Comparisons of Stereoscopic Viewing Devices in Digital Dental Stereoradiography

Hsien-Huang P. Wu[1*], Chien-Chih Lin[1]

Soon-Lin Chen[2], Ping-Kuo Weng[2], Ying-Yih Wu[2]

[1]Deparpment. of Electrical Engineering

National Yunlin University of Science and Technology

Douliou 640, Taiwan, ROC

{wuhp, cclin}@yuntech.edu.tw

[2]Materials RD Center, Solid-State Devices Materials Section

Chung-Shan Institute of Science and Technology

Lung-Tan, Tao-Yuan 325, Taiwan, ROC

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Abstract. This paper presents a brief overview of the applications of stereoscopic viewing in various medical fields and dental application was selected for performance evaluation using the proposed viewing apparatus. Because of the prevalence of digital imaging in radiology and the developments of electronic three-dimensional (3D) viewing devices, digital stereoradiography will become an efficient and economical way for improving the diagnostic efficacy. A viewing system based on one compact mirror and two flat-panel LCD monitors to achieve high resolution of digital dental stereoradiography is proposed and its effectiveness was evaluated. The performance based on student's paired t-test revealed that the proposed viewing method shows statistical significance compared with the other two popular approaches. Clinical use of the viewing instruments can be expected to show similar results.

Keywords: Stereoscopic viewing, digital dental stereoradiography, 3D viewing devices , depth perception, autostereoscopic LCD

1 Introduction

Depth perception is very important for human being to sense the environment and fully understand the scene. It can be utilized to judge the position of objects in space or features in an image which greatly enhance an observer's understanding of the true nature of the 3D scene under observation. Stereoscopic viewing has found widespread applications in the fields of entertainment, simulation, teleconferencing, and tele-operation to provide vivid 3D depth information, improve the efficiency of communication and augment the reality of presence. As for the X-ray imagery, the 3-D imaging group in UK has also developed several binocular stereoscopic X-ray screening techniques for aviation security and inspection applications [1-2]. In medical applications, stereo techniques have been available to radiologists for a long time, and application of stereoscopic methods to X-ray imaging can even be traced back to 1898 by Davidson [3].

Because of its educational and clinical values, the use of stereoscopy gained popularity among radiologists for the past decades [4-8]· Stereoscopic imaging was utilized for easier understanding of normal anatomy and for various types of radiographic examinations. It has also been used to determine the location of small intracranial calcification and multiple foreign bodies in dense or thick body sections, and to evaluate the relationships of margins of bony fractures. Despite these advantages, the doubled film cost and patient exposure, the need to train the eyes to perceive the stereoscopic effect using natural stereopsis (or to use cumbersome film stereoscope), and the recent availability of computed tomography (CT), hindered its widespread acceptance in clinical practice.

Current developments in digital imaging and display technologies, however, have made the stereoscopic method enjoys a renewed interest in several medical applications. The digital detector has higher contrast sensitivity than film which provides good-quality images at a reduced radiation. This not only reduces patient exposure but also allows multiple images to be taken without additional film cost. Furthermore, recent improvements in video

* Correspondence author

display technology have made high-quality stereoscopic X-ray viewing possible. While the CT can provide more detailed 3D information, the relatively high radiation dose of CT usually makes it inappropriate for common clinical application. Therefore, for initial diagnostic examination, stereoradiographic approaches may well fill a technological niche of considerable public health importance.

2 Current applications of stereoscopic imaging in radiography

Stereoradiography has proven to be a viable approach in several medical imaging applications and some of them were briefly reviewed below

2.1 Angiography

In the past, some stereoscopic work has been done in angiography with conventional film-based X-ray images [9], live-time fluoroscopy for digital subtraction angiography (DSA) images from dual-focal-spot X-ray tubes [10-11], and DSA acquisitions with the X-ray source at two locations [12]. Using stereoscopic x-ray systems in coronary angiography, physicians can better visualize the location of a blood vessel and insert the catheter to the correct depth and site. Furthermore, computational stereo techniques can be applied to extract quantitative data such as amount of narrowing of arteries and the blood flow therein [13]. In their recent study, Talukdar and Wilson conclude that X-ray stereoscopy can become an attractive, low-cost alternative for real-time 3-D angiography imaging [14]. One example of angiography images [15] to show the viewing effect of stereoscopy for a brain tumor is illustrated in Fig. 1.

