

The future of acupuncture education: 3D Augmented Reality (AR) acupuncture model for Chinese Medicine

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ABSTRACT

Acupuncture is a therapeutic modality in Traditional Chinese Medicine which aims to improve the flow of Qi (chi) or energy around the body by applying needles to specific points on the skin. Traditional Chinese Medicine teaches that Qi must flow freely through the body's meridians, or channels, to ensure health and well-being. Traditionally, Chinese Medicine practitioners used a wooden, copper or bronze acupuncture model to show the points where needles should be applied to the skin and the meridians through which Qi flows around the body. However, as traditional models depict acupuncture points which are too rigid for teaching purposes, understanding the descriptions of acupuncture points from textbooks in 2D is also another hurdle for beginners to apply them to the human body in 3D. With modern computing and 3D-printing technologies, this article introduces a realistic human model in the form of a 6-foot copper acupuncture sculpture with over 370 virtual acupuncture points using state-of-the-art Augmented Reality (AR) and metal 3D-printing techniques for enhanced teaching, learning, and demonstration of acupuncture principles. It will be a new training model for Western and Chinese medical practitioners as well as for the public to gain interactive acupuncture experience that is beneficial to their own health.

KEYWORDS Acupuncture; copper 3D printing; infrared tracking; Augmented Reality (AR); smart learning

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1. Introduction

Acupuncture is a key component of Traditional Chinese Medicine (TCM). The ancient repertoire evolved through cumulative observation and experience of manual and manipulative therapy to handle ailments and pains (Djaali et al., 2021; Hou et al., 2015). Over the years, sophisticated theories and ways of using needles through the body surface at strategic points have been established. While modern scientific studies have not led to a full understanding of acupoint anatomy, the therapeutic practice of acupuncture is now generally and widely accepted around the world, even in academic circles (Long et al., 2022; Zhang et al., 2021).

From acupoint localisation and needling techniques to the teaching of acupuncture, the ancient methods are passing down through TCM heritage. Historically, the first standardised acupuncture model was constructed a thousand years ago in 1027 AD (Schnorrenberger, 2013). Produced by metal copper craftsmen, this first model which was about 1,750 mm tall was constructed by Wang Weiyi under the order of Emperor Renzong of the Song Dynasty of China. It served to standardise previous possible incoherent localisation of acupoints. In that model, the acupuncture points and meridians were hard coded on the metal surface cast with 657 standardised acupoints as a teaching tool in the Chinese imperial medical school (Wentz, 2016). The hollow life-size statue would be filled with water and surface-covered with wax. Students who were being tested on their knowledge of acupuncture were required to insert a needle into the acupoint whereupon water inside would flow out from the point accordingly,

if correct. Such replica has been placed in the lobbies of many world-renowned universities and centres but without the water-flow mechanism for teaching purposes. In fact, over the centuries, similar acupuncture models have been displayed in the national museums of Britain, Japan, Korea, etc., as part of their collections.

The current understanding of acupuncture has been advanced tremendously with more precise mapping. Besides knowing the surface map, advanced understanding has been developed regarding the probable sites of acupoints inside the body through gauging the depths and directions of needling (Chou et al., 2015). Plenty of information has been gained from clinical experience and research, so that nowadays knowledge has greatly expanded. Therefore, more effort should be made to educate and train acupuncture practitioners apart from simply using rigid old traditional wood or plastic manikin models.

Generally, most learners can at best try to appreciate the acupoints by studying the 2D pictures and descriptions in textbooks as well as gaining hands-on experience. Some virtual 3D software demonstrations of acupoints have been developed, but notably such expanded magnifications do not in fact produce the necessary greater resolution since more details about the acupoints, and the number of acupoints, remain fixed, unlike when using Google Earth™ which can be used to zoom inside to search for details. In addition, these software programmes are not complemented by a physical model for an actual touch, the lack of which would reduce the user's grasp of details. All these limitations have hindered the learning of acupuncture through experience and appreciation.

Nothing would be better than using our hands to hold a needle and insert it into a realistic model representing the full size of a human, by which detailed acupuncture information, such as the name and function of each acupoint can be instantaneously depicted. Inspired by personal experience of the project team members in virtual and augmented reality in medical training of surgical procedures, this article introduces the design and manufacture of our recently patented “3D Printed Copper Acupuncture Human Model (3D Acu-Man)” which is a physically approachable acupuncture model whereby a click at the correct acupoint results in useful acupuncture information being provided. As a complex design, such as having some capacitive touch sensors being embedded into the model, could entail an unaffordable substantial cost, innovative applications of existing technologies (Chen et al., 2019) have been adopted in the acupuncture model with acceptable cost and manpower outlays.

