Development of Dental Light Robotic System using Image Processing Technology

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Robot-assisted illuminating equipment based on image-processing technology was developed and then its accuracy was measured. The current system was designed to detect facial appearance using a camera and to illuminate it using a robot-assisted system. It was composed of a motion control component, a light control component and an image-processing component. Images were captured with a camera and following their acquisition the images that showed motion change were extracted in accordance with the Adaboost algorithm. Following the detection experiment for the oral cavity of patients based on image-processing technology, a higher degree of the facial recognition was obtained from the frontal view and the light robot arm was stably controlled.

Key words: Automated system, Image processing, Oral recognition, Robot, The illuminator for dental practice.
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INTRODUCTION

World-wide health care expenditure corresponds to 16% of the United States Gross domestic product. As a society becomes aged, its proportion is expected to further rise. The robot system was introduced circa mid to late 1980 for stereotactic brain surgery. During the 21st century state-of-the-art medical equipment has been actively affiliated with the robot system.[1-3] Actually in the field of surgery, surgery using an image-processing robot system has been actively performed. Based on this, future clinical applications can be expected.[4] In recent years, the dental treatment system has not advanced substantially in comparison to state-of-the-art electronic technology. The current treatment system is still predominantly manual and therefore offers enormous possibility for advancement.

Keeping pace with the forthcoming era of ubiquitous technologically will necessitate the

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replacement of manual labor with robot systems. Likely, the first target for innovation in the field of dentistry will be the unit chair. Among the innovations focused on the field of dentistry, an automated light source would be pertinent as the light source is constantly and exactly moving during dental treatment. In general, the intensity of illumination that is required is comparable to that which is needed in a minor surgery room and it is equivalent to more than 10000lux.[5] The current study used a collaborative approach based on a combination of electronic, mechanical and dental sciences in conjunction with state-of-the-art IT and BT technology in an attempt to develop a dental treatment system that would establish consensus among those in the dental field.

The robot system designed in the current research utilized automatic mobility to detect the oral region of patients with a camera and then it illuminated the oral region with an appropriate degree of illumination. Robot-assisted illuminating equipment based on image-processing technology had not been developed in Korea or any overseas country prior to this study. In the current study, the robot-assisted illuminating equipment based on image-processing technology was developed and then its accuracy was measured. By way of the current study: dentistry, electronics and mechanics were merged into a novel type of science, dental engineering.

MATERIAL AND METHODS

1. System composition and mechanisms

1) Hardware

The current system was composed of a 4-axis motion control component, a light-control component and an image-processing component. Control was achieved using a PC-based S/W (Fig. 1). A 4-axis motion component was composed of a 2-Linked Arm and a 2-Axis Tilting Head. The head was designed to direct the roll axis and yaw axis in the direction of the LED Light (Fig. 2).

In the Motor which was used to generate the motion, a total of four Stepping Motors were used. In a 2-Linked Arm requiring a higher degree of the torque, a 5-phase Stepping Motor (AK-M566W-RB5, Autonics, Korea) with a decreased rate ratio of 10:1 was used. In the 2-Axis Tilting Head, a Stepping Motor (Ez-Step 42, Autonics, Korea) was used. While entering the value of slow sinusoidal voltage, the value of output torque was measured. Thus, a Static torque test was implemented using a ATI Gamma FT US 30/100 force transducer.[7] The value of measured torque was less than the published value. A Step Motor Driver which was used to operate the motor was manufactured and then installed. With the use of RS422 Protocol based on a PC, the Step Motor Driver was controlled with a control S/W on real-time basis.

The camera which was used herein was a IEEE1394 digital Camera (CSB1100CL-10, Toshiba, Japan) having 640-by-480 pixel resolution, for which the images were obtained using an IEEE1394 Frame

