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Improving Reverse Engineering Processes by using Articulated Arm Coordinate Measuring Machine

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Abstract

The invention relates to a coordinate measuring machine (CMM) for determining a measuring position of a probe. The AACMM is depends on the robot kinematics (forward and reverse) in their measurement principle, i.e., using the AACMM links and joint angles to determine the exact workspace or part coordinates. Hence, the measurements are obtained using an AACMM will be extremely accurate and precise since that is merely dependent on rigid structural parameters and the only source of measurement error is due to human operators. In this paper, a new AACMM design was proposed. The new AACMM design addresses common issues such as solving the complex kinematics, overcoming the workspace limitation, avoiding singularity, and eliminating the effects of design error by designing a new and compatible AACMM that will incorporate all affective design factors into consideration. Different types of design factors and limitations, which significantly affect the AACMM production fabrication processes, and ultimately. accuracy are given. Cost and time factors effects on the design and manufacturing are found to be the most significant. Two primary manufacturing techniques were used, both of which relied on rigors CAD/CAM iterations resulting in an entirely usable G-Code. Those methods are CNC and 3D printing, the most widely used methods in any industry. Nevertheless, accuracy and ergonomics factors must be considered for precise measurements. The design was validated through various methods, such as the use of finite element measurement techniques, to make sure that the design was structurally correct.

Keywords: *AACMM, robotic kinematics, G-Code, CAD/CAM.*

1. Introduction

The novel design of the AACMM is discussed in the following, including the design of the electric/electronic circuitry and the control model. The design concept was based on the three-axis robotic arm that will serve as the primary tool to obtain the required coordinates measurements. This was to utilize the kinematic model to obtain the measurements with ease. The complete forward and reverse kinematic modeling resulted in the following governing equations, where both q_1 and q_2 represent the AACMM joint angles needed to reach any point within the machine workspace,

$$q_2 = A\ \tan 2\left(\pm\sqrt{1-\left(\frac{p_x^2+p_y^2-l_1^2-l_2^2}{2l_1l_2}\right)^2}, \frac{p_x^2+p_y^2-l_1^2-l_2^2}{2l_1l_2}\right) \quad \ldots(1)$$

$$q_1 = A\ \tan 2\left(\pm\sqrt{1-\left(\frac{p_x(l_1+l_2\cos q_2)+p_y l_2\sin q_2}{p_x^2+p_y^2}\right)^2}, \frac{p_x(l_1+l_2\cos q_2)+p_y l_2\sin q_2}{p_x^2+p_y^2}\right) \quad \ldots(2)$$

where, q_1 and q_2 are the arm joint angles calculated by the rotary encoders and resolved using the algorithm. p_x, p_y, and p_z are the corresponding positions of the workpiece geometrical points, l_1 & l_2 are the arm links length. This model is useful and can be used with no further complications. The design process had several constraints that needed deep consideration as can be seen in Figure 1, namely: Cost, Time, Size, Manufacturing method, and Programming Environment [1].

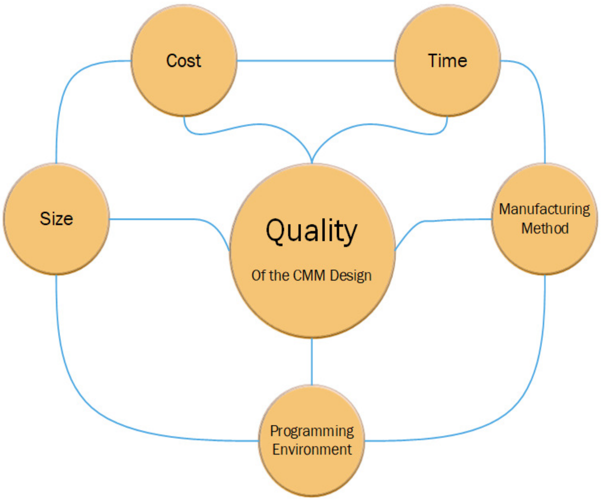

Fig.1. CMM Design Constraints.

The cost was the first limiting factor, where everything had to be designed around that constraint. Also it is a known fact that this work had a minimal budget. The second factor is time, where the work and design activities associated with it had to be accomplished within a very tight time window [2]. The choice of manufacturing technique was a challenge, since all the options available were all dependent on the first two constraints, cost and time. Lastly, the choice of the programming environment was a significant consideration. This factor will untimely affect the choice of some of the most critical hardware components of the CMM, which is the controller. This choice is then connected to and affected by the other design constraints, all of these constraints, as illustrated in Figure 1. As with all articulated arm CMMs (AA-CMMs) [3]. The position of the probe may be controlled manually by the operator or maybe controlled by the computer. The AA-CMM Agile Development Cycle is illustrated in Figure (2).