2. Design of the human acupuncture model

2.1. Creation of a digital model of meridians and acupuncture points

To start with, a series of ordinary human body Computed Tomography (CT) and 3D scanned data were acquired (Figure 1). A life-sized 3D digital model of the human body was created by employing 3D reconstruction and computer graphic techniques. The isosurface of the acquired CT dataset in Digital Imaging and Communication in Medicine (DICOM) format was converted into STereoLithography (STL) format by the medical image viewer, OsiriXTM. The 3D scanned dataset was also in STL format and was combined with the CT dataset using a prototype design tool, MeshMixerTM. Next, a digital sculpting tool, ZbrushTM, was used to modify the model to give it a lifelike appearance. The normal head to body ratio is 1 to 7. In order to present the complex acupuncture points on the head, the head to body ratio for the model was adjusted to 1 to 6.78. The model was then normalised to a height of 1,750 mm.

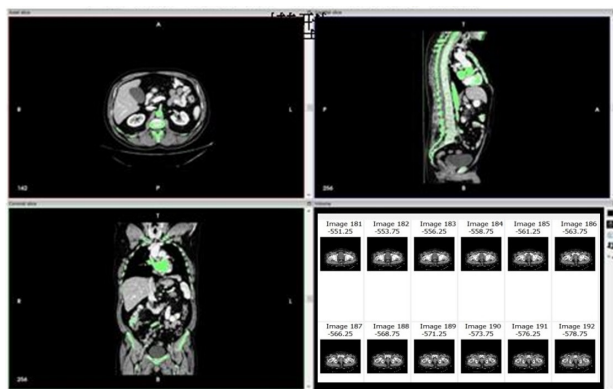


Figure 1. Reconstruction of 3D images from DICOM.

The next step was to translate the graphical acupuncture data described in 2-dimensional (2D) information resources (e.g. textbook) into a 3-dimensional (3D) virtual body template before the subsequent copper 3D printing (Tran et al., 2019). After creating the digital human model, the acupuncture points were manually marked onto the digital model using software by a team of professional acupuncturists, computer-aided design / computer-aided manufacturing (CAD/CAM) engineers and medical physicists (Figure 2).

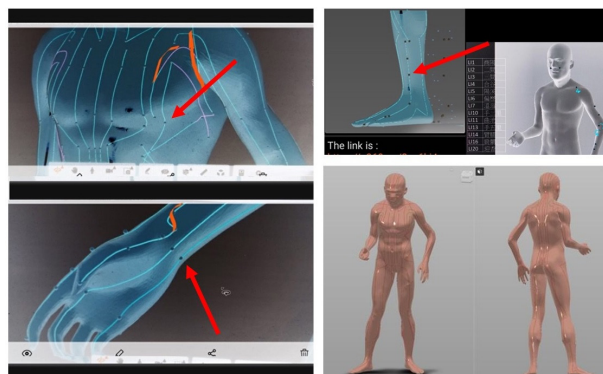


Figure 2. Marked acupoints (arrowed) on the digital model.

Rather than simply transforming the textbook surface map, acupoints had to be set according to the true anatomy in relation to surface prominences, defined checkpoints on bones, musculotendinous insertions, and other anatomical structures. Besides, the set of acupoints along each meridian had to be positioned correctly in proportion to the distances from each other according to TCM knowledge (Figure 3). One of the challenges was that, as the digital model template is an exact true copy of a human being as obtained through computerised tomography and 3D scans, its dimensions would not be that of the typical build of a “Standard man”, and some body parts may be even more skewed and thereby cause definitional difficulties for correctly and precisely marking acupoints.

The placement of acupoints after all the above steps was along the lines of meridians. A total of 374 common acupuncture points were defined and labelled on the digital model which has a dimension of 636.7 mm × 613.5 mm × 1,750 mm (Length × Width × Height).

