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3D-printing based Transducer Holder for Robotic Assisted Ultrasound Guided HIFU

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Abstract

The InnoMotion (Synthes Inc., previously by Innomedic GmbH) is a Conformité Européene (CE) marked (in 2005) robotic system for image-guided percutaneous interventions, providing five pneumatically driven degrees of freedom (DoF) and two manually adjusted DoF. It is a fully MR and CT compatible pneumatic driven tele-manipulator for image guided insertion of cannula and probes for biopsy, drainage, drug delivery, and energetic tumor destruction.

In order to achieve the robotic assisted ultrasound guided HIFU therapy, a specific holder was designed for the INNOMOTION robotic arm by using SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France). The holder provides at least seven degrees of freedom (DoF), which let the InnoMotion robotic arm hold a HIFU transducer and an ultrasound imaging probe at the same time. The HIFU transducer is mounted to the holder, while the ultrasound (US) probe could be adjusted manually to cover the expected ablation area before therapy.

The main components of the holder were 3D-printed by using plastic material and were well compatible with the MR system and InnoMotion robotic arm. And the robotic assisted HIFU experiment could be performed based on this designed setup.

Keywords: 3D Print, HIFU, Robotic arm

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1. Introduction

The InnoMotion (Synthes Inc., previously by Innomedic GmbH) is a Conformité Européene (CE) marked (in 2005) robotic system for image-guided percutaneous interventions. InnoMotion robotic arm is a fully MR and CT compatible pneumatic driven tele-manipulator for image guided insertion of cannula and probes for biopsy, drainage, drug delivery, and energetic tumor destruction [1-3].

In 1998, the development of a fully MR compatible robotic system began at the Forschungszentrum Karlsruhe (FZK, Karlsruhe, Germany) in collaboration with the University of Applied Sciences Gelsenkirchen (Germany) and later the German Cancer Research Center (joined in 2001). The final product development was performed by the start-up company Innomedic [2].

In 2003, the first generation of InnoMotion robotic system, the MIRA (Manipulator for Interventional Radiology, Figure 1), was presented as a manipulator for interventional radiology, whose initial design concept of was derived from a tele-manipulator project for endoscopic surgery. The robotic arm had six degrees of freedom (DoF) and was driven by piezoelectric motors [1, 2, 4, 5].

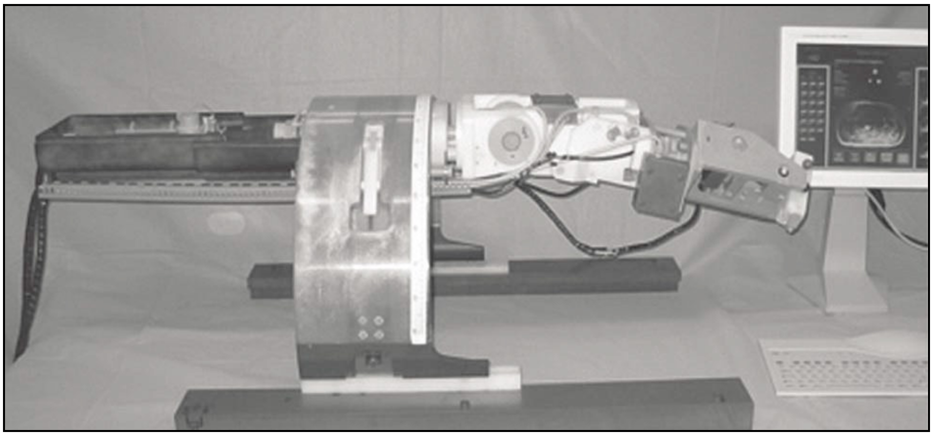

Figure 1 The prototype MIRA driven by piezoelectric motor (FZK, Germany) [2] .

The second generation was a fully MR and CT compatible assistance system, which was driven by pneumatic motors, this system received CE mark for image-guided percutaneous interventions, except for the central nervous system, and brand InnoMotion in 2005 [2]. After obtained CE mark, the InnoMotion system was introduced to market by Innomedic GmbH (Herxheim, Germany), which was later acquired by Synthes Inc. (Solothurn, Switzerland) in 2008 [1].

