A Study on The Factors for Improving Performance of The Stereo Camera for The TMS Navigation System

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Summary
Transcranial Magnetic Stimulation (TMS) applying magnetic stimulation directly on neurons of the brain noninvasively is being used to treat stroke, Parkinson's disease, depression, and so on. TMS can provide treatment through more effective stimulation when accurate stimulation is applied to an anatomical position of the patient. So a navigation system for obtaining accurate information about location is necessary for effective stimulation. The TMS navigation system is composed of a transducer, an infrared stereo camera, and an infrared marker attached to the patient's head. The stereo camera provides real-time information about location of the infrared marker attached to the patient's head and the transducer, and with the information, the patient's head and the transducer, both of which are on real-time movement, are located by using time-delay algorithm, space intersection, camera calibration, and inner elements of the camera. This location information is crucial in that location of the transducer and the patient varies according to precision of the stereo camera module. In this study, we used two different models of WebCam to make a comparison of distortion and FOV and examine those factors for improving performance of the stereo camera with the objective of improving accuracy of the TMS navigation system.

Key words:
Transcranial Magnetic Stimulation(TMS), Field of View(FOV), Navigation System, Registration, Stereo camera , Camera Calibration

1. Introduction

While people in today's complicated and diversified society are frequently exposed to various types of environmental stress, the number of patients with depression is on the increase. As depression is significant mental illness whose lifelong prevalence ranges from 12% to 17% and 10% to 15% of those suffering from depression commit suicide, it is becoming an important social problem as a serious disease [1][2]. In general, 30% of depressed patients known to fail in medication are classified into treatment-resistant depressed patients. To solve the problem of these treatment-resistant depressed patients, transcranial magnetic stimulation (TMS) applying local stimulation to the brain of human beings, among many other therapies, is frequently employed along with development of new antidepressants. As brain stimulation for controlling activation of cortical neurons by passing locally-induced magnetic-field waves, which are produced by a high-voltage current streamed into conducive electromagnetic coil near the head, through the skull, TMS is the transcranial magnetic stimulation system introduced by Barker and his colleagues in 1985 to make up for those problems of patient's inconvenience and pain caused by the existing electric stimulation therapy [3]. TMS was principally used to test conductivity of central and peripheral nervous systems in the neurological area at its early stage; then, it has been widely used to treat pain, rehabilitate post-stroke cranial nerves, treat depression, and globalize various functions of the brain, including visual information, language, emotion, motion, and memory. Since it is particularly known to be a possible therapy for various neuropsychiatric diseases, TMS has also been used for the therapeutic purpose in Korea since its introduction to the neuropsychiatric field in 2002 [4]. TMS therapy, which intermits a very strong stream into electromagnetic coil to generate a strong magnetic field around 2 Tesla lasting 100 to 200 msec or so and applies stimulation directly to the patient's brain through the coil, requires a navigation system to provide accurate location information since it is essential to apply accurate stimulation to an anatomical position of the patient's brain in case of brain stimulation [5].
The navigation system for TMS visualizes accurate anatomical image from MR imaging and coordinate information data of the infrared passive marker attached to the head with the infrared stereo camera composed of two cameras, maps actual location of the patient's head, tracks the anatomical location and head movements of individual patients, and makes it efficient and convenient to determine the position and direction of stimulation. While it is impossible to immediately check accuracy of the current position of stimulation during treatment with general types of TMS, preventing magnetic stimulation from being concentrated on the desired position, the use of the navigation system makes it possible to visualize the position of magnetic-field stimulation in real time during treatment, thus focusing stimulation on the desired position for stimulation [6]. In the TMS navigation system, accuracy of the stimulation position depends heavily on

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performance of the stereo camera; to solve this problem, different models of WebCam were used to make a comparison of distortion and the field of view (FOV) of the stereo camera for more accurate 3D coordinate tracking and analyze factors for improving its performance.

2. Methods

To test improvement in performance of the stereo camera for the TMS navigation system, two cameras were used, as shown in Figure 1: Camera A is the C-3000 model (angle of view: 75°) of Alpha Cam and Camera B is the LifeCam Studio model (angle of view: 75°) of Microsoft. Two types of WebCam have identical resolution of 1280 x 720 and different instrumental properties, and we made a comparison of distortion and FOV of the two WebCams to analyze factors for improving performance of the stereo camera.

