in which an experienced physiotherapist employs simple two-dimensional measurements and visual estimation to handcraft each device. The resulting devices not only vary substantially in fit to wearers, but also are not compatible to modern developmental technologies such as three-dimensional (3D) printing. This study incorporated substantial quantities of anthropometric data to construct a parametric 3D hand model. This study employed a customized assistive device - splint for carpal tunnel syndrome as a target object for testing the feasibility of the proposed method and verified the practicability through 3D printing implementation. Moreover, a wearable device embedded with inertial measurement unit sensor and vibration module will be integrated into the customized assistive device to offer a smart way for rehabilitation. With the help of this developed wearable device, continuously tracking user’s activity wirelessly and provide the real-time physically intervention feedback of vibration module based on back-end monitoring system platform. This new concept by integrating customized design and the IMU sensor and vibration module open a new window for the field of customized assistive device and improve its practical values.

INDEX TERMS Assistive device, Parametric modeling, Anthropometry, 3D printing technology, Human activity monitoring, Feasibility assessment.

I. INTRODUCTION

According to the report of cooperation, We Are Social [1], in 2021, they surveyed Internet users in more than 150 countries worldwide for computer and mobile phone use time. 4.66 billion people around the world use the internet in January 2021, up by 316 million (7.3 %) since this time last year. Global internet penetration now stands at 59.5 percent. However, COVID19 has significantly impacted the reporting of internet user numbers, so actual figures may be higher. So far, the usage rates of mouse and keyboard became higher. With the increase in the usage time of consumer electronics products, the pressure on the cervical spine increased owing to long-term lowering of the head to use the mobile phone, and the damage to the wrist relatively increased.

Global computer peripherals companies reported that one American spends average 7 hours in front of a computer daily making about 6000 to 10000 mouse clicks and scrolls about every five clicks. The average travel distance of a mouse moving distance is around 6.9 to 11.5 miles each year [2]. It was also reported that using consumer electronics products by repetitive movement and overuse would easily cause the pain felt in muscles, nerves and tendons. Notably, the use of the mouse is inseparable from daily life, but the pressure on the wrist caused by the extensive use of the keyboard and mouse will greatly increase the probability of causing wrist discomfort such as carpal tunnel syndrome and tenosynovitis. Carpal tunnel syndrome is the cause of 20 to 25% of the cases with wrist numbness.
According to studies, wearing an effective assistive device for 12 months can significantly improve carpal tunnel syndrome in 72% of patients [3][4]. Currently, the channels for obtaining assistive devices are roughly divided into two methods: purchasing from pharmacies and requesting functional therapists to manufacture the assistive devices. Most assistive devices purchased from pharmacies are made of fabric and hook-and-loop fasteners. Although they are very convenient to obtain, they do not fit perfectly. Moreover, because the fabric absorbs water, it often causes airtightness or smells after sweating or dipping in water. Furthermore, the hook-and-loop fastener used for fixation can be easily stained with impurities, such as cotton batting, that leads to the problems of reduced viscosity and insufficient fixation.

Some evidences show that wearing the assistive device or not will affect the rehabilitation effect, because it is difficult to overcome the traditional fabrication process, in which the thermoplastic materials is molded manually, is not comfortable for daily use [5]. This study introduces a parametric design in the design process of assistive devices as the operating medium for prototype evaluation and adds personalized design to achieve the purpose of customization, allowing occupational therapists to conduct customized production and design evaluation in a more intuitive way and to really meet the rehabilitation requirements of individual users.