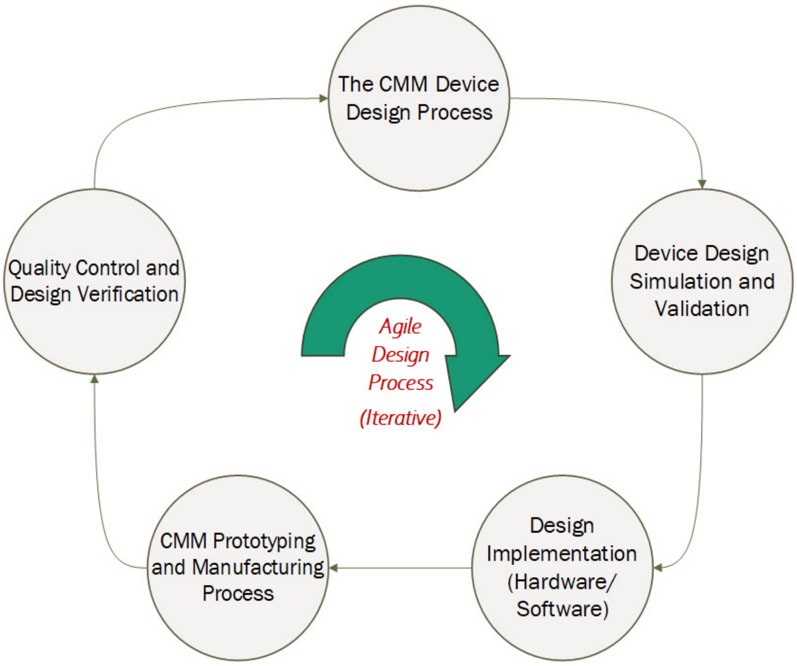

Fig. 2. The AA-CMM Agile Development Cycle.

To create CAD sketches, SolidWorks was used. To creating accurate 2D drawings. Where can be automatically updated on-the-fly, especially with agile development, when changes to 3D models are expected. Moreover, SolidWorks offers comparison capabilities of design against real-world conditions to ensure the achievement of the best design before building it [4].

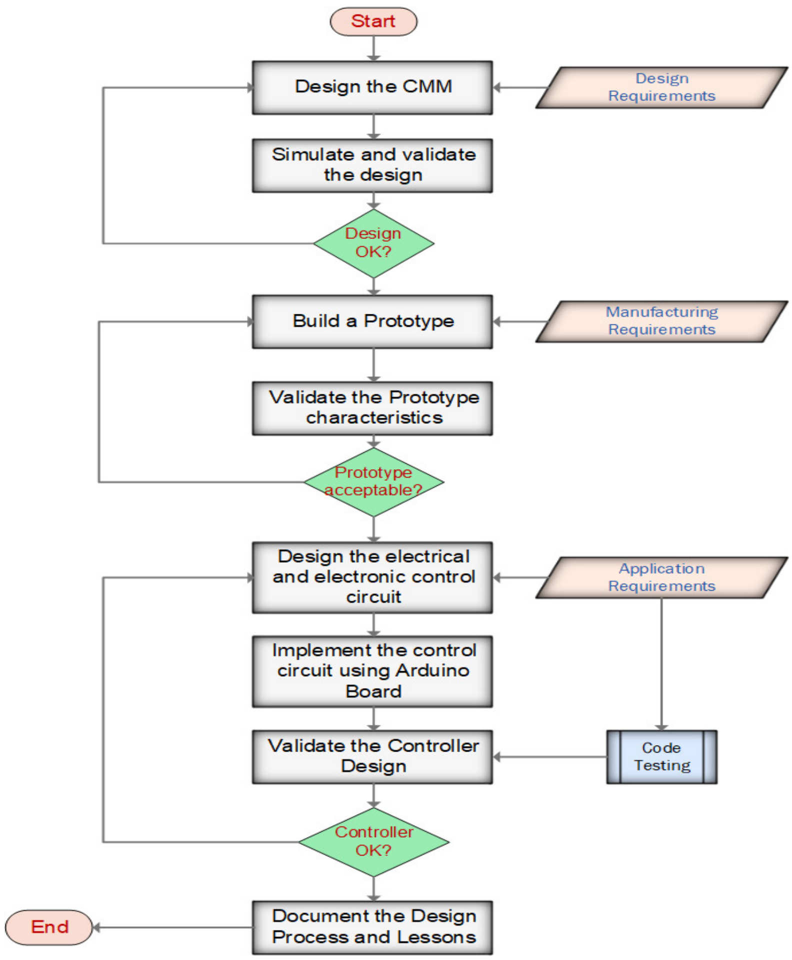

Fig. 3. Coordinate Measuring Machine device design and manufacturing process flow.

2. AACMM Part Design

A coordinate measuring machine (CMM) device is composed of the structure of transparent and transparent acrylic material, consisting of a base which is the leading platform of the device where the part to be examined and drive it to a three-dimensional model, two arms and a rotary joint. Each unit is connected mechanically and electrically with other units in an electronic system to make the desired device. Each unit is basically a control system to find out the juxtapositions and dimensions of the material to be examined, and the device is operated using the controlled with Arduino Uno.

2.1 Mechanical Components

As mentioned before, the AACMM consists of two categories, leading and supporting.

2.1 A. Main Components

1. The Base

The base can be described as a rectangular table, which is used as a base for the part to be measured and will be holding the main arm as well. Therefore, it has a circular pattern to hold the base rings, and ultimately the arm-probe assembly. Each (bolt hole) with a radius of 0.04cm, with six holes to ensure that the base will be able to hold the arm-probe assembly, along with the supporting components and the encoders. The base design is shown in figure (4). The base will be stationed on four “stand” to provide some elevation from the ground and to make sure that the work surface will be isolated from its surroundings. The base dimensions are designed 21cm length and 18cm width, and 1 cm thickness. The larger the dimensions, the larger the object to be measured will be. However, the other components will have to be increased accordingly, all of which will increase the cost, manufacturing time, and other constraints that had to be adhered to during the design process.

