Robotics Using Artificial Intelligence in Dentistry

Shifa Syed[1], Tirth B Dalwadi[2] , Mohd Zaheen Khan[3*]

[1] Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India,
[2]Department of Computer Engineering, Jamia Millia Islamia, New Delhi, [3]India,
Department of Mechanical Engineering, IET, Lucknow, India,
*zhnkhan4@gmail.com

Abstract

AI is a next-generation technology that has already aided the medical field in achieving new frontiers. AI has given lives to machines that are now more capable than a surgeon to operate on a living being. The use of such living machines in Dentistry has enhanced the accuracy and precision of the treatments and has reduced the chances of errors. Robotics systems continue to support doctors in the medical field with assistance in the cardiac space, orthopedics, and neurosurgery. However, robotic systems have not as yet been altogether acquainted with dental research nor have they accomplished expense adequacy and innovative status to be completely fused into the dental market. In this paper, we will discuss Robotics & AI and their combined application in various fields of dentistry. We will also be discussing the AI technologies which are used to assist the dentist.

Keywords: Artificial Intelligence, Artificial Neural Network, Dentronics, Dental Robotics, Nanodentistry.

1. Introduction

The application of robots in the medical field has opened new boundaries with vast areas of exploration and expansion specifically in the dental field, but it has not been explored much to date. The idea of robotics was first applied in 1969. Even before the introduction of robotic surgery, laparoscopic surgery was performed with the help of small instruments and incisions. It was monitored using miniature cameras. Then with the innovation, robotic arms were introduced which were used to mimic the dexterity of a surgeon's hands and assisted them in dental surgery. Earlier X-rays were used to diagnose teeth that were not that efficient. Then an intra-oral scanner was invented that can be used to directly scan the mouth and have the inner view of the mouth on a screen. Then with time, 3-D printed models were used. Dental training robots were introduced in the dental study to help the students to get an experience of dentistry on human-like machines which proved much better than the earlier used mummies. Then with the

innovation, the first realistic humanlike robot was made and was named Showa Hanako which was capable of showing gestures and responses just like a human. But the inventors were not satisfied with this much. They wanted to make a robot that was much closer to humans and can be used for robotic surgery. And in this process to achieve efficiency many robots were created like Geminoid-F which could mimic human expression and could even laugh, and HRP-4 which was capable of singing too. But these results too were not sufficient enough to satisfy the scientists. So, with much hard work and with the help of evolving artificial intelligence techniques they made a robot that could undergo surgery, can show emotional human responses, and can even rate & evaluate the treatment procedures, named SIMROID.

2. Methods and Methodologies

2.1. Need for Robotics in dentistry

Next-generation technology is robotics. With the development of modern technology, robots are now used in every field of science. It aids in completing activities that are challenging for a dental clinician to complete. It made it possible to investigate and advance several dental fields in new ways. Because of their ability to do accurate work without overtiredness, it has even made its way into dentistry. The use of robotics in dentistry gives advantages over freehand techniques for placing instrumentation. These systems with navigational guidance, offers improved accuracy and precision in dental treatment even streamlined work processes and better workflows, resulting in a higher quality of maintenance.

2.2. Artificial Intelligence (AI)

AI is the branch of Computer Science that builds smart machines that are capable of performing human activities. It is an ability of a computer or computer-controlled robot to perform tasks of intelligent beings i.e., Humans. Robots using AI can now simulate human intellectual processes like sensing, navigating, learning from past experience (past data) and take decisions, and even can make decisions in vague situations which are too complicated for humans. Robots learn all these human processes using Machine Learning which is again a part of Artificial Intelligence. AI has given robots a computer vision to perform all these human tasks more efficiently as compared to humans [1].