II. RESEARCH METHOD

A. DESIGN FOR PARAMETRIC 3D HAND MODEL

In this study, a parametric 3D hand model based on anthropometric data collected by the 3D human body scanner is built, and we also introduce the customized product design into the assistive device development process. Although the used scanner contains the advantages of a fast data capturing rate via the non-contact measurement, the captured point groups occasionally exhibited poor quality with several issues of overlapping, porosity, and noise. Therefore, data post-processing is required to ensure the consistency of the body dimension database. Figure 1 illustrates the isometric mesh processing procedure of the 3D anthropometric hand database, and it mainly contains several steps, including material removal, smoothing, cropping, patching, feature point selection, and cross-parameterization. Each of the raw data sets captured by the scanner contains tens of thousands of 3D coordinate points. However, there is no parametric model directly constructed from these raw sets, because the model construction will encounter the excessive computational complexity. Therefore, the dimension of each data set has to be reduced to 5000 points through uniform sampling. Subsequently, the remaining meshes are processed through cross-parameterization. Because the meshes have to be enclosed, the holes on the boundaries are filled in this step. Finally, the codes of filling triangles are recorded to facilitate their removal after cross-parameterization to ensure the consistent numbers of meshes and connecting methods in each data set.

The main idea of parametric hand modeling is to synthesize a 3D hand model using a number of feature parameters measured from a user’s hand to approximate user’s hand geometry. For the problem of dimensionality reduction, the most commonly used algorithm is principal components analysis (PCA). In this study, PCA was applied to reduce the data complexity while preserving acceptable data variances. Linear regression was used to define the correlations between a set of parameters and coordinates of mesh points in 3D space. Therefore, parametric design techniques to human hand model with a small set of measurable parameters were applied. This study is a continuation of the earlier study, using previous 3D anthropometric hand database for size designs [6]. Parameterization can make future personalized size designs more accurate. Using the models in the database, later users must only enter the defined parameters, such as the palm width, wrist width, and other defined sizes. An estimated parametric 3D hand model is built and fitted from these sizes using the calculation of the database for a personalized design. The procedure of the proposed parametric hand modeling method is shown completely in Figure 1.

![Figure 1. The procedure of the proposed parametric design of the hand method.](image-url)
B. DESIGN OF THE ASSISTIVE DEVICE

After the parametric 3D hand model was constructed, only a set of feature parameters were required to generate a 3D hand model that simulated the affected extremity. The Figure 3 is the 3D hand generated by the parametric hand modeling. Thus, the result could serve as a geometric reference during assistive device design - splint and enabled the selection of the most suitable splint shape in simulated 3D space.

This study used a two-piece design as the main axis to achieve a balance between easy putting on and taking off as well as fixing the wrist, while ensuring that the other joints of the hand are not affected by the assistive device to maintain flexibility, as shown in Figure 4. According to the design drawing of this study, the assistive device was worn on the right wrist with a rubber band and rivets. Later, because the IMU sensor and vibration module had to be integrated, a Sensor Box conforming to the modules body was added to the assistive device, as shown in Figure 5. After the completion of the design, it was re-imported into Computer aided design/manufacturing (CAD/CAM) software for assembly.

C. 3D PRINTING TECHNOLOGY

3D printing is also called Additive Manufacturing (AM). 3D printing can meet the requirements of functionality, human
factor engineering and even aesthetic requirements at the same time. Although 3D printing has not yet proposed a commercial method or product for rehabilitation in the past, many research institutes have been working on the feasibility of 3D printing to produce splints which are a supportive device that protects a broken bone or injury. The splint keeps the injured part of your body still to help with pain and promote healing [8][9]. Compared with the traditional manufacturing method of assistive devices, using 3D printing technology as a production method can not only meet the above advantages, but the most important thing in wearing is easy to use and store. In addition, it can also avoid the problems of sweating, itching, and difficulty in putting on and taking off caused by traditional assistive devices such as plaster and thermoplastic plates [10].

First, the proposed splint was sliced into layers and generating a printer-specific G-code. Once finished, the G-code can be sent to the 3D printer for the manufacture of the physical splint.