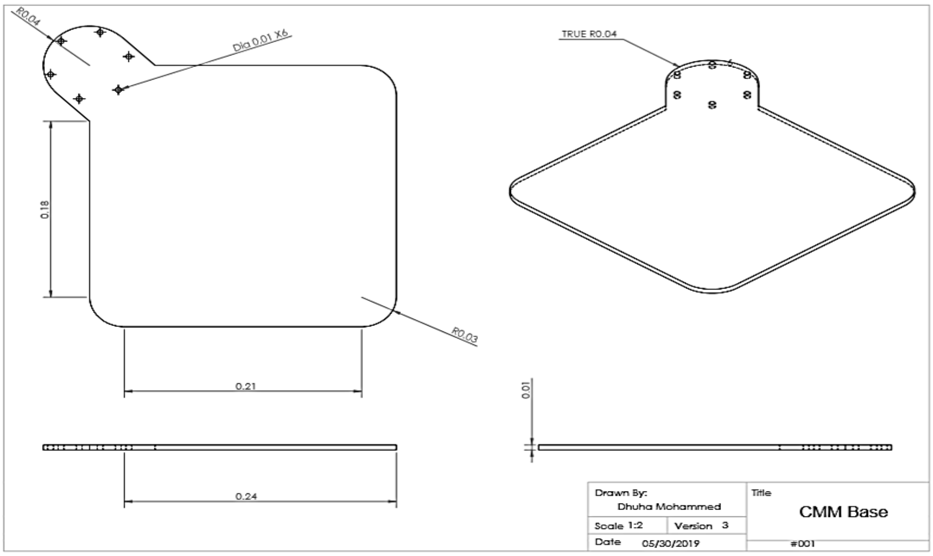

Fig. 4. Design of the CMM base.

2. Arm

The arm is the second of the main component's category. The primary function of the main arm is to serve as the link connecting between the base joint and the shoulder joint (2nd joint). This, of course, means that the main arm will play a significant role in the kinematic model calculations and the resulting AACMM measurements. The arm will be 3D printed, which keep the design simple, minimalistic, and to the point. Figure (5) shows the arm design. The arm dimensions are 19cm length, 2cm width, and 1cm thickness. Each end contains three bolt holes for the join encoders.

3. The Probe Arm

The third component in this category is the probe arm. It is the most crucial part of the AACMM since it has two primary functions. The first, as the case with the main arm, it will act as the second link in the robotic arm joint-link assembly, providing all the remaining information for the kinematic model calculations. The second function is to act as the "touch" probe for the AACMM, which will be vital in the coordinate measurement process. Figure (5) shows the probe arm design. Where the arm length is 19cm with a 2cm touch point.

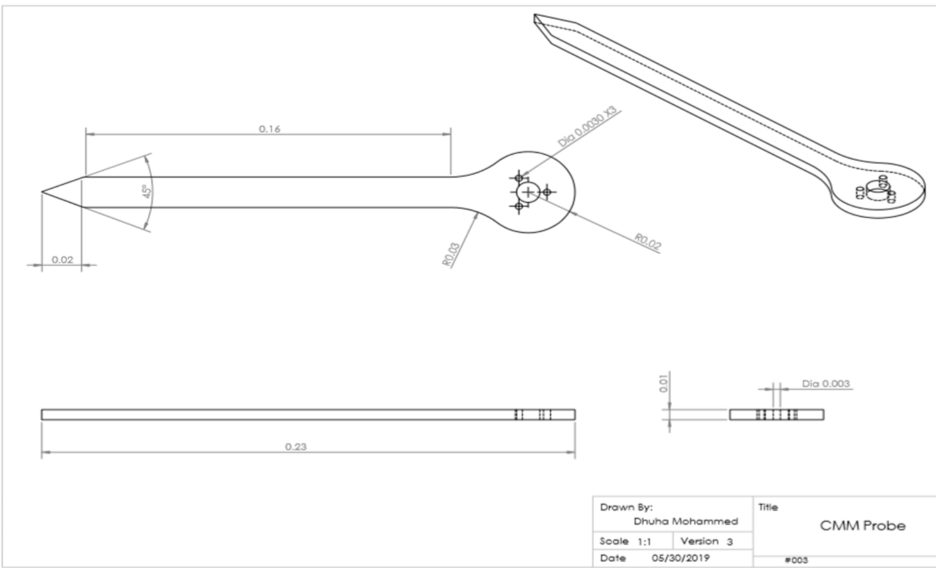

Fig. 5. CMM Probe Arm.

2.1 B) Supporting Components

The support equipment plays an important role, as well. They provide the geometric integration between the robotic arm link-join assemblies and allow the AACMM to function as it's supposed to. The support equipment includes positioning base, base rings, flanges, spacers, and washers as shown in figure (6).