The InnoMotion robotic system can be divided into four parts, i.e. (i) robotic arm with application module (AMO), attached to an orbiting ring, (ii) system trolley, (iii) pneumatic supply unit, and (iv) graphical user interface (GUI) [2, 6, 7]. Figure 2(a) shows the constituent parts of InnoMotion robotic system, and the diagrammatic view of its set-up for MRI-guided procedures for Siemens and Philips MRI platforms.

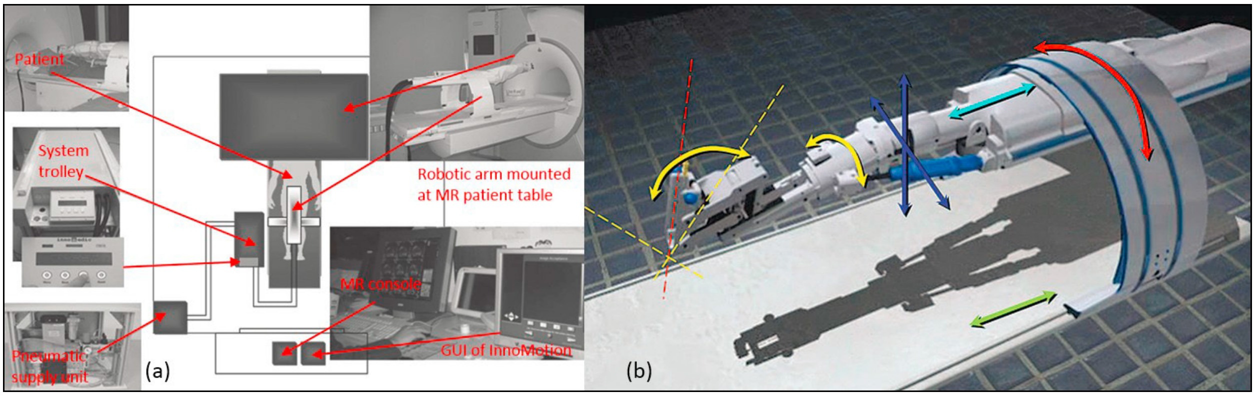

Figure 2 (a) The constituent parts of InnoMotion robotic system and its diagrammatic view of set-up for MRI-guided procedures [2]. (b) The InnoMotion robot arm with orbiting ring provides five DoF of pneumatically driven, as well as two DoF of manual adjustments (for the prepositioning at orbit (red arrow) and at MR patient bed (green arrow)) [2].

For MR compatibility, the InnoMotion robotic system is fully MR compatible, with arm being pneumatically driven and joint sensing is via MR-compatible encoders [8]. It is made from MR compatible materials: plastic, fiber-reinforced epoxy, and ceramics [6]. The InnoMotion robotic system provides five pneumatically driven degrees of freedom (DoF) and two manually adjusted DoF, the Figure 2(b) is the schematic view of the DoF [2, 6, 9].

A special holder is designed for the InnoMotion robotic arm. This holder is fixed to the application module (AMO) of the InnoMotion robotic arm and could hold both an ultrasound imaging probe and a HIFU transducer. The HIFU transducer is required to be mounted to the holder, and for convenience of positioning, the surface plane of the HIFU transducer should be perpendicularly intersected with the positioning plane which is defined by the four spherical markers attached to the AMO, and the focal point should be located inside the positioning plane as far as possible. The imaging ultrasound probe should have enough free adjustment space, to fit different positions of interest. Moreover, its FOV (field of view) should cover the FUS ablation area.

2. Materials and Methods

The CAD / CAE software program SolidWorks (2015 SP1.1, Dassault Systèmes, Vélizy-Villacoublay, France) was employed to assist the design work of this holder. Several component parts were designed for 3D-printing manufacture.

Foundation Support Module

The foundation support module (Figure 3) played the role of supporting the whole structure of the holder and fixed to the AMO of InnoMotion robotic arm, it was the most complex component for design.

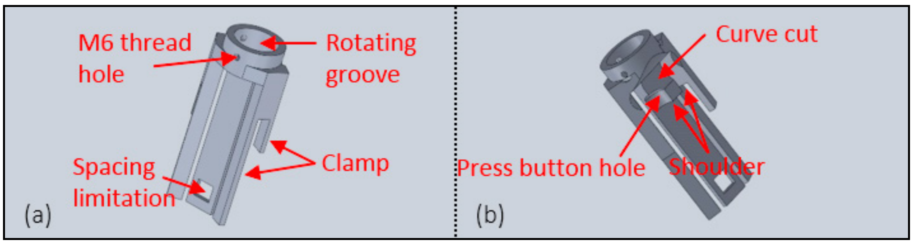

Figure 3 The 3D shaded views of the foundation support module: (a) the front side; (b) the reserve side.