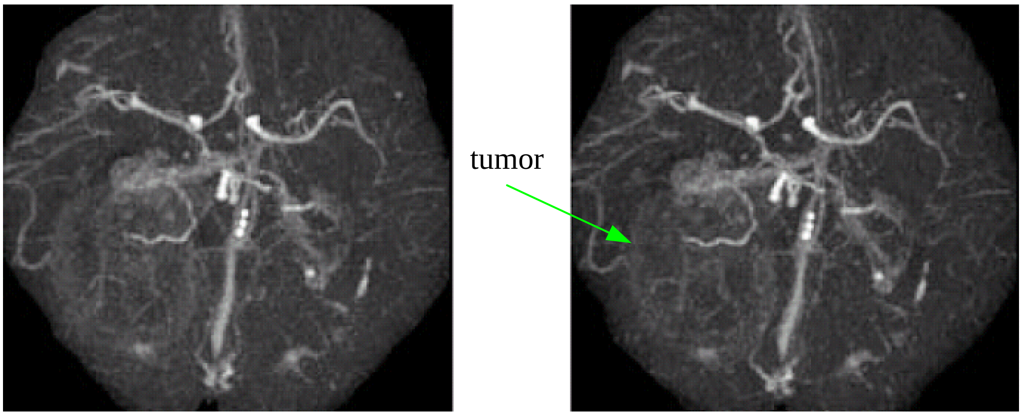


Fig 1. Stereoscopic viewing of the angiography can reveal the relative position of a brain tumor (©IEEE).

2.2 Mammography

Stereoscopic radiography has also been used in mammography for different types of examinations (lesion, mass, architectural distortion, and calcification). A stereo mammogram consists of two X-ray images of the breast taken sequentially from slightly different points of view. Radiologists determined empirically that a tube shift of 10% of the source to detector distance worked well for stereoradiography [16]. This translates to a stereo shift angle of about $6^\circ - 10^\circ$ between exposures while the position of the object remains stationary. A digital X-ray detector captures each X-ray image directly and stores it as a data file on a computer. The depth information provided by stereo display may allow better radiographic definition of abnormal masses and architectural distortion thereby increasing the observer's ability to distinguish and characterize abnormal masses. Moreover, the geometric structure of clustered calcification can be directly perceived in 3D. An observer performance study by Getty et al [17]. indicated that digital stereomammography improved the estimate of the probability of malignancy of mammographic lesions and allowed the detection of additional lesions that were obscured on screen-film mammogram. The research conducted by Chan et al [18] indicated that statistically significant improvements were achieved for detection of micro-calcification and for classification of malignant and benign lesions.

2.3 CT/MRI

Stereoscopic image viewing can also improve the appreciation of the 3D image acquired by CT or MRI. When informed consent for patients becomes important in clinics, the doctors have to explain disease and treatments to patient. However, X-ray images or CT and MRI imagery are hard for the patients or their family who are not medical specialist to understand. Because the internal organs, bones and blood vessels are overlapped, it will be very difficult for the patient who has no knowledge of anatomy to recognize an affected part and compare them with normal condition. In contrast to plain 2D image, taking stereoscopic image pair from CT/MRI slices and display them on stereo-viewing device would greatly improve patients' comprehension of their condition, as illustrated in Fig. 2 [15].

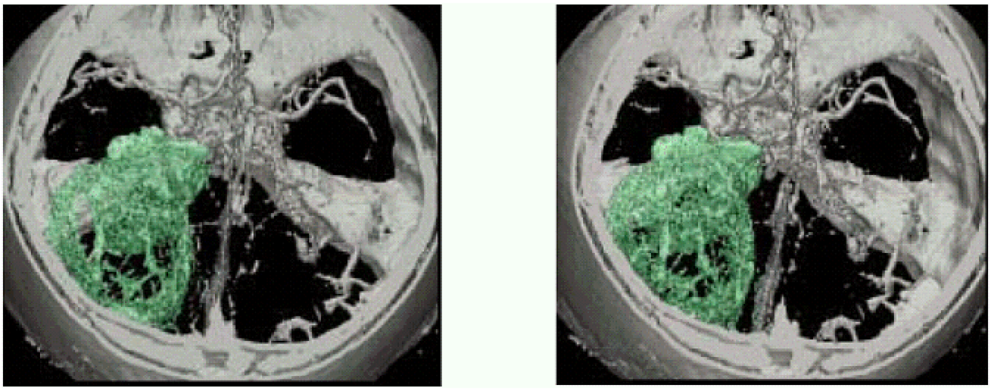


Fig 2. Image pair reconstructed from CT slice of a brain with tumor. Stereoscopic viewing can clearly show the 3D view of the tumor and the surrounding structures (©IEEE).

2.4 Dental radiography

In dental radiography, stereoscopy was once commonly used in diagnostic examination based on natural stereopsis or stereoscope to obtain relative location of objects hidden in the oral region. However, it then fell from favor due to extra exposure and film cost. Nowadays, buccal-object rule [19] is usually taught in dental schools for determining the bucco-lingual relationship between a tooth and other anatomical structures [20]. Yet, stereoscopic viewing can directly show this relationship and the structure can be appreciated without the need for mental reconstruction from the two separate 2D views.

Stereoscopy currently enjoys a renewed interest for evaluation of bony pockets in patients with periodontal disease, study of the morphology of the temporomandibular joint area, determination of root configuration of teeth that require endodontic therapy, assessment of the relationship of the mandibular canal to the roots of unerupted mandibular third molars, and assessment of bone shape when placement of dental implants is considered [21]. Wenzel [34] conducted a study to investigate if the use of natural stereovision influences the interpretation of radiographic depth. Seventy two dental students were involved in the diagnoses of (1)the position of the crown of an impacted third molar in relation to the second molar and (2) root deviations in the bucco-lingual plane. The results showed that for those students who could perceive a 3D image in a particular case they were more accurate in diagnosing third molar localization and root deviation than those who could not. Training in stereopsis has therefore now been included in the curriculum for oral radiology in their dental college.

