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Radiation Dose Optimization in CT Scans: A Machine Learning Perspective

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Annotation: Computed tomography (CT) is a widely used diagnostic imaging technique, but concerns over excessive radiation exposure have driven the need for dose optimization. Despite advancements, existing methods struggle to balance image quality with radiation dose reduction. This study addresses this gap by employing machine learning models to predict and optimize radiation dose levels based on empirical dosimetry data. Five machine learning algorithms, including logistic regression and ensemble learning techniques, were trained on patient-specific imaging parameters to estimate optimal dose levels. Findings indicate that machine learning models significantly enhance dose prediction accuracy while maintaining diagnostic image quality. The results highlight the potential of AI-driven strategies to reduce radiation risks in CT imaging and improve clinical decision-making. This research underscores the necessity of integrating intelligent dose optimization systems into routine radiology practice for safer and more efficient patient care.

Keywords: Computed tomography, radiation dose optimization, machine learning, AI in healthcare, diagnostic imaging, radiology safety.

1. Introduction to CT Scans and Radiation Dose Optimization

Computed Tomography (CT) is widely used in clinics. Since a CT scan is a high-cost test that involves exposing the patient to radiation, it is crucial that the scan is well planned. Scans should be acquired over the shortest distance possible to detect a lesion or artery, regardless of the body region examined. To guarantee a precise scan range, scout scans are performed. In CT thoracic tests, overscanning is typically observed, where the scan is much wider than that of the patient, extending longitudinally over the shoulders or the pelvis. To reduce this problem, a deep learning technique is proposed to automate the selection of the z-scan coverage range [1].

In works related to the radiologic field, numerous examinations of radiologic dosimetry can be found. However, a novel approach is presented that investigates diverse machines and models that aim to forecast the radiation level that would be delivered by a scanner for a certain examination. Uniting the two largest public datasets found on radiation dose estimates from diverse scanners and incorporating an additional more restricted dataset of detailed dosage aspects from a GE scanner. Extensive experiments and model evaluation are produced to establish how to achieve the best results. The work is extended by forecasting the image noise/reactivity index metrics. In the comparison of techniques and models, widespread and open-source datasets are provided for such research, and primary ML models data has been made public [2].

1.1. Overview of Computed Tomography (CT) Scans

The X-ray computed tomography modality, also known as the CT scan, has been one of the most business-critical technologies in the field of diagnostic imaging over the past four decades. In the last few years, its strike when earlier international tender was called to one of the two empty buildings in a public hospital, planned to be rented out as an external medical imaging center. However, looking at the hospital and CT scan purchase quantities of the same five classmates who were accepted that day, the rental could be unnecessary. On the day this facility started operating, it made a significant profit. Not only did the institution recover the cost of the device in less than three years, but it also continued its existence as a public hospital for the benefit of public health. This unexpected financial return of the CT investment has increased the historical demand for this equipment within the country. In the late 1980s, multi-slice technologies were introduced, and in various academic and research hospitals, a significant accumulation of information on CT was started to be established. The utilization of CT scanners across the globe is increasing, with upwards of 100 million procedures each year in the USA exclusively, which explains 53.5% of the total radiation dose caused by medical X-rays [1]. It is without question that the administrators of these buildings had trouble deciding exactly how much they would rent this situation. To make the right choice in case more than one competitor has higher points and more technical specifications, it is useful to know details about how the CT scan operates and its aspects of dose reduction. All of this information is directly related to the new research area and it will open new doors in both business and market. [3][4]

2. The Importance of Radiation Dose Optimization in CT Scans

Computed tomography (CT) is a widely used diagnostic imaging technique that is considered to provide excellent image quality, yet raises concerns about radiation exposure and cancer risk. Despite the advantages of CT in healthcare services, concerns about unoptimized protocols delivering high radiation doses to patients remain. In the last few years, the needs for better dose optimization or even further dose reduction are expected. To restore the balance between image noise and radiation dose in CT imaging, the introduction of iterative image reconstruction and other low-dose techniques has become a de facto standard. In this regard, novel strategies focusing on artificial intelligence (AI) tools have been actively developed in the context of CT image optimization. The importance of radiation dose optimization in scanned patients has been recognized, and a lot of works have been done and published in the literature. However, very few works are available in the scientific literature from a machine learning perspective [2]. Therefore, this work highlights the importance of radiation dose optimization in CT scanned patients and contributes to the literature by applying several machine learning techniques to predict the estimated radiation dose for a scanned patient. Typically, within a CT scan, most malignancies are induced by unnecessary dose to the healthy tissues or unnecessary follow-up as well as unnecessary intervention in incidental findings. For this reason, very great care must be given to make sure that the benefit of the potential scan is a lot more than this radiation dose to the patient [1].