2.2. Production of the 3D copper acupuncture model

2.2.1. Preparation work for 3D copper printing

Due to the large size of the model and the build volume of our 3D printer being limited to 600 mm × 600 mm × 600 mm, the computer model was cut into 11 pieces to fit into the printer (Figure 4). The Fused Deposition Modelling (FDM) 3D printing technique was adopted for the copper acupuncture model production (Kirby et al.,

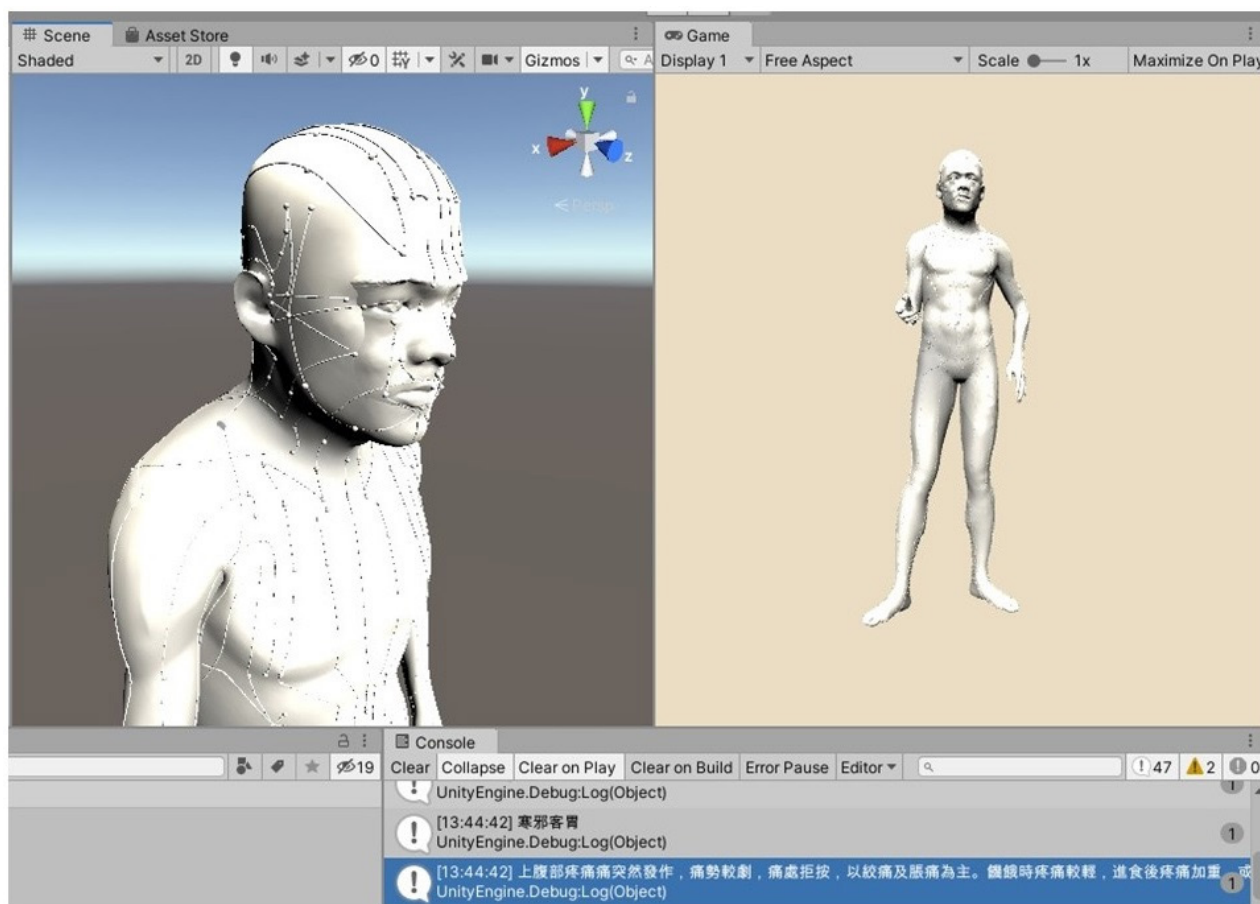


Figure 3. Acupoints with TCM knowledge (highlighted text at bottom).

2021; Zohdi and Yang, 2021). FDM requires a continuous filament of thermoplastic-composite material. In our 3D acupuncture human model, a filament with a combination of polymers and copper fibres was used for printing. The filament was fed from a large spool through a moving, heated extruder head, and was deposited on the growing work. The print head was moved under computer control to define the printed shape. The head moved in two dimensions to deposit one horizontal plane, or layer, at a time. The work or the print head was then moved vertically by a small amount to begin a new layer. The speed of the extruder head was also controlled to stop/start deposition and form an interrupted plane without stringing or dribbling between sections. The above FDM 3D printing technique was further optimised to accommodate the copper materials used in our application.

