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Optimization of the Dental Direct Digital Imaging by Applying the Self-Recognition Technology

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***Abstract*—**This paper is intended to introduce the technology to solve some of the deficiencies of the direct digital radiology. Nowadays, digital radiology is the latest progression in dental imaging, which has become an essential part of dentistry. There are two main parts of the direct digital radiology comprised of an intraoral X-ray machine and a sensor (digital image receptor). The dentists and the dental nurses experience afflictions during the taking image process by the direct digital X-ray machine. For instance, sometimes they need to readjust the sensor in the mouth of the patient to take the X-ray image again due to the low quality of that. Another problem is, the position of the sensor may move in the mouth of the patient and it triggers off an inappropriate image for the dentists. It means that it is a time-consuming process for dentists or dental nurses. On the other hand, taking several the X-ray images brings some problems for the patient such as being harmful to their health and feeling pain in their mouth due to the pressure of the sensor to the jaw. The author provides a technology to solve the above-mentioned issues that is called “Self-Recognition Direct Digital Radiology” (SDDR). This technology is based on the principle that the intraoral X-ray machine is capable to diagnose the location of the sensor in the mouth of the patient automatically. In addition, to solve the aforementioned problems, SDDR technology brings out fewer environmental impacts in comparison to the previous version.

***Keywords*—**Dental direct digital imaging, digital image receptor, digital x-ray machine, and environmental impacts.

I. Introduction

HUMAN is constantly exposed to different types of radiation from different sources such as natural sources, radioactive substances, solar rays, and X-ray machines which are used to take the images of the body’s organ. Radiation began to be used as a method of diagnosing and therapy from when Wilhelm Conrad Roentgen discovered it and called it X-ray [1]. X-ray has the ability to penetrate body tissues and provides an image of the patient’s internal organs, which plays a significant role in human health and life [2]. After a while, it was determined that it brings out negative impacts on the health, and interest in radiation protection was aroused when there were reports of cancers, amputations, and DNA damages [1]. X-ray is a type of electromagnetic radiation, which is ionizing radiation that is so energy-rich that can change the chemical composition of various substances and it can convert atoms into ions. Ionization occurs when the atom is supplied with such high energy that electrons can be provoked from the inner shells and leaves the atom [3], [4]. Ionizing radiation such as X-rays can damage cells and DNA molecules because it breaks down atoms and molecules. Although the cells can withstand most of the damages due to the repair system they have, there is a risk of cancer later in life [5]. Some studies estimate an X-ray diagnosis gives 1000 microsievert (μSv) as the risk of cancer is one in 10000 [6]. An effective dose is a term used to indicate how great the risk is with an X-ray diagnosing and has the unit millisievert (mSv). Since the dose from X-ray diagnosing in dentistry is low, they are stated in microsievert (mSv).

In today’s world, dental radiology has become a mainstay for diagnosing and treatment of the patient, which has undergone major changes recently due to electronic and computer science. Intraoral X-rays are used for instance to detect cavity, fracture, periodontitis, and tumor or tooth loss before they lead to major problems. X-ray carries a low risk in dental care; however, in any case, the benefit from X-ray diagnosis must be much greater than the risks. Dental diagnostics such as bitewing and panorama are the most common radiology techniques that are used in dentistry and it requires a high knowledge of X-ray physics and radiation biology. To take an intraoral X-ray image, the equipment namely an X-ray machine, a digital sensor or a film, and an object are needed. The dental X-ray passes through the teeth and it is received by a digital sensor or a film. It delivers a low radiation dose in comparison with other X-ray examinations. Through the panoramic X-ray, the entire mouth is imaged and it is equal to almost 10 intraoral X-rays. To protect the patients, there are several considerations as following:

1- Thyroid collar must be used.
2- Digital X-ray machine is placed as close as possible.
3- Old images must be investigated.
4- Right techniques must be applied.

As mentioned, the utilization of the radiation has increased in the dentistry to examine the patient and there is the risk of unnecessary radiation for both patients and treatment staff. Consequently, all the treatment staff needs to have the knowledge to protect themselves and patients from unnecessary rays.

A. Literature Review

Wilhelm Conrad Roentgen (1895) discovered a new kind of ray and presented his findings entitled “A Preliminary Communication of the New Kind of Ray”. He was the first scientist who introduced X-ray and he was awarded the first Nobel Prize in physics [7].

Friedrich Otto Walkhoff (1896) provided glass

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photographic plates during the X-ray process. He triumphed in decreasing the exposure time of taking extraoral radiographic images 30 to minutes [7].

Wilhelm Konig (1896) was the first person to use this technology for dental issues and he used the X-ray for his own mouth. The fillings of his teeth were visible in the images due to the good quality of the images. To achieve high-quality images, he employed a "focus tube" to penetrate more in the tissues and increased the concentration of X-rays [7].