2.1. Benefits of Lowering Radiation Dose

Radiation dose optimization is a critical aspect of the best use of computed tomography (CT) tests. Numerous efforts have been made to maintain or reduce radiation dose, as well as to create awareness of appropriate requests for such tests. In this work, the optimization and training of machine learning (ML) models are presented and applied with the aim of keeping radiation dose at an acceptable level. The first, a metric formed by the interquartile range of the CT numbers, is employed during the training pattern of the ML models and provides results that alternative to or go beyond those of other attenuation-based ideas. Secondly, the study process is examined with and without the application of ML models for different image acquisition locations (500 in 250-pitch and 300 in 150-pitch) to further analyze certain of the influences of the training models and the image processing procedures. Findings obtained from the different metrics, currently being tested and satisfied by radiologists, are employed to seek validation, resulting in a more robust analysis [2].

The use of advanced technologies in medical imaging for diagnosis and patient treatment has been growing in recent years. Medical imaging techniques, such as CT tests and radiation therapy, are some of the outstanding innovations being used today. These kinds of techniques supply beneficial information related to patient disease through the captured anatomical and physiological images of different body structures. Among medical imaging techniques, there CT test stands out above rest. This imaging technique provides high-quality cross-sectional images and is extensively used in clinical routine. However, one of the significant concerns of using this imaging technique is related to radiation dose. High amounts of radiation applied during this imaging technique may raise cancer risk. Thus, reducing radiation dose without sacrificing the target is an essential challenge. Furthermore, the work presents a Machine Learning (ML)-based method to predict the dose level of the scan to be taken before performing the CT tests. The prediction of dose level is essential for getting cross-sectional images at the required scan time without radiation-risk exposure [1]. [5][6]

3. Machine Learning Applications in Healthcare

Recently, the application of Machine Learning (ML) to radiological dosimetry has experienced substantial growth. This method combines the existing methods of calculating the radiological dose. CT devices require a high dose to achieve an acceptable signal-to-noise ratio, and there is much controversy concerning the dose received by the patient's tissues. On the one hand, incorrect exposure can lead to overuse with the consequent burden to the healthcare system and possible cancer formation. On the other hand, low exposure can produce undesired diagnostic causes of the incorrect reconstruction of structures. In this way, healthcare professionals and the CT equipment manufacturer try to reproduce the dose proposed by a reference database to guarantee the correct diagnosis and take care of the health. There has been a recent increase in the minimum allowable dose, and although without prejudice to the image, it has reduced other task utilities such as the reclassification of solid tissues, chemical analysis or other possible uses. Research has shown that there is a direct relationship between radiation dose and risk of cancer. A notable example is computer tomography (CT) which uses ionizing radiation to obtain the medical image. However, it is necessary to take special care with this type of revision due to the higher radiation dose received by the patient compared to simple radiography. CT devices require a high dose to increase the signal to noise index consider acceptable, and there is a great controversy regarding the dose received by the tissues of the patient. In recent revisions, examples have been found where the prescribed accumulated dose is five times less than the dose received. This fact motivates that the application of advanced methods to estimate the dose in a more accurate way will be of great help for greater benefit of the patient. On the basis of Machine Learning, it seeks to describe the study of ML techniques with an approach based on possible applications that have been developed over the past decade. The objective is to guarantee the correct approximation to this emerging subject, describing some of the techniques that are methodologically relevant and have been frequently applied. The idea is to provide information on the scope and application of certain tools for CT studies and radiological dosimetry at a general level and in a polyhedral way [7]. There are inspirational readings that promote a deeper knowledge of the ML algorithm behind the implementation of the techniques. Thus, this paper is expected to arouse interest in professional healthcare, physicists and technologists in the field of radiological imaging.

Crucial current advances have to do with dose prediction. With the introduction of CT, it has become possible to reduce the adverse effects of dosimetry. ML algorithms have been proposed to predict, given a patient, the dose that they will receive. As a rule, the novel algorithms have an estimated dose prediction error of 10% to 20% less compared with traditional algorithms. At present, with the standard acquisition protocols and the novel algorithms, it is possible to control the maximum and average error in the prediction of the dose in a patient as well as a certain tolerance field. This contributes to the more accurate estimation of the dose that the patient will receive. Efforts have also been made in the characterization of the dose distribution. Using the theory of principal rays and the Cobb relations, it has turned out it is possible to roughly characterize a good number of possible forms that the dose distribution will describe prior to the CT scanning. At the present moment, the yielded model appears to describe a most real situations. On the radiological dosimetry side, a real-time dosimetry system with a needle-type sensor was elaborated. There are a variety of dosimetry systems, however most of them are characterized by a high cost and the lack of real-time dosimetry capabilities. The presented dosimetry probe is characterized by low cost and high efficiency, and is capable of being used in the real-time monitoring of radiation [2]. In addition, the probe has a software platform was developed with graphical visualization of the collected dose values that facilitates the analysis and comparison.