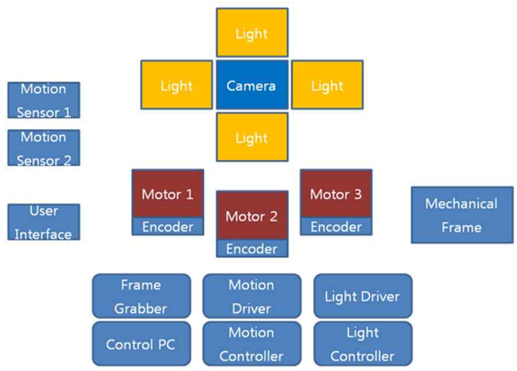

Fig. 1. System Architecture (PC based S/W) : Control was achieved using this S/W

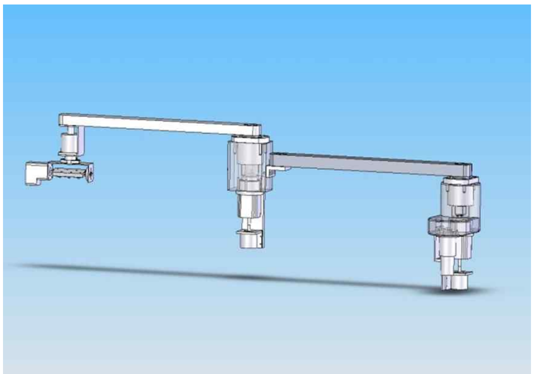

Fig. 2. 2-Linked Arm with Axis Tilting Head : A 4-axis motion component was composed of a 2-Linked Arm and a 2 Axis Tilting Head. The head was designed to direct the roll axis and yaw axis in the direction of the LED Light.

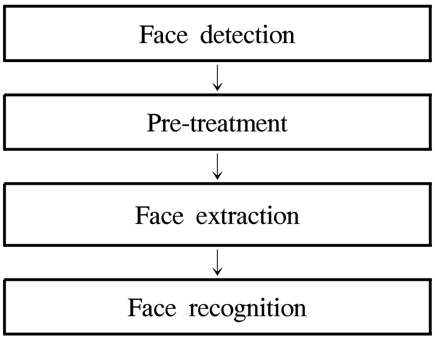

Fig. 3. 4 steps of the image processing : The stages of image processing were mainly based on what was shown in this Fig.

Grabber. For the purpose of measuring the location of the oral region of patients, the camera was placed on the left superior corner of the light lamp and the superior part of a unit chair. Because the coordinate system should be fixed, the mobility of the camera was not considered. For the light lamp, rather than using the conventional type of halogen lamp, an LED (Z-power LED, Seoul Semiconductor, Korea) was installed. The LED was designed to examine the oral cavity of patients using a warm white LED.

The current system measured the location of the oral cavity photographed on the camera by perceiving the pattern and then transferring it to the part of Motion operation. In the motion component a comparison of the current arm coordinates and the target values was made. Control was achieved in this manner and the arm was transferred to the target location.

2) Software

Image processing technology detects facial characteristics from halted images or video clips with a computer and then the images are processed.[6)] In the current manuscript, the technology used to perceive the oral cavity used object tracking. It is a basic component of motion-based object recognition technology.[7)] The stages of image processing were mainly based on what was shown in Fig. 3. In general, within the images, the unique characteristics that the facial region owns in a differential manner from the background and ratio are used herein.[8)]

A substantial number studies have been conducted to examine the technology used to detect facial appearance but these studies have disclosed some problems. There are various methods for detecting facial appearance: knowledge-based, feature-based,[9)] template matching,[10)] and appearance-base.[11)] In the current manuscript multiple facial appearance detections were made on a real-time basis from image pixel information. Feature data was created and relevant methods were used to analyze it. The characteristic information was used for the detection of the facial region, many calculations were needed to locate faces of varying sizes. To resolve this, Adaboost methods for the prompt detection of objects was proposed.[12,13)]

3) System control

The control of motion was determined by entering the coordinates from the PC program. The real-time coordinates on the axis were collected using a Multi-Link Motion Controller (Fig. 4) with the use of an encoder which was attached to each axis and then underwent feedback. Once the primary target order was given to the controller, the controller performed feedback control based on the difference between the current values and the target ones based on the PID mode.