2.3. Use of Data Mining in robotics

Robotics is all about data. Data is the invaluable treasure of knowledge and insights which can be processed using ML to extract important information. In the medical field, it can be used to diagnose the health condition of patients. Robots deal with a large amount of data to perform specific tasks - from collecting data to generating important results (internal data) from them. Data is available in many different forms. So, managing and dealing with all this data is an important issue. All these processes from collecting to cleaning the data and generating meaningful responses and predictions from them are termed Data Mining. Figure 1. represents the complete data mining process. Data mining is considered to be a super-influential phenomenon in the field of science. Once, data

mining was used to analyze the direct cause of extraction and was done on a large number of medical records. The study concluded that the direct causes of teeth removal were dental caries (43.8%),fractures (6.8%), prostheses (4.3%), impaction (3.1%), orthodontics (2.7%), periodontal diseases (37.2%), and deciduous teeth (0.3%).

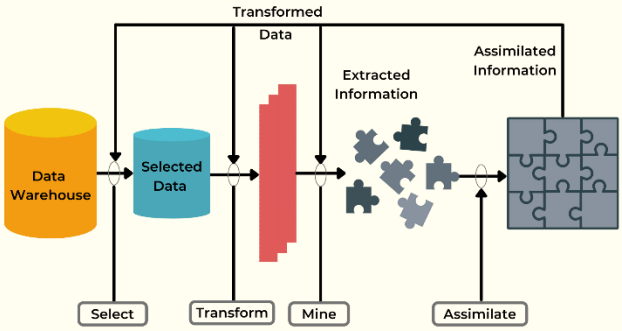

Figure 1. Depicts the flow of data from the source to the predictors passing through all data mining steps

2.4. AI Methodologies

Methodologies are the contextual framework of a research i.e., a body of rules or methods that is used to analyze the techniques and methods used by the researchers to solve a particular problem rather than the whole program. AI methodologies used in dentistry have immense capabilities to detect and diagnose even the small defects in the human mouth(teeth) that a normal human eye can't even notice. Various AI methodologies are being used in dentistry [2-3]. Some of which are Artificial Neural Networks (ANN), Genetic Algorithms (GA), and Fuzzy Logic (FL). In the next part, we will discuss these methodologies in-depth and their application too.

2.5. Artificial Neural Networks (ANNs)

In order to comprehend and make decisions similarly to a human, ANN models the networks of neurons seen in the human brain. Artificial neurons, a mathematical model based on networks of human neurons, are the main elements of ANN. A network made up of these layers of artificial neurons is put together and integrated to accomplish specific tasks like image classification (e.g., locating canals during RCT, a radiographic image showing a decayed tooth). Learning is used by ANN.

In a study by Kim et al. [2], ANN was employed to develop a model to anticipate toothaches based on their relationship to daily brushing frequency and time, toothbrush replacement pattern, and many other aspects like daily food and exercise. A highly accurate toothache prediction model was created with the help of all the data gathered for the aforementioned parameters and ANN. It came to the conclusion that maintaining

good oral hygiene, eating a healthy diet, and managing stress are key elements in reducing toothaches.

2.6. Genetic Algorithm (GA)

An adaptable algorithm that is inspired by Charles Darwin's idea of natural selection is known as a genetic algorithm and is a subset of evolutionary algorithms. The concept of "Survival of the Fittest" is at the core of the genetic algorithm, a stochastic search technique. The genetic algorithm mimics the process of natural selection, in which only those species that can adapt to environmental changes can endure and pass on to the following generation. GA is utilised to produce excellent answers to search and optimization issues. Although it is a strong optimization tool, it is simple to use and may be put into practise [4].

2.7. Fuzzy Logic (FL)

Fuzzy logic Figure 2. was introduced by **Lotfi Zadeh** in 1965. In our daily life, we come across many vague problems, finding solutions to which humans fail. Fuzzy Logic comes useful in such situations for the reasoning of fuzzy problems. The FL forms the basis of AI by allowing the use of more advanced decision-tree processing and better integration with rules-based programming. The FL imitates the decision-making process of humans which involves intermediate possibilities between digital values YES and NO. It produces acceptable solutions to incomplete and ambiguous problems [1, 2].