3 Dental stereoradiography

While natural stereovision has proven to be helpful in film-based diagnosis [34], the trend of using digital images in dentistry has actually setup a favorable environment for applying better digital apparatuses for stereovision. How this digital setting can affect the practice of dental stereoradiography will be discussed next.

3.1 Digital dental radiography

Developments in digital dental imaging have been made to minimize patient radiation exposure, reduce image acquisition time, avoid environmental contamination, and improve cost effectiveness as well as maintain high image quality. Several studies have been published on the efficacy of digital imaging vs. film-based imaging in a variety of diagnostic tasks: the assessment of caries [23-26], the estimation of bone loss [27], the detection of lesions [28-29], the determination of canal length [30-31] and other miscellaneous diseases [33]. The findings are generally consistent in demonstrating that the diagnostic quality of digital images is sufficient clinically.

n conclusion, quality of images obtained by the current digital dental radiography systems (CCD and PSP) is the same or better than that of film with reduced exposure, cost, and time. The reduction of the exposure to only 10% of the film-based system has made the extra images taken for stereoscopic viewing become more acceptable. Similar to the stereo mammogram, the X-ray source is rotated by approximately 6° between two consecutive exposures for acquiring stereoscopic images.

3.2 Viewing method in stereoradiography

It was shown that there are about 13.5% of the dental students could not perceive 3D by natural stereovision [34]. Of the students who could obtain 3D perception, 56% use parallel-eye technique and 38% use cross-eye technique and the others are uncertain. Although there was no difference between the two categories of students on their diagnostic performance, those who use the cross-eye technique (38%) must understand that their viewing position is from the inside of the patient's head when they interpret the bucco-lingual relationship between tooth and adjacent anatomical structures, whereas those who use the parallel-eye technique (56%) obtain a depth image as if the patient were examined from the outside. Note that the viewer can not control the technique that he or she uses to obtain the depth image.

Fortunately, the development of digital dental acquisition systems has naturally paved the way for the use of electronics-based stereoscopic viewing system. Replacing natural stereovision with these new viewing systems can make every viewer perceive the same 3D viewing since the viewing technique (parallel- or cross-eye) is now controllable. Digital stereoscopic images can now be viewed more conveniently than stereo film radiographs because of the high-resolution electronic display. Furthermore, viewers who could not achieve a depth image based on natural stereovision will not have difficulty in perceiving 3D based on these electronic apparatuses.

3.3 Available viewing approaches

The available 3D viewing methods can be divided into two categories of glasses-based stereoscopic and glassless auto-stereoscopic displays. Glasses-based stereoscopic display includes color filter glasses (color anaglyphs), polarizing glasses and shutter glasses. Glassless auto-stereoscopic device includes holographic film, volumetric display, and parallax image based LCD monitors.

Left and right images for stereoscopic viewing based on color anaglyph need to be combined into one single image in red/blue shade by software [35], and one example is illustrated in Fig. 3. The current trend is red for one channel (usually the left) and a combination of both blue and green in the other filter. The most advanced viewing device for polarizing glasses is the beamsplitter-based stereoscopic monitor made by Planar Systems, Inc [36]

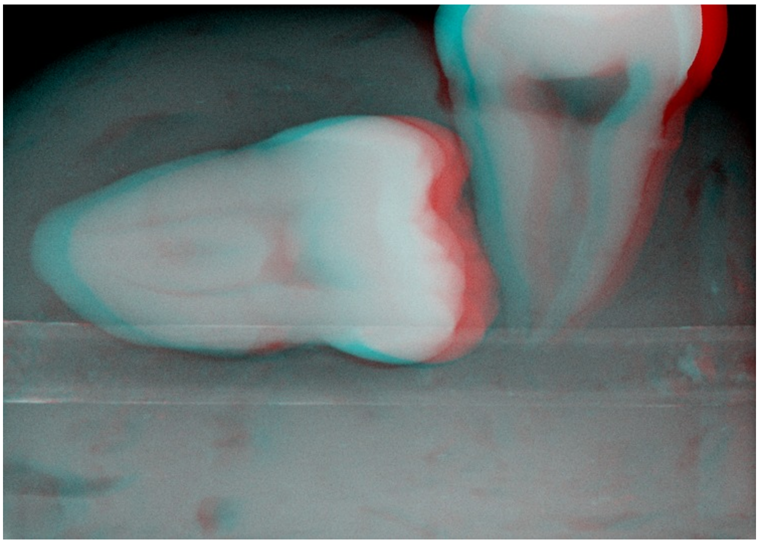


Fig 3. Image pair combined for stereoscopic viewing based on color anaglyph.