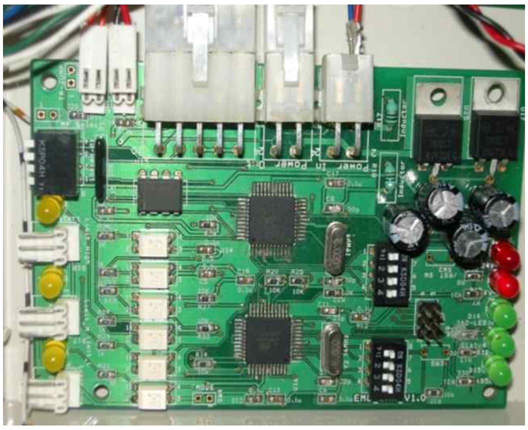

Fig. 4. Multi-Link Motion Controller : The real-time coordinates on the axis were collected using a Multi-Link Motion Controller.

Coordinates of the 2-Linked Arm (Fig. 5) were expressed as (α, β) values. L1 and L2 were both given fixed values and then calculated as a constant. L1 and L2 of the system were designed to have a length of 0.5 m. Besides, α was controlled within a range of (0 to 90)° and β was controlled within a range of (-45 to 45)°. When facial appearance was perceived, the coordinates of the imaging module detected the oral cavity structures of the craniofacial regions. The 2-Linked Arm migrated to the upper part of facial region using macroscopic mobility. By detecting the illumination of the oral cavity, it arranged the Tilting Head (Fig. 6).

The Tilting Head was positioned using the

Fig. 5. 2-Linked Arm : 2-Linked Arm requiring a higher degree of the torque, a 5-phase Stepping Motor (AK-M566W-RB5, Autonics, Korea) with a decreased rate ratio of 10:1 was used.

Fig. 6. Tilting Head Light System : In the 2-Axis Tilting Head, a Stepping Motor (Ez-Step 42, Autonics, Korea) was used.

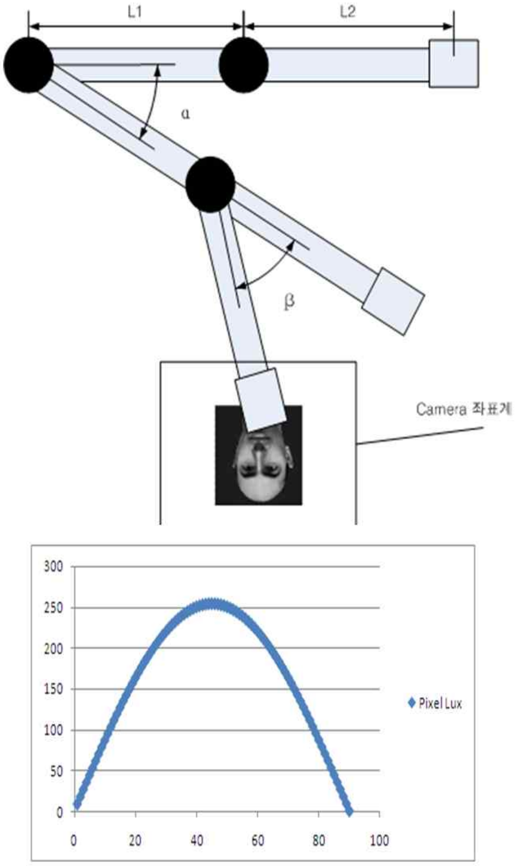

Fig. 7. 2-Linked Arm coordinates system and Scanning Pixel Lux : On the graph, in a 45 degree area which corresponds to the vertex, the Tilting Head had migrated. Thus, the illumination of oral cavity was maintained at maximum level.

following methods: Scanning Area techniques were applied, a scan was performed from the initial point to the terminal point and a resolution graph was plotted. The vertex was extracted from the resolution graph and subsequently transferred. When a Scan was performed for Tilting Head at an angle of (0 to 90)°, the resolution data from the oral cavity region was modeled from a camera. Thus, a Pixel Lux Scanning Graph (Fig. 7) was obtained. On the graph, in a 45 degree area which corresponds to the vertex, the Tilting Head had migrated. Thus, the illumination of oral cavity was maintained at maximum level.