(a) C-3000 (b) LifeCam Studio

Fig. 1 Experimental WebCam

2.1 Camera Calibration

The stereo camera has a structure in which two cameras can see a single object. Two cameras, which are on the horizontal line, can use time delay between them, like human eyes, to track the 3D location of an object. This method is called space intersection [7]. However, general types of camera have focal length, distortion of lens itself, radial distortion caused by the shape of lens, and tangential distortion caused in the process of assembling the camera. These properties and distortions of cameras can significantly affect getting the accurate 3D location from image on the camera. So the process of camera calibration is required for more accurate 3D coordinates. For camera calibration, methods suggested by Tsai [8] and Z. Zhang [9] are frequently used. We employed Z. Zhang's method, which could improve accuracy of calibration by analyzing relations between the coordinate system of camera and that of image to create a closed-form solution and making it possible to deal with even non-linear radial distortion based on maximum likelihood for inner variable calibration [10]. Those dots found in the checker board, as shown in Figure 2, show the process of calibration operation and its results in Figure 3, where focal length refers to the distance from the center of lens to focus, and principal point refers to the point where the principal planes cross the optical axis. Four distortion coefficients - K1, K2, P1, and P2- were obtained from checker board calibration by using equation (1).

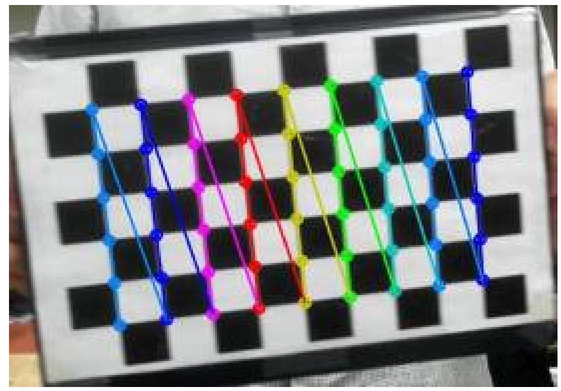


Fig. 2 Camera calibration using checker board

$$x_u = \left(1+\sum_{i=1}^{\infty} K_i r^{2i}\right)x_d + \left(2P_1\overline{xy} + P_2\left(r^2+2\overline{x}^2\right)\right)\left(1+\sum_{i=1}^{\infty} P_{i+2} r^{2i}\right) \quad (1)$$
$$y_u = \left(1+\sum_{i=1}^{\infty} K_i r^{2i}\right)y_d + \left(P_1\left(r^2+2\overline{y}^2\right)+2P_2\overline{xy}\right)\left(1+\sum_{i=1}^{\infty} P_{i+2} r^{2i}\right)$$
$$x_u = \left(1+K_1r^2+k_2r^4\right)x_d + \left(2P_1\overline{xy} + P_2\left(r^2+2\overline{x}^2\right)\right)$$
$$y_u = \left(1+K_1r^2+k_2r^4\right)y_d + \left(P_1\left(r^2+2\overline{y}^2\right)+2P_2\overline{xy}\right)$$

K_i=radial distortion, P_i=tangential distortion,
x_d=x-coordinate before undistortion, y_d=x-coordinate before undistortion
x_u=x-coordinate after undistortion, y_u=x-coordinate after undistortion
where $\overline{x} = x_d - C_x,\ \overline{y} = y_d - C_y,\ r^2 = \overline{x}^2 + \overline{y}^2,$ and C_x, C_y are optcal center.

As shown in Figure 3, the results of calibration show that LifeCam Studio has a lower distortion constant than C-3000. This means that image on LifeCam Studio is less distorted than C-3000. Focal length in the pixel coordinate system refers to the distance from the focus to the image plate. In the same resolution, therefore, the camera with a larger angle of view has a shorter focal length, as can be found in the data about LifeCam Studio with a relatively large angle of view.
Since the center of image is different from that of the camera, the principal point constant is shown to indicate on which coordinate of image the center of the camera is located. At the center of image (640, 360), the difference is (116, 46) for C-3000 and (14, 23) for LifeCam Studio. Figure 4 and 5 show the results of calibration of distorted image using intra-camera constant obtained through calibration for C-3000 and LifeCam Studio.