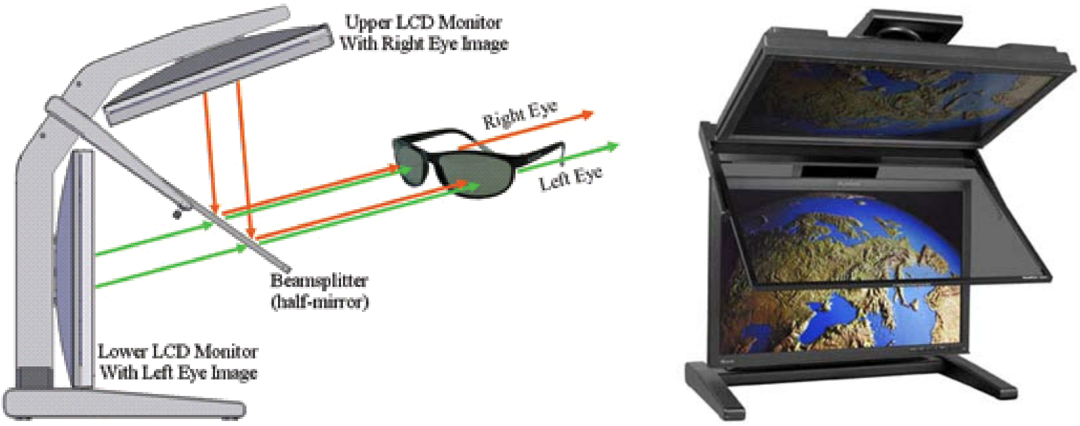
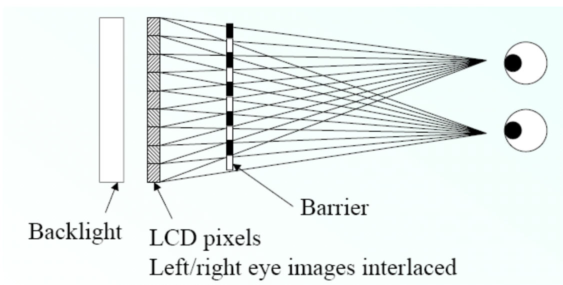


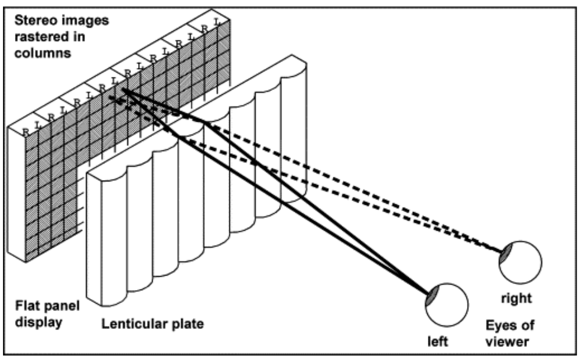
Fig 4. Stereoscopic monitor made by Planar Systems Inc., which is used for polarizing glasses.

(Fig. 4). A user of such a stereoscopic monitor wears polarized glasses that allow the left eye to see the lower monitor and the right eye to see the upper monitor. The beamsplitter is properly positioned so that the users feel like they are looking at one display. Shutter glasses, which is based on time-multiplexed principle, provides the observer with displayed images through a stereo goggle such as a pair of liquid crystal display (LCD) glasses [37]. These small LCD panels act as electronic shutters, blocking the light from the screen to the left eye and the right eye alternately.

The color anaglyph has the lowest quality compared with the other glasses-based approach, nevertheless, it has the advantage of low cost and works for both LCD and CRT monitors. The polarized approach can achieve stereoscopic effect at very high quality and resolution ($20''/1600\times1200$ and $24''/1920\times1200$). While the polarized glasses is cheap, the display system is sold at a relative high price (list prices: $20''/\$5995$ and $24''/\$7995$ US dollars) [36] in comparison to about $20''/\$380$ and $24''/\$600$ for ordinary LCD monitor from the same maker. The shutter glasses can also give very high quality viewing, yet CRT monitor with high refresh rates (Hz) must be used to avoid the flickers and no LCD panels can work with shutter glasses. These glasses-based devices somewhat suffer from ghosting effect because of the overlaying of the left-eye and right-eye images; however, they provide freedom of head-position for stereo viewing and allow multiple users to see the stereo image.



(a)



(b)

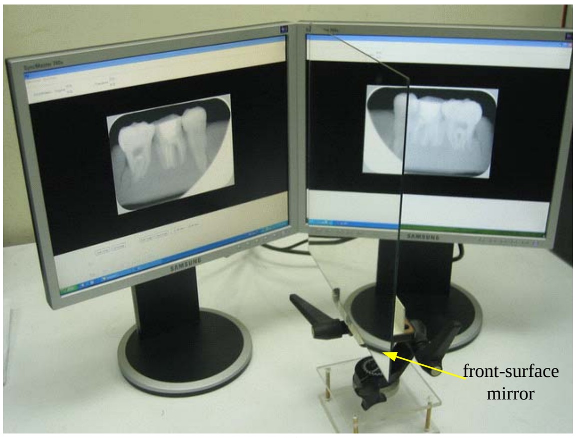
Fig 5. Autostereoscopic displays LCD monitors based on (1)barrier parallex and (b)lenticular screen.