William James Morton (1845-1920) reported the radiation burns and injuries caused by radiography during the X-ray process. He illustrated that the level of the injuries depends on the intensity of the X-rays as well [7].

Charles Edmund Kells (1865-1928) created the first film holder and he was the first dentist that utilized radiography in root canal therapy. He was also the first advocate of paralleling or right-angle techniques in making intraoral radiographic images [7].

William Herbert Rollins (1852-1929) designed an intraoral camera. He exposed his hand to a high x-ray dose and he was motivated to study in the radiation protection field. He encouraged other radiologists to use the smallest X-ray dose and he recommended them to use radiopaque glasses. This method is beneficial to cover other patients' organs by utilizing radiopaque materials [7].

II. METHODOLOGY

This invention is in the conceptual idea phase and the authors hope to have sponsor(s) to develop this idea. In this section included two general parts of this system are explained:

1- Study on the intraoral X-ray machine.
2- Study on the sensors.

To conduct the intraoral X-ray machine, the possible arrangements for the device members were discussed. It is significant to consider the size of the device to be fit for the different sizes of rooms. Another parameter to investigate was the material of the arms of the intraoral X-ray machine. Since the intraoral X-ray machine acts like a robot, it needs to tolerate the self-weight as static analysis and also to be able to deal with the dynamic movement without any errors and vibration in the joints [8]. The type of engines and gears that have been employed in the intraoral X-ray machine played a significant role as well. Since the motions of the intraoral X-ray machine is quite related to the engines and gears, the study on them is vital.

The location of the sensors was investigated according to the characteristics of the sensors and probable movement of the patients' heads. The probable risks of failure in the system were considered as much as possible. Different types of sensors were reviewed to select the most suitable one for this technology. The sensors were applied to the both intraoral X-ray machine and the holder of the receiver. The main idea is the intraoral X-ray machine recognizes the sensors which are attached to the holder automatically and even if the patients move their head, the intraoral X-ray machine can move automatically and find the exact place of that.

The intraoral X-ray machine delivers 2 main modes. Fig. 1 shows the first mode which is when the system is shut down. To avoid occupying the space of the room, when the dentist does not need the radiography device, it automatically shrinks toward the wall. As it is clear in Fig. 1, to prevent the probable damages for the head and lens of the intraoral X-ray machine, the head is turned downward to be in the same alignment of the wall.

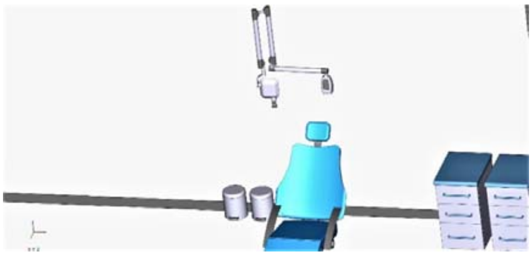

Fig. 1 Shut down mode of the intraoral X-ray machine

Upon the intraoral X-ray machine received any signal from the computer, it starts to move to the intended location as demonstrated by Fig. 2. The initial location of the head of the intraoral X-ray machine can be predefined by the operator based on the room size, patient's chair place, and probable patients' head situation. It can be different for different heights and body shapes of patients. Besides, there is a possibility to integrate the memory for this system to define the best position for each patient after the first visit.

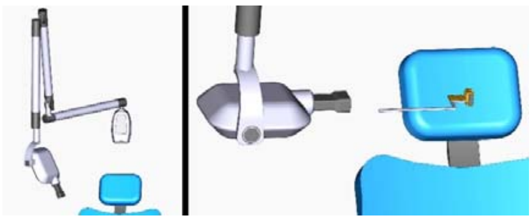

Fig. 2 Turn-On mode of the intraoral X-ray machine

To navigate the intentional point, the operator who is already trained selects the intended tooth/teeth utilizing a computer 3D software. Furthermore, the age of the patient can be effective in the recognition of the system due to the different sizes of jaws which are assessed by the system automatically. All the assessment and recognition for the navigating are approximate so far. Hereinafter, more details will be provided to clarify how the system can detect the exact position with the minimum error.

III. RESULTS

In this section, the details of the idea are expressed. It includes the sensor's package, holder's package, and the way that they cooperate.

A. Sensor's Package

The sensor's package comprises four VL53L1X sensors which are presented in Fig. 3. To obtain the highest accuracy and function of the sensors, they should connect to the electrical circuit with the minimum distance. After that, the data are transferred to the control circuit which is placed into the intraoral X-ray machine by wiring. The data transferring is performed after data analysis by a separate circuit which is installed in the sensor's package chamber.