D. INTEGRATION WITH THE IMU SENSOR AND VIBRATION MODULE

In this study, “active” was used as one of the main design concepts of assistive device production. The assistive device is mainly composed of a development board (Doit ESP32 Dev Kit v1, Shenzhen Doctors of Intelligence & Technology Co. Ltd, Shenzhen, China), a vibration motor module, an IMU (MPU9250, InvenSense, San Jose, CA, USA), a voltage regulator IC (BB-3602A, Blkbox.me, Taiwan), and a Lithium-ion battery. The clearest definition of an active assistive device embedded IMU sensor is that in addition to the most basic fixing function, the assistive device itself can be adjusted according to the usage habits of different users to achieve the purpose of soothing, and simultaneously provide dynamic physically intervention feedback in the form of vibration. In this study design, a vibration motor module was integrated in the assistive device to meet the requirements of an active assistive device. In recent years, some research has pointed out that vibration can be used to treat carpal tunnel syndrome or relieve uncomfortable symptoms [13][14], and can reduce the pain threshold. Therefore, this study integrates the vibration module into the smart assistive device. The sensor box on the back of the hand was used as the place for the battery and the circuit board body, and the cable was connected to the modules through the hole reserved at the bottom. The module was fixed on the user’s wrist using a strap, as shown in Figure 7.

Today, the development and application of 3D printing is getting growing. It has a wide range of uses and can print products with different material characteristics according to needs. Even if the material is the same, the parameters can be adjusted to control the hardness according to the needs. 3D printing technology was subdivided into several methods. After evaluation, this study used the Fused Deposition Modelling (FDM) technology as the main production mode of the finished product. In addition to the low experimental cost of the development process, the finished product in this study was a wrist assistive device. Therefore, the required accuracy was not very high. Thus, the FDM technology was finally selected [11]. The process is as shown in Figure 6.

FIGURE 6. (a)The simulation by Ultimaker Cura [12]; (b) the physical splint with support material and (c) the final product.

FIGURE 7. The design of splint integrated with the IMU sensor and vibration module.

FIGURE 8. The monitoring user interface for attitude angle data tracking.
Finally, the acquired attitude angle data will be sent to the back-end monitoring system platform wirelessly via Bluetooth to display and store, as shown in Figure 8. The system provides main two functions for long-term observation: Display part - present the received attitude angle in the form of numerical value and coordinate axis, display vibration frequency (vibration intensity, the value is 0 ~ 255), and display the current time. Interaction part - the correction button in the upper left corner can correct the current coordinate axis so that the X, Y, and Z axes re-calibrate the sensor to their factory zero points for the zero-calibration procedure. The X, Y, Z, and level fields in the lower left corner can set the vibration coordinate axis and vibration frequency by the user monitoring by the back-end monitoring system. Press the “Vibrate” button to send the signals to the IMU sensor, as long as the current coordinate axis takes the "absolute value", one of the axes greater than the corresponding vibration coordinate axis will trigger the vibration. It not only triggers the vibration instantly but also countdown trigger to reduce the pain threshold or massage in order to avoid holding position for long periods at a time.

E. EXPERIMENT OF HOLDING A PEN AND WRITING-THREE GRAPHIC MAZES
The pen-holding and writing experiment in this study was conducted by holding a pen to walk through the maze [15]. To avoid the learning behavior, the maze was divided into three different shapes, square, triangle and circle, for testing (Figure 9). The tester had to only hold a pen to trace the maze and time the experiment under the condition of wearing assistive devices made of different materials (bare hand, Thermoplastic Elastomer (TPE), Polylactic Acid (PLA), Thermoplastic Polyurethane (TPU), and vibration module).

F. MOUSE OPERATION TEST
In the mouse operation test, Mouse Accuracy [16] was used as the application for testing the reaction time. The time was set to a normal difficulty of 30 s. It was mainly used to test the difference in the reaction time of the test subject with and without assistive devices, as well as whether various materials (TPE, PLA and TPU) and the addition of the vibration module had a significant impact on wrist movements. Mouse Accuracy counted and calculated the click rate, hit rate, and other values according to the test situation. Figure 10 shows the testing.