Glassless autostereoscopic displays, which look like ordinary LCD monitors, are gaining popularity in the market of stereoscopic viewing [38-40]. They are built with parallax barrier or lenticular screen which allow the viewer to perceive the 3D effect on the flat panel displays. The parallax barrier or lenticular screen inside the monitor directs pixel images to two separate regions so that each eye receives a slightly different image, as shown in Fig. 5. This allows the viewer to perceive the 3D effect on the flat panel displays without wearing the stereo goggle. However, it also comes with a high price tag (Sharp $15''/1204\times768$ @US $\$1499$, DTI $19''/1280\times1024$ @US $\$3695$), especially when the screen size gets bigger. Furthermore, multiplexing the left and right in vertical direction, it has the disadvantage of reducing brightness of the display.

3.4 Problems of the current viewing devices for stereoradiograpy

Ghosting, or crosstalk, is a problem that is less evident in stereo movies and gaming due to motion of the scene and lower contrast levels as well as the presence of color in the images. Medical images viewed in stereo are not forgiving if the viewing system has even a small level of ghosting. This is because images are typically gray-scale, static, have areas of very high contrast and also areas in which fine gradations of gray are used to differentiate structures.

In using any viewing system where light from the images is physically superimposed, a small percentage of the image destined for the contra-lateral eye does leak through the coding device, whether shutter glasses, polarized glasses, anaglyph glasses or an autostereoscopic screen. With shutter glasses the ghosting arises from two components: Firstly, the persistence of the image on the monitor phosphor persists for a bit longer after it has been switched off and this time lag allows some of the image to be still present at high enough levels to be perceptible when the contra-lateral shutter opens. Secondly, even with the shutter closed, a small proportion of light still does leak through from the wrong image.



(a)

(b)

Fig 6. Dual-monitor system proposed for stereoscopic viewing. (a)Original design, (b)proposed design with compact mirror

To eliminate perceptible ghosting, the amount of light leakage to the contra-lateral eye should be below 2% of what is being displayed to the active eye (the Weber fraction). To make shutter glasses or autostereoscopic screens truly useful for radiology, the ghosting will have to be eliminated or minimized in future generations of stereoscopic equipment. However, the obvious and best solution for the problem is to use an optical viewing system which has no chance of ghosting, and this will be discussed next.

3.5 Proposed Dual-Monitor Compact-Mirror (DMCM) approach

With the rising popularity of LCD monitor and the availability of "dual-head" graphics card, dual monitor has become another viable choice of an inexpensive 3D viewing system. One set of dual-monitor 3D viewer built by following Hart's instruction [41] is shown in Fig. 6(a), where a single front-surface mirror is placed on the diagonal between the monitors. This is based on the principle of stereoscopes [42] using split screens and a single mirror. The original design is heavy and clumsy. In comparison, Fig. 6(b) shows our modified design where a more compact mirror is used. The size and weight of the mirror in Fig. 6(b) was greatly minimized which reflects only the region of the left screen. By directing right eye to the right screen, and left eye to the mirror, the viewer can perceive a sharp high-resolution 3D image.

While the system has simple construction, it provides several advantages: (1) There are no ghosts and flicker. (2)The images are bright and at full resolution. (3)The angle of view can approach orthostereo (for a normal taking lens). (4)Angling out the left monitor provides the mirrored image with no keystone effect (with the mirror positioned properly). (5)Head position is important but not critical so setup is relatively easy. (6)Illumination is uniform with two identical monitors.