4) An algorithm which was used for the system

From the input images of the camera, the target system located the facial region and extracted the coordinates of the oral cavity from the other craniofacial structures. Facial detection performed was based mainly on information obtained from facial movement. Previously, facial detection methods have been based on the detection of movement between frames.[14] In most cases, however, a mathematical approach that disregarded a real-time base was used. Otherwise, the algorithm used was complex and this was not appropriate for real-time construction. In the current system, for real-time detection of facial appearance, the camera images were converted to YCbCr images. Then, the difference between two consecutive images was obtained. Following this Classfire Labeling was used to extract the images that showed movement. The AdaBoost algorithm was applied to the data from the study and the major facial areas that were detected, which included the eye, nose, mouth and chin were extracted. After the location of primary facial targets was determined the accurate location of both eyes was identified. To make the location of both eyes matched the reference point, the images were geometrically processed. After matching both eyes to the reference point, the relative distance from eyes to nose and mouth were determined within the permitted error range.

The YCbCr tint model is a mode of color space, where Y represents hue and both Cb and Cr are color components. YCbCr is absolutely not a color space and it is one of the methods used for encoding

RGB information. The color of images which are actually visualized are dependent on the data of the original RGB which was used to display the signals.[15] From the RGB information, the conversion to YCbCr was performed as follows (1).

$$Y = k_r R + (1 - k_b - k_r)G + k_b B$$
$$C_b = \frac{0.5}{1 - k_r}(R - Y)$$
$$C_r = \frac{0.5}{1 - k_r}(R - Y) \quad (1)$$

5) Difference Picture

In the previous system, due to the increased amount of calculation involved, in order to improve the areas where real-time detection of the facial region was difficult, Difference Picture was used. Thus, the images for the detection of movement should have been extracted first.[16] When Difference Picture was used directly, the methods for capturing the domain around movable objects were subject to noise, camera movement and changes in illumination.[17] However, because the camera was used in a fixed position the effects of environmental movement were minimized. Besides, when the YCbCr color model was used, the data that was affected by illumination had to be ruled out before the color information could be used. Therefore, the facial region detection error rate was minimized due to the exclusion of data tainted by changes in illumination.[18] Accordingly, following the conversion to YCbCr images, the difference between the two consecutive images was obtained.

6) Glassfire Labeling

The grayish values were used from the difference pictures. If the calculation results exceed the critical value which was obtained from the experiment, the occurrence of movement was determined.[17] After a comparison of the critical values, to reduce the rate, block-based processing rather than pixel-based processing should be performed. Pixel-based processing performs 1-on-1 matching. Accordingly, it cannot be used in a real-time environment where many frames are processed per second. Accordingly, with the use of block-based processing, the accuracy was slightly decreased. But the enhancement of velocity was mainly focused. Block-based processing was used as the labeling method. Several pixels were selected as a single block and the representative values were obtained for calculation. This method is different from pixel-based processing.[19] The labeling search stage, selected two-digit images and performed a labeling when pixel values of 255 were encountered and then, the point was transferred to an 8-proximal center. Following this, in such a manner that a 255-pixel value from the adjacent pixel was labeled, the procedure was repeated. From the two-digit images, a labeling algorithm was used as shown in (2), the corresponding images were labeled.

$$P(R_{\tau}^{(k)} \cup x) = \begin{cases} True & \text{if } x > T, \\ False & otherwise \end{cases}, \quad For\, i\ 1, 2, \ldots N \quad (2)$$

P represents the logical interpreter of (R, x, T); (k) represents each stage; x represents the illumination value of pixel images; and T represents the critical point. In each area, R was labeled according to a region with the Glassfire algorithm. Glassfire algorithm labels the adjacent pixels of the target pixel in a sequential manner until all the adjacent factors are labeled.

7) The detection of facial region using Adaboost-algorithm

The basic concept of the Adaboost algorithm binds to a weak classifier in a linear form. Thus, it eventually produces a strong classifier with a higher degree of detection performance.[20] A powerful classifier produced by the Adaboost algorithm has a class-like system. This method forms a simple mask in multiple layers unlike previous methods that used a single complex mask-like classifier. The conventional type of single complex classifier performs the calculations with the complex mask by detecting the facial region. Therefore, the amount of calculation is relatively greater and a lot of time is spent. However, the systematic classifier which was produced using the Adaboost algorithm places what the facial region is best detected for the frontal part. In the rear part, it is composed to have a wrong detected facial region removed. This showed an excellent profile of the detection performance as compared with the conventional methods when it came to real-time detection.