G. SYSTEM USABILITY QUESTIONNAIRE SURVEY
Based on the Brooke’s System Usability Scale (SUS)[17], this study modified the questionnaire for analysis and counting. The SUS was used because of its wide application and high reliability of the results [13]. Its characteristics meet the needs of this study—concise questioning methods are designed to compare the products of the same type. Multiple studies have confirmed that the SUS is effective, and it has been proven to be suitable for multiple systems and technologies. SUS closed-ended and open-ended questionnaire types and statistical methods could obtain the results quickly and with high reliability. Furthermore, as long as the tested samples are of the same types or have strong correlation, the SUS can be applied to various conditions and tests. In order for the SUS score to be well understood, Bangor et al. [18] have defined the rating scale in adjective ratings on users’ perception of scores for SUS, for example, “Awful” (<51), “Okay” (51–71), “Good” (71–85) and “Excellent” (>85). Table I is the general guideline on the interpretation of SUS score and adjective ratings. The SUS questionnaire has 10 fixed questions. The format is the same, but different test samples can be used to change the vocabulary to complete the questionnaire that meets the requirements. However, the fixed rules of odd positive and even negative questions must be maintained. In the calculation of scores, the scores are first converted and then counted. The conversion method is divided into two parts, odd-numbered positive questions and even-numbered negative questions. The conversion scores are added and then multiplied by 2.5 to get the total SUS score. This can be a base to see the usability of the assistive device which we proposed.

FIGURE 9. Three graphical mazes

FIGURE 10. Testing of Mouse Accuracy [13]
III. RESULTS

This study focused on testing the feasibility of the conceptual prototype; therefore, the experimental test was conducted with a small sample. Because holding a pen and operating a mouse are the two most frequently used movements of the wrist in daily life, the design of the experimental process was based on those two. The results in this section start with the pen-holding and writing experiment for the moving path, followed by a test of the mouse operation.

A. MOVING PATH COMPARISON

There should be a visual comparison of moving path by pen-holding experiment to trace the triangle maze between the proposed module with the IMU sensor and the consumer product (MTw Awinda [19]) simultaneously in Figure 11. The figure shows recording position axes synchronously in 1011 seconds with these two sensors and the average distance error is 0.48 mm, so that the proposed active assistive device with the IMU sensor can integrate wireless human motion tracker for real-time applications and rival the consumer product. The proposed smart splint can be used in daily life to help the people for rehabilitation and long-term monitoring.

| SUS Score | Adjective Ratings |
|-----------|------------------|
| > 85      | EXCELLENT        |
| 71 - 85   | GOOD             |
| 51-71     | OK               |
| < 51      | POOR             |

![Figure 11. Moving path comparison between the proposed module and the consumer sensor.](image)

B. MOUSE OPERATION TEST DATA

This experiment used the same procedure in the mouse operation test as that in the pen-holding experiment, but the analysis was divided into three parts: time, click rate, and hit rate. First, because the time in the mouse operation test was 30 s, the time analysis in this part was to calculate the time of hitting 10 points with zero error. The TPU spent the s among shortest time in the test (10.468 s), but the average test time (11.832 s) after adding the vibration module was only better than PLA, and the test results were not outstanding. ANOVA showed that there was no significant difference the variances, and the same was true for multiple comparisons. There was no significant difference with the Scheffe method or the Least-Significant difference (LSD). The results of the time comparison of the mouse operation test showed that no factor was significantly different. The Figure 12 showed that the user took pen-holding experiment using the proposed smart splint.

The first was the time it took for 10 red dots. This calculation was to complete one click when it was determined that the click position was in the center of the red dot and there was no possibility of error. As noted from the Table II below, before adding the vibration module, the time difference of TPE and TPU from free hands was not significant according to time statistics, whereas the average time after adding the TPU module was slightly increased, but it was closer to the results of free hands.

![Figure 12. Mouse operation test using the proposed smart splint.](image)

IV. DISCUSSION

In this study, the data analysis was mainly divided into two parts. First, according to the statistical results, samples that were closest to the freehand or the best material for the assistive device were summarized, and then the most suitable samples among the three materials were added with the vibration module for soothing massage to be used for testing. The analysis in this section starts with the pen-holding and writing experiment, followed by a test of the mouse operation.