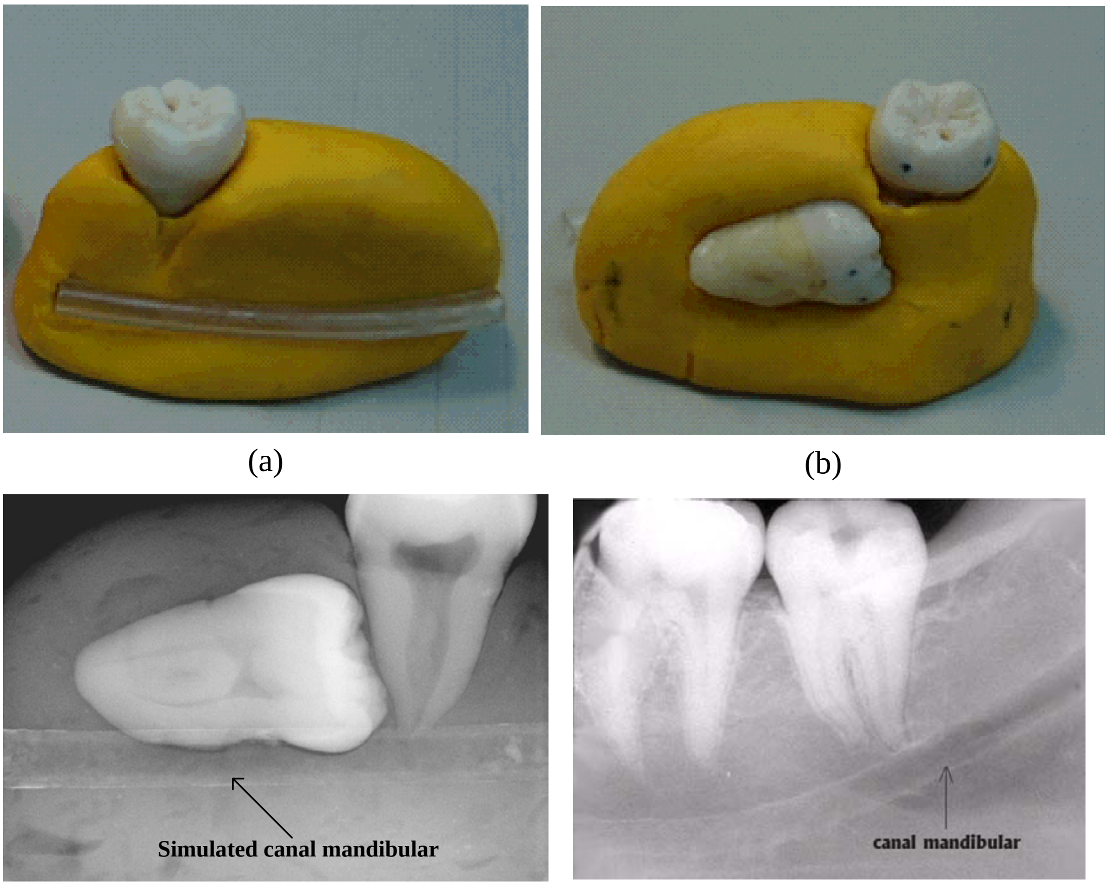
With the continuous drop in price of the LCD monitor, the budget to build a system with two $20''$ monitors can be less than US $\$600$. One extra advantage of this viewing system is that it can easily be set up by adding a compact mirror and an extra monitor to the available screen to start the stereoradiographic diagnosis. This split screens approach, similar to autostereoscopic screen, has the advantage of dispensing with the glasses; however, they have a somewhat restricted range of head-position and don't allow multiple users to see the stereo image simultaneously.

4 Material and methods

To study the performance of dental stereoradiography based on the proposed DMCM system, two other approaches with reasonable cost were also chosen for comparison. Only LCD monitors will be used in the experiments since they are more prevalent than CRTs. We selected color anaglyph for the glasses-based method because it is commonly used in the dental society. Autostereoscopic display ($15''$ Sharp LL-151, 2d/3d switchable) was chosen as the other glassless method because of its compact size and affordable price. It has the specifications of 1024×768 resolution, $500:1$ contrast ratio, $370\ cd/m^2$ brightness at 2D mode, and $140\ cd/m^2$ brightness at 3D mode. The $15''$ LCDs used in the DMCM and color anaglyph systems were made by Viewsonic with 1024×768 resolution, $700:1$ contrast ratio, and $350\ cd/m^2$ brightness. The settings of the ambient light for the three viewing apparatuses under tests were measured with a digital light meter (TES-1335) to maintain at around $340\ lux$ illuminance.

Preparation of image pairs

The phantoms for X-ray image acquisition were built by planting the extracted molars into putty soft mixture, and two of them are shown in Figures 7(a) and (b). When the putty soft mixture hardened after 2-3 minutes, its property is similar to plaster cast which can imitate the bone of the mandible and the maxilla. The mandibular canal can be simulated by a plastic tube coated with a thin layer of the mixture of glue and barium sulfate (Fig. 7(a)). While the tube is translucent to X-ray, the barium sulfate can effectively attenuate the X-ray and vividly reflect the characteristics of the mandibular canal, as can be seen in Fig. 7(c). A real X-ray image of the mandibular canal is shown in Fig. 7(d) for comparison to show the resemblance of the simulated canal to the real one.



(c) (d)

Fig 7. One of the phantom used for acquisition of image pair. (a)Rear view, (b)front view and (c)X-ray image of (b) where the simulated mandibular canal is visible, (d)real canal image.

Fifteen phantoms were built for acquiring digital periapical radiographs by paralleling technique. Thirty image pairs in all were taken by PY-70C X-ray system (70KVP/0.5 second exposure time) with E2V CCD sensor [43] for evaluation. Two items selected for stereoscopic evaluation are: (1)the buccal-lingual alignment of the crown of the impacted third molar in relation to the erupted second molar (five phantoms used for 10 image pairs), and (2)assessment of the relationship between the mandibular canal and the roots of unerupted mandibular third molars, which includes the buccal-lingual alignment and whether the canal is in contact with the third molar (10 phantoms used for 20 image pairs). Two images in each pair used in item (1) were acquired with a relative shift of the X-ray tube in horizontal direction, and one example pair is shown in Fig. 8. In contrast, the two images in each pair evaluated in item (2) were obtained with a relative shift of the X-ray tube in vertical direction and the images were then rotated counterclockwise by 90° for stereoscopic viewing. One example pair for item (2) evaluation is illustrated in Fig. 9.