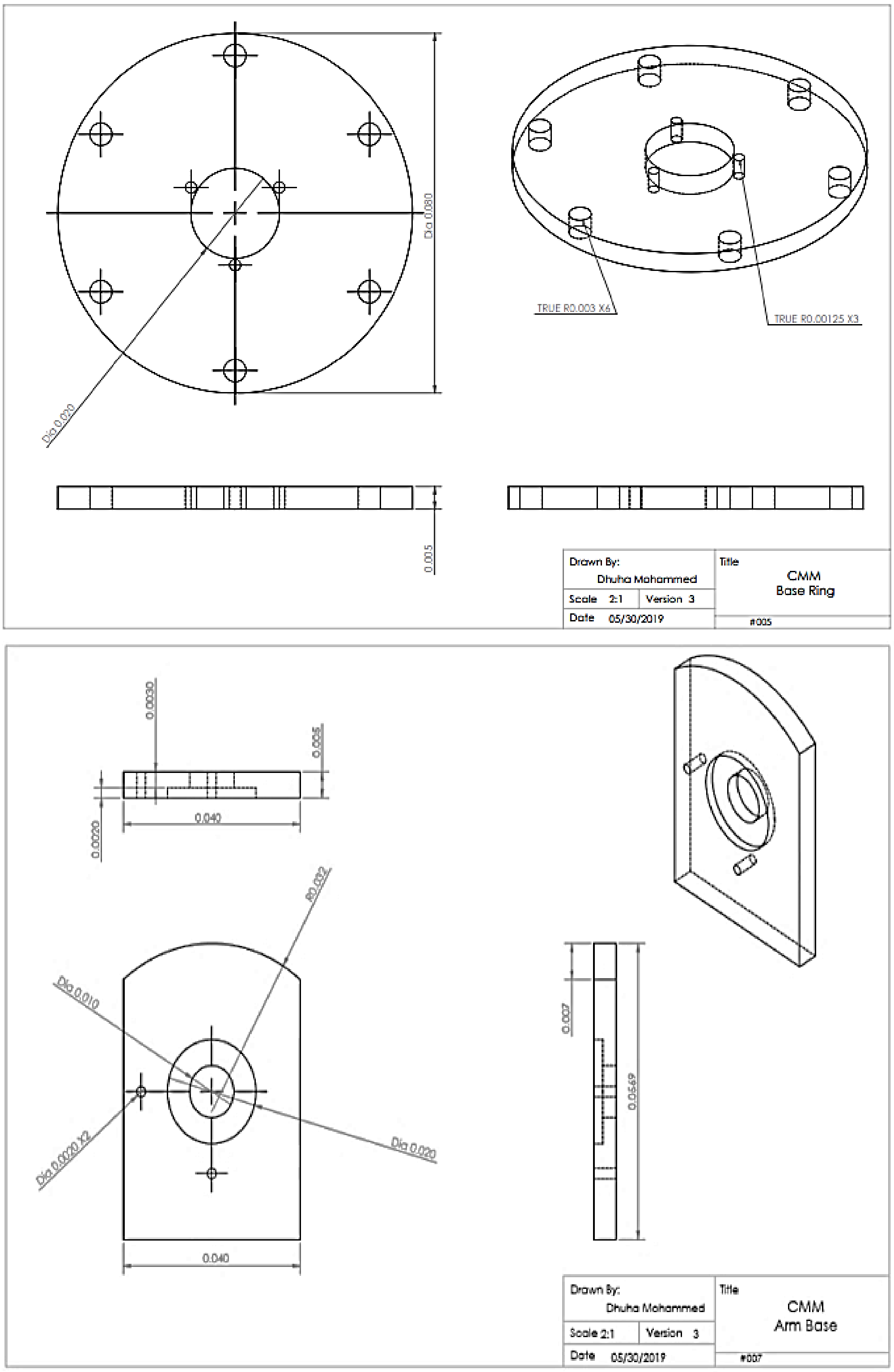

Fig 6. A. AACMM Base Ring. B. AACMM Base.

3. The AACMM Complete Assembly in Solid Works

Now that all the components have been designed according to the concept specifications, the next step is to assemble all the components to create the AACMM final design. Utilizing the assembly drawings feature in SolidWorks, it is possible to assemble the AACMM part by part to create the final layout as Shown in figure (7). The "Mate" function in SolidWorks is vital in ensuring that the AACMM link-joint assembly is correct, and the "Motion Study" function verified that the design would work as required. All of these verifications were done in SolidWorks, and it gave the "Green Light" to go ahead with the manufacturing process.

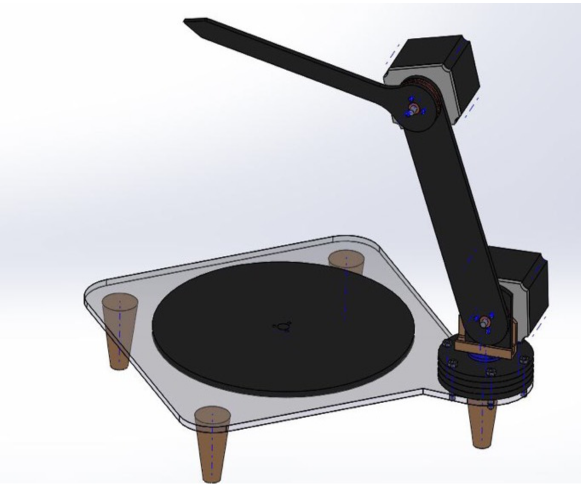

Fig. 7. Articulated Arm Coordinate Measuring Machine AACMM after Assembly.

4. Control Components

The AACMM control components include the optical encoders, to capture the joints angular position, and the control board (Arduino Uno, shown in Figure 8) will be used to translate the encoder's signal into actual measurements with the help of the control interface and the control program. Electrical yield in digital structure relating to the angular position of the info.