A. EXPERIMENTAL DATA ANALYSIS OF THE PEN-HOLDING AND WRITING EXPERIMENT

The first part is the descriptive statistics part. Among all the materials, the standard deviation of TPU is the smallest (21.506). Notably, the stability of TPU was the highest in the pen-holding test, and according to the mean value graphics, the time spent in the TPU experimental process was also the shortest (162 s). After the analysis of variance (ANOVA), the test results and multiple comparison results showed that the significance was less than 0.05, which implied that there was
no significant difference between the three materials and the freehand test. For multiple comparisons, the Scheffe method, which is relatively conservative, and the least significant difference method, which can easily identify significant results in pairwise comparisons, were used, but the results of the analysis were not significant. In the case that all materials did not show significant difference, this study used the TPU with the shortest average test time and closest to the freehand test as the sample to be added with the vibration module.

The standard deviation of the pen-holding and writing experiment was reduced from 21.506 to 3.493 after the vibration module was added, and the average time was 8.2 s shorter than that of the pure TPU sample (162 s shortened to 153.8 s). In ANOVA, the significance among the three was still not significant. Furthermore, in multiple comparisons, the results of the post-hoc tests performed by both the Scheffe method and the LSD method did not show significance. According to the analysis of the pen-holding and writing experiment, the results of completing the experiment with a free hand and wearing an assistive device or adding vibration modules for soothing were not significant, which suggested that whether or not wearing an assistive device did not affect the actual performance.

Next was the click-through rate, which was calculated by dividing the total number of points (52 points) by the number of clicks, as shown in Table III. Notably, before adding the vibration module, TPU and TPE had similar effects, but after adding the module, the difference was significantly increased (2.4% to 10.2%).

The last part was the hit rate, as shown in Table IV. The total number of clicks was divided by the number of hits. As evident from the figure below, the results of wearing assistive devices were better than that of the freehand test, and the results after the addition of the vibration module were better than those of only wearing assistive devices.

| TABLE II | TEN DOTS |
|----------|----------|
|          | S01      | S02      | S03      | S04      | S05      | Average |
| BARE HAND| 12.240   | 10.550   | 10.830   | 12.110   | 10.180   | 11.182  |
| TPE      | 10.420   | 12.650   | 11.810   | 11.050   | 08.490   | 10.884  |
| PLA      | 14.390   | 13.750   | 12.390   | 10.710   | 09.630   | 12.174  |
| TPU      | 10.030   | 12.610   | 08.910   | 10.130   | 10.660   | 10.468  |
| TPU + IMU and Vibration module | 11.810 | 12.380 | 11.050 | 11.540 | 12.380 | 11.832 |

| TABLE III | CLICK RATE STATISTICS |
|------------|-----------------------|
|            | S01      | S02      | S03      | S04      | S05      | Average |
| BARE HAND  | 56%      | 58%      | 75%      | 73%      | 77%      | 67.8%   |
| TPE        | 56%      | 58%      | 65%      | 69%      | 79%      | 65.4%   |
| PLA        | 50%      | 48%      | 65%      | 65%      | 77%      | 61%     |
| TPU        | 54%      | 52%      | 69%      | 69%      | 83%      | 65.4%   |
| TPU + IMU and Vibration module | 50% | 46% | 62% | 63% | 67% | 57.6% |
In the experimental test of 10 dots, TPU showed the best effect. In terms of the hit rate, TPU and TPE provided the same effect, but significantly better than that of adding the vibration module. Conversely, in terms of the hit rate, TPU plus the IMU sensor and vibration module provided the best test results.