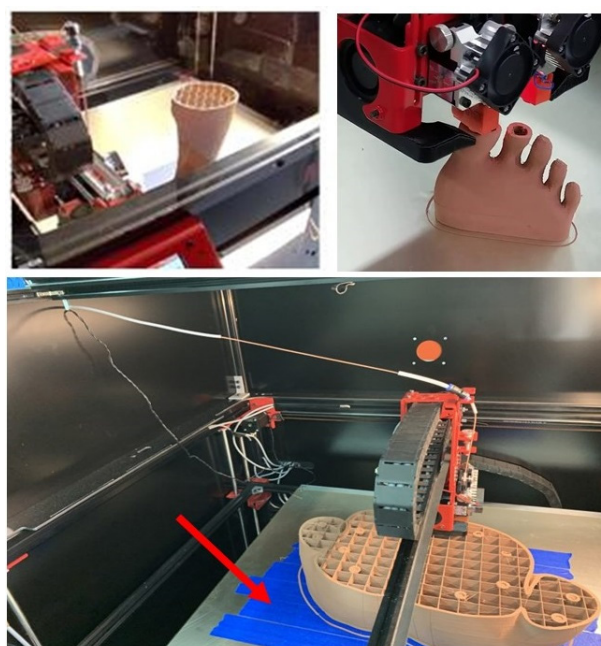


Figure 4. 3D printing different pieces on adhesive paper (arrowed).

2.2.2. Optimising the FDM 3D printing technique

Some 3D printers operate with pre-set nozzle and table temperatures, printing speed, and nozzle size. For large-scale 3D metal printing such as in this application, an adjustable-type FDM 3D printer is used. During 3D printing of a large object, warping occurs due to many reasons, such as i) uneven build plate, ii) uneven temperature distribution, and iii) partial detachment of the work during printing.

Build plates are usually very flat at ambient room temperature. However, with the heating up in the process of printing, the build plate can become deformed. It is common to insert some additional aluminium foil to keep the build plate flat enough so that the various printed parts can join together nicely without distortion. In our application, automatic calibration together with manual compensation of the build plate using aluminium foil was applied to ensure that deformation was within an acceptable range.

While heating up during printing, besides entering the liquid state, the copper FDM filament also expands. And when it cools down, returning to a solid, it shrinks again. This transformation creates some movement in the extruded material, and the root of 3D printing is also susceptible to warping, i.e. colder layers pulling on still hotter ones. If this occurs when the hotter layers expand below colder ones, the printed object would be forced to detach from the grip on the build surface, and curl up. If material contracts too much, it causes the print to bend up from the print plate. In order to have a good large-scale 3D print, it is important to keep the whole 3D printed model at an even temperature at all times. This is the reason why a hot bed and temperature control were used. To effectively prevent the print from bending up and hold the model on the build surface, glue sticks and 3D printer tapes were also used to secure it.

Another problem of 3D metal printing is the moisture in the filament. Spools of filament used for printing can be degraded by moisture if left out in the open air, yielding poor print quality and fragile parts. As the 3D copper printing filament contains polymers, which are made up of chains of molecules strung together, moisture introduces water molecules that break up these chains, ruining the filament and causing problems of slewing while printing. Filament dryers and pre-heaters were used to remove the moisture successfully in our application which helped to keep the filament flexible.

2.2.3. Post-processing after 3D printing

After all the model parts were printed, each part was polished by various polishing tools (Figure 5). After polishing, all model parts were assembled with the support of an internal steel framework followed by polymer filling internally (Figure 6). After assembly, there were still gaps between each 3D printed part. To fill these gaps, a professional 3D printing pen was used as a welding tool to

connect the parts together. After welding, the whole model was covered with a protective coating as finishing.