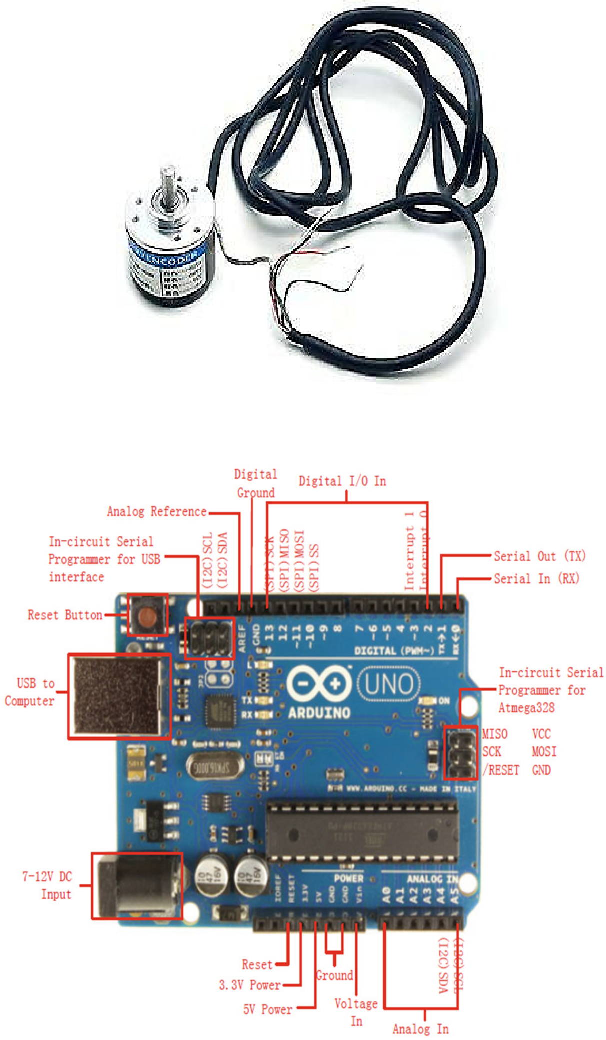

Fig. 8. A. Optical encoder. B. Arduino Controller.

5. Working Concept

As mentioned earlier, optical encoders (Rotary Encoder) was used to convert the angular position or motion of the device joints to a digital output signal. In this work, four rotary encoders were used. The first was installed between the circular platforms, the second between the first arm and the rotating base, the third between the first arm, and the second and the last rotary encoder was installed between the base of the first arm and the table. The circuit schematic is shown in figure (9).

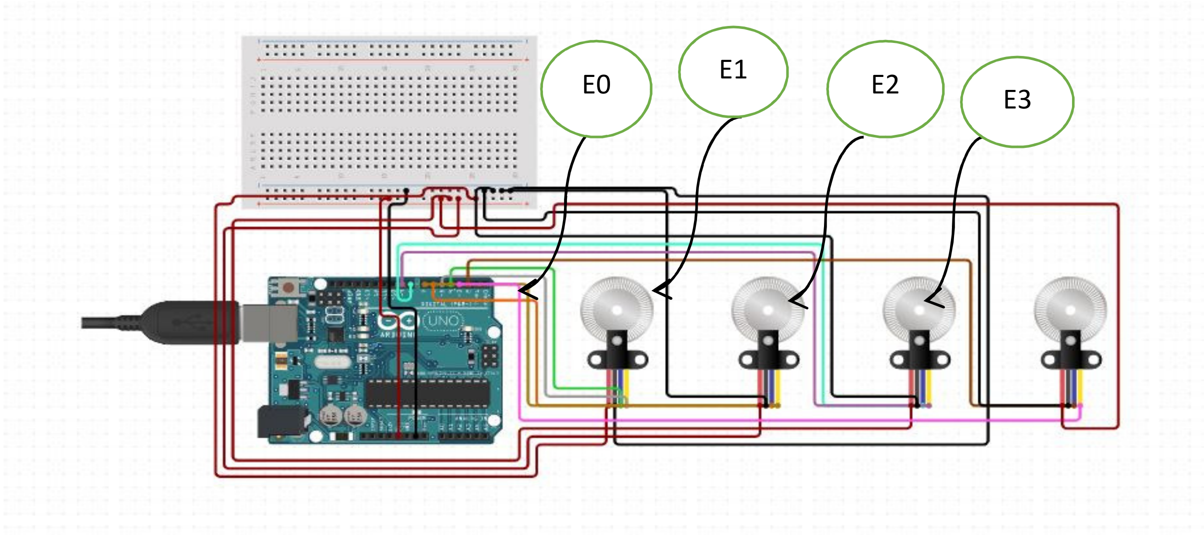

Fig. 9. Controller Circuit Schematic.

All encoders are transmitted via an electronic circuit controlled by the Arduino Uno. As it's known, the Encoder possesses two outputs A and B. If A operates before B, the rotation is to the right and if the opposite is to the left. The speed of operation is relative to the speed at which the object moves (the rotation speed of the table).

The interval between A and B is the distance from which A and B are moved. Number A and B represent the number of pulses transmitted. Where the number of A and B of the most critical specifications of the Encoder. In this work, each cycle gives 200 pulses to the Arduino. When moving the Arduino's arm receives 200 pulses, the pulses of the four encoders are grouped with equations after the pulses are converted into distances.

the probe tip diverted from the base of the arms, using equations, thus determining the position of the tip using the reverse kinematic. When knowing the location of the tip of the robot. The coordinates of the tip of the robot are sent to the software that is stored in the processing program. It was programmed in C ++ to control the coordinates programmatically via the computer with six buttons programmed shown in Figure (10):

1- Button (q) scans and adds all the points recorded on the interface.
2- Button (p) draws a point at that location.
3- Button (c) draws a circle at that location.
4- Button (f) draws a rectangle at that location.
5- Button (m) adjusts the coordinates in the case of moving the figure.
6- Button (z) stores the shape drawn by the user in the form of XYZ, where it can be reopened by editing programs to adjust and mislead to the clarity of the shape drawn.