### TABLE IV
**Hit rate statistics**

|                  | S01 | S02 | S03 | S04 | S05 | Average |
|------------------|-----|-----|-----|-----|-----|---------|
| BARE HAND        | 100%| 83% | 93% | 97% | 85% | 91.6%   |
| TPE              | 100%| 88% | 89% | 100%| 91% | 93.6%   |
| PLA              | 93% | 93% | 87% | 100%| 95% | 93.6%   |
| TPU              | 100%| 84% | 90% | 97% | 98% | 93.8%   |
| TPU + IMU and Vibration module | 100%| 96% | 89% | 97% | 92% | 94.8%   |

### TABLE V
**Statistics of the results**

|                              | TPE   | PLA   | TPU   | TPU + IMU and Vibration module |
|------------------------------|-------|-------|-------|--------------------------------|
| Holding a pen and Writing-three graphic mazes |       |       |       |                                |
| Square                       | 411   | 366   | 353   | 352                            |
| Triangle                     | 201   | 186   | 179   | 169                            |
| Circle                       | 285   | 294   | 279   | 248                            |
| Sum                          | 897   | 846   | 811   | 769                            |
| Mouse operation test         |       |       |       |                                |
| Ten dots                     | 10.884| 12.174| 10.468| 11.832                        |
| Click rate                   | 65.4% | 61%   | 65.4% | 57.6%                          |
| Hit rate                     | 93.6% | 93.6% | 93.8% | 94.8%                          |

### SUS questionnaire statistics

|                              |       |
|------------------------------|-------|
| Satisfaction ranking         | 1     |

B. **Statistics of Experimental Results**

According to the statistical results of various data, Table V can be obtained. TPU was the best among the three materials in the pen-holding and writing experiment, and the total time to complete the experiment was significantly shortened by 42 s after the vibration module was added. In the mouse operation experiment, the top material was still TPU,
followed by TPE. In the SUS questionnaire and interview user satisfaction survey, the most popular materials were TPU and TPE respectively.

C. QUESTIONNAIRE INTEGRATION

Data analysis concluded that there was no significant difference between whether or not an assistive device was worn for the experiment. In other words, wearing an assistive device did not affect the performance. However, the vibration module did affect the performance of the mouse operation test. The statistics of the questionnaire were added to integrate the complete study results. In this study, the questionnaire was counted into the table below, and the results were calculated according to the SUS score conversion method. As noted from Table VI, the total score of SUS after conversion ranged from 55.0 to 72.5. According to Figure 13, the red line showed the range of the score and the adjective rating scale converted from the SUS score was between “OK” and “GOOD”. However, the usability connoted an acceptable experience at the edge marginal and

|       | S01 |       |       |       |       |       |       |
|-------|-----|-------|-------|-------|-------|-------|-------|
|       | TPE | PLA  | TPU   | V.M. | TPE  | PLA  | TPU   | V.M. | TPE  | PLA  | TPU   | V.M. | TPE  | PLA  | TPU   | V.M. | TPE  | PLA  | TPU   | V.M. | AVG  |
| 1     | 4   | 3    | 3    | 3    | 4    | 3    | 3    | 4    | 4    | 3    | 3    | 4    | 4    | 4    | 4    | 4    | 4    |      |
| 2     | 4   | 4    | 4    | 5    | 3    | 2    | 3    | 2    | 3    | 4    | 3    | 3    | 3    | 3    | 4    | 3    | 4    | 4    |      |
| 3     | 4   | 4    | 4    | 4    | 3    | 3    | 3    | 4    | 3    | 4    | 3    | 3    | 3    | 3    | 4    | 4    | 4    | 4    |      |
| 4     | 4   | 4    | 4    | 4    | 3    | 3    | 3    | 3    | 3    | 2    | 2    | 2    | 2    | 2    | 2    | 2    | 2    | 2    |      |
| 5     | 4   | 2    | 4    | 4    | 3    | 3    | 4    | 4    | 3    | 4    | 3    | 4    | 5    | 4    | 4    | 4    | 4    | 4    |      |
| 6     | 3   | 3    | 3    | 3    | 3    | 2    | 2    | 2    | 3    | 2    | 3    | 2    | 3    | 2    | 2    | 3    | 3    | 3    |      |
| 7     | 5   | 5    | 5    | 5    | 3    | 4    | 4    | 4    | 2    | 3    | 2    | 2    | 2    | 2    | 2    | 2    | 3    | 3    |      |
| 8     | 4   | 4    | 4    | 4    | 3    | 2    | 2    | 2    | 3    | 2    | 3    | 2    | 3    | 2    | 3    | 3    | 3    | 3    |      |
| 9     | 5   | 4    | 5    | 4    | 3    | 4    | 4    | 4    | 4    | 4    | 3    | 4    | 5    | 5    | 4    | 5    | 5    | 5    |      |
| 10    | 1   | 1    | 1    | 1    | 2    | 2    | 2    | 2    | 3    | 3    | 3    | 4    | 2    | 1    | 1    | 4    | 3    | 3    | 3    |