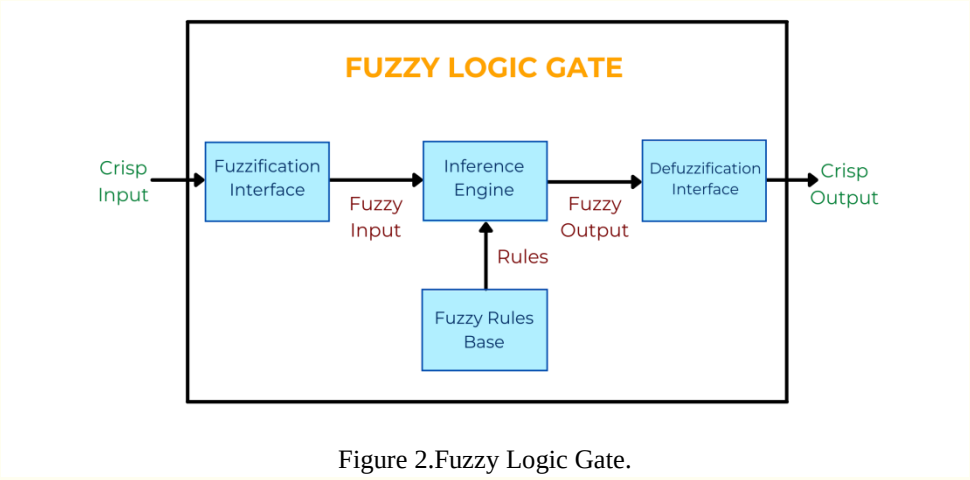

Figure 2.Fuzzy Logic Gate.

3. Literature Review

3.1 Application of AI in Dentistry

3.1.1 AI and Orthodontics

It has always been a matter of dilemma for orthodontists during a treatment to decide whether to extract the teeth or not. With the innovation in the field of AI and ML, we

expect the development of systems that can assist orthodontists to practice efficiently and improve the quality of decisions & care. Here, AI comes into play. AI-driven customized orthodontic treatment is the recent revolution in the field of orthodontics. This led to the development of several decision support systems which reduced the subjectivity of decision making and the dilemma. ANN(s) have been used to develop such a support system to help orthodontists and it has proved to be successful at predicting the extraction decision. AI is used in different periods of orthodontics from diagnosis to treatment planning and extraction decision. 3-D scans & virtual models are used to assess dental and craniofacial abnormalities. With the help of the 3-D scans, aligners are printed, and afterward, the treatment is customized. Here the Data algorithm helps intelligently to decide how to remove the teeth/tooth, the exact point of application of pressure, and how much pressure should be applied. The AI-driven treatment enhances the efficiency of the treatment and reduces the time and chances of error in treatment [5].

3.1.2 AI and Endodontics

The diagnosis, treatment, and prevention of any illness in the dental pulp and lateral tissues is known as endodontics. The procedure known as root canal therapy involves removing the damaged dental pulp and replacing it with filling material. The use of AI's ANNs in the field of endodontics has been demonstrated, and they have aided in the study of the anatomy of the root canal system, the detection of periapical lesions and root fractures, the prediction of the viability of dental pulp stem cells, and the efficacy of treatment methods. In endodontics, AI has aided in the attainment of accuracy and precision in disease detection, assessment, and prediction. The advancement of endodontics is a result of better diagnosis and treatment.

3.1.3 Benefits of AI

- AI technology can help doctors in making better data-driven decisions.
- AI helps in increasing disease diagnosis efficiency.
- AI eases research and development by introducing *insilico* experimentation options.
- AI has the potential to make healthcare more participatory by increasing the time for interaction between patients and the doctor**.**

3.1.4 Challenges to AI

We realize that the use of AI in medical services plays an extremely encouraging part however difficulties both in technical and ethical aspects exist all over the place. Artificial intelligence-based frameworks are machine-based and constrained by computer researchers with no clinical preparation which can cause limitations in the advancement of AI application in healthcare delivery. Artificial intelligence additionally can't supplant Contemporary healthcare delivery models whose functioning relies upon clinician abilities and patient-doctor communication. Using robots as assistants have likewise made different issues in medical services. Dental professionals are hesitant to

acknowledge AI-based innovations. A better idea would be a model which obliges both AI and human components so that thedata collection process and classification turns out to be simple and simultaneously safeguard the human aspects of clinical consideration.

