Technology Trends in Diagnostic Imaging Systems

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Keywords: diagnostic imaging, imaging principles, image reconstruction, artificial intelligence

ABSTRACT

Diagnostic imaging systems generate images of the inside of a patient's body for the purpose of making a medical diagnosis. Therefore, ensuring high quality images is one of the top priorities for these systems. This manuscript outlines the imaging principles in these systems. Recent technology trends, including breakthroughs in image quality improvement, such as the introduction of AI technologies, are also briefly described.

1 Introduction

Diagnostic imaging has revolutionized medicine since the advent of the x-ray radiograph by Wilhelm Rontgen in 1895. As late as the 1970's, exploratory surgery was a common technique to diagnose a patient. Despite the inherent risk of permanent injury or death from the procedure itself, exploratory surgery often did not yield a definite answer to a medical question, leaving the patient and the treating physician with no positive direction for treatment.

Advances in the technology of medical imaging since that time has led to the emergence of a whole new medical specialty: radiology. The radiologist specializes in applying the advanced technology of medical imaging to create and interpret images of the human body. Today medical imaging and radiology are an indispensable part of the patient care cycle from primary diagnosis, to image guided medical procedures, and follow up and monitoring of therapeutic response. Diagnostic imaging is also very cost effective. A Harvard Medical School study found that every dollar spent on patient medical imaging translates into three dollars of savings for the entire patient care cycle.

Today the radiologist has a diverse set of imaging tools at his or her disposal including x-ray and x-ray computed tomography, position emission tomography, magnetic resonance imaging, and ultrasound. Techniques and tools are continually emerging as new technology is adopted in sensors, image formation computational methods, and applications that aid in the visualization and interpretation of images. This innovation is fueled by a global 32 billion USD market that constantly provides new technology to benefit the patient and physician and generates revenue which can be re-invested into research and development of the next generation of technology.

Diagnostic imaging systems visualize the inside of a patient's body as images for diagnostic purposes. There are several types of imaging systems depending on the physical principle of imaging and the clinical purpose of the system. The type of imaging principle is generally referred to as the modality.

Imaging modalities are classified based on the physical principles used such as radiation, magnetic resonance, ultrasound, etc. The technologies required for imaging generally include signal sensing, image reconstruction, and analysis applications. Medical imaging systems have been designed to satisfy image quality requirements for diagnosis, i.e., sufficiently low noise, minimal artifacts and high spatial and temporal resolution. In recent years, image quality has been dramatically improved by the introduction of AI technologies. Recent technology trends, including such breakthroughs in image quality, are briefly described in this manuscript.

2 Principles of Diagnostic Imaging

Diagnostic imaging systems detect signals transmitted through or emitted by a patient's body and convert the signals into images as a visualization of the inside of the patient's body. The physical phenomena include radiation attenuation or emission, magnetic resonance, and ultrasound. The systems are equipped with mechanisms that generate the primary physical signal, sensors that measure the signals transmitted through or emitted from inside the patient's body, and signal processing (generally called image reconstruction) that converts the measured signals into images. Sensors include radiation detectors (x-ray or gamma-ray detectors), RF coils (antennas), and ultrasound transducers (probes). The mechanisms that generate the primary physical signals include radiation sources (X-ray tubes or radioisotope tracers in nuclear medicine), static magnets and gradient coils, ultrasound transducers etc. The signals detected by the sensors are digitized and transferred to image reconstruction units along with additional information about the positions of signal generation necessary for image reconstruction.

Image reconstruction is a signal processing technique that uses sensor signals with position-encoded information to create 2D and 3D images inside the patient's body, and sometimes 4D data including the time domain. The best known modality is probably X-ray radiography or projection radiography. The principle is simple: X-rays from an X-ray tube penetrate the patient's body, and the degree of attenuation of the X-rays, which depends on the density of the body parts, such as bones and organs, is detected by an X-ray detector, such as an image intensifier or a flat panel detector and converted into the contrast in the X-ray image. By rotating the set of an X-ray source and X-ray detector around the patient and introducing tomography technology for image reconstruction from X-ray signals, it is possible to build an X-ray computed tomography system or X-ray CT. MRI uses a different physical principle: a strong magnetic field is used to align the hydrogen protons in the body along the direction of the field. An RF signal is then used to tip the orientation of those protons away from the main field direction. These protons then process around the main field and emit another RF signal as they relax back to the original direction. This emitted RF signal is then detected by RF coil antennae in an MRI system. Because the signal is a radio wave, the signal itself has little specificity about the location of the signal emission. Therefore, an MRI system encodes physical location through modulation of the spatial frequency and phase of the RF signal using a secondary magnetic field generator called a gradient coil. A detailed description of the principles of MRI can be found in a number of published references.