| SCORE | 62.5 | 55.0 | 62.5 | 57.5 | 62.5 | 65.0 | 70.0 | 72.5 | 60.0 | 60.0 | 65.0 | 55.0 | 65.0 | 60.0 | 62.5 | 57.5 | 65.0 | 60.0 | 62.5 | 67.5 |

FIGURE 13. Adjective rating scale.

The splint can be used directly without major adjustments. As a matter of fact, the result proved that although the method of this study was feasible but there is still room for improvement.

In this study, three materials were used by 3D printing as product research elements. According to the results of user experience interviews, with the exception of PLA, which was generally less satisfied, TPE and TPU were even in the satisfaction comparison; but, the data results showed that TPU provided the best time statistic, and the time spent was the shortest. However, there was no significant difference in the performance of the task; whether an assistive device was worn, did not affect the actual performance. In contrast, 3D
printing applied on orthoses have been introduced in papers by Górski et al [20]. However, the parametric 3D hand model proposed by this study allow quick generation of 3D hand geometry approximating to a user’s actual hand. The individual hand geometry produced without the need of complex scanning devices serve as effective design references for improving hand products, especially during the COVID-19 pandemic seriously. On the other hand, PLA indeed provided more supporting constraint satisfaction for reaching more tensile force due to the character of the hand according to the past research in materials [21][22]. However, the questionnaire indicated that PLA has less satisfaction than other materials because the splint made by PLA is too hard to wear. The result is consistent with previous studies but being able to use in daily life is really the motivation of this research. This part achieved the goal of having a fixed effect, but not interfering with the task.

After the vibration module was added, although it had a slight impact on the performance of the task and the test time was short, according to the result of users’ questionnaire with the addition of the module, if it was worn for a long time, it would be able to achieve a soothing effect. Conclusively, the proposed 3D printing assistive weighs 69 grams plus the weight of the IMU sensor and vibration module plus 27 grams (total weight 96 grams). Actually, the weight of the proposed splint can be accepted for users’ daily use like wearing a watch or a hand-band. When monitoring and tracking attitude angle via the IMU sensor, a physically intervention feedback of the vibration module can provide real-time reactions. The proposed smart splint cannot only support the user’s hands but also provide the practical force feedback actively with soothing and reminding functions further. In the feasibility assessment, actual interviews were conducted in addition to the performance of the SUS system usability questionnaire survey of the experimental samples, and direct investigations were conducted on user experience. According to the results, the current status was above OK but not GOOD.

V. CONCLUSIONS

The purpose of this study is to use the parametric model combined with CAD designs and use 3D printing technology to manufacture tailor-made assistive devices for patients. The experimental results proved that the conceptual prototype of the personalized active assistive device in this study is feasible, but there is still considerable room for improvement in the material parameters and wearing methods. Subsequent studies can consider a simpler wearing method to replace the current rivet and rubber band fixing method. For example, the side can be changed to a zipper, and the circuit board can be miniaturized such that it can be closer to the main body of the assistive device. Furthermore, the assistive device, circuit board, and vibration module can be integrated, such that it is more convenient to wear and remove and lighter to use in daily life.

