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Proposal for Conceptual designing of An Innovative C-arm Calibration Target

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***Abstract*-In the existing fluoroscopic-image-based orthopedic surgical navigation system, C-arm calibration target has several shortcomings. In order to overcome these shortcomings, an innovative conceptual design for calibration target is proposed. If the redesigned calibration target can be materialized and substituted for the existing one, and relevant software can be adapted accordingly, performance of surgical navigation system is hopefully to be promoted, and development-running cost be decreased.**

***Keywords*-Calibration target, Conceptual design, Innovative design**

Ⅰ. INTRODUCTION

Because of its many advantages over CT-based surgical navigation system, fluoroscopic-image-based orthopedic surgical navigation system has more and more attracted attention in academia and medical field[1-4]. In the whole navigation system, calibration target fixed on the image intensifier end of C-arm is a key component. Indicators(LEDs or reflecting spheres) for locating C-arm spacially must be fixed on it. Calibration plates for undistorting X-ray image and calibrating fluoroscopic camera must be fixed on it too. C-arm locating, image undistortping and camera calibrating are key attribution that influence navigating quality and precision of the whole surgical navigation system greatly.

Ⅱ. SHORTCOMINGS OF EXISTING CALIBRATION TARGET

Calibration target`s performance influences function and performance of the whole orthopedic surgical navigation system. In order to ensure the performance of surgical navigation system, calibration target`s performance must be guaranteed at first. Nevertheless, existing calibration target has several shortcomings that hampers the whole surgical navigation system`s function and performacne. These shortcomings mainly come from target`s stiff mechanical structure. The existing calibration target has an onepiece structure with two calibration plates attached on[5][6]. Each plate is a plane of small metal spheres embedded in macromolecule material. Shortcomings of existing calibration target are shown below.

A. Images acquired are of poor quality

Because the existing calibration target has an onepiece structure, and when patient fluoroscopic image is acquired it is fixed on the image intensifier end of C-arm, the image acquired is not pure patient anatomic image but overlapped images of patient and two calibration plates. This kind of image has low optic contrast and is contaminated by shadows of metal spheres. In course of a surgery C-arm is used at first to acquire a "blank" image, which is pure image of calibration plates. Then, C-arm`s pose is adjusted relating to patient and acquire image, the image is actually overlapping of patient anatomic image and image of calibration plates acquire above mentioned. Thereafter computer program "subtract" the former image from the latter images to get a theoretically pure patient anatomic image. In fact, pure anatomic image of patient can not be acquired with the "subtraction" computation, because the image of calibration plates can not be eliminated successfully, especially sphere shadows can not be erased completely[7]. In Fig. 1 the surviving sphere shadows are enclosed by a blue ellipse. Fig. 2 shows images with surviving sphere shadows used in surgical navigation. The sphere shadows confuse with patient tissue image and are likely to be misidentified by surgeon. This is dangerous in real surgeries because medical malpractice may happens.

B. Cost and difficulty of fabrication are too high

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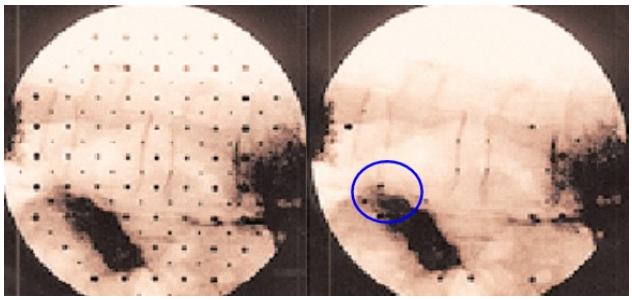

Fig. 1. image before and after "subtraction"

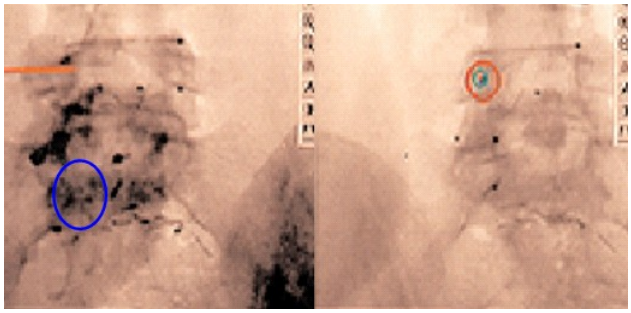

Fig. 2. image used in navigation

Calibration plates are the most important parts in a calibration target, their manufacturing precision must be ensured. In existing calibration target each calibration plate is a plane of metal spheres embedded in macromolecule material. It is difficult to ensure high precision with common manufacturing technique and too costly with special technology. Neither low precision nor high cost is expected by either manufacturers or buyers.

C. Complexity and running cost of corresponding program are too high

As above mentioned, in order to get patient anatomic image a "subtraction" computation must be done. Result of "subtraction" depend on robustness and quality of algorithm. The algorithm must meet the following requests: automatic identification, area limitation and location memory of sphere shadows; elimination of sphere shadows from overlapped image; robustness against noise. Furthermore, in order to get rid of sphere shadows completely without eliminating any patient anatomic image information unintentionally, the algorithm should possess functions of sampling and interpolating. It will be very difficult to design such an ideal algorithm. Even if the ideal algorithm could be found, complexity will be great. If the algorithm is programmed into software, running cost of such software may be very high and running time long. This is not proper for clinical application because it will prolong operation time and increases risk of operation.

Shortcomings of existing calibration target mainly lie in three aspects: image quality, manufacturing cost, and image processing algorithm. It entails a great effort trying to improve performance of calibration target form the above three aspects respectively. Even if the effort is made, it is of slim hope to get a satisfactory result. It is more likely to promote performance of calibration target by redesigning and optimizing its overall structure.

III. AN INNOVATIVE AND INTERESTING CONCEPTUAL DESIGN OF NEW CALIBRATION TARGET

Redesigned calibration target should meet the follow requirements:

A. Images acquired through it must have higher quality;

B. It should have simpler structure, lower fabricating cost and difficulty;

C. Image processing algorithm related to it should be simpler;

D. It still must meet the requirement of C-arm spacial location indicating, image undistorting and fluoroscopic camera calibrating.

We referred to design theories and methods proposed in reference[8-12] for innovative structure designing. Under guidance of these theories and methods we sketched out several primary conceptual models of calibration target. After extensive discussion, the most feasible one was chosen. On this basis, after further analysis and improvement, we got an innovative and interesting conceptual calibration target, Fig. 3shows the CAD model of it.

On the basis of strict analysis and reasoning, it is sure that the above mentioned requirements can be met theoretically

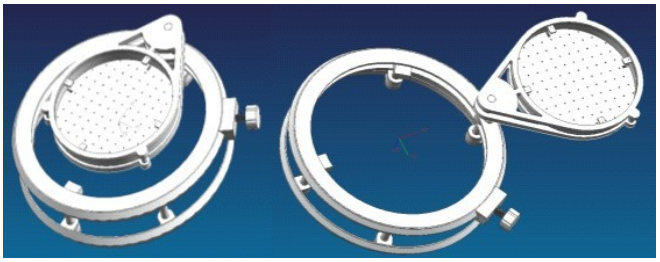

Fig.3.target with calibration plates folded and unfolded

with the redesigned calibration target. Compared with existing calibration target, the redesigned one possessed two novel aspects on mechanical structure:

A. The redesigned calibration target consists of two pieces

Contrast to the onepiece structure of existing calibration target, the redesigned one consists of two pieces that are mated with a rotary movement pair.

One piece may be named "indicator base." This piece consists of two ring-shaped structures. The first ring`s main function is fixing the whole calibration target on C-arm and holding a group of indicators(LEDs or reflecting spheres) simultaneously. The ring has three extruding blocks, two of them are attached on the ring, the last one is adjustable. Internal cylindric surface of the three blocks and external cylindric surface of image intensifier is the interface of calibration target and C-arm. The ring has a pair of external conical surfaces for indicators to be settled on. Another ring serves as a pure indicator base for another group of indicators to be settled on. This ring has a pair of external conical surfaces too. Two ring-shaped structures are connected through four poles. External surface of piece one is shown in Fig.4.

Another piece may be named "calibration plate," its main function is to meet the requirement of image undistorting and fluoroscopic camera calibrating. This piece consists of three main parts. The first part may be named "calibration plate frame," its main function is holding two calibration plates and serving as connector of calibration plates and the "indicator base" piece. The remaining two parts are calibration plates.

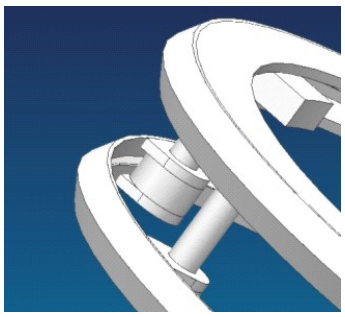

Fig.4.close-up view of external surface of piece one

With this two-piece structure the calibration target still can fulfill the requirement of image undistorting and camera calibrating, but operating method is a little different. In course of a surgery a "blank" image is acquired at first. Then, C-arm`s pose according to patient is adjusted and the "calibration plate" piece is turned away (180^{o}) from in front of C-arm image intensifier. Then patient anatomic image is acquired(shown in the right part of Fig.3). The turnning-away operating seems a little troublesome, but the following "subtraction" computation is no longer necessary. Image quality can be improved by using the redesigned calibration target, because image acquired the second time is pure patient anatomic image without contamination by sphere shadows.

B. Fabricating calibration plates with different technique

Contrast to the sphere-embedding technique of existing calibration plates, material-removal technique is used in the prospective fabricating of redesigned calibration plates.

Calibration plate near the image intensifier is in fact a thin metal plate drilled with a group of tapered holes and milled with four narrow slots. Another calibration "plate" is not a plate any more, it is in fact a ring with four Internal bulges. Each bulge is drilled with a tapered hole. Calibration plates are shown in Fig.5.

In order to fulfill fundamental requirement of image undistorting and fluoroscopic camera calibration as well as facilitate identification and location of tapered holes` projection, following items must fulfill certain request strictly. Geometry and arrangement of holes and slots on the first plate; geometry and location of holes and bulges on the second plate; orientation of the two plates towards each other. If above request can be fulfilled, the "blank" image of calibration plate should be pure and intact projections by holes of the two plates(as shown in Fig.6 left part). If the request can not be fulfilled strictly, some holes may be curtained off by bulges(as shown in middle part of Fig.6) , or some slots may not be curtained off successfully (as shown in Fig.6 right part). If abovementioned design problems

happen, some errors may

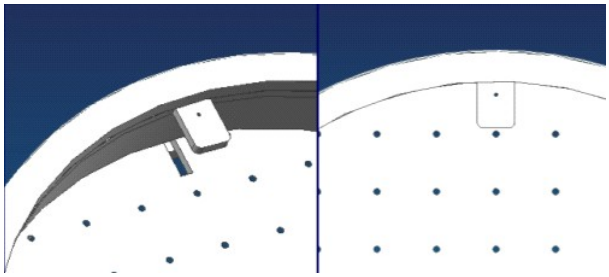

Fig.5.close-up view of calibration plates

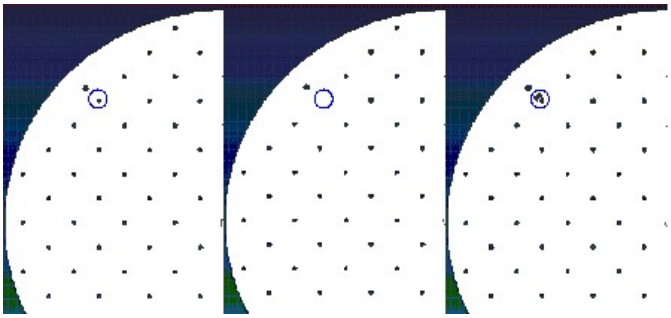

Fig.6.suppositional image of calibration target(left normal, middle and right abnormal)

happen in the following image undistorting and camera calibrating computation. Redesigned calibration plates possess many advantages over existing ones: fabricating difficulty and cost are to be decreased; precision is easier to be guaranteed; weight of two plates are likely to be decreased.

Ⅳ. Conclusions

This paper points out shortcomings of calibration target of exiting fluoroscopic-image-based surgical navigation system. Based on this, an innovative conceptual redesign for a new calibration target is proposed. Redesigned calibration target possesses many advantages over the existing one: fabricating difficulty and cost are surely to be decreased; weight is likely to be decreased; precision that in turn influences quality of image undistorting and camera calibrating is likely to be promoted; quality of acquired image is surely to be promoted; corresponding processing algorithm is likely to be simplified. If the proposed calibration target can be materialized and relevant software can be modified accordingly, overall performance of surgical navigation system is to be promoted hopefully and manufacturing cost to be decreased.

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