3 Technology Trends in Diagnostic Imaging Systems

A recent breakthrough in radiation sensors is the photon-counting X-ray detector. When it is used in X-ray CT, it can significantly reduce the radiation dose to the patient while improving spatial resolution compared to conventional X-ray CT. The principle of operation is to detect each individual X-ray photon that comes from the X-ray tube, penetrates patient's body and impinges on the detector. This is done through ultra-fast solid state semiconductor radiation sensors and electronics that measure the pulse of each individual x-ray photon. The detector signal is not affected by thermal noise because the pulse is measured over a very short integration window of only tens of nanoseconds as opposed to conventional sensors that integrate both noise and true signal over long time periods [1]. CT using this type of detector is called photon counting CT [2].

In recent years, image quality has been dramatically improved by using Artificial Intelligence (AI) technology, one of which is image reconstruction using deep learning (Deep Convolutional Neural Network, DCNN) (Fig.1, [3]). In order to obtain high quality images, various limitations are imposed on the diagnostic imaging systems. For example, CT requires radiation dose to the patient, MRI can have long acquisition time because of the need to encode many spatial frequencies, and generally a large amount of computation time is required. AI technology has been introduced to solve such problems, by constructing a DCNN and training it with input of images obtained under poor conditions such as low dose, low spatial sampling, or short computation time and images obtained under the ideal conditions as the training target data, this DCNN can be used as an image reconstruction technique to generate high-quality images from data acquired under poor imaging conditions [3]. AI reconstruction technology is being further developed, one of the examples is to obtain super high-resolution images (Fig.2, [4]). The AI reconstruction has been proven technology that ensures accurate diagnostic images can be reproduced for better diagnosis.

In addition, AI technology is also being used to

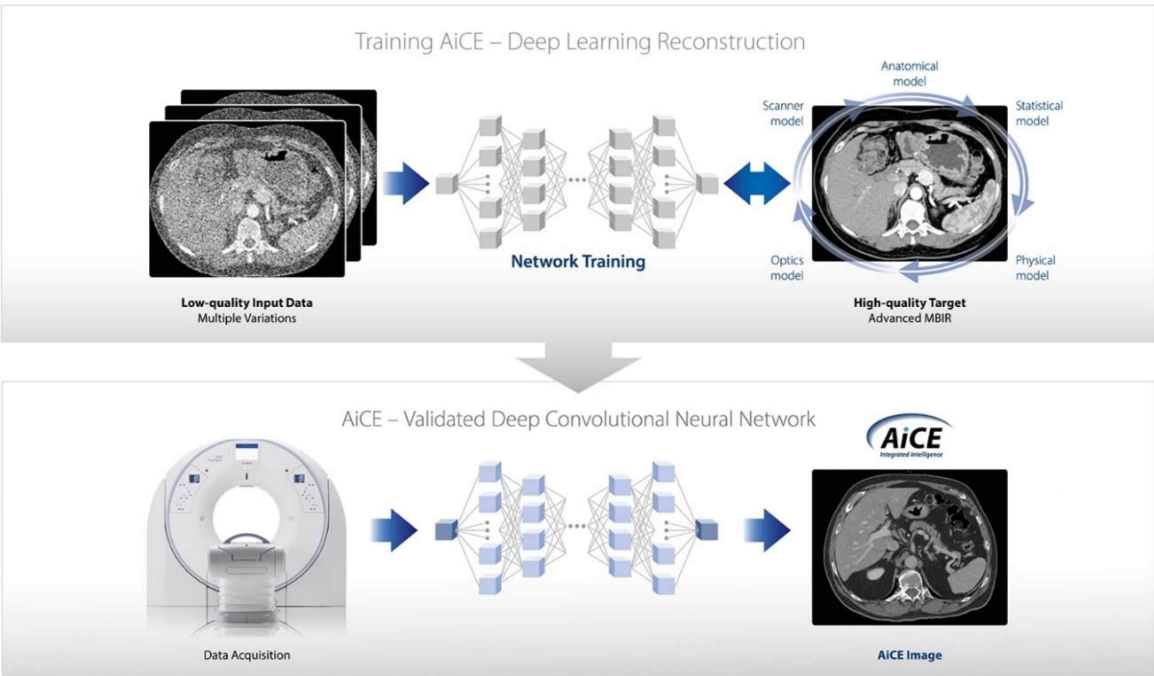

Fig. 1 Schematic explanation of image reconstruction using Deep Convolutional Neural Network [3]

analyze clinical images obtained by diagnostic imaging systems. For example, clinical images are read by a radiologist, but reading images of many patients is sometimes extremely burdensome for the radiologists. Therefore, there is a high demand for assistive technologies to improve the efficiency of reading or even automation. Figure 3 shows an example of such technologies. AI is also used to ensure a fast and appropriate workflow even for urgent patients with time-critical conditions such as intracerebral ischemia or hemorrhage.