1. Given N examples $(x,y),\cdots,(x,y)$
   with $x \in R,\ y \in \{1,-1\}$
2. Initialize weighs $w(i)$ = , $i=1,\ldots,N$
3. Repeat for t = $1,\ldots,T$

(a) Normalize the weights

(b) Get weak hypothesis

$$h = X \rightarrow \{-1, +1\},$$

with error $e_j = \sum_i \omega_i (|h_j(x_j) - y_t|)$

(c) Choose the classifier h_t , with the lowest error e_t

(d) weight update : = $\omega_{t+1,i} = \omega_{i,t}\ \beta_t^{1-e_t}$

where $e_i = 0$ if example x_i is classified correctly, $e_i = 1$ otherwise, and $\beta_t = \frac{e_t}{1-e_t}$

4. The final strong classifier is :

$$h(x) = \begin{cases} 1, & \sum_{t=1}^{T} \alpha_t h_t(x) \geq \frac{1}{2} \sum_{t=1}^{T} \alpha_t \\ -1, & otherwise \end{cases}$$

where $\alpha_t = \log \frac{1}{\beta_t}$ (3)

The anterior part of the training images represented the facial images and the posterior part represented the non-facial images. In the second stage, attempts were made to initialize the weighted value (w): (w) represented the importance of each training image. Thereafter, during the learning process, it played a role in determining which images were more important to learn.[21] The third stage was referred to as the stage during which a weak classifier was produced. A weak classifier selected only one characteristic with a minimal degree of error. In the current system however, after considering its efficiency and the provision for a critical error value, attempts were made to select multiple characteristics in a single stage. This was associated with the role that a strong classifier plays in systematical classification.[22] Besides, T represented the role signifying the stage. In (b), j represents the number of characteristics and it identifies a higher degree of the value as compared with the critical value while repeating to such an extent as j. The magnitude of error was divided into the positive cases and the negative cases. This was an attempt to reduce the rate of positive errors in the early stage of learning and negative errors in the latter stage of learning. In (d), the weighted value was updated. The training images which were incorrectly classified increased the weighted value of ω. The training images which were correctly classified decreased the weighted value of ω. In association with this, the characteristics which were selected in the early stage played a role in differentiating between facial and non-facial images. However, the characteristics which were selected in the latter stage played a role in differentiating between the facial and non-facial images.

2. Experiment

The current experiment was performed after a 2-Linked Arm was installed in a unit chair : which was subsequently occupied with human subjects (Fig. 8, 9). The main focus of the experiment was on the rate of facial recognition and the stability of light control when the faces of the subjects varied in shape. The experiment focused on face shape was performed using S/W on the facial data from approximately 100 faces.[23] For the light control stability experiment, the hypothesis that the intensity of illumination is the highest in cases where the illumination angle is a right angle between the illuminator and the oral cavity was assumed and the vertical angle formed between the midline of the maxillary anterior tooth and the center of LED lamp was measured for a comparison. The distance was determined to be 80cm which is an appropriate length of the illumination for dentists' treatment.

RESULTS

1. Experimental results

Through image processing technology for the frontal images, lateral images (less than 20°) and lateral images (less than 45°), following the experiment on the detection of facial images, the location of oral cavity could be detected (Fig. 10). The results were shown in Table I. In the frontal images and lateral images (less than 20°, 45°) where the detection possibility was the highest, the vertical angle was measured and then compared.

2. An analysis of the results

Following the facial region detection experiment it was found that: in cases where the angle formed between the target and the center of the LED deviated by more than 20° from the vertical there

Fig. 8. Unit chair with robotic light system

Fig. 9. Robotic light system field test

Fig. 10. Result pictures of the face detection : Following the experiment on the detection of facial images, the location of oral cavity could be detected.

was a discrepancy in the symmetry of the frontal learning image. The rate of recognition was 85% and this was lower than the frontal image. In cases where the face was tilted at an angle of 45° the rate of recognition was found to be 50%. The system developed through the current study recognized the facial region by priory learning from the frontal images. Therefore, a higher degree of frontal image discrepancy resulted in a lower recognition rate.