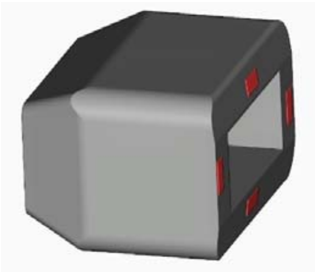

Fig. 3 Perspective view of the Sensor's Package

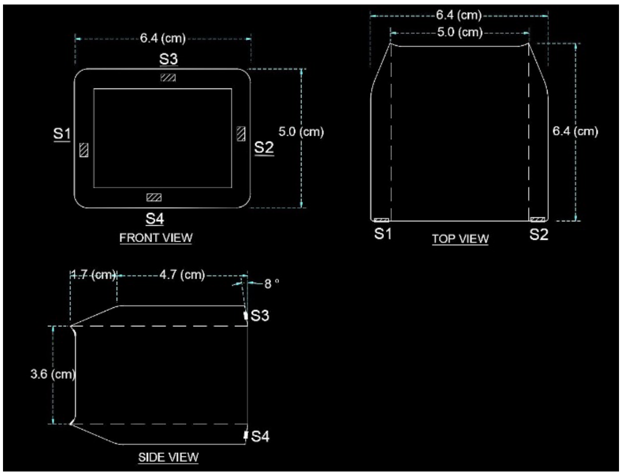

Fig. 4 Different views of the Sensor's Package

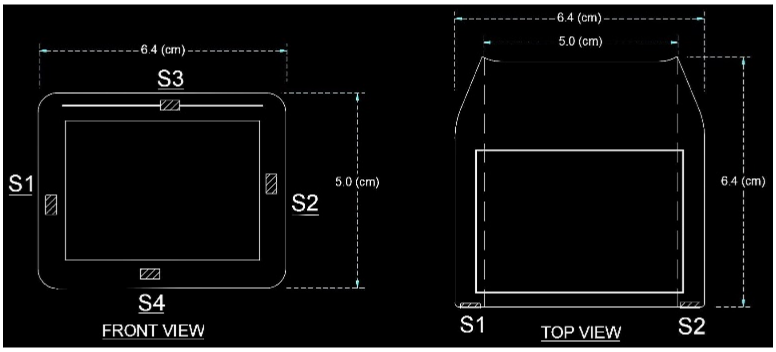

Fig. 5 Position of the circuit in the Sensor's Package

Fig. 4 shows the exact positions and dimensions of the sensors through 3 different views of the sensor's package. In this figure, S1, S2, S3, and S4 stand for sensors numbers 1, 2, 3, and 4 respectively.

The position of the circuit represents in Fig. 5 in the sensor's package. The rectangle and the highlighted line show the position of that in different aspects.

In front of the intraoral X-ray head, there is an intermediate part which can orientate the rays and prevent the scatter of them. Also, it can rotate within 360° to regulate the intended angle simultaneously. Figs. 6 and 7 illustrate the intermediate parts from perspective view and two-dimensional views.

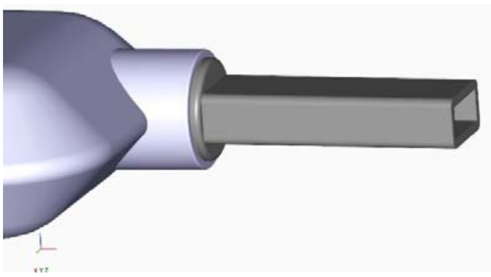

Fig. 6 Perspective view of the intermediate part

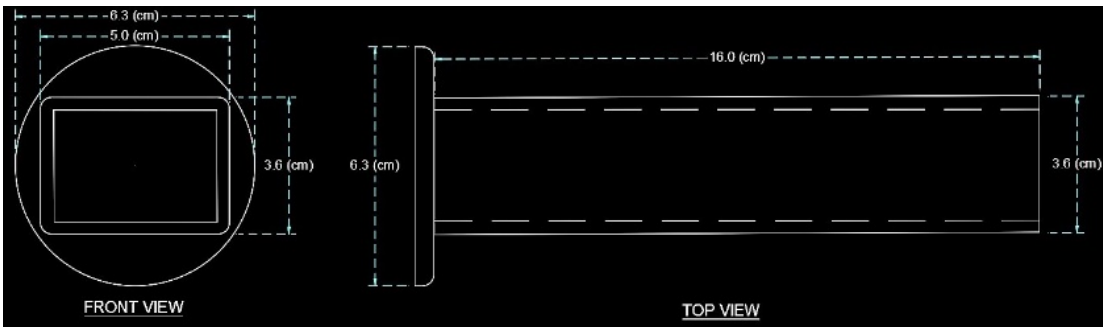

Fig. 7 Two-dimensional views of the intermediate part

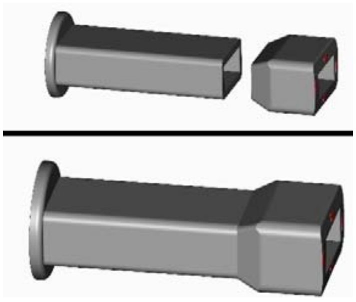

Fig. 8 Installation of Sensors' Package on the intermediate part, perspective view

The sensor's package is installed on the intermediate part as clearly represented by Figs. 8 and 9. Since it is fixed to the intermediate part, it has the ability of rotation as well as an intermediate part. Also, the installation of the sensor's package on the intermediate part provides more accurate results due to the lower distance to the holder's sensors.