6. Software Components

Programming for the device was accomplished by combining two types of programming. The first was to convert the pulses that received from the movement of the first, second, third and fourth. Pulses meet using equations, and pulses are converted to distances and by geometric equations are converted in to ratios after the head from the base where the head movement is converted to any location within the workspace.

This is translated to a pulse to the Arduino where it is recorded, and then sent the location of the head coordinates (X 'Y' G) to the program processing where it decides whether the user of the device pressing the button draw point or the user did not press that button.

Fig. 10. AACMM Programming.

7. Steps to Manufacture the Machine by CNC Machine

The AACMM is manufactured by a CNC laser machine. The code for the work was done by the program sold works and experimented with the program to be transferred to the machine to be cut and drilling using it as shown in the figure below Fig. (11).

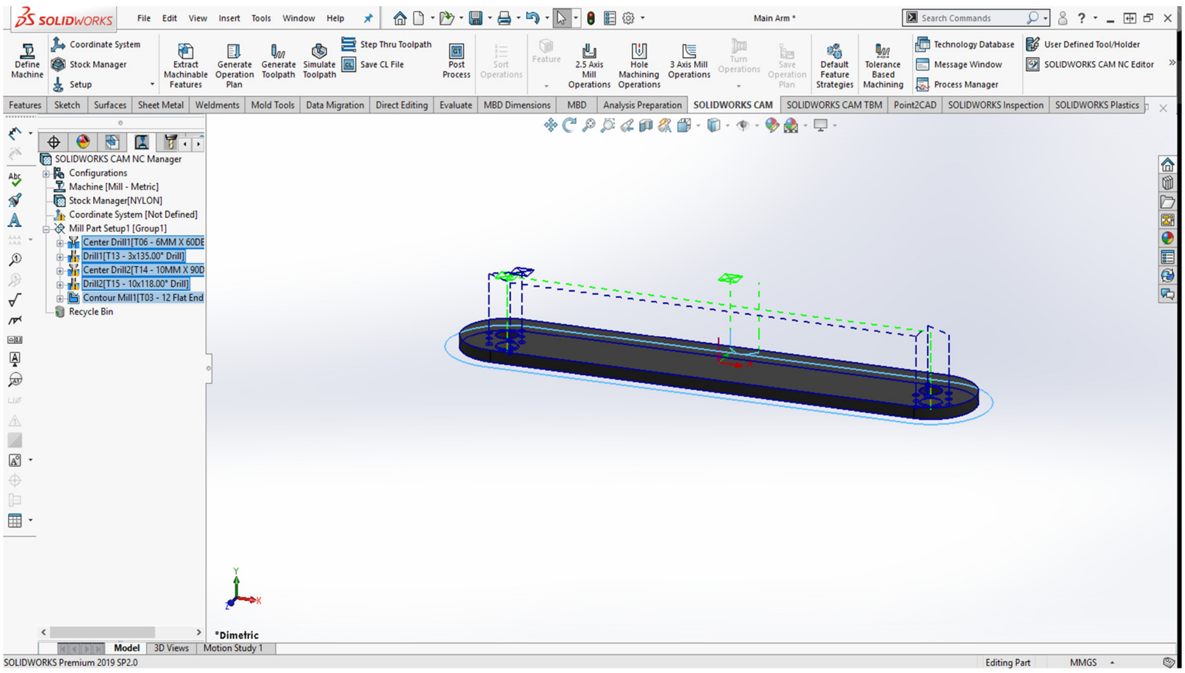

Fig. 11. SolidWorks CAM CNC Manager.

8. Building the AACMM kinematic Structure (Implementation of AACCM)

The subsequent stage is to choose the detail of each connection, joint, and the base. The structure of the AACMM is implemented with plexiglass sheets so as to diminish the general load of the AACMM. The plexiglass sheets are additionally sufficiently able to keep and hold the entire parts firmly together. The arm is connected to a base, which is the base piece of the AACMM. The base should have an extensively substantial load so as to keep up the general equalization of the AACMM in the event of estimating the various elements of an item. In spite of the fact that utilizing joins and optical encoders are splendid, however physical development of the AACMM is finished by utilizing manual movement as shown in figure (12).

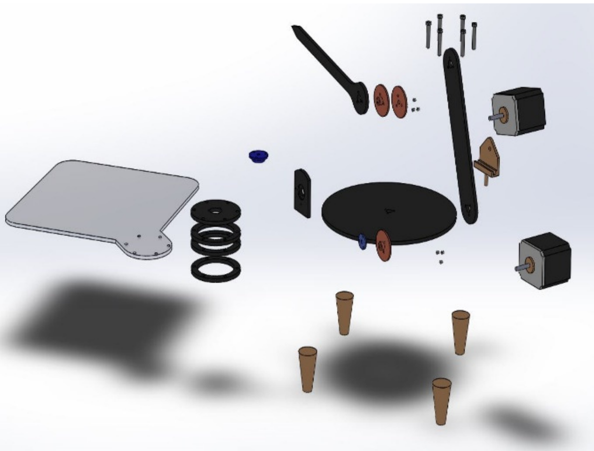

Fig. 12. Simulation of AACMM in Solid works.