The spacing limitation hole was reserved for the cotter, which helped the positioning of itself to cling to the

InnoMotion AMO. And the HIFU transducer could be fixed to the proper location aligned to the reference plane defined by the spherical makers on AMO.

At the back of foundation support module, there was a curve cut, which reduced the limiting influence caused by the structure of foundation support module, when the folding grille of InnoMotion AMO reached its extreme position in sagittal direction.

Rotary Base

The lower part of rotary base (Figure 4) was fitted to the foundation support module and had one DoF allowing rotation. And its upper part supplied two DoF for the rod.

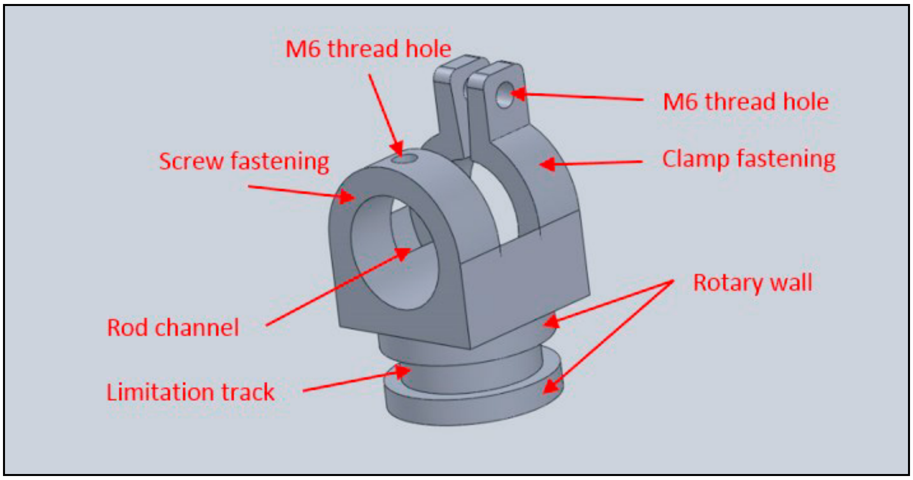

Figure 4 The 3D shaded view of the rotary base.

The rotary base had two fastening mechanisms for tightening the rods, which were clamp fastening and screw fastening. The bottom rotary wall was fit to the rotating groove of foundation support module, and a limitation track was used to entrap the screw bolts, this mechanism limited the rotary base having one DoF allowing rotation. Figure 5 shows the assembly schematic diagram of foundation support module and rotary base.

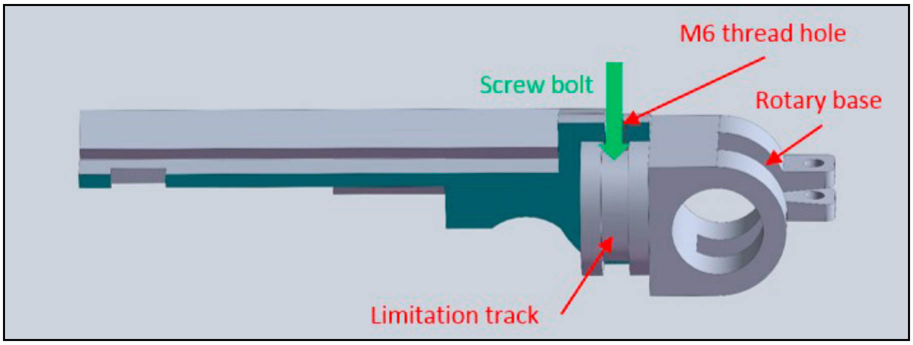

Figure 5 The 3D assembling view of foundation support module and rotary base, and the foundation support module is a section view.

Kinematic Joints

Two sizes of kinematic joints (Figure 6) were designed. Each one supplied two DoF for the rod. Similar to the rotary base, each kinematic joint also had clamp fastening and screw fastening mechanisms for tightening the rods.