Calibration date	2013-01-19 오전 3:15:53
Number of images	30
Square size	23,000 (mm)
Focal length	[1363,212 1368,073] ± [5,678 5,622]
Principal point	[524,013 314,117] ± [2,040 2,020]
Distortion	[-0,185954 0,053339 0,001304 0,005281] ± [0,002912 0,010769 0,000228 0,000276]
The camera matrix	[1363,212 0 524,013; 0 1368,073 314,117; 0 0 1]
Pixel error	[0,18 0,19]

(a) Results of calibration for C-3000 Camera

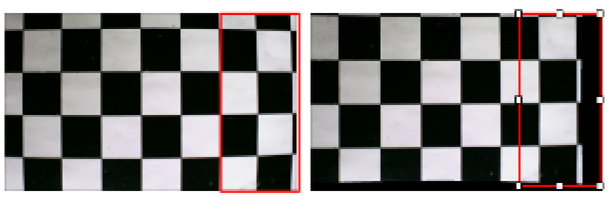
Calibration date	2013-01-19 오전 3:04:53
Number of images	30
Square size	23,000 (mm)
Focal length	[939,839 943,340] ± [2,266 2,164]
Principal point	[625,570 382,605] ± [1,403 1,142]
Distortion	[-0,014215 0,029896 0,000892 -0,000374] ± [0,002649 0,007759 0,000379 0,000479]
The camera matrix	[939,839 0 625,570; 0 943,340 382,605; 0 0 1]
Pixel error	[0,46 0,44]

(b) Results of calibration for LifeCam Studio Camera

Square size = one square size of chessboard
Focal length = distance form center of lens to focus
Principal point = the points where the principal planes cross the optical ax is

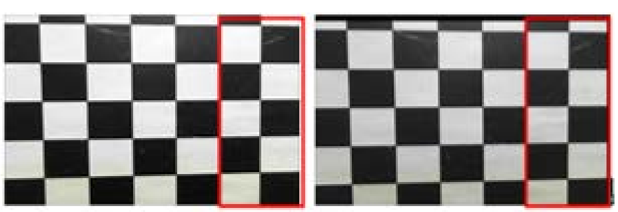
Fig. 3 Results of calibration for two cameras

Figure 4 and 5 show the results of calibration of distorted image using intra-camera constant obtained through calibration for C-3000 and LifeCam Studio. 4(a) shows the original distorted image within the square and 4(b) shows its calibrated image; likewise, 5(a) shows distorted image and 5(b) shows its calibrated image. Figure 4 shows great differences between the original image, which is severely distorted, and its calibrated image, whereas Figure 5 shows small differences between the original, which is very slightly distorted, and its calibrated image. Calibration of the principal point changed the center of image: C-3000 and LifeCam Studio had image loss of 28.58% and 8.43%, respectively. This demonstrates that calibration of image of the camera with a big principal point leads to reduction of FOV and loss of precision in 3D tracking.



(a) Before calibration (b) After calibration

Fig. 4 Images before and after removing distortion in C-3000 Camera



(a) Before calibration (b) After calibration

Fig. 5 Images before and after removing distortion in LifeCam Studio Camera

2.2 FOV Comparison

In the stereo camera, baseline, which is one of the external factors possibly having a great influence on FOV and precision by the gap between two cameras, is very important [11]. Identical baseline (300mm) was applied to make a comparative analysis of FOV between C-3000 and LifeCam Studio, with a 17x5 checker board used at the interval of 200 mm horizontally and 200 mm vertically to make a comparison of image from the same distance.

Pixel error was calculated to set a reliable error range, which was used to set a proper error range. The results are shown in Table 1.