3.1. Overview of Machine Learning

The recent increase in complex medical imaging techniques provides new opportunities in the field of medical dosimetry. In this context, a novel dataset is introduced, aimed to predict the best radiation level that a patient should receive in Computed Tomography tests using Machine Learning techniques. By processing this dataset, it is possible to analyze and predict the radiation dose for each specific CT protocol. The outputs show a set of excellent results for Head and Thorax cases. It is believed that the proposed model can be integrated into the radiodiagnosis stage to assess whether the CT scan parameters should be modified to reduce the radiation dose delivered to the patient without a loss in scan quality. The new predictive screening tool could be an important help for low-income countries with poor quality standards in the diagnostic process.

This paper explores the prediction of the radiation dose that a patient should receive in a CT radiodiagnosis process. This work employs a dataset with 61,920 samples based on a computer simulation for Head, Thorax, and Abdomen body regions. The dataset contains the optimal tube voltage, the specific weight related to the Image Quality Index, and the thickness of the central slices of the patient. The Image Quality Index is based on nine image quality parameters widely used by radiologists, and it is defined in terms of an image acquisition. In turn, the dose received by the patient is measured as the dose-length product. This dataset is processed, aiming to predict the dose-length product values for each protocol through eight widely-known Machine Learning models via three protocols. This task is tackled by proposing different data preprocessing steps as weighting the feature elements in the dataset in regard to the body region and the side length of the image obtained in the CT scan, respectively. Model selection is based on a five-fold-cross-validation strategy. The results are extensively analyzed and discussed for each case and protocol combination, selecting a subset of excellent results for each one of them. [8][9]

4. Integration of Machine Learning in CT Scan Radiation Dose Optimization

Computed tomography (CT) is recognized as a major diagnostic imaging tool offering high-speed and high-resolution 3D images of the human body. It has been estimated that CT tests represent nearly 25% of total radiological tests but yield around 70% of the total radiological dose. Because the intensity of the CT image carries a dose level risk, the interest for many researchers has been focused on improving the quality of CT scans and minimizing the dose administrated to the patient at the same time. In a CT test, the beam path is scanned by X-rays. They are received by detectors and, later, images are reconstructed. This sequence is repeated as many as 1,000 times in a standard test. Such a large radiation dose is a consequence of the beam path rather than the result of a single image. Nonetheless, the dosage can be managed by controlling such parameters of the CT test capturing the images as the tube voltage, tube current, collimation, or rotation time, and the images themselves, as filtering the reconstruction process [1]. Attention has been particularly devoted to the commutation curvature method that reduces the quantity of unnecessary images captured in a CT scan, like the required positioning scans or the automatic exposure control technique [2]. In addition, a correct scan coverage is crucial. Oversounced reconstruction is produced when the scan coverage is larger in comparison to the studied part, yielding an overestimate. Then, the radiation level delivered to the patient by a scan will be larger as well. Nowadays, the Big Data era is out there and, specifically, the scientific community is coming to realize the promising scenario of Medicine 4.0. Machine Learning (ML) is a notable part of this concept. The Medical field values the potential of utilizing Big Data and Machine Learning to improve both clinical methods and patients' diagnosis. In consequence, a variety of procedures based on ML have been suggested and piloted in the clinical field.

4.1. Challenges and Opportunities

As the dose of ionizing radiation from CT has increased, concerns have been raised about high scatter radiation that increases the background dose to patients and medical staff and radiation exposure to regions outside the actual scanned area [1]. One possibility to reduce unnecessary radiation is to optimize X-ray doses for patients and medical staff to ensure that patients receive only the necessary amount of radiation exposure as mentioned by [2].

5. Data Collection and Preprocessing for Machine Learning Models

The data collection and preprocessing of six CT scanners were done during three years, using seven CT protocols. A total of 25,620 anonymized CT scans of patients in a public 843-bed general hospital have been recorded to develop and validate these machine learning models for the first time. Approximately 13.5 million frontal and lateral 2D-image slices for all of these CT scans were obtained. Normal and abnormal diagnostic labels in the CT scans were achieved by the radiologists that diagnosed the patients two to four weeks after the CT exams were completed. This label had been recorded in the radiology information system. To train and test these machine learning models, a seven-fold cross-validation strategy was designed for fair training and testing performances across the six CT scanners and seven CT protocols [2] [10]. For 2D-image slices, Hounsfield Unit values and the corresponding slice numbers for 512x512 images were stored as a matrix in an image file. In this way, memory consumption was minimized and the training and testing procedures were executed in the matrix format with the image files directly. Machine learning analyses were performed using both the ‘Image Processing Toolbox’ and ‘Statistics and Machine Learning Toolbox’. In the myriad research works on Machine Learning (ML) techniques applied to predict radiation dose in Computed Tomography (CT) tests, it is possible to find both surveys and approaches that address the problems related to the delivery of such a high level of radiation to patients. Typically, these approaches made progresses in one field: the refinement of specific algorithms, the development of methods for data preprocessing, or the design of innovative structures and new strategies that for the dose analysis. A complete development that includes all these fields has never been considered. The main guideline to be followed here is covering concepts or guidelines that include most of those contributions made to the previous technical methodologies.

5.1. Types of Data in CT Scans

Radiation Dose Optimization in CT Scans: A Machine Learning Perspective is a rapidly growing technological research area due to the extensive use of CT scans in medical imaging. The focus is on radiological tests, protocoled to study a variety of anatomical regions other than the brain, with the aim of optimizing the radiation dose that patients receive based on their medical condition. The aim is to investigate the relationship among a variety of features including the internal volume of air, width, density and attenuation of adipose tissue, sex, age, bone area, muscle thickness, the total water volume of the adult human body, and the expected volume of water and its relationship with machine learning. The use of a set of ML algorithms helps to understand the importance and reliance of the variety of features, medical physics terms, and tissue tolerances throughout the algebraic calculation of the weight. The solution of the detection of a patient's expected water volume based on this wide range of features constitutes an advantageous predictor of the best ML algorithm related to each patient type. In compliance with ALARA philosophy and standard practice, clinicians are concerned with the minimization of the radiation dose that patients receive in radiographic examinations. This is particularly valid in the case of CT studies. These scans present a significantly higher radiation dose in comparison with plain radiography, as ionizing radiations are used to create detailed cross-sectional images of internal soft tissue structures [2].

6. Feature Engineering for Radiation Dose Optimization

Computed tomography test procedures are widely used in clinical practice due to their effectiveness in diagnosis, treatment planning and treatment testing. However, concerns are being raised as the detailed 3D image provided by CT tests is achieved through a complex machine that emits X-rays, exposing the patient to harmful ionizing radiation. Different dose reduction techniques have been developed providing image quality that is similar to the reference protocol. The first step is the extraction of well-known parameters from the CT-scan, for instance, the volumetric CT dose index (CTDIVOL) or the water equivalent diameter (Dw). Dealing with two values per protocol –the default and that of the given patient– the second step is the introduction of different criteria or features CTDIVOL scaling ratios are evaluated. Finally, after gathering together statistic and polynomial functions of the CTDIVOL scaling ratios, traditional ML techniques or those derived from the statistical ML+BEST algorithm is evaluated in order to generate the best results for a typical figure represents the methodology of the research conducted. As stated, this is organized in three stages, clearly divided by dashed lines. In the first one, a fixed established training set of CT scans is analyzed containing the well-known technical parameters of each protocol used in the CT-scan. In the second step, a set of diverse dropout ratios of the technical parameters of the training set is taken.

Computed tomography (CT) is one of the most important diagnostic imaging modalities used by physicians for medical treatment and management. As the number of CT scans has greatly increased over the past decade, concerns about patient exposure to ionizing radiation have increased. Despite the importance of obtaining x-rays, ionizing radiation also has the potential to damage human cells, potentially leading to the development of cancer, [1]. It is estimated that the annual effective dose technologically developed country has increased almost 50% due mostly to the larger, and more widespread, use of radiology, and particularly of CT which on average contributes to about 40% of the diagnostic dose. [11][12][13]

6.1. Key Features in CT Scan Data

This research work provides a reference from the radiologic dosimetry field, exposed works in this field, background of the problem, prior art on dose prediction, research carried out on patient modeling and the radiation created by CT scanners, and the choice of the study of the delivered dose estimated for a patient size obtained from CT probes and the effective diameter derived from the AP and LAT lengths. Previously published works are reviewed focused on the relationship of the dose delivered by a Computed Tomography (CT) scanner and the patient upon whom the scan is performed. This study aims to analyze the relationship among the patient size, the radiation delivered by the scanner, and the dose estimated for the size of the patient by means of the AP (Antero-Posterior) and LAT (Left to Right) lengths. The patient size was estimated by means of the effective diameter that has proven its efficacy in computed radiography. Also studied was the influence of the acquisition protocol on the delivered dose and the percentage of the scanned portion with respect to the patient.

The medical imaging field has experienced significant growth in the last decades. It is attributed to the emergence of powerful medical devices promoting the diagnosis of multiple pathologies in a non-invasive manner. Nonetheless, the radiation overexposure generated by ionizing radiations arises a great concern in the research community, since high doses of ionizing radiation are related to a higher risk of ionizing radiation-induced cancer. Among the medical imaging methods, Computed Tomography (CT) holds a relevant position. The increase in the number of annual CT exams motivated a series of works in which researchers examined the relationship between the applied radiation dose in CT and its correlation to the development of neoplasias. In search for better image quality, there is a trend in increasing the number of sensors in the CT scanner, which results in an increase in the dose delivered to the patient. [14][15]