To fabricate the AACMM parts rapidly, several factors had to be studied, including the limiting factors discussed previously in the design process. Based on those reasons, the fabrication process started with the preparation and cutting of the rotating AACMM base, which will allow the user to be able to rotate the work part. The finished part is shown in figure (13) below.

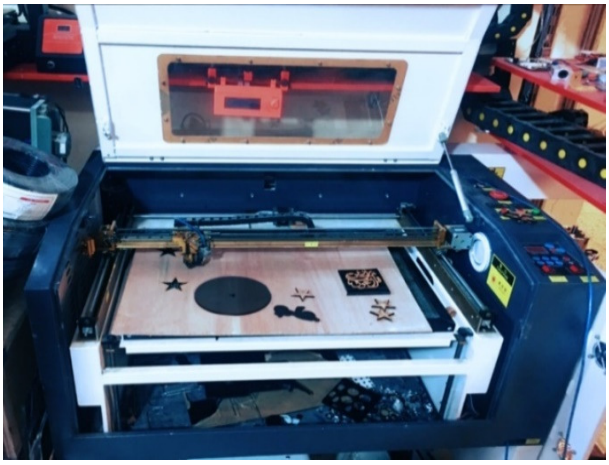

Fig. 13. CNC Laser machine.

Next, the AACMM arms (links) were manufactured. Those are the most vital parts of the measurement process since they will determine the accuracy of the kinematic model and the resulting measurements. Figures (14) and (15) shows the final design of both parts.

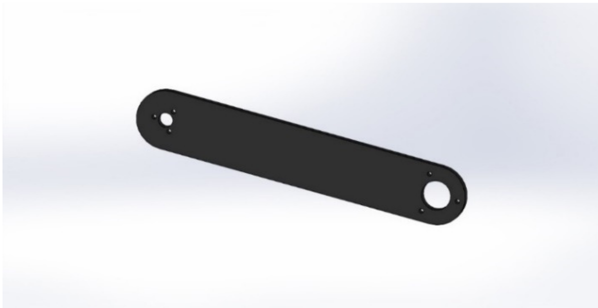

Fig. 14. The Main Arm.

Fig. 15. The Arm Probe.

It should be mentioned that these two parts went through several design-fabrication cycles to bring their characteristics to the supposed and required criteria. Those changes include the fact that the design had to be altered in connection to the work environment. The second modification required that the weight of the two parts to reduced, design outcomes can be seen in Figure (16) below.

Fig. 16. The Manufactured AACMM Arms.

It was necessary to incorporate the new changes to bring these parts to their ultimate design requirements. The steps are illustrated in Figures (17), and (18).

Fig. 17. The Machined Parts.

Fig. 18. Fabricated the two Arm.

Other components had to be 3D printed, such as the base legs, the arm fixtures pulleys, and the support rings. The support rings play an important role in providing the AACMM with the geometric integrity to fulfill the kinematic structure and kinematic model requirements. Those are shown in figure (19).

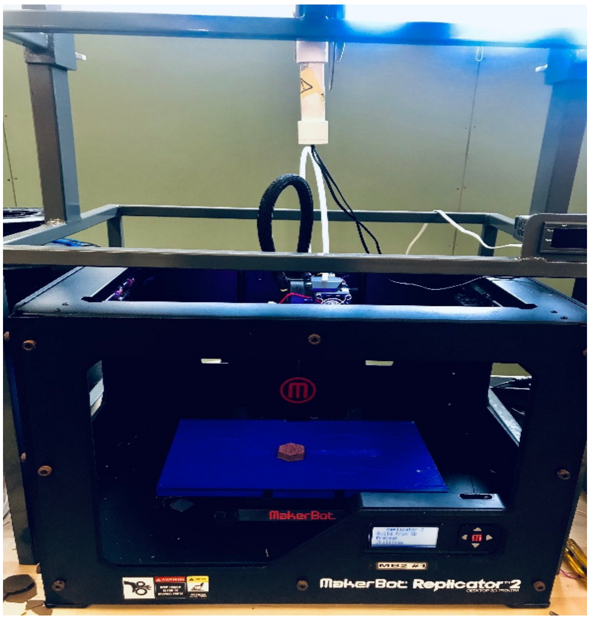

Fig. 19. The progress of the 3D Printing Process.

9. The AACMM Assembly

The process of assembling the various parts of the AACMM was undertaken as soon as the fabrication and 3D printing processes were finished. The process required the same progress of assembling the parts as the design and fabrication processes. Starting with the base and the 3D printed base legs, moving to the rotating base, and then the central arm fixture. Once the fixture was installed, the main arm was attached, followed by the probe arm. During the assembly, various M3 and M2 screws were used. Figure (20) shows the progress of the AACMM assembly process.

Fig. 20. Assembly Parts.

10. Results and Conclusion

In this exploration, a beneficial model of the AACMM was proposed implemented, to show the machine and to demonstrate the structure idea. The AACMM model was utilized to approve the arrangement of the kinematic model. Results demonstrate that the kinematic position model is proficient in deciding the position when contrasted and estimations are taken physically. A common distinction of under 0.5 mm more than 30 points was accomplished. This consequence of the AACMM estimations falls inside the blunder spending plan. The device was tested on a freeform surface part (mouse) as shown in Figure (21).