The dimensions of the sensor's package and the intermediate part are determined corresponding to each other. Furthermore, there is the possibility to upgrade the excising radiography systems by integrating this sensors' package with the intraoral X-ray head. According to the traditional method of radiography, the rotation of the intermediate part is conducted by an operator to achieve the desired angle, while in the SDDR system the rotation is performed by a small stepper motor which is located at the bottom of the intermediate part automatically. The stepper motor is capable to execute highly tiny movement which provides a high level of accuracy in the motor. In other words, it is feasible to manage and implement the movement less than 1 mm with the help of this type of motor including creating the desired angle, laevorotatory movement, and dextrorotation movement with the highest level of precision. The wires which are used to transfer the data are very thin and they are not problematic for the rotation of the sensor's package. To upgrade the traditional radiography systems by the SDDR system, there is the possibility to design the requisite parts based on the sizes and requirements of the traditional systems.

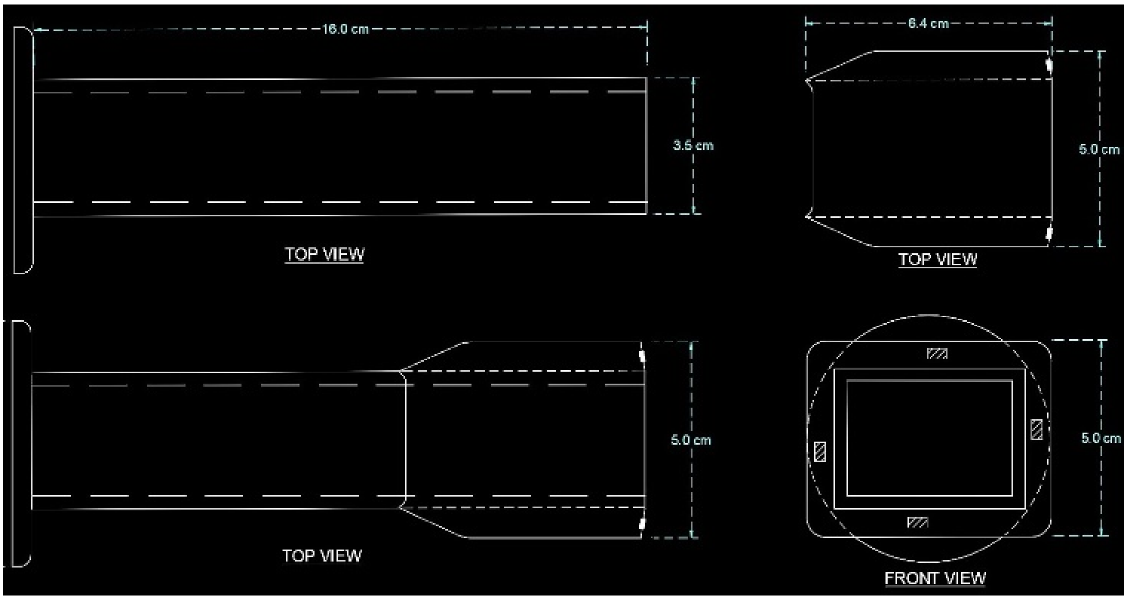

Fig. 9 Installation of Sensors' Package on the intermediate part, Two-dimensional view

The sensors can change the angles of frequency from 15° to 27°. If the distance of the system is high the sensor package will use the maximum value, while in case of lower distance it will employ the minimum value. By applying this strategy, one could utilize the highest efficiency and accuracy of the linear behaviour of the sensors.

It is also worth mentioning that, the angle of 8° is conducted on the sensors S3 and S4 to achieve the higher factor of safety regarding the Interference of the frequencies. This angle is also applied for the obstacles E3 and E4 which are mentioned later on in Fig. 15. Figs. 10 and 11 will provide the details of the 8° angle.

B. Holder's Package

The holder's package encompasses three main parts namely stand, L-bar, and receiver. The sensors are installed on the stand. The stand is connected to the L-bar with help of a screw which is adjustable for different positions as well. At the end of the L-bar, there is a plastic part that holds the receiver. The plastic part does not impair the final X-ray image due to its intrinsic characteristics and highly thin thickness. The receiver part is placed in the patient's mouth and if the patient moves his/her head the sensors which are installed on the stand part will move correspondingly. In this case, the intraoral X-ray machine will adjust itself to be in the right direction. Fig. 12

indicates all parts of the holder's package.