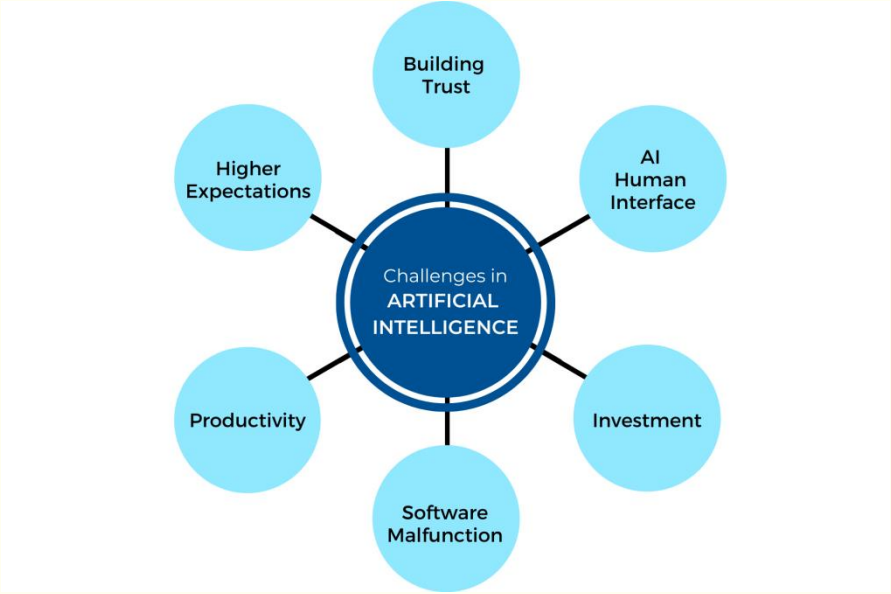

Figure 3 Challenges to AI

3.1.5. Robotics in navigational surgery

Progressions in technology and computer science have led to growth in the use of robotics in navigational surgery for multiple medical specialties. Similar revolutionary technologies are now being introduced into the dental industry that can assist practitioners with a different variety of procedures, similar to the growth of the da Vinci surgical system in the early 2000s to more advanced Artificial Intelligence (AI) techniques in use today [5]. By employing nanomaterials, nanorobots, and the engineering of novel diagnostic and healing modalities, robotics-assisted dentistry has progressed beyond conventional navigational surgery to more complicated systems that will be crucial in maintaining oral health and removing oral lesions. Robotics systems are already being employed in dental procedures and helping practitioners with implant therapy, even though these therapeutic interventions change our current ideas and understanding of the world.

3.1.6. Nano dentistry

Nanotechnology is used in nano dentistry to diagnose, treat, and prevent disorders of the mouth and teeth. It makes treatment options in periodontics, orthodontics, and restorative dentistry possible. Nanorobotics can be utilised in restorative dentistry for cavity preparation, restoration, and dental re-naturalization. The use of nanostructured

components is done to maintain and enhance oral health. Faster, more precise, more accurate diagnosis is made possible by nanotechnology in dentistry. It gives dental materials improved qualities, which improve their superior treatment capabilities and increase the material's tensile strength. It provides superior hardness and increased flexural strength.Due to their size, nanobots work at the atomic, cellular, and molecular levels to perform major tasks and can help dentists in managing complicated cases at the microscopic level with ease and precision. Nanotechnology can also aid in bone replacementand antibiotic delivery via nanoencapsulation while offering continuous oral health maintenance using dental robots to destroy pathogenic bacteria found in plaque biofilms. Additionally, nano dentistry can offer alternative techniques to induce anesthesia and manipulate tissue to aid in managing complicated restorative and periodontal treatments [6]