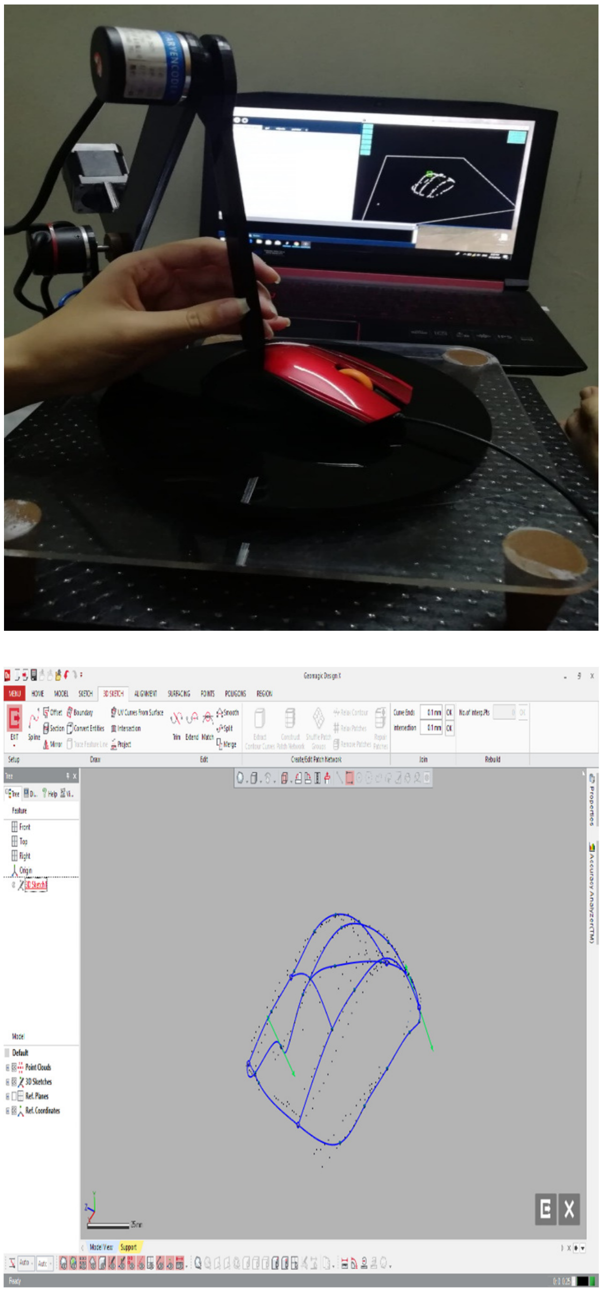

Fig. 21. During the examination of the AACMM device.

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تحسين عمليات الهندسة العكسية باستخدام آلة قياس إحداثيات الذراع المفصلية

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الخلاصة

فكرة البحث هو في الهندسة العكسية من خلال تصميم وتصنيع جهاز ،من خلاله يتم الحصول على المخططات التصميمية لأي جزء ميكانيكي عن طريق تصويره فتكون له بيانات رقميه مجسمه على صيغة (StI) لهذا المنتج المعين ومن ثم نقل تلك المعلومات الى احدى المكائن المبرمجة رقميا وبهذا تكون العملية سهله لتصنيع الأجزاء الغير معروفة المخططات. في هذه الرسالة ، تم اقتراح نموذج وتم تصنيعه واستخدامه في الهندسة العكسية ،تمت محاولة تصميم AACMMجديد وصنعه. حاول تصميم AACM الجديد معالجة المشكلات الشائعة لـ AACMM مثل حل حركيات الحركة المعقدة ، والتغلب على حدود مساحة العمل ، وتجنب التفرد والتخلص من آثار خطأ التصميم من خلال تصميم AACMM جديد ومتوافق يدمج جميع عوامل التصميم المرنة. يتم إعطاء أنواع مختلفة من عوامل التصميم والقيود التي تؤثر بشكل كبير على عمليات الإنتاج والتصنيع AACMM وفي نهاية المطاف دقة. يُقال إن عوامل التكلفة والوقت في التصميم والتصنيع لها التأثير الأكثر أهمية. ومع ذلك ، يجب مراعاة عوامل الدقة وبيئة العمل لإجراء قياسات دقيقة. تم التحقق من صحة التصميم من خلال أساليب مختلفة ، مثل استخدام تقنيات قياس العناصر المحدودة ، للتأكد من أن التصميم كان صحيحًا من الناحية الهيكلية.حيث يتم الحصول من خلاله على ما يسمى بالغيمة النقطية في علم المجسمات ثلاثية الابعاد . تم اجراء الحسابات والقياسات باستخدامه وتم التتعديل على النتائج باستخدام برنامج (Geomagic x) للأجزاء الأصلية والتقليدية لبيان الانحرافات والتفاوتات بالأبعاد . وتم بالفعل الحصول على جهاز فعال وعملي حقيقي يتضمن الهدف الرئيسي من هذه الورقة البحثية تصميم وتنفيذ نموذج ألة تنسيق الاحداثيات المفصلية الذراع .يتم التحكم والبرمجة الخاصة بالجهاز باستخدام برنامج Processing 3 مع المتحكم Arduino. يقوم المتحكم باستلام حالات المتحسسات الموزعة بجميع الفاصل للروبوت وينفذ القرارات نسبة للبرنامج لتشغيل المشغلات. يمكن استخدام هذا النموذج في المختبرات الهندسية العلمية لتقريب الجانت النظري على الجانب العملي.