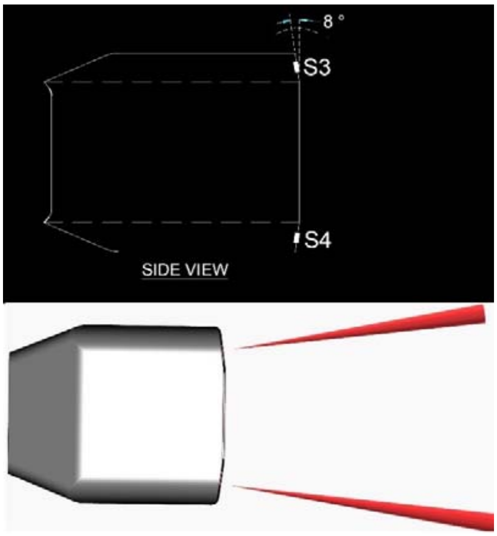

Fig. 10 Side view of the 8° angle for the sensors S3 and S4

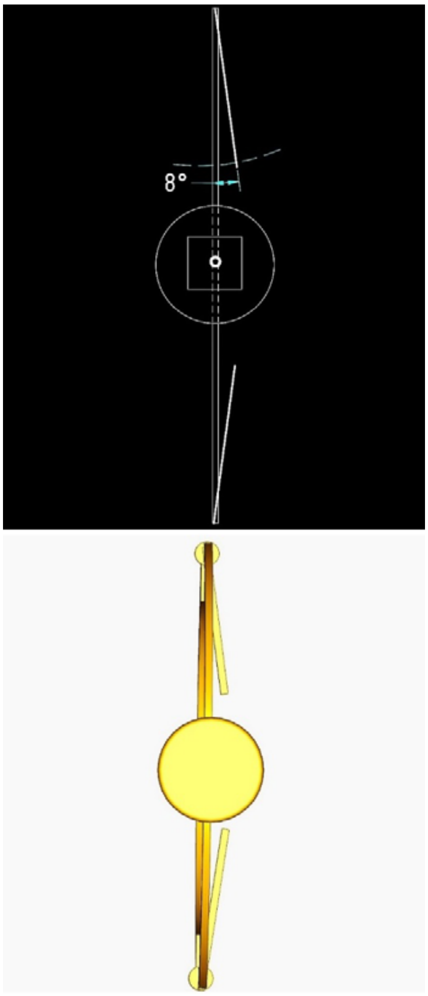

Fig. 11 Side view of the 8° angle for the obstacles of stand E3 and E4

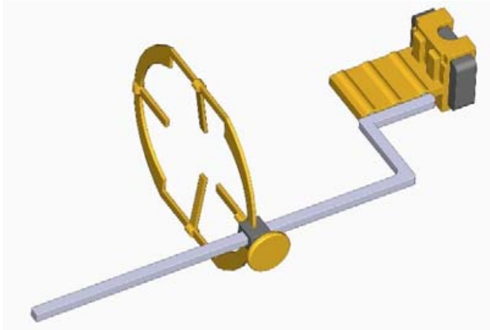

Fig. 12 Holder's package

The dimensions of the stand are designed based on the positions of the sensors in the sensors' package. Fig. 13 provides the two-dimensional view of the stand.

C. Contribution of the Sensors' Package and the Stand

In this project, four VL53L1X sensors are employed in the sensors' package which works with the laser. There are four obstacles on the stand and they can calculate the distance of four sensors to the stand simultaneously. This sensor operates with a high-speed frequency and it has a linear function having a narrow-angle. If there is one obstacle in the course of laser the frequency reflects the sensor and the delay time is sent to the sensor by the data. With the same method, when the laser hits the obstacle, it returns to the sensor and it can calculate the distance between the sensor and the obstacle with help of time and speed of the laser. There are four sensors in the sensors' package and four obstacles on the stand. All these sensors act at the same time and if one of the sensors does not receive the reflected signal, it means that the sensors' package is not in the right direction and angle with the stand. So, in this case, it tries to readjust the location of itself to achieve the alignment.

The frequency type is IR and it is quite safe for the eyes and other organs in the body. Also, there is no interference with four sensors when they are working simultaneously due to their specific location. It means that each reflection returns to the corresponding sensor without any interruption by other laser reflections. Fig. 14 shows the principle of the contribution of the sensors' package and the stand.

D. Functional Analysis

Fig. 15 demonstrates the positions of the sensors and obstacles in the two-dimensional views. Obstacles E1, E2, E3, and E4 are located in front of the sensors S1, S2, S3, and S4 respectively.

Sensors S1and S2 scan the position of obstacles E1 and E2 to assess the vertical balancing of the receiver and sensors S3 and S4 scan the position of obstacles E3 and E4 to investigate the horizontal balancing of the stand. Sensors S1 and S2 are not in the same alignment and there is a 0.3 mm difference between the location of them. The same strategy was applied with the sensors S3 and S4. The main reason for this arrangement is that sensor S1 is more susceptible to the lowermost edge of obstacle E1, sensor S2 is more responsive to the uppermost edge of obstacle E2, sensor S3 is more susceptible to the rightmost edge of obstacle E3 and sensor S4 is more responsive to the leftmost edge of obstacle E4.

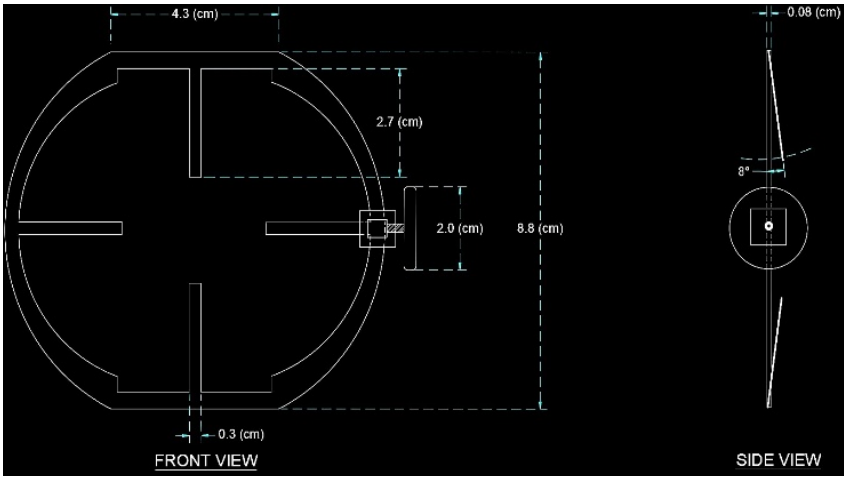

Fig. 13 Two-dimensional views of the stand

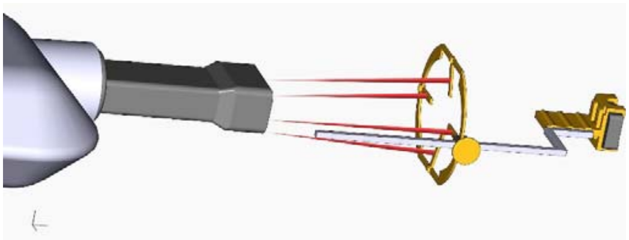

Fig. 14 Contribution of the Sensors' Package with the stand

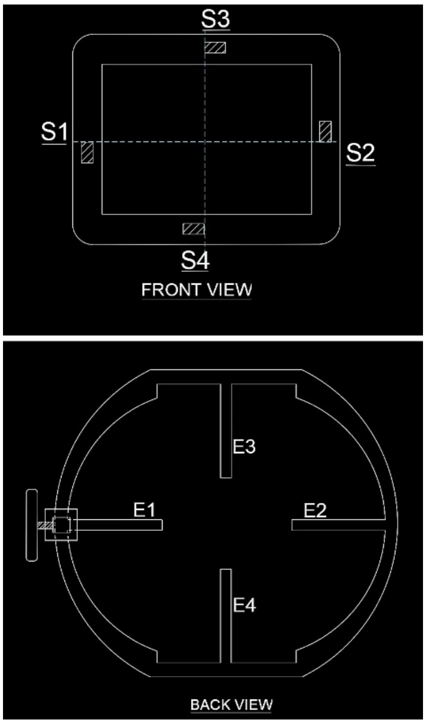

Fig. 15 Positions of the sensors and the obstacles

In general, the process of balancing the system performs in four main steps:

Step1: Recognition of Lack of Receiving Reflected Laser

It is considered that the initial position of the intraoral X-ray head is beside the patient. In the traditional system, some errors could happen by moving the head of the patient to result in an unacceptable X-ray image. The movement can be upward movement, downward movement, leftward movement, rightward movement, rotational leftward movement, rotational rightward movement, longitudinal forward movement, longitudinal backward movement, and radial movement. SDDR technology is capable to recognize all these movements and it will correct its location immediately after receiving the signals from the sensors. In the following, all these movements are discussed one by one.

Recognition of the Upward Movement

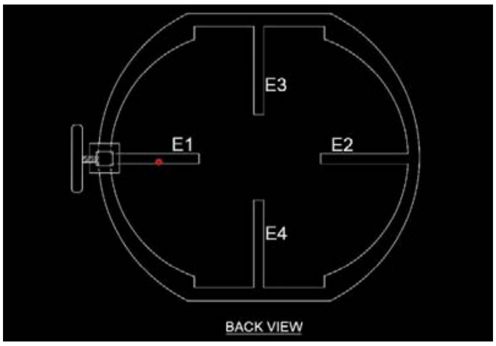

Fig. 16 Recognition of the upward movement

Sensor S1 is susceptible to the lowermost edge of obstacle E1 and if the obstacle is moved even by 1 mm toward the up, the system will recognize as an unacceptable adjustment to take the image. This movement can be by moving the head of the patient which triggers off moving the receiver. Fig. 16

illustrates the recognition of the upward movement.

Recognition of the Downward Movement

Sensor S2 is responsive to the uppermost edge of obstacle E2 and if the obstacle is moved even by 1 mm toward the down, the system will recognize as an unacceptable adjustment to take the image. Fig. 17 demonstrates the recognition of the downward movement.

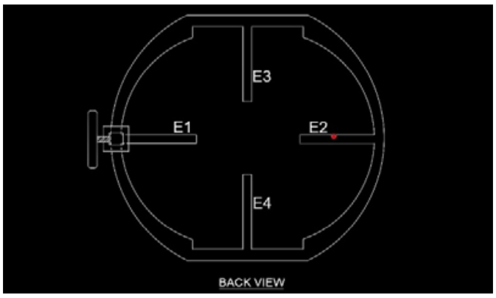

Fig. 17 Recognition of the downward movement

Recognition of the Leftward Movement

Sensor S3 is responsive to the rightmost edge of obstacle E3 and if the obstacle is moved even by 1 mm toward the left (from the patient's viewpoint), the system will recognize as an unacceptable adjustment to take the image. Fig. 18 provides the recognition of the leftward movement.

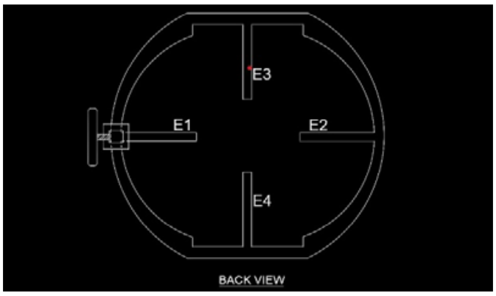

Fig. 18 Recognition of the leftward movement

Recognition of the Rightward Movement

Sensor S4 is responsive to the leftmost edge of obstacle E4 and if the obstacle is moved even by 1 mm toward the right (from the patient's viewpoint), the system will recognize as an unacceptable adjustment to take the image. Fig. 19 represents the recognition of the rightward movement.

Recognition of the Rotational Leftward Movement

As already mentioned, sensor S3 is responsive to the rightmost edge of obstacle E3 and sensor S4 is responsive to the leftmost edge of obstacle E4. If the receiver experienced a rotational movement toward the left, the reflectance of S3 and S4 are not at the same time. In this case, the system will recognize as an unacceptable adjustment to take the image. Fig. 20 shows the recognition of the rotational leftward movement.

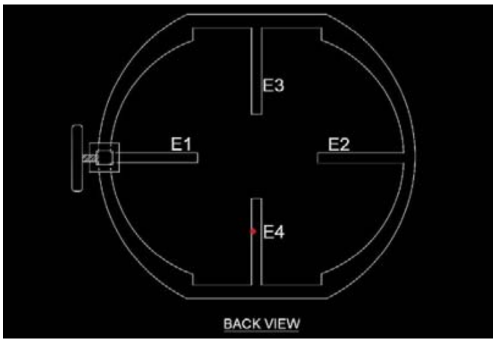

Fig. 19 Recognition of the rightward movement

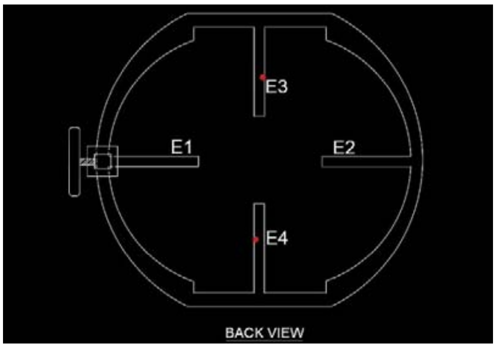

Fig. 20 Recognition of the rotational leftward movement

Recognition of the Rotational Rightward Movement

As already mentioned, sensor S1 is susceptible to the lowermost edge of obstacle E1 and sensor S2 is responsive to the uppermost edge of obstacle E2. If the receiver experienced a rotational movement toward the right, the reflectance of S1 and S2 are not at the same time. In this case, the system will recognize as an unacceptable adjustment to take the image. Fig. 21 demonstrates the recognition of the rotational leftward movement.