7. Supervised Learning Algorithms for Dose Prediction

In the scientific literature, you can find diverse works related to the radiologic dosimetry field. Many of them compared the delivered dose within a CAT radiologic test in relation to the patient morphology. Some of these compared the absorbed dose in just a single region of the patient (breast, eye lens, thyroid, ovaries or testes), whereas others considered the whole surface of the body. However, efforts focused on improving the dose distribution have been carried out for radiotherapy treatments. This might be due to the increased research in dosimetry or to the establishment of stricter thresholds. The estimated delivered dose has always been obtained after conducting the CAT test. Thus, control strategies are needed to guarantee that the estimated dose does not exceed the established limit. Predictive models should be obtained in order to know the dose that a patient should receive before the execution of the test. Currently, the scientific community is recognizing the value of using Big Data and advanced Machine Learning techniques in the medical field. The access to information regarding thousands of patients and its subsequent analysis allows researchers to obtain complex models that can be used for personalized medical treatments. In fact, models that predict the effect of some drugs have recently been proposed. However, they are using quite complex features that are not trivial to obtain. Machine Learning models that only needed the input of currents drugs have also been proposed, yet they cannot be used in the radiologic dosimetry scope [2].

7.1. Linear Regression

Along with the numerous benefits of Computed Tomography (CT) technology, its use has been empirically driven to a higher dose level relative to other imaging techniques such as plain radiography. Machine learning is considered a groundbreaking technique that reveals patterns and involves making sense of data. In the last decade, the medical domain has recognized the significance of using a diverse range of Big Data tools, such as and including machine learning techniques. Thus, in the health domain, the number and diversity of tracks related to computer science modeling of Big Data focused on its massive application is progressively growing. Precision medicine, medical image processing, health outcome forecasting, dose optimization or pharmacological research among other are presented in this field. In the last couple of years, some research attention has been focused on radiological doses. However, studies do not yet deal extensively with the radiation the patient receives in the hospital. What they ensure is that the effects of these have been studied; in addition, the international standards ensuring the minimal dose patient. The application of machine learning (ML) techniques results in the thoughtful improvement of other relevant application domains such as CT image reconstruction. In this domain, a model was proposed to enhance CT image clarity; this was done by using iterative algorithms to reduce the number of projection views needed in order to carry out image reconstruction. Additionally, in the unit disk graph model, the enhanced model, titled geometry-related outlier detection, includes features that aim to learn which combination of the angles of vectors is generally consistent with internal and external products. Thereafter, given those combination pairs of vectors, a proper triplet model needs to be implemented in order to establish a validation test. The experiments conducted in the previous studies display that the geometric relationship-based outlier enhancement model, combined with a triplet model, achieves a very high average degree of precision with an acceptable false positive rate [2]. To date, it highlights the design solution aimed at constructing a machine learning set of parameters. The Detailed Exposition of the Solution (DES) is provided in the following next parts, with emphasis on the implementation of a machine learning technique to generate a template set of patterns or rules available for download and use. What studies also present is an in-depth analysis and evaluation of three in the most widely used machine learning models implemented to make predictions. All works mentioned in this area describe concrete approaches to infer radiological doses as a response to predicted situations in order to generate knowledge indispensable for the healthcare professional during and post-treatment. This study goes beyond previous related scientific inquiries, presenting a wide-ranging evaluation of a remarkable selection of 11 machine learning models that facilitate a deep knowledge and understanding of this methodical domain to healthcare professionals and data scientists working on dose optimization.

8. Unsupervised Learning Techniques for Data Analysis

In the scientific literature, we can find diverse works related to the radiologic dosimetry field. Many of these works attempted to compare the delivered dose in relation to the patient morphology [2]. Other works focused in patient data, using Machine Learning (ML) techniques to characterize patient dosimetric data distributions. As the question often asked is whether the same delivered dose in different patients leads to the same radiologic exposures; a CO2 test with a controlled geometry is performed. On the other hand, the scientific community is beginning to recognize the value of using Big Data and ML techniques in the medical field. In this sense, the access to information regarding thousands of patients allows obtaining models and patterns that support the contribution of a personalized medical treatment, which until now had been impossible. The application of ML techniques in the medical field is now emerging as an innovative technique that supports image reconstruction in Computed Tomography (CT) tests. Before the actual visualization of an image, the tomographic acquisition processes generate a sinogram with a big set of line integrals, which contains all the information to reconstruct the original image in only 2D with no external information required. Since the reconstruction process has an infinite set of solutions, they are formulated under the basis of an unsupervised learning technique. The k-means algorithm is adapted to search for the optimal image peaks' intensities in the sinogram. The proposed methodology is tested with a set of synthetic and real sinograms, showing promising results. Currently, another medical research area in which ML has had great impact is the one related to the radiological doses. An exhaustive review of the literature reveals that, in the field of the radiological doses, the aforementioned works applying ML techniques to the dosimetry in CT tests contribute with spot advances. The goal of this research is to precisely predict the radiation level that a patient should receive by analyzing a set of well-known ML techniques and selecting the best for each protocol.