3.2. Application of Dental Robotics

3.2.1. Dental Patient Robots

For clinical training of dentists and dental students, and to advance their clinical skills and practice in patients, dental patient robots have been designed to mimic real-life treatment situations. They are popularly known as “Phantoms”. Mostly used dental patient robots are:

3.2.2. Showa Hanako

With aid from the robotics firm Tmsuk, Showa University produces Showa Hanako in Tokyo, Japan. Hanako is made to mimic a range of patient actions and reactions, including blinking, coughing, sneezing, moving its tongue, shaking its head, rolling its eyes, and even becoming tired from having its mouth open for an extended period of time. This gives dental students a realistic experience treating real patients. Additionally, the robot has the ability to mimic a gag response, which happens rather frequently during dental treatments. The speech recognition technology, created by Japanese engineers to enable conversational functionality, is also now available [7].

Figure 4. Showa Hanako

3.2.3. Geminoid DK

Professor Hiroshi Ishiguro of Osaka University and his associates at the Advanced Telecommunications Research Institute International in Japan created the Geminoid DK. It is an exact duplicate of Aalborg University's Henrik Scharfe, a Danish professor. It is a robot equipped with cutting-edge motion-capture technology that can accurately replicate head movements and simulate human facial emotions. The robot is the first in a line of characters with non-Japanese personalities. The device, according to its creator, is meant to advance philosophy and android science in the pursuit of basic solutions [7-9].

Figure 5. Geminoid DK

3.2.4. Simroid

Simroid was created at The Nippon Dental University Kokoro in collaboration with the manufacturer of dental equipment Morita Manufacturing. It is a realistic dental training robot for dentists that focuses more on the student's attitude toward the patients than the technique when performing a procedure. It is an improvement over the Simroid robot, a less advanced dental training robot created in 2007. Simroid, according to its creators, is a next generation dental patient simulator created to give dentists and dental students in training more emotional feedback. The interesting thing about this robot is that advancements in robotics and artificial intelligence make it react more lifelike and give emotional responsesjust like a real patient. Sensors are being fixed in and around its mouth that allows the robot to feel simulated pain and discomfort which the robot can express by gestures making students more conscious of their techniques. A new variety artificial skin has been used instead of Silicone, which used to get torn easily when the robot had to open its mouth wide. Simroid is now equipped with far better speech recognition capabilities allowing it to respond and react to questions or commands [7].

Figure 6. Simroid

3.2.5. Endo Micro Robots

Endo Micro Robots were created to enhance endodontic treatment's precision and effectiveness and provide top-notch root canal therapy. The endo micro robot accomplishes autonomous drilling, cleaning, shape, and three-dimensional filling of the root canal system with the aid of cutting-edge computer-assisted endodontic technology through online supervision and an intelligent system. It gives precise treatment with error-free outcomes, causing the dentist less discomfort and anxiety. Micro position and orientation adjustment equipment, a travel distance controller, microsensors, an automatic feed rate, and apex sensors with flexible drill and vacuum attachments are all components of an endo-micro robot [10].