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APPENDIX

Assistive Device Test—Original Freehand Test/TPE/PLA/TPU/+Vibration
User Evaluation Questionnaire—Original Freehand Test/TPE/PLA/TPU/+Vibration

**SQUARE**

- Time: ___________
- Misses: ___________ (cm)
- Accuracy: ___________
TRIANGLE

- Time: _______ _______ _______ _______ _______
- Misses: _______ _______ _______ _______ _______ (cm)
- Accuracy: _______ _______ _______ _______ _______
### Mouse Accuracy

| Targets | Clicks |
|---------|--------|
| Hits    | Hits   |
| Misses  | Misses |
| /sec.   | /sec.  |

**Total Score**

| Points | Total   |
|--------|---------|
| Bonus  | Click Accuracy |

**10 Dots**

| The Completion Rate |
|---------------------|

**CIRCLE**

- Time : __________
- Misses : __________ (cm)
- Accuracy : __________
System Usability Scale Questionnaire (Original Freehand Test/TPE/PLA/TPU)

Instructions
Based on your experience today, check the box that reflects your immediate response to each statement. Don’t think too long about each statement. Make sure you respond to every statement. If you don’t know how to respond, simply check box “3”.

| No. | Please answer according to your feeling | 1=Strongly disagree | 2=Disagree | 3=Neither Agree nor Disagree | 4=Agree | 5=Strongly agree |
|-----|----------------------------------------|---------------------|------------|----------------------------|---------|-----------------|
| 1   | I think that I would like to use the assistive device frequently. | □ □ □ □ □ |
| 2   | I thought the wearing process of the assistive device took time. | □ □ □ □ □ |
| 3   | I thought the assistive device was easy to use. | □ □ □ □ □ |
| 4   | I think that I could use the assistive device without the support of a technical person. | □ □ □ □ □ |
| 5   | I found the various functions of the assistive device were well integrated.(fix and flexibility) | □ □ □ □ □ |
| 6   | I thought there was a lot of consistency of the assistive device. | □ □ □ □ □ |
| 7   | I would imagine that most people would learn to use the assistive device very quickly. | □ □ □ □ □ |
| 8   | I found using the assistive device very intuitive. | □ □ □ □ □ |
| 9   | I felt very confident using the assistive device. | □ □ □ □ □ |
| 10  | I could use the assistive device without having to using anything for supporting | □ □ □ □ □ |

Comments
Please provide any comments you have about this assistive device:
System Usability Scale Questionnaire (+Vibration)

Instructions
Based on your experience today, check the box that reflects your immediate response to each statement. Don’t think too long about each statement. Make sure you respond to every statement. If you don’t know how to respond, simply check box “3”.

| No. | Please answer according to your feeling | 1=Strongly disagree | 2=Disagree | 3=Neither Agree nor Disagree | 4=Agree | 5=Strongly agree |
|-----|----------------------------------------|---------------------|------------|----------------------------|---------|-----------------|
| 1   | I think that I would like to use the assistive device frequently. | 1 2 3 4 5          |            |                           |         |                 |
| 2   | I thought the wearing process of the assistive device took time. | 1 2 3 4 5          |            |                           |         |                 |
| 3   | I thought the assistive device was easy to use. | 1 2 3 4 5          |            |                           |         |                 |
| 4   | I think that I could use the assistive device without the support of a technical person. | 1 2 3 4 5          |            |                           |         |                 |
| 5   | I found the various functions of the assistive device were well integrated.(fix, flexibility and vibration for massage) | 1 2 3 4 5          |            |                           |         |                 |
| 6   | I thought there was a lot of consistency of the assistive device. | 1 2 3 4 5          |            |                           |         |                 |
| 7   | I would imagine that most people would learn to use the assistive device very quickly. | 1 2 3 4 5          |            |                           |         |                 |
| 8   | I found using the assistive device very intuitive. | 1 2 3 4 5          |            |                           |         |                 |
| 9   | I felt very confident using the assistive device. | 1 2 3 4 5          |            |                           |         |                 |
| 10  | I could use the assistive device without having to using anything for supporting | 1 2 3 4 5          |            |                           |         |                 |

Comments
Please provide any comments you have about this assistive device: