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# A Machine Vision System with CCD Cameras for Patient Positioning in Radiotherapy: A Preliminary Report

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**Abstract**

Purpose: To determine positioning accuracy of a machine vision system in radiotherapy.
Materials and Methods: The machine vision system was composed of 640×480 pixel CCD cameras and computerized control systems. For image acquisition, the phantom was set up for the reference position and a single CCD camera was positioned 1.5 m from the isocenter. The image data of the fiducial marker with 1.5 mm lead pellet on the lateral surface of the phantom was captured onto the CCD, and then the position of the marker was accurately calculated. The phantom was moved 0.25, 0.50, 0.75, 1.00, 2.00, and 3.00 mm from the reference position, using a micrometer head. The position of the fiducial marker was analyzed using a kilo-voltage fluoroscopic imaging system and a machine vision system.
Results: Using fluoroscopic images, the discrepancy between the actual movement of the phantom by micrometer heads and the measurement was found to be 0.12 ± 0.05 mm (mean ± standard deviation). In contrast, the detection of the movement by the machine vision system coincided with the discrepancy of 0.0067 ± 0.0048 mm.
Conclusion: This study suggests that the machine vision system can be used to measure small changes in patient position with a resolution of less than 0.1 mm.

## Introduction

Highly precise radiotherapy is increasingly being used in the management of head and neck tumors. Three-dimensional conformal radiotherapy and intensity modulated radiotherapy techniques can deliver radiation beams close in shape to the target volume. Precise reproducible patient positioning is essential for successful delivery of optimal radiotherapy treatment. In current clinical practice, the magnitude of patient localization errors are analyzed by means of portal imaging. In particular, high-resolution electronic portal imaging devices enable more precise and efficient positioning[1)2)]. An alternative approach to the quantitative assessment of patient position reproducibility is based on kilo-voltage diagnostic X-ray tubes, which are mounted on the treatment machine[3)~5)]. These kilo-voltage fluoroscopic images are considered to have more accurate detectability of positioning than mega-voltage portal images. The patient can be adjusted more precisely according to the imaged location of the bony structures or the implanted

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radiopaque markers before or during treatment.

Machine vision systems are composed of optical components and computerized control systems. Charge-coupled device (CCD) cameras are in common use as an optical component, and geometrical pattern-matching software has improved the precision of detecting object location. Machine vision systems are widely used in the manufacturing industry to achieve greater productivity from existing automated manufacturing equipment. Although video cameras or CCD cameras are employed for precise location of patients[6)7)], few reports exist regarding the effectiveness of machine vision systems in patient positioning in precise radiotherapy.

In this preliminary study, we assessed the capability of a machine vision system, in comparson with kilo-voltage fluoroscopic images, in an attempt to achieve a more precise verification system for patient positioning.

## Materials and Methods

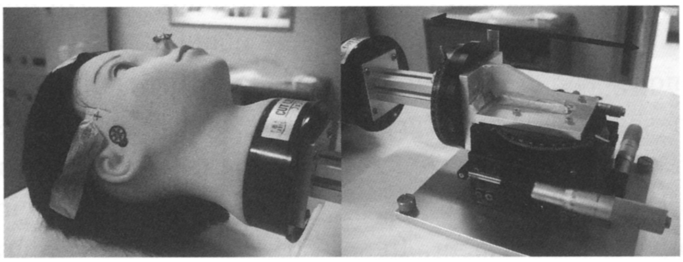
*Phantom*

To assess the accuracy of the detection of target movement by a machine vision system, we made a phantom mounted on the plates with the spindle micrometer heads (Mitutoyo co., Kawasaki, Japan), which allowed us to achieve exact movement of the phantom with resolution of 0.01 mm (Fig. 1). Markers with a 1.5-mm lead pellet (X-Spots, Beekley, Bristol, CT, USA) were affixed onto the anterior and lateral surfaces of the phantom. In the present study, the phantom was moved 0.25, 0.50, 0.75, 1.00, 2.00, and 3.00 mm, respectively, from the reference position in the craniocaudal direction, using a micrometer head. After each movement, the position of the fiducial marker was analyzed using a kilo-voltage fluoroscopic imaging system and a machine vision system.

*Digital kilo-voltage fluoroscopic imaging system*

For the analysis of phantom movement, a digital fluoroscopic imaging system (XimaVision 6.1, Varian Inc., Palo Alto, CA, USA) was used. XimaVision takes an X-ray simulator (Ximatron EX, Varian Inc., Palo Alto, CA, USA) into a digital imaging system, making the image accurate to be used in planning treatment fields. The images acquired in XimaVision had a pixel size of 0.2 mm x 0.2 mm (Fig. 2).

The accuracy of the detectability of kilo-voltage fluoroscopic images was assessed by comparing the movement of the lead pellet in the fiducial marker on the anterior surface of the phantom, on fusion images of



**(a)** **(b)**

**Fig. 1** The head phantom (a) was mounted on the plates with the spindle digital micrometer heads (b). Markers with a 1.5-mm lead pellet were affixed onto the anterior and lateral surfaces of the phantom.

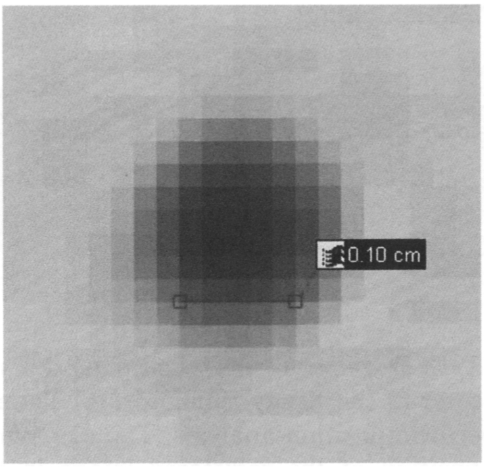
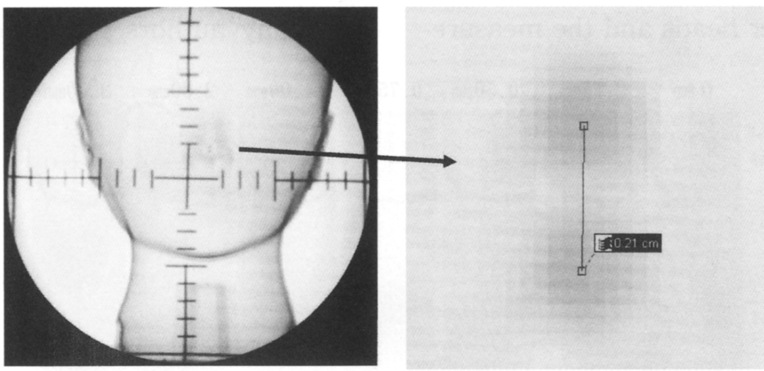



**Fig. 2** The magnification of the acquired fluoroscopic image shows that the pixel size is 0. 2 x 0.2 mm.

the fluoroscopic images acquired before and after movement (Fig. 3). Two observers (T.Y., K.N.) measured the shift in the center of the radiopaque lead spot directly by using a digital ruler in this system. This ruler had a resolution of 0.1 mm.

*Machine vision system*

A commercially available high-speed machine vision system (XV-1000, KEYENCE, Osaka, Japan) was used. The machine vision system was composed of 640×480 pixel CCD cameras and computerized control systems. For image acquisition, the phantom was set up for the reference position on the bed of the X-ray simulator, and a CCD camera was positioned 1.5 m from the isocenter. The CCD camera was directed towards the isocenter and approximately parallel to the line defined by the wall laser (Fig. 4). The image data of the fiducial marker on the lateral surface of the phantom was captured onto the CCD, converted to digital data within the camera unit, and transferred to the controller, after which the position of the marker was accurately calculated. The image data could be captured at a rate of more than 10 images per second.




(a) (b)

**Fig. 3** a) Fusion fluoroscopic images of the lead pellet on the phantom. The acquired image which was moved by 0. 25 mm was fused pixel by pixel with the image of the reference position. b) magnified image of the fusion image (a).

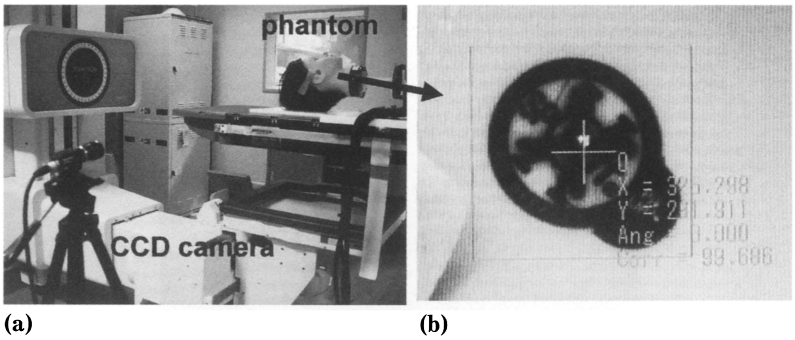



**Fig. 4** (a) A CCD camera was positioned 1.5 m from the isocenter of the X-ray simulator. (b) The regions used to perform position analysis. The (+) symbol reflects the position of the registered image in the machine vision system.

The average calculation time was approximately 50 milliseconds.

## Results

Figure 5 shows the fusion images of acquired fluoroscopic images of the phantom according to linear displacement from the reference position in the craniocaudal direction.

Table 1 shows the actual movement of the phantom by micrometer heads and the measurement by the fluoroscopic images or the machine vision system. The results of measurement were not changed by two- or three-time-repeated measurements. Using the fluoroscopic images, the discrepancy between the actual movement of the phantom by micrometer heads and the measurement was 0.12 ± 0.05 mm (mean ± standard deviation). In contrast, the detection of movement by the machine vision system coincided with a discrepancy of 0.0067 ± 0.0048 mm.

## Discussion

Our study results indicate that the detection accuracy of the machine vision system was less than 0.1 mm. The machine vision system can recognize the outline and/or pattern of the marker on the patient surface, and precisely calculate the position of the marker. We believe that the machine vision system has the possibility of overcoming the precision limitations of current positioning methods in radiotherapy.

Many authors have proposed incorpora-

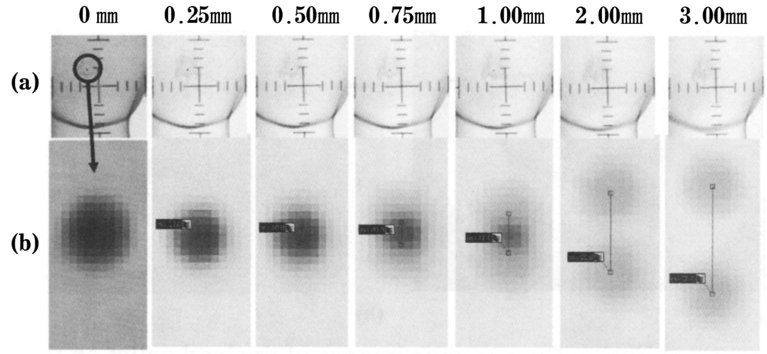



**Fig. 5** (a) The fusion images of acquired fluoroscopic images of the phantom according to the linear displacement from the reference position. (b) The magnified images.

**Table 1** The actual movement of the phantom by a micrometer head and the measurement by the fluoroscopic images or the machine vision system

| Displacement | Fluoroscopic image (n=3) | Machine vision system (n=2) |
|---|---|---|
| 0 | - | - |
| 0.25 mm | 0.2 ± 0.1 mm | 0.253 ± 0.000 mm |
| 0.50 mm | 0.4 ± 0.1 mm | 0.505 ± 0.000 mm |
| 0.75 mm | 0.6 ± 0.1 mm | 0.757 ± 0.000 mm |
| 1.00 mm | 1.1 ± 0.1 mm | 0.997 ± 0.000 mm |
| 2.00 mm | 2.1 ± 0.1 mm | 2.006 ± 0.000 mm |
| 3.00 mm | 3.2 ± 0.0 mm | 3.016 ± 0.000 mm |

tion of body surface or contour information to improve the positioning accuracy. In some studies, CCD cameras have been used to improve the accuracy of the patient set-up. Swarnaker et al[7] have shown that a new system using a pair of common CCD cameras can achieve accuracy on the order of 1/10 of a millimeter for the phantom case. Milliken et al[6] have developed a patient positioning system based on real-time subtraction of images. They have reported that object position can be measured with a resolution of 0.04 mm. However, they have pointed out that with their system in-house software control is an important issue and that keyboard interactions by the therapist are necessary. In contrast, the machine vision system in this study has various inspection tools, including area, pattern search, multiple searches, edge angle, trend edge position, and trend edge width. Users can make the programming menus flow from top to bottom, guiding users through simple set-up procedures. Since no personal computer is required, even novice users can quickly and easily program and customize this system.

The accuracy of the system may be compromised when surface markers are used for positioning. When bony anatomy is considered as a reference for the target volume, movement of the skin with respect to bony structures may limit the overall accuracy. However, if the marker is attached to a region that moves little[6], an estimate regarding the magnitude of movement of the patient's skin is considered to be matched to that of the bony structure. Alternatively, markers that are attached to fixation devices such as a custom bite plate that incorporates the maxillary dentition[8] may be recognized accurately by the machine vision system.

Setup accuracy by digital kilo-voltage fluoroscopic imaging system is restricted to the pixel size of the images. Because the pixel size of the fluoroscopic image was 0.2 mm in the present study, it was difficult to determine the position of the lead pellet with accuracy of less than 0.2 mm. If bony structures are used as a reference point instead of radiopaque fiducial markers, the accuracy of the detectability of movement may be worse. In clinical practice, setup variability is based on orthogonal portal imagings, which have less accurate detectability of positioning than kilo-voltage imaging. Under the condition that computed tomography (CT) with a 3-5 mm slice thickness is achieved for treatment planning, a setup accuracy of around 1 mm may be enough. However, the recent development of diagnostic imaging technologies, including multidetector-row CT, renders it one of the most distinguished modalities in the detection of tumors and anatomical structures with less than 0.5 mm slice thickness. Under these circumstances, verification systems of patient positioning with submillimeter accuracy will be necessary in the near future.

The machine vision system is a straightforward solution for improvement of patient positioning and monitoring. This study suggests that the machine vision system can be used to measure small changes in patient position with a resolution of less than 0.1 mm. In addition to the accuracy, the machine vision system allows real-time monitoring of patient positioning during treatment more easily than the fluoroscopic imaging system. Although this study is still preliminary, we emphasize the potential of achieving high-precision positioning of patients. We are now beginning studies of its use for treatment of head and neck cancer and lung tumors.

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（和文抄録）

# 放射線治療の患者位置あわせにおける，CCDカメラを用いたマシンビジョンシステムの有用性

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山口俊博[1]，鳥羽隆史[1]，穴井重男[2]，寺嶋廣美[3]，本田　浩[1]

マシンビジョンシステムは，640×480ピクセルのCCDカメラとコンピュータコントロールシステムより成る．マシンビジョンシステムの位置あわせ精度について検討した．まず，ファントムから1.5 mの位置にCCDカメラを設置し，ファントム上のマーカー（1.5 mm径の鉛球を有する）の画像を認識させた．マイクロメータを用いて，ファントムを0.25 mm，0.50 mm，0.75 mm，1.00 mm，2.00 mm，3.00 mmほど正確に移動させた．マーカーの位置は，キロボルトで撮影された透視画像とマシンビジョンシステムを用いて評価した．透視画像では，実際の移動距離と測定値との差は，0.12 ± 0.05 mm（平均±標準偏差）であった．一方，マシンビジョンシステムでは，実際の移動距離との差は，0.0067 ± 0.0048 mmであった．マシンビジョンシステムは，0.1 mm以下の精度で移動距離を正確に検出できることが推察された．