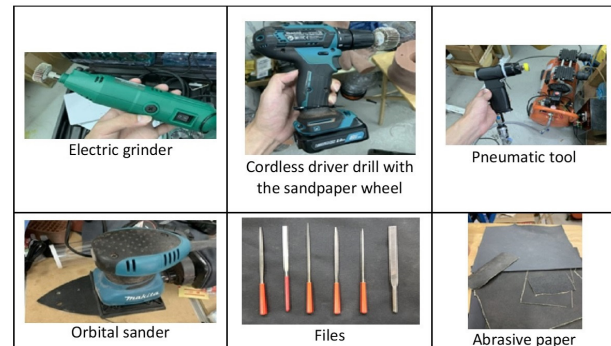


Figure 5. Different polishing tools used.



Figure 6. Assembly of different pieces onto the steel framework.

2.3. Augmented reality tracking system (hardware and software)

The locations of 374 acupuncture points marked on the digital model were also stored in the computer of the tracking system (Liu et al., 2014). On the floor, there was a four-sided square band surrounding the model with a number of infrared light emitters (Figure 7). The tracking device is a receiver which continuously measures the distances and angles from each emitter. There were two tracking devices used in the system. One was mounted on the acupuncture model. Another was installed in the pointer (i.e. a surrogate of the acupuncture needle) for the purpose of touching the acupoints during teaching and training (Figure 8).



Figure 7. Infrared tracking system (arrowed).

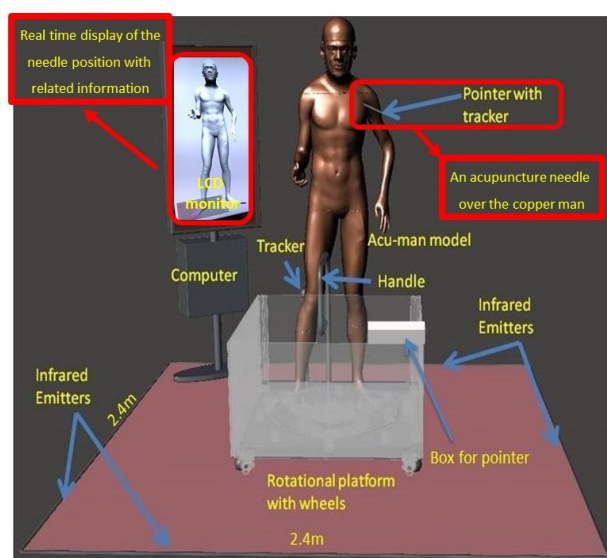


Figure 8. System components in detail.

A computer with a database of marked acupuncture points was installed for the tracking system of the model. All peripherals including a large display monitor, a small touch-screen monitor and two trackers were connected to this computer. The large screen monitor was used to show

the meridians, the acupuncture points, and the human model with their labels in 3D (and stereo). The 3D locations of the acupoints of the human acupuncture model were continuously tracked by one of the installed trackers. A user using the pointer with the other tracker installed would be able to report, in real time, the position and direction of the pointer. The computer after receiving the inputs from the trackers compares them with the meridians and acupuncture points stored in the database to identify if the pointer is pointing to the correct acupoint or not. In this way, the tracking system is able to provide acupuncture point searching. For users' convenience, automatic and manual zooming features are included.

Since the 3D printed model is based on the digital model, in theory, any surface point on the physical model can be correctly tracked by the tracking system and compared with the acupoint data in the digital model. However, since errors might be introduced during manufacturing, calibration is required and is therefore included as one of the software features of the model. The accuracy of tracking points of the acupuncture model is ± 5 mm in the XYZ axis.

The tracking software includes information about various illnesses with the related acupuncture points stored in the database. Users are able to search for the acupuncture points which correspond to the symptoms of their illness using the small touch screen monitor. The computer already has multi-media support so that the result of the illness or the acupuncture point searching can be output using display pictures, texts, and sounds. The software was designed so that the medical information contained in the database is able to be updated by an administrator even without strong computer skills. Users are classified into two groups (beginners and experts) according to their Chinese Medicine knowledge level.

2.4. Erecting of the model

The copper 3D printed acupuncture model was erected on a rotational table for display, teaching and training. Four lockable wheels were installed under the rotational table for easy relocation for various exhibitions, teaching and training. A steel arm was installed for users to manually rotate the model.