DISCUSSION

The Adaboost algorithm which was used herein is a statistical learning-based algorithm. In a learning-based algorithm, users should directly determine the learning sample data, parameter values and the kernel function during the learning process.[24] Accordingly, to reconstruct optimal functions, a variety of data should be used for a learning-based algorithm and the optimal experimental values should be selected. In the cases where an algorithm was used in the current study there was a higher degree of dependence on a learning-based model. As shown in the results, in the cases where a learning-based model was derived from the frontal view of the face and in those cases where an asymmetric facial image of greater than 45° was obtained, the rate of recognition was impaired. Actually in a clinical setting, to enhance the rate of recognition, learning should also be performed for the asymmetric lateral view as well as the frontal view. Thus, it would be necessary to arrange a recognition

Table. I. Result of the face detection experiment

	Frontal view	Lateral view (less than 20°)	Lateral view (less than 45°)
Total number	100	100	100
Success number	98	85	50
Probability	98%	85%	50%

algorithm in a row. In these cases, the velocity of real-time image processing could be problematic. In cases where the PC which has become currently commercially available, it would be unproblematic to operate using three types of learning models. However scanning is time consuming. Response time delay in the motion component which was operated by signal value reception was a problem which should be resolved. In cases where the light was illuminated to the visible area of patients and the actual difference was applied, in preparation for the incorrect operation due to the processing error of motor signals, by establishing the restricted scanning area, the operation range of robot illuminator for dental practice should be permitted.

To address the issue of cross-infection between patients a pedal-controlled illuminator unit has been developed and will become commercially available. Most of the treatment equipment such as hand pieces used in a unit chair is operated in a pedal-controlled manner. In some cases spatial recognition was inaccurate and this could impede medical treatment. The robot-assisted illuminator which was developed through the current study used an embedded control system. Thus, the problems with spatial confusion and the adjustment of the location of the illuminator could also be solved. During the procedure, there is no necessity that the intensity of illumination depending on the location of patients' oral cavity cannot be concerned. Therefore, the accuracy and efficiency of medical treatments can be enhanced. If the response time of the Multi-Link Motion Controller which is required for the calibration of coordinates could be improved, there would be no need to adjust the location of the illuminator and interrupt treatment. Thus, the procedure time could be reduced

As mentioned above, with the remarkable development of medical engineering in modern society, the robot system has been applied to state-of-the-art medical equipment. With the development of the robot-assisted surgical system (da Vinci TM operating robot), the robot has become a substitute for human labor.[1,2] The partially developed robotic technology developed in this study could be integrated into a dental unit chair and in conjunction with image-processing technology and voice-recognition technology enhance the efficiency of the dental practice.

CONCLUSIONS

In the current study, following the detection experiment on the oral cavity of patients through image-processing technology, it was found that there was a higher degree of facial recognition from the lateral view as well as the frontal view when a smaller angle of deviation existed from the ideal angle of 90°. Along the oral cavity which was recognized, light focus was found to be stably controlled. In cases of the lateral view of greater than 45° in angle, an operation of the algorithm which is arranged in a row by learning the lateral view, the application of actual difference would become possible.

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영상처리 기술을 이용한 치과용 로봇 조명장치의 개발

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본 연구에서는 영상처리 기술을 활용한 치과용 로봇 조명장치를 개발하여 그 정확도를 측정하여 보고자 한다. 본 연구를 통해 개발된 치과용 로봇 조명장치는 환자의 얼굴을 카메라로 인식을 하여 구강의 위치를 찾아 로봇이 움직여 라이트를 비추게 하는 것으로서 모션 제어 부, 라이트 제어 부, 영상 처리부로 구성되어 있다. 카메라로 영상을 획득 후 동작변화 영상을 추출 한 다음 아다부스트 알고리즘(Adaboost algorithm)을 통해, 얼굴 검출에 필요한 특징을 추출하여 실시간으로 얼굴 영역을 검출하도록 하였다.

영상처리를 통한 환자 구강의 추출 실험 시 정면영상에서 높은 얼굴인식률을 나타냈고 얼굴영역이 인식이 되면, 안정적인 라이트 로봇 암(Light robot arm)의 제어가 가능했다.

주요어: 자동화 시스템, 영상처리, 구강인식, 로봇, 치과용 조명장치.

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