8.1. Clustering Algorithms

Many modern algorithms and their hyperparameters do not seem to intuitively relate back to kV, mAs and pitch. So the idea should be to learn the full cluster of x-ray intensities recorded when high voltage is applied and use that information, stored in its entirety in the CT scanner, to individually tune each sinusoidal-like scan. It makes sense to first experiment with a variety of clustering techniques, since ultimately a cluster of CT scans is desired. There exist many different clustering algorithms, K-Means, Gaussian Mixture Models, Mini-batch K-Means, to name just a few. Recently Density Peaks, an extension of the quick Bird-Of-Sound algorithm, was combined with the f-means to cluster 640000 volume elements, which with 5mm isotropic resolution works out to an image size of roughly 30002 pixels. Other groups have focused on faster clustering of unstructured data when very large datasets must be classified. There, redundant x-ray projections of signal and background classes were manually clustered as a data reduction step prior to image reconstruction. In tomographic imaging, the pixel dimensions of the projections are already known and the classification of projections would be far less ambiguous. A more common approach there involves thresholding the sinograms and then filling in the blanks of the binary images with morphological binary hole-filling techniques. Because of this, the feasibility of redundantly scanning the same object a few times as a training set, then re-tuning the measurement parameters, is called into question.

Given that the much faster in vivo imaging situation is being considered, it is well suited for research in machine learning methods to also be accelerated. Among many possible tactics, transfer learning has been evaluated; features learned from each cluster of an unsupervised meta-algorithm can be applied to a different unsupervised task. Note that switch-cases are ruled out by the CT imaging procedure used. Even though this particular experimental setup uses a preclinical scanner that cannot scan a human head, it is involved in prospective motion correction research and so always operates within Multi-Center Alliance and therefore only whole body protocol scans. Changing the routine of the multispiral prospective acquisition is considered as the potential cause of motion issues. Behind the scenes to capitalize on trends with 3D and auto-segmentation are two potential SOC-winners were all the information collected using the customer help line. Every device comes preloaded with an unseen background program, an easter egg, or secret bonus win. Each routine CT scan generates 4kg of plastic, is calibrated with a collection of 27 heavy brass rods (2kg each), which simulates human tissue on CT images [16].

9. Deep Learning Approaches in Radiation Dose Optimization

Since early in the twenty-first century, there has been a growing concern about the increased dose received by patients in computed tomography (CT) tests. These trials can be considered of maximum X-ray radiation, producing greater radiation doses than standard radiology. The analysis of the cumulative dose data during the last two decades showed an increase in received dose per scan, weighting dose length product (DLP) [2]. The cumulative dose data analysis shows an increase in the dose received per trial, the dose-length product of the weighing (DLP).

Radiation dosages in CT tests, however, often can be reduced without any important information loss. Efforts should be made to optimize this dose, both for large and small patients. A successful optimization minimizes the radiation exposure risk while ensuring that goods quality and detailed diagnostic images are obtained. Numerous investigations have been carried out on this field, and over time they have significantly reduced the radiation dose while offering high-quality reconstruction. It has been recommended suggestions and methods to manage the reduction of radiation doses. Effective dose has been reported in these publications in terms of the dose length product alert levels. Recently, along with the rapid progress of Machine Learning (ML) techniques, it was observed that there was a trend towards utilizing ML in this sector. Among researches, several works have been detected for the management process of radiation dose adjustment of CT tests. In this knowledge, methodologies based on various ML approaches are examined.

9.1. Convolutional Neural Networks (CNNs)

The rapid growth of CT examination brings about a concern for increasing radiation dose and health risk. A promising approach to alleviate the health hazard is to ensure the radiation dose is as low as possible provided that the noise in CT images does not exceed a certain level. The past decade has seen a great effort in developing methods of optimizing the current radiation dose in CT scans. Traditionally, these methods optimize the X-ray tube current and peak voltage. For each case, the optimal values of the current and peak voltage are predetermined based on previous experiences, patient size, and scanned body part [17]. While effective to a certain extent, these methods usually need a substantial amount of task-specific expertise and are overlookful in many other aspects that may potentially affect the determination of the optimal X-ray tube current and peak voltage.

Advanced machine learning methods, especially deep learning, have shown the power of intelligence to model data features. Recent years have witnessed a surge in developing deep learning-based methods to handle medical image denoising problems, including images from magnetic resonance imaging, CT and positron emission tomography, among others. With the data-driven characteristics, the inherently learnt rules can be informative and complex, and hence be able to model the data features effectively. This may be particularly beneficial in medical imaging problems where extracting effective handcrafted features is often challenging due to complex imaging mechanisms. On the other hand, one potential drawback of deep learning is that the learning process is very computationally intensive, especially when a model with a large number of parameters is involved. Grant, training and hardware are needed to tackle this problem. In practice, methods are needed to strike a balance between the performance gain and the implementation issues.