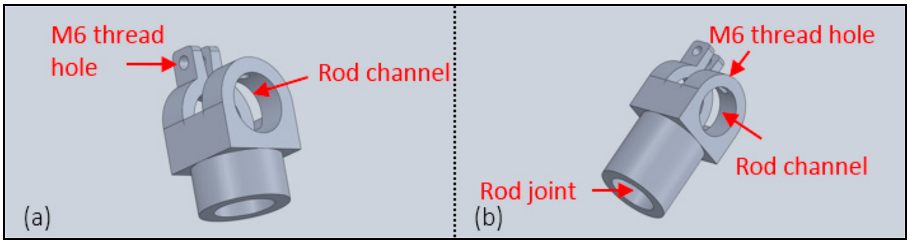

Figure 6 The 3D shaded views of kinematic joints: (a) small size; (b) big size.

Cotter for Connecting HIFU Transducer

The cotter (Figure 7) was used to connect the HIFU transducer and mount it to the AMO of InnoMotion robotic arm, it also had the function of spacing limitation to the foundation support module.

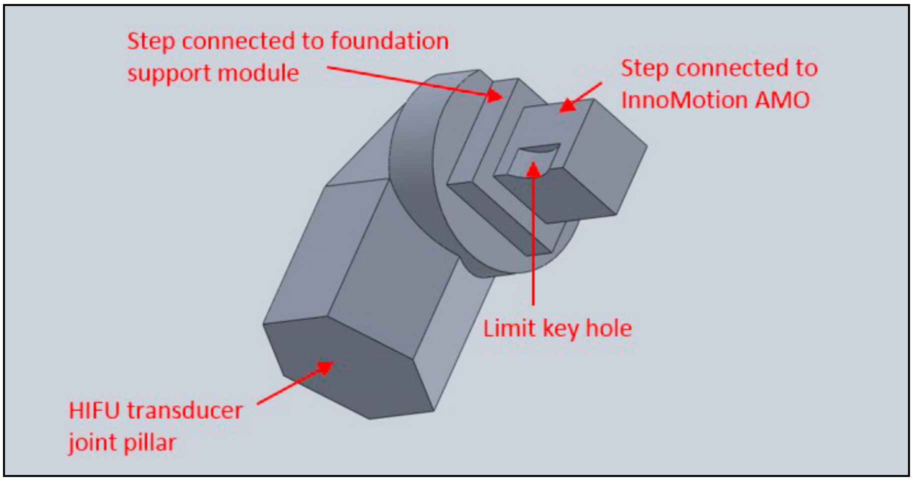

Figure 7 The 3D shaded view of cotter for connecting HIFU transducer.

Two steps were designed with precise dimensions. The step for InnoMotion AMO was used to insert into the connecting hole on the AMO, and the limit key hole was used to be fixed with a limit key inside the AMO connecting hole. The step for foundation support module was used to insert into the spacing limitation hole on the foundation support module.

Ultrasound Imaging Probe Connector

Three kinds of holder components (Figure 8) were designed to connect ultrasound imaging probes with various dimensions. These holders were all designed as two assembled parts, the part I equipped a rod joint, for connecting Φ 20 mm rod, while the part II was used as a cover.

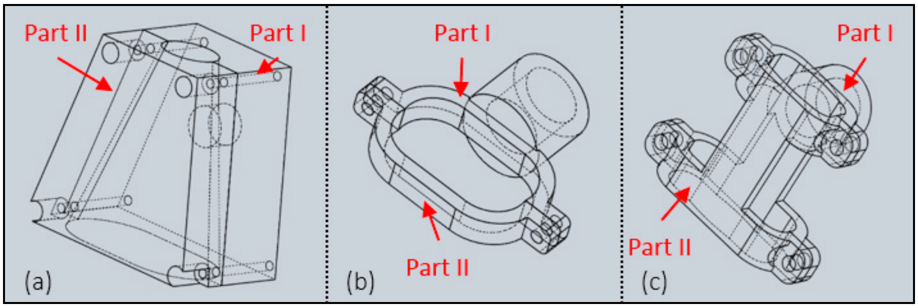

Figure 8 The 3D perspective views of three ultrasound imaging probe connectors: (a) Type-A; (b) Type-B; (c) Type-C.

Spherical Joint (Optional)

The spherical joint (Figure 9) was designed as an optional component, which supplied extra DoF and suited for the ultrasound probe demanding more flexible position and angle.