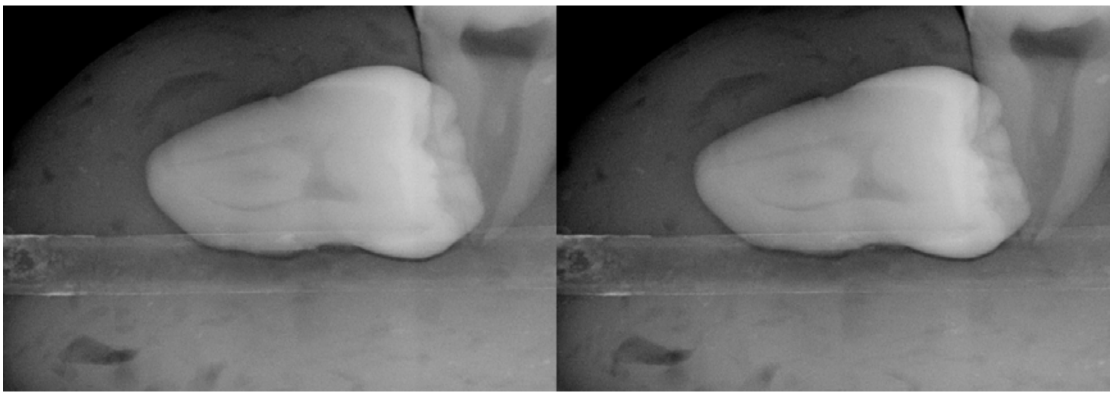


Fig 8. Stereoscopic image pair used for the alignment of the crown of the impacted third molar in relation to the erupted second molar.

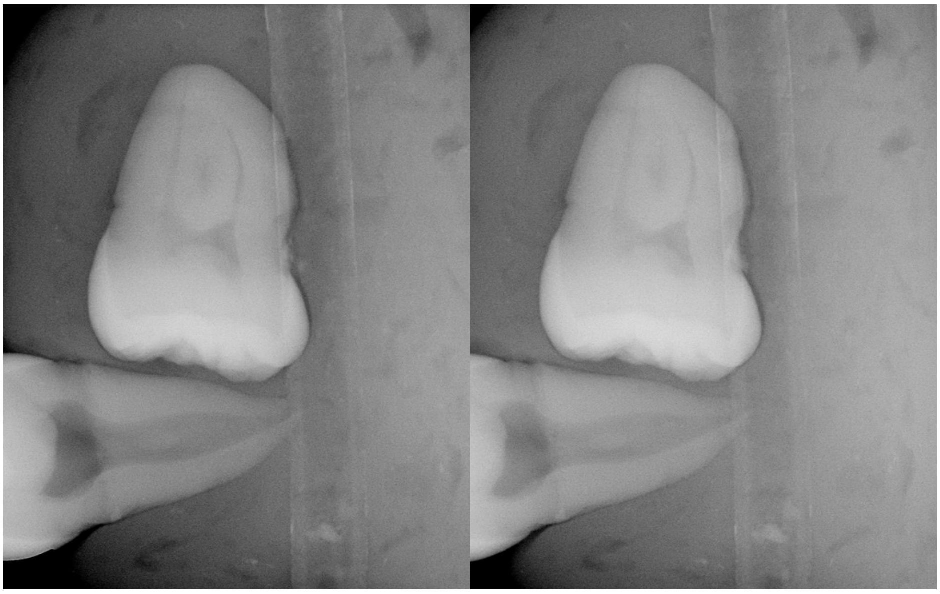


Fig 9. Image pair used for assessment of the relationship of the mandibular canal to the roots of unerupted mandibular third molars. The image pair were taken with a relative shift vertically and rotated by 90° for stereoscopic viewing.

5 Results and discussions

In order to ensure that the radiographic localization was achieved by depth perception only without using buccal-object rule (BOR) [19], 18 students with no training in BOR were selected to participate in this study. These students were taught and practice to use the three viewing devices under evaluation based on stereo image pairs of both reflected and transmitted nature before their participation. All 18 students were arranged to come in the same day for evaluating the first viewing device. Thirty image pairs were shown to the students in random order for accessing the two items defined above stereoscopically. The next viewing system will be evaluated at least after one week based on the same 30 image pairs with different orders. Given three types of viewing devices, the experiments can be completed within one month.