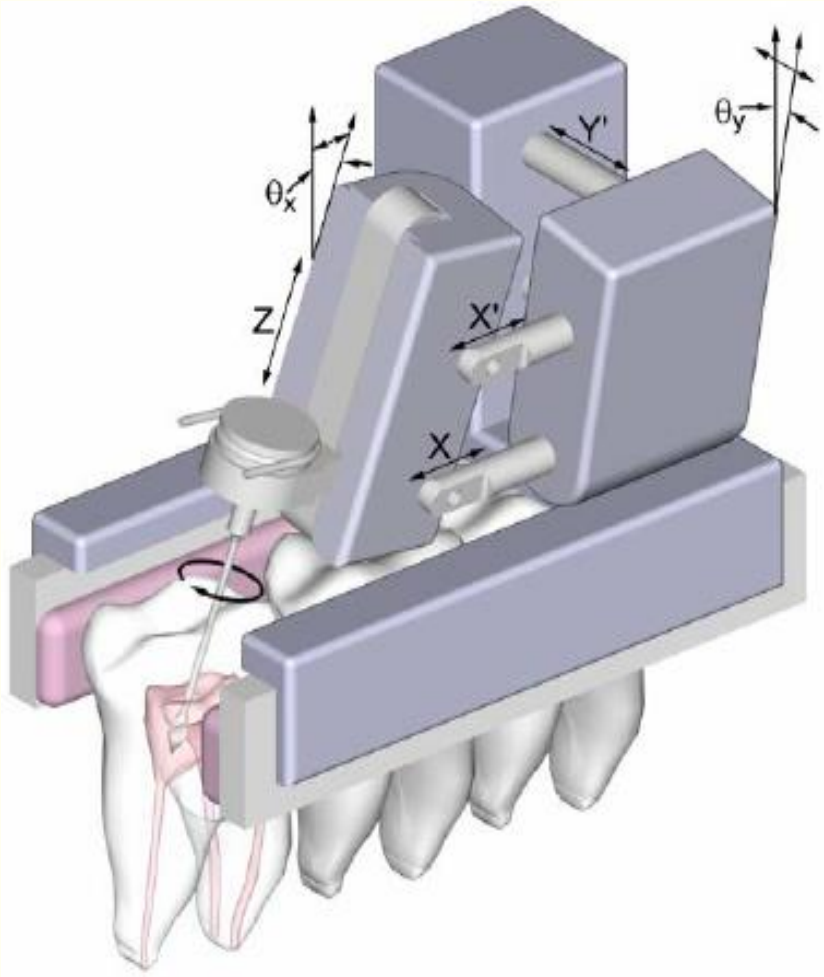

Figure 7. Endo Micro Robot

3.2.6. Dental Nanorobots

Nanomaterials, which are measured in nanometers, are the building blocks of nanorobots. These nanotechnology-based robots can be utilised for tooth repair, local drug delivery, dentin hypersensitivity, single-visit orthodontic realignment, endodontic and conservative dentistry, cavity preparation and restoration, local anaesthetic, and dental robotics. The nanoscopic dental robots offer quick and accurate care [1].

Figure 8. Dental Nanorobot

3.2.7. Surgical Robots

Application of robotics in oral and maxillofacial surgery, where the surgeon programs the robot at the time of surgery after which the robot performs pre-programmed tasks in the operation theatre such as osteotomy cuts, milling, and drilling of bones,selecting and positioning of plates,surgical planning etc and also interacts with the surgeon [10].

Figure 9. Surgical Robot

3.2.8. Dental Implantology Robots

The latest system of computer-assisted surgery for guided implant settlement is accomplished by getting a 3-D built model that resembles the patient's jaw formed from cone-beam CT imaging data. The robot is then executed to drill a jaw splint at the site assigned by a software planning system that forms a surgical guide [10].

Figure 10. Dental Implantology Robot

3.2.9. Robotic Dental Drill

Recent advancements were designed by tactile technologies. In which very thin needles us used and pierced into the gum to find the site of the alveolar bone in a restrained patient's jaw, which is then transmitted wirelessly to a PC and amalgamated with CT scan data that gives a set of drills guides.

3.2.10. Tooth–Arrangement Robots

A single manipulator robotic system is used for the fabrication of whole denture prosthesis via 6 DOF (Degree of Freedom) CRS robots manufactured in Canada. They are commonly used in the field of prosthetic dentistry. A 3-D virtual tooth plan programming software commences the whole procedure.