3. Operation

Users first turn on the programme by using the touch screen monitor either in beginner or expert mode. A few pre-defined questions are set to identify different types of body constitution. Once the patient's body constitution is ascertained, the user is asked a series of questions about the symptoms that the patient is suffering. Finally, the computer makes a diagnosis and suggests some acupuncture points for the user to identify. At this stage, the user should stand

in front of the human model and pick up the pointer (i.e. the surrogate of the acupuncture needle) to touch the human model to find the acupuncture points. The wireless tracker inside the pointer sends its 3D coordinates to the computer. After a comparison with the stored meridians and acupuncture information in the database, the computer reports whether the selected position is the correct acupuncture point or not. It also presents the user with the information about the functions of the selected acupuncture point in relation to the illness.

4. Discussion

To promote the advancement of TCM and acupuncture, we have designed and manufactured the “3D Printed Copper Acupuncture Human Model” which is a physically approachable model whereupon a click at the correct acupoint results in the output of useful information (Chan, 2021). Hopefully, it should help the training of students of acupuncture in TCM through a close-to-actual hands-on experience. The public, through the AR technologies (Dey et al., 2018), can try out acupuncture by participating in interactive therapy simulation sessions to learn about the location of acupuncture points and their functions.

We overcame several technical challenges in the development of this “3D Printed Copper Acupuncture Human Model” before it could be successfully manufactured. Firstly, according to authors’ understanding, this is the first life-sized “3D Acupuncture Model” in the world ever produced (i.e. 6 feet) with fine details based on the DICOM format of medical imaging using 3D metal printing in combination with the Fused Deposition Modelling (FDM) technique. A lot of time was spent to optimise the temperature (about 220°C) used to prepare the copper printing materials, refined the traditional 3D printing technique, such as improving the printer bed adhesion to avoid misalignment, reduced the resistance to minimise interruption by using a specific guiding tube to feed the filament materials, and increased the nozzle diameter and filament dryness to avoid moisture affecting the homogeneity of materials, and also the subsequent processing steps such as polishing using a combination of electric grinder, orbital sander, pneumatic tools, driver drill with sandpaper wheel, files, abrasive paper, metal polishing cream, and spray polish. Secondly, since its purpose is for teaching and training, the fine details of acupuncture points and meridian systems were carefully validated by a number of professional Chinese Medical Practitioners before we performed calibration of the infrared tracking system. This was another challenge as the accuracy requirement is expected to be high when used by healthcare professionals. Digitalising the hundreds of acupoints onto a 3D software model before the 3D printing required a lot of skill and expertise.

Recently, some high-precision tracking systems such as those using wireless electromagnetic techniques

have been applied to surgical navigation in the healthcare industry. It can achieve up to sub-millimetre accuracy which is beneficial to patient safety and improve treatment efficacy (Eppenga et al., 2020). However, in order to minimise our manufacturing cost, we decided to adopt well-developed AR technology to overlay our acupoints on the copper model. A recent systematic review of the accuracy and precision in regard to acupuncture point location reported that the understanding of point locations between different acupuncturists can be in the centimetre range (Godson and Wardle, 2019). The position uncertainty of our model is ± 5 mm which is much smaller than the inter-observer agreement. The model is definitely applicable and effective for education and the standardisation of practise in the field.

As the first of its kind as a physical and digital model of meridians and acupoints produced in Hong Kong, one of the primary aims is to provide the trainees of TCM a close-to-actual and hands-on experience of acupuncture, as well as promoting Hong Kong to the world as a unique place to combine Chinese and Western acupuncture knowhow. The “3D Printed Copper Acupuncture Human Model” is now an exhibit at the Hong Kong Museum of Medical Sciences on Caine Lane in Mid-Levels on Hong Kong island (Figure 9). In addition, the idea of this 3D Acupuncture Human Model has been promoted on various other platforms, such as television and newspaper reporting, seminars in major universities with Chinese Medicine Schools and the Hong Kong Yearbook 2021.



Figure 9. Demonstration in the Hong Kong Museum of Medical Sciences.

5. Conclusion and future work

This article introduces the design and manufacture of the “3D Printed Copper Acupuncture Human Model” which can serve as a new training model for Western and Chinese medical practitioners as well as for the public to gain interactive experience in acupuncture. Furthermore, it will help to promote Traditional Chinese Medicine in Hong Kong. The general public, especially youngsters, will be able to find out about the interesting side of Traditional Chinese Medicine. This is the first attempt to perform 3D

metal printing on a large scale, and the idea of using AR technologies to mimic the locations of acupuncture points on the body is state of the art. Further advancement, such as the flow of Qi, and its relation to disease treatment and management will be explained in the coming publication.

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