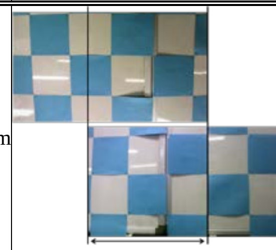
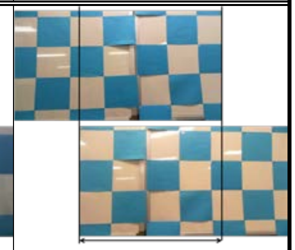
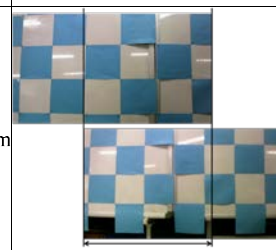
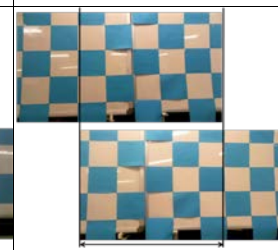
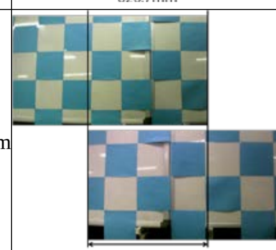
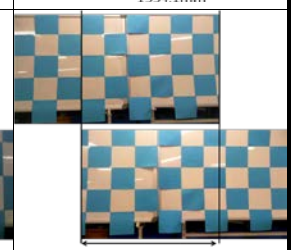
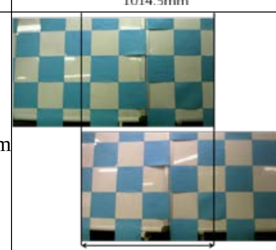
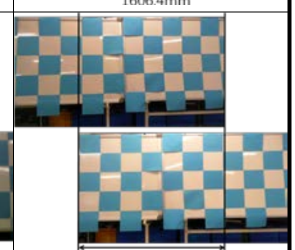
Distance	C-3000 Camera module	Life Studio Camera module
1000mm	 650mm	 1120mm
1200mm	 826.7mm	 1334.1mm
1400mm	 1014.5mm	 1606.4mm
1600mm	 1202.3mm	 1878.8mm

Fig. 6 Comparison of FOV between C-3000 and LifeCam Studio Camera modules

Table 1: Pixel error for each camera
(Resolution 1280 × 720)

Distance	C-3000 Camera	LifeCam Studio Camera
1000 mm	1.224	1.776
1200 mm	1.763	2.559
1400 mm	2.400	3.484
1600 mm	3.136	4.552

1800 mm	3.970	5.764
2000 mm	4.902	7.118

Figure 6 shows images of the checker board photographed in each camera module. The space displayed on the screen shows FOV used for actual 3D measurement, which actually becomes a treatment space within a hospital. FOV in C-3000 and LifeCam Studio Camera modules is shown to be 639 mm and 1061.7 mm, respectively, from the distance of 1000 mm. That is, the LifeCam Studio Camera module with a greater angle of view has larger FOV than that of C-3000 Camera.

Calibration of the distorted image using FOV obtained in this way led to image loss due to calibration of the principal point. The rate of image loss was around 28.58% and 8.43% for C-3000 and LifeCam Studio Camera modules, respectively. The range of FOV being used in practice is shown in Figure 7.

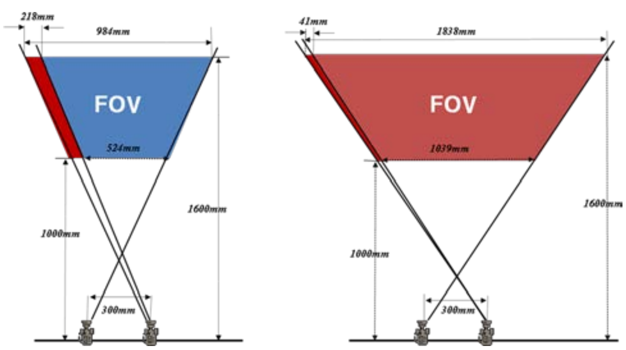


Fig. 6 FOV calibrated by image loss

3. Conclusion

In this study, we used two different models of WebCam to make a comparison of distortion and FOV of the stereo camera and analyze those factors for improving its performance in pursuit of more accurate 3D coordinate tracking. In general, cameras have differences in such properties as focal length and distortion of the lens. Since these properties significantly affect obtainment of accurate 3D location, we calculated the distortion coefficient of two types of WebCam and then calibrated images for camera calibration. As can be seen from the results of the experiment for calibration of two cameras, C-3000 had greater differences in the principal point than LifeCam Studio, and there were also differences in post-calibration image loss: 28.58% for C-3000 and 8.43% for LifeCam Studio. The LifeCam Studio module also had larger FOV than that of C-3000, and the former with less image loss actually had larger FOV than the latter in consideration of distortion removal and image loss for clinical application.

As can be seen from the results of this study, the stereo camera needs a small principal point affecting image distortion along with high resolution, precision, and FOV in order to make good performance. However, larger FOV needs a larger angle of view, which can reduce precision by increasing the angle of view to be expressed in one pixel while maintaining resolution. We could use the stereo camera modules of WebCam for the TMS navigation system to analyze factors necessary to improve many aspects of performance and obtain high precision and sufficient FOV.

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