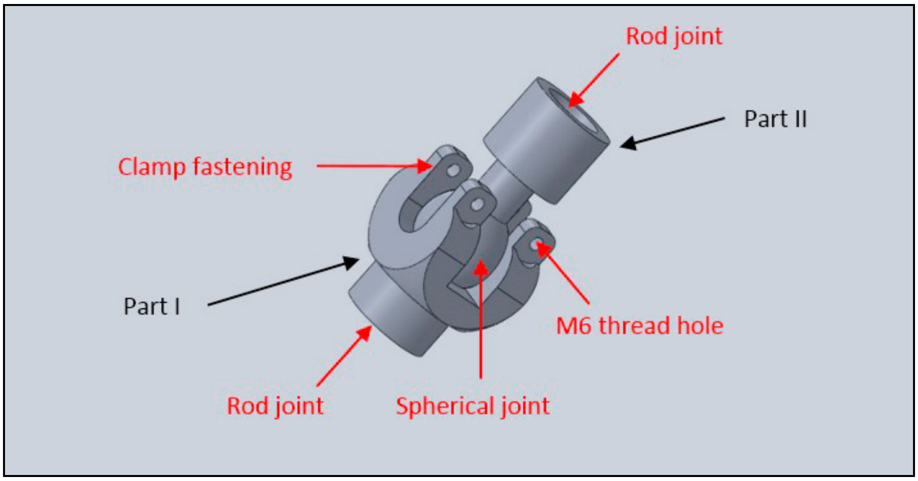

Figure 9 The 3D shaded view of spherical joint.

The spherical joint had two parts, each part equipped a rod joint for connecting Φ 20 mm rod. Generally, the Part II was used to connect the US imaging probe connector. The spacing between the two spherical walls of two parts was 0.25 mm, and two sets of clamp fastening mechanisms were designed on the Part I for limiting the motion and position of the Part II of spherical joint.

Assembly

Using the function of 3D assembling view from SolidWorks software. A kind of assembly of the whole holder is shown in Figure 10(a). This assembling structure connected a single element HIFU transducer, and held a C-type ultrasound imaging probe connector. This holder could supply the ultrasound imaging probe with seven DoF, even the spherical joint was not added into this holder structure. The diagrammatic view of the degrees of freedom is shown as Figure 10(b).

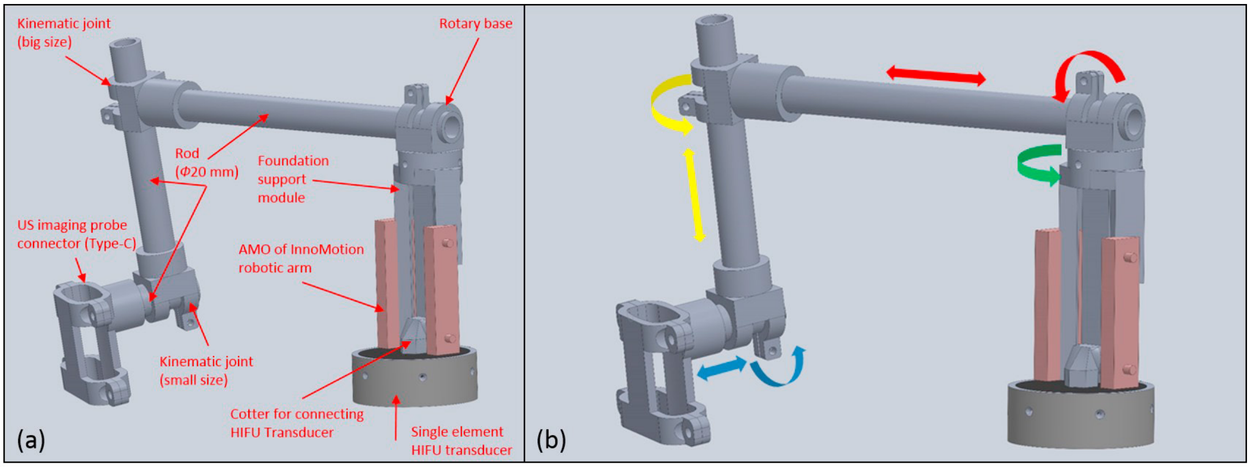

Figure 10(a) The 3D view of a kind of the holder assembling, using a single element HIFU transducer and a Type-C ultrasound imaging probe connector, and the spherical joint was not employed. (b) Seven degrees of freedom supplied to the ultrasound imaging probe.