Table 1 Correct answers for the buccal-lingual alignment of the crown of the impacted third molar in relation to the erupted second molar

	DMCM	SAS	GCA
1	10	10	10
2	10	5	9
3	9	7	9
4	10	9	7
5	9	7	7
6	9	6	8
7	8	8	9
8	10	9	10
9	8	10	8
10	10	10	9
11	8	9	8
12	6	7	6
13	6	6	6
14	9	5	8
15	8	6	6
16	9	8	7
17	8	10	8
18	9	9	9
Av.	8.67	7.83	8

Table 2 Correct answers for the assessment of the relationship between the mandibular canal and the roots of unerupted mandibular third molars

	DMCM	SAS	GCA
1	20	17	19
2	19	15	15
3	16	16	7
4	16	15	15
5	16	13	16
6	20	15	14
7	18	16	12
8	20	15	11
9	17	14	13
10	20	16	9
11	19	15	18
12	19	16	16
13	19	19	17
14	17	17	11
15	15	14	13
16	15	15	14
17	14	11	11
18	15	13	11
Av.	17.5	15.1	13.4

All students were given one point for each correct answer for third molar crown alignment or correct relationship of the mandibular canal to the roots of unerupted mandibular third molars. The maximum sum score is 30 for each student for all the diagnostic tasks, and the collected results are shown in Table 1 for item (1) and Table 2 for item (2) respectively. The symbols used in the tables and in the following discussion to represent each viewing device are: (1)**DMCM** (the proposed **d**ual-**m**onitor with **c**ompact **m**irror), (2)**SAS** (the **S**harp **a**uto-**s**tereoscopic LCD monitor), and (3)**GCA** (**g**lasses-based **c**olor **a**naglyphs using Viewsonic LCD monitor).

Using the student's sum score as the statistical sampling unit, the difference of performances between two selected viewing instruments was tested by Student's grouped *t*-tests for each evaluation item. A paired *t*-test was used for whether any difference existed between the two selected stereoscopic viewing methods. In order to evaluate performance of the proposed viewing method in contrast to the other two available devices, the selected pairs for comparisons are (DMCM-SAS, or 1-2) and (DMCM-GCA, or 1-3).

Since we only want to investigate if the proposed method is better than the other two approaches, a right-tailed test was chosen. On the basis of the differences between the sampled pairs, the null hypothesis (H_0) that the mean of each method is equal and the alternate hypothesis (H_a) that the means are higher for the proposed method can be formulated as:

$$\begin{aligned} H_0 &: \mu = 0 \\ H_1 &: \mu > 0 \end{aligned} \tag{1}$$

We first compute the mean ($\bar{d}_{i-j}$) and the standard deviation (s_{i-j}) of the differences between all the sampled pairs. The value of test statistics can then be calculated from the following formula:

$$t_{i-j} = \frac{\bar{d}_{i-j}}{s_{i-j} / \sqrt{N}} \tag{2}$$

where N (=18) is number of samples in each group in the experiments, and index $i-j$ represents the two groups in the pair for comparison. Select a 95% confidence level (significance level $\alpha = 0.05$), the critical t values can be found in a t-distribution table as $t_{N-1;\alpha} = t_{17;0.05}$ =1.74 (righted-tailed) for a 17 ($N-1$) degree of freedom.

Given the data in Table 1, the statistics obtained by equation (2) are: $\bar{d}_{1-2} = 0.833$, $s_{1-2} = 1.917$ and $\bar{d}_{1-3} = 0.667$, $s_{1-3} = 1.029$, which correspond to $t_{1-2} = 1.844$ ($P = 0.0415$) and $t_{1-3} = 2.749$ ($P = 0.007$), respectively, The results ($t_{i-j} > 1.74$) show that for the determination of buccal-lingual alignment of the crown of the impacted third molar in relation to the erupted second molar, the proposed method show significant difference based on 95% confidence level.

Given the data in Table 2, the statistics obtained are: $\overline{d}_{1-2} = 2.389$, $s_{1-2} = 1.72$ and $\overline{d}_{1-3} = 4.056$, $s_{1-3} = 3.19$, which correspond to $t_{1-2} = 5.893$ ($P < 0.0001$) and $t_{1-3} = 5.395$ ($P < 0.0001$), respectively. The results ($t_{i-j} > 1.74$) confirm that for the assessment of the relationship between the mandibular canal and the roots of unerupted mandibular third molars, the proposed method is correct significantly more often and the paired *t*-test show significant difference based on 95% confidence level

On the basis of the experimental results, we found that the proposed device can obtain satisfactory 3D viewing effect; furthermore, it performed better than those of autostereoscopic LCD monitor and color anaglyphs. A system setup with dual-screen has become very popular recently due to the low cost of LCD monitor, it actually creates a natural environment for the proposed method. Moreover, the design of the compact mirror makes the holding of it for stereoscopic viewing become convenient and easy. While dental stereoradiography were used in the evaluation, the proposed method can also be used for the other stereoscopic viewing applications.

6 Conclusions

The current applications of digital stereoradiograph in different medical fields have revealed its efficacy in improving diagnostic performance. Maidment et al [44] found that human eyes can reduce the noise when the left-eye and right-eye images are integrated. This binocular summation can increase the detectability of simulated low contrast objects on a uniform noisy background. The experimental results conclude that the proposed DMCM approach has better performance since it does not overlay the image which can avoid the crosstalk and make the image clearer. We hope this efficient and economical viewing device can be used to improve the diagnostic efficacy. Similar type of display has also been investigated in therapeutic applications using virtual reality [45], where a dual LCD approach has also been proved to be the design of choice for VR therapy in order to obtain wide field-of-view with high resolution at a reasonable cost.

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