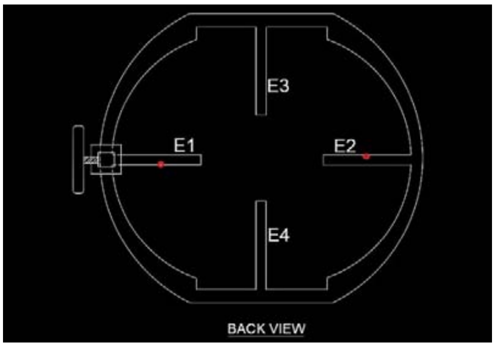

Fig. 21 Recognition of the rotational rightward movement

Recognition of the Longitudinal Forward Movement

This situation occurs when a patient moves his/her head forward. In this case, the sensors detect the changing in the distance (lower distance) between the sensors and obstacles and it means it is not the right time to capture the image. When the distance is constant for a while, the system captures the image immediately.

Recognition of the Longitudinal Backward Movement

Similar to the previous case, this situation is taken place when a patient moves his/her head backward. In this case, the sensors detect the changing in the distance (higher distance) between the sensors and obstacles and it means it is not the right time to capture the image. When the distance is constant for a while, the system captures the image immediately.

Recognition of the Radial Movement

This type of movement is the combination of two or more of the previous case simultaneously.

Step2: Sending the Recognition Signal to the Microcontroller

All the signals are sent to the microcontroller to perform the data analysis and make a decision for the correct reactions to adjust the intraoral X-ray head with the holder's package. The sensors send their signal to the microcontroller according to Table I. Value 1 means the sensor recognizes the obstacle, while value 0 means the sensor does not recognize the obstacle. Moreover, L refers to decreasing the distance and H stands for increasing the distance. The radial movement is created by a combination of the movements that are presented in Table I.

TABLE I
POSSIBLE MOVEMENTS FOR THE RECEIVER

Movement of the Receiver	S1	S2	S3	S4
Upward movement	0	1	1	1
Downward movement	1	0	1	1
Leftward movement	1	1	0	1
Rightward movement	1	1	1	0
Rotational leftward movement	1	1	0	0
Rotational rightward movement	0	0	1	1
Longitudinal forward movement	L	L	L	L
Longitudinal backward movement	H	H	H	H
Movement of patient's head to the right	L	H	*0*	0
Movement of patient's head to the left	H	L	0	0

To clarify the performance of the system based on Table I, let us consider an example. If the system is in an acceptable position, it should be reported position 1111. Whilst, if the report is altered to position 1011, the microcontroller understands that there is a downward movement. Then the SDDR system attempts to adjust itself to receive an acceptable signal.

Step 3: Sending a Signal to the Motors by the Microcontroller

In this step, the microcontroller sends a correction signal to the motors to shift to the new position for adjustment. This step continues until the microcontroller receives an 1111 signal from the sensors.

Step 4: Translocation of the Intraoral X-ray Head in Compliance with the Target Point

In the last stage, the intraoral X-ray head will move to achieve an acceptable position for capturing. This step is going on continuously as well to accomplish the correct position.

Another example is if the system received a signal like HL00+1100, it means that the receiver experienced a rotational leftward movement and movement of the patient's head to the left simultaneously. The SDDR system endeavors to readjust itself to achieve an acceptable position.

IV. Discussion

The advantages and disadvantages of this idea are presented in this section. There are several advantages of employing this system in the dental Clinique as following:

1- Nearly-zero probability of failure in taking X-ray image by SDDR technology in comparison with the traditional system which is performed by a dentist or a dental nurse. Since the number of failures are much lower (close to zero) in this technology, the negative health impacts of the X-ray are much lower.
2- Fewer environmental impacts of SDDR due to minimizing the failure of the X-ray process. In other words, the number of tries to capture an acceptable X-ray image is much lower and it means that the lower energy is consumed to run the system. The lower energy consumption, the lower is the environmental impact.
3- The SDDR technology is adaptable to the old radiology systems. In other words, there is a strong opportunity to upgrade all the old systems with this system without changing the old system entirely.
4- Since the number of failures are much lower (close to zero) in this technology, the treatment staff can save their time for something else.

Disadvantages: The only disadvantage of this system is the economic issues since more equipment such as sensors and motors for the arms need to be purchased. However, the advantages of this system are much higher and they strongly overcome this negligible disadvantage.

V. Conclusion

This study has investigated an invention which is named Self-Recognition Direct Digital Radiology (SDDR). This invention is performed by the authors of this research and all the rights are reserved for the authors. As the main conclusions of this study, we can point out that the SDDR technology provides a wide range of advantages as mentioned in the discussion section.

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