4 Conclusions

Imaging principles and technology trends of diagnostic imaging systems are outlined. In recent years, AI technology has been used not only to improve the clinical image quality. In addition to image information, the use of non-image patient information, such as blood/diagnostic test results and genetic information, is expected to provide more accurate diagnoses and treatments that are more appropriate for individual patients. Diagnostic imaging systems will also continue to evolve to contribute to advanced medical care.

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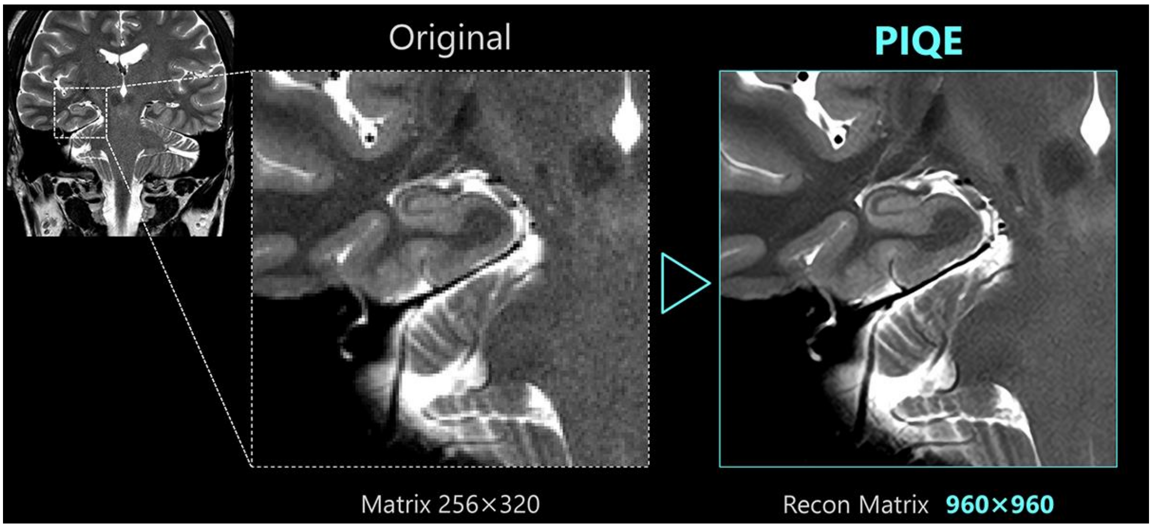

Fig. 2 Example of MRI images reconstructed with and without super-high resolution using DCNN [4]

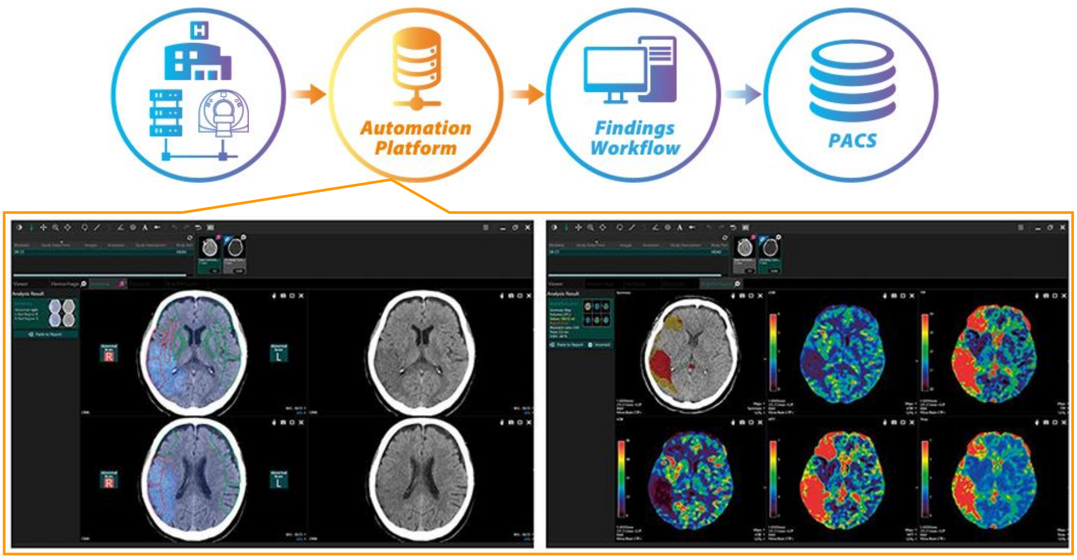

Fig. 3 Example of reading assistive technology (ischemia analysis, brain perfusion) [5]