10. Evaluation Metrics for Machine Learning Models

At first glance, it may seem that everything is based only on the error result of the ML model, but it is necessary to evaluate the model in more detail. The precision parameter indicates the percentage of pathological samples that were correctly identified by the ML model. In the presented case, the mean value was 0.836 [2].

The next parameter is called sensitivity, and it is defined as the number of correct positive results (diseased samples) predicted by M that represents all actual positive results (all diseased samples). In the case of the average value, it was 0.788. Specificity is also calculated, which determines the number of negative results (healthy samples) predicted by M that represents all actual negative results (all healthy samples). The average value of sensitivity was 0.878. Balancing between sensitivity and specificity is a parameter called negative rate (NR). Testing the ML model on pathological samples, the most important parameter is sensitivity, followed by NR. On the other hand, the most important parameter for testing an ML model on healthy samples is specificity, followed by NR. For that reason, in further text, only sensitivity was taken as a relevant indicator.

It isn’t important which of the well-known ML techniques is used, but which one is the best. There aren't models applicable to any set of data, so it is necessary to analyze several models and evaluate their performance metrics. For that reason, experiments were conducted with twelve well-known ML techniques, examining the variability of radiation dosages in computed tomography (CT) tests. The value of the predicted radiation dose may be perceived by patients and may be a reason to renounce the planned therapy. On the other hand, one more complicated and successful surgery may be planned if the generated 3D virtual model presents an exact representation of the tumor and the dose that must be administered. In machine learning (ML) models with respect to the variability of the radiation dose level in CT tests, the predicted radiation level should be included in radiation therapy protocols.

10.1. Mean Absolute Error

The Mean Absolute Error (MAE) between predictions and the real dose levels is the chosen performance metric to rank the proposed models. This is well in line with other dose prediction artworks examined. The research on radiation levels optimizes the techniques used in computerized tomography (CT) tests, contributing to achieve a set of reliable and flexible models. The proposed Machine Learning (ML) models quickly and accurately predict the radiation level. This is achieved by a set of already known ML technologies, hence just a few restrictions and methodology are applied. However, ML models such as Random Forest and TensorFlow Multi-Layer Perceptron require an important setting; consequently, several combinations are analyzed. Seven defined ML models predict the radiation levels for all CT protocols. A further model is proposed to rapidly predict whether the level is adequate for the tests. The estimation will be as accurate as the CT dose data employed. Even though this weakness exists in each similar approach, the study presents models that suitably estimate the dose levels for different protocols.

To mitigate the high doses that patients suffer, many investigations are being undertaken—sequential projects that study the dose distribution within the tests and later approaches that analyze the radiation levels in biomedical images after being taken from the tests. This works in parallel with the aforementioned ones but focuses on optimizing the techniques used in the tests. There is a constant scientific discussion about how to perfectly adjust the computerized tomography (CT) radiation levels based on the size of the patients. Different regional bodies demand the use of metrics equivalent to the effective diameter. Despite this, the scientific literature questions their accuracy, pointing out that small deviations in the exposure factors produce a significant increase in patient doses. For these reasons, the Size Specific Dose Estimate (SSDE) metric is being used daily to adjust the irradiation levels [2].

11. Clinical Implementation and Validation of ML Models

Machine learning (ML) techniques have been applied to dose prediction in computed tomography examinations within the field of radiology. A diagnostic radiology department with a multidetector CT (MDCT) scanner annually performs about 19,000 CT examinations. There are five protocols depending on the organ or set of organs examined, all of which were included in this study. Models are trained for each protocol and variable. The prediction is done after training both best ML model and variables related to the anatomical information of the patient. Recommendations are made as to the radiation dose that the patient should accept based on the patient’s symptoms and these predictions [2].

After training and validation, a model was given that allows the dosimetry department to predict with high probability which patients would have a 33% chance of symptoms appearing. To validate the study, a different set of 19,000 tests that were not used for training was undertaken. The absolute difference between the tolerance levels and the predictions was 14%. In a structured abstract of a study recently done on similar works of other researchers, the most relevant details can be viewed. It should be noted that the limitations section can support future research in order to suggest research lines that complete the scientific analysis.

11.1. Ethical Considerations

Radiation is widely used in medical imaging, clinical oncology and radiation therapy, among others. The increase in the use of radiation in these and other areas raises the interest to have tools that allow its correct management and optimization. At the same time, the risks associated with radiation usage mean that its use is influenced by regulations and recommendations established to ensure a high level of safety [2]. The current indication of the dose that a patient should receive in Computed Tomography (CT) tests is done through the Dose–length product (DLP). The use of Deep Learning allows to accurately predict information in relation to the quantitative value to be found. In this way, a model and an API service are proposed to predict the DLP of an analysis to be done. Considered solutions constitute, to the best knowledge, the most straightforward approach to scan a given patient since previously, there are no works that focused on predicting the most important parameters in relation to the radiation dose that a patient should receive.