3.2.11. Orthodontic Arch Wire Bending Robots

This robotic technology is used for bending orthodontic archwires to a precise shape automatically. The bending equipment is known as SureSmileArchWire bending robot. It consists of a resistive heating system and gripping apparatuses combined with the application of 3D imaging, CAD/ CAM, and arranging and execution works out in a good way, and those completed insufficiently by the unpractised and clueless staff bring about terrible outcomes. Thus, the outcomes would just be pretty much as great as the workforce updating the data into the robotic system**.**

4. Limitations of Robotic dentistry

At whatever point another innovation is presented in a setup, it is exposed to a few impediments of differing nature. One such deterrent is that mechanical improvements in clinical/dental applications are amazingly costly. Additionally, robotic systems are complex and require the ability for their legitimate activity. In addition, another crucial perspective may be the obscure patient acceptance and consistency among dentists. The input of data is very critical. As of now, in dentistry, we see two fundamental aspects— Those cautious preoperative dentists that positively impact the field of dentistry. However, compared to their counterparts in the medical field, dentists have been slow to adopt this new technology. The realization that new and emerging technological innovations may provide alternative treatments to patients while enhancing workflow, increasing production, and improving the quality of care is on the horizon. Considering that the overall goal in dental care is to provide optimal patient treatment, it is worth reviewing these applications and their potential to increase the quality of dental care. Robotics and AI techniques can provide dental practitioners with valuable

5. Conclusions

Dentistry is gaining ground toward another universe of robot-assisted and data-driven medication. However, robotic systems have not as yet been altogether acquainted with dental research nor have they accomplished expense adequacy and innovative status to be completely fused into the dental market. Undoubtedly, various possibilities for the future exist where dentistry and robotics merge. Considering that the overall goal in dental care is to provide optimal patient treatment, it is worth reviewing these applications and their potential to increase the quality of dental care. Robotics systems continue to support doctors in the medical field with assistance in the cardiac space, orthopedics, and neurosurgery. Robotics, microrobots, and nanotechnology have the potential to support computers for the fabrication of orthodontic appliances.

7. Conflict of Interest

There is no conflict of interest in this work.

References

[1]. Roy P, Vivekanand L, Singh GP. Artificial Intelligence in Dentistry and Its Future. GSC Advanced Research and Reviews.2021; 7(1):082-086.

[2]. Tandon D et al. Present and future of artificial intelligence in dentistry J Oral Biol Craniofac Res. 2020; 10(4):391-396.

[3]. Bhat, B.D.; Bhandary, S.; Naik, R.; Shetty, D. Robotics in dentistry: Fiction or reality. J. Dent. Res. Rev. 2017;4:67

[4]. Habib, S., & Umer, F. Artificial intelligence applications in restorative dentistry: A systematic review. The Journal of Prosthetic Dentistry.2022; 127(1): 196-197.

[5] Vilas Bansod A, Pisulkar S. Artificial Intelligence & Its Contemporary Applications in Dentistry. Turkish Journal of Computer and Mathematics Education. 2021; 12(6).

[6] Alicia Webb,R. 2022. Innovations in dentistry: Navigational surgery, robotics, and nanotechnology. Dentistryiq.com [Accessed: 2022-07-05]

[7] Rawtiya M, Verma K, Sethi P and Loomba K. Application of Robotics in Dentistry. Indian Journal of Dental Advancements.2014; 6940:1696-1702.

[8] Hassani H, Amiri Andi P, Ghodsi A , Norouzi K , Komendantova N, Unger S. Shaping the Future of Smart Dentistry: From Artificial Intelligence (AI) to Intelligence Augmentation (IA).IOT. 2021; 2: 510–523.

[9]. Fatima M, Sherwani NUK, Khan MZ. Assessing and predicting operation variables for doctor employing industry 4.0 in health care industry using an adaptive neuro-fuzzy inference system(ANFIS).2022;3:286-295.

[10] Kumar PY, Dixit P, Kalaivani V, et al. Future advances in robotic dentistry. J Dent Health Oral DisordTher. 2017; 7 (3):278-280.