3. Results and Conclusion

3D printing assumed the manufacture works of most of holder components. The 3D printer Objet 30 Pro (Stratasys Ltd., Eden Prairie, Minnesota, USA) was employed. The Figure 11 shows the components manufactured by the Objet 30 Pro 3D printer.

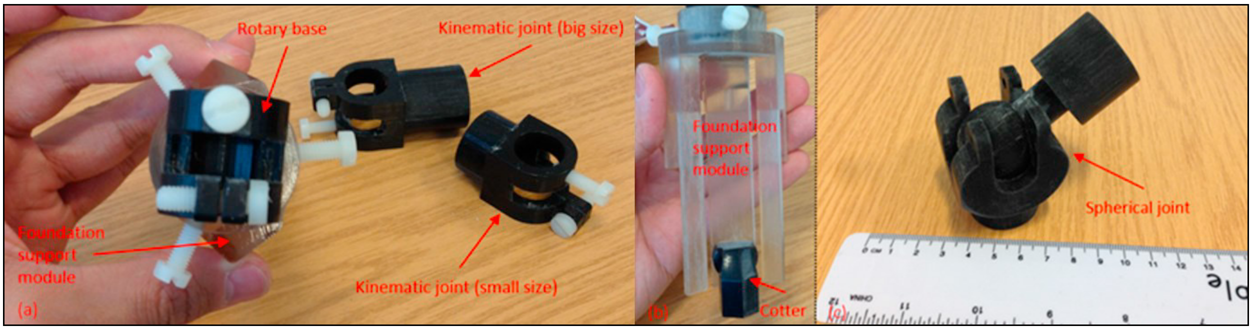

Figure 11 The components manufactured by Objet 30 Pro 3D printer: (a) foundation support module, rotary base and kinematic joints; (b) foundation support module; (c) spherical joint.

Although the spherical joint was designed as separate two parts, but due to the special structure and mutual relation, the spherical joint was printed as an integrated component. In detail, the gap between the two spherical walls, which was 0.25 mm (Figure 12(a)), was printed by using support material, and after finish whole printing process, the support material could be washed out by special solvents.

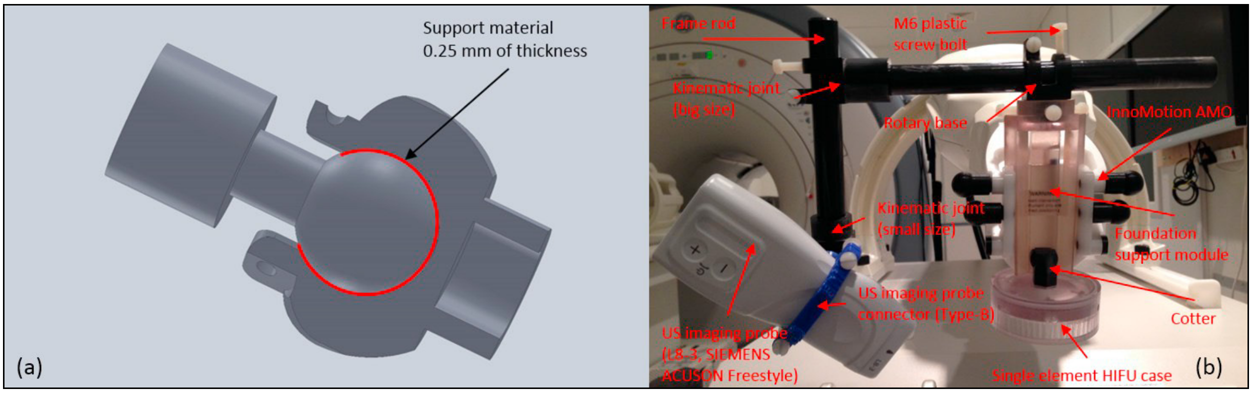

Figure 12 (a) The section view of the spherical joint. (b) The image of holder assembly with single element HIFU transducer and an ultrasound imaging probe (L8-3, SIEMENS ACUSON Freestyle, Germany), the use of imaging probe connector was Type-B, and the spherical joint was not aviliable.

According to the design, the holder could be assembled as several structures. Figure 12(b) shows an example of holder assembly. This assembling structure held both a single element HIFU transducer and a wireless ultrasound imaging probe (L8-3, SIEMENS ACUSON Freestyle, Germany), and the US probe was supplied with seven degrees of freedom.

Acknowledgements

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