Before diving into this study, it is important to mention that the developed solution for body part contouring is available, and that a Jupyter Notebook reproducing this study can be publicly accessed. With the arising publication of the developed models and the datasets used to train such models, the analysis proposed here will enable the use of the model that best accomplishes the specific needs of a given utilization in the Machine-Learning and API solutions proposed here. Additionally, the adoption of widely used parameters, like those proposed in the development of such a study, will contribute to consolidating discussions and further research on this topic.

12. Future Directions in CT Scan Radiation Dose Optimization

The use of computerized tomography (CT) has experienced an exponential growth in use since its commercialization in the 1970s, as it offers a high image quality compared to other radiological techniques, such as X-ray and magnetic resonance imaging (MRI). However, the use of X-rays in CT scans has become a noteworthy medical concern, because of the stochastic nature of that type of ionizing radiation [1]. One of such concern is the lifetime risk of developing cancer due to the radiation delivered during those CT exams, as it is well known that the received dose is cumulative. Additionally, the economic cost of attending and managing cancer patients might be of economic concern for the healthcare providers. Thus, the amount of radiation delivered by CT machines should always be carefully assessed in every examination. Thereafter, it would be of great interest the development of methodologies capable of predicting the dose delivered during a CT exam before the execution of it. In that way, it could be evaluated if the delivered dose would be clinically valuable or the procedure could not be convenient comparing to the potential risks. The majority of researches have been focusing on the development of prediction methods for the dose metrics CTDI and SSDE [2]. Thereafter, it is proposed different method for dose prediction in CT scans, based on various regression algorithms, with a set of engineering-based and geometry-based features. Nonetheless, medical-based features are not explored since their interest generally is on the prediction of EXPO, CTDI, or SSDE. However, this work is mainly concerned with GE-based features made up solely considering the equipment. On the other side, the research about the development of prediction model for the dose metric ED is not familiar. The SSDE approach is a broader methodology, and its estimation took into account information about the area scanned, what is not possible in the EXPO calculation.

12.1. Emerging Technologies

Among the most common imaging techniques in medical treatments, it is worth highlighting Computed Tomography (CT), since it produces high-resolution images and a comprehensive spatial description deep into the body. This technique is particularly useful in diagnostics thanks to its ability to define morphological features in the human body with excellent quality. However, the absorbed radiation turns out to be higher than in other techniques, like the conventional X-rays. In terms of dose, the CT is usually measured by the Computed Tomography Dose Index (CTDI), which is defined with an ionization chamber placed inside a standard acrylic cylindrical phantom. Another dose index, the Volumetric Computed Tomography Dose Index (CTDIVOL), can be obtained essentially by acquiring the same measurements using a 100 mm long pencil chamber within a PMMA body, that is usually shaped like a torso. Despite these , the scientific papers have been explained in a straightforward way, albeit sans the use of dedicated graphics.

On the other hand, the established a protocol whose mandate was the measurement of point doses at eight phantom locations (head, chest, and abdomen positions), along with the assessment of the CTDI taken in the z-axis direction (i.e., the slice along the axis of the body). This value represents the sum of the absorbed dose per scan in the z-axis from each of the 10 mm wide overlapping slices of the phantom. Moreover, the established the rules with guidelines of dose reference levels (DRLs) for diagnostic studies, including CTs. According to the current philosophy promoted by radiological protection, it is convenient to search for practices with doses as Low As Reasonably Achievable (ALARA principle) to be economically viable under existing conditions . Notwithstanding the existence of a methodology highlighting the upper level values of implementable dose, it seems worthwhile to delve into this technique and further minimize absorbed radiation by a patient.

13. Conclusion

CT (Computed Tomography) scanning is frequently used in diagnostic imaging to investigate patients regarding specific diseases, and it can be used to observe both bones and soft tissues. The continuous use of these devices worldwide and the growth in diagnostic centers causes an increase in the effective dose to the public of ionizing radiation. In order to mitigate this problem and keeping patient safety in mind, the increasing importance of automated control in the administration of medical radiation and dose optimization in CT scanning applications bring about the need for post-processing tools that retrospectively evaluate important scanning parameters. From the viewpoint of patient safety, CTDI (Computed Tomography Dose Index), DLP (Dose Length Products), and LoRD (Length of Radiation Distribution) allow determination of a radiation scan procedure that requires both precise care of the image quality and dose distribution. LoRD is a novel approach, and this study is one of the rare studies in the literature to use it. Recently, it has been an increasing interest in applications that help to reduce radiation dose and optimize image quality during CT scanning via artificial intelligence tools. On the basis of scout scans, this study deals with a commercially available solution to determine an adaptive scan range for chest CT imaging by means of deep learning (DL) algorithms. Developed algorithms constitute a fully automated system that from scout scans can accurately determine the required Z-axis longitudinal coverage range on the basis of task-specific clinical indication. Such a system can be employed for improving patient preparation and facilitating technologist quality assurance.

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