Q 11: Radiometry and Photometry

Radiometry is the measurement of optical radiation, which is electromagnetic radiation in the frequency range between 3 x 1011Hz and 3 x 1016 Hz. This range corresponds to wavelengths between 10 nm and 1000 mm, and includes the regions commonly called the ultraviolet, the visible, and the infrared. Typical radiometric units include watt (radiant flux), watt per steradian (radiant intensity), watt per square meter (irradiance), and watt per square meter per steradian (radiance). Photometry is the measurement of light, which is defined as electromagnetic radiation detectable by the human eye. It is thus restricted to the visible region (wavelength range from 360 nm to 830 nm), and all the quantities are weighted by the spectral response of the eye. Photometry uses either optical radiation detectors constructed to mimic the spectral response of the eye, or spectroradiometer coupled with appropriate calculations for weighting by the spectral response of the eye. Typical photometric units include lumen (luminous flux), candela (luminous intensity), lux (illuminance), and candela per square meter (luminance). The difference between radiometry and photometry is that radiometry includes the entire optical radiation spectrum (and often involves spectrally resolved measurements), while photometry deals with the visible spectrum weighted by the response of the eye.

Quantities and Units in Photometry and Radiometry

In 1960, the SI (System International) was established, and the candela became one of the seven SI base units. Several quantities and units, defined in different geometries, are used in photometry and radiometry. While the candela is the SI base unit, the luminous flux (lumen) is perhaps the most fundamental photometric quantity, as the other photometric quantities are defined in terms of lumen with an appropriate geometric factor.

i) Radiant Flux and Luminous Flux Radiant flux (also called optical power or radiant power) is the energy Q (in Joules) radiated by a source per unit of time. Luminous flux (φv) is the time rate of flow of light as weighted by V(λ).

ii) Radiant Intensity and Luminous Intensity Radiant intensity (Ie) or luminous intensity (Iv) is the radiant flux (luminous flux) from a point source emitted per unit solid angle in a given direction.

iii) Irradiance and Illuminance Irradiance (Ee) or illuminance (Ev) is the density of incident radiant flux or luminous flux at a point on a surface, and is defined as radiant flux (luminous flux) per unit area.

iv) Radiance and Luminance Radiance (Le) or luminance (Lv) is the radiant flux (luminous flux) per unit solid angle emitted from a surface element in a given direction, per unit projected area of the surface element perpendicular to the direction.

v) Radiant Exitance and Luminous Exitance Radiant exitance (Me) or luminous exitance (Mv) is defined to be the density of radiant flux (luminous flux) leaving a surface at a point.

vi) Radiant Exposure and Luminous Exposure Radiant exposure (He) or luminous exposure (Hv) is the time integral of irradiance Ee (t) or illuminance Ev (t) over a given duration Δt.

vii) Radiant Energy and Luminous Energy Radiant energy (Qe) or luminous energy (Qv) is the time integral of the radiant flux or luminous flux (φ) over a given duration Δt.

viii) Total Radiant Flux and Total Luminous Flux Total radiant flux or total luminous flux (φv) is the geometrically total radiant (luminous) flux of a light source.

ix) Radiance Temperature and Color Temperature Radiance temperature (unit: kelvin) is the temperature of the Planckian radiator for which the radiance at the specified wavelength has the same spectral concentration as for the thermal radiator considered. Color temperature (unit: kelvin) is the temperature of a Planckian radiator with radiation of the same chromaticity as that of the light source in question.

Q12: Electrical Impedance and Biological Impedance

Electrical impedance and biological impedance are important concepts used to describe the opposition offered to the flow of alternating current, particularly in electrical circuits and biological systems.

Electrical impedance is defined as the total opposition offered by an electrical circuit to the flow of alternating current (AC). It is a complex quantity consisting of two components: resistance, which represents the opposition to current due to energy dissipation, and reactance, which represents the opposition due to energy storage in capacitors and inductors. Electrical impedance depends on the frequency of the applied AC signal and is expressed mathematically as $Z = R + iX$, where R is resistance and X is reactance. It is measured in ohms and plays a vital role in the analysis and design of AC circuits, power systems, filters, and electronic devices, as it determines current flow, phase difference between voltage and current, and power consumption. Biological impedance, also known as bioimpedance, refers to the opposition offered by biological tissues and fluids to the flow of alternating current. In living systems, the impedance arises from the resistive nature of body fluids, which contain ions, and the capacitive nature of cell membranes, which behave like dielectric layers separating conducting intracellular and extracellular fluids. Biological impedance varies with factors such as tissue type, water content, cell structure, and frequency of the applied current. At low frequencies, current mainly flows through extracellular paths, while at higher frequencies it can penetrate cell membranes. Measurement of biological impedance is widely used in medical and biomedical applications such as body composition analysis, assessment of hydration levels, monitoring of blood flow, detection of tissue abnormalities, and bioelectrical impedance analysis (BIA). Thus, while electrical impedance is a fundamental concept in electrical engineering, biological impedance extends this concept to living tissues, providing valuable diagnostic and monitoring information in biomedical engineering.

Applications of Electrical Impedance

i) AC Circuit Analysis Used to analyze RLC circuits Helps in calculating current, voltage, and phase difference

ii) Impedance Matching Used in communication systems and antennas Ensures maximum power transfer and minimum signal reflection

iii) Electronic Circuit Design Used in amplifiers, oscillators, and filters Controls frequency response and stability

iv) Measurement Instruments Used in LCR meters and impedance bridges Measurement of resistance, capacitance, and inductance

Industrial Applications Used in sensors for pressure, moisture, and level measurement Used in industrial control systems

Applications of Biological Impedance

i) Body Composition Analysis Determines body fat, muscle mass, and body water Used in Bio-electrical Impedance Analysis (BIA)

ii) Medical Diagnosis Used to detect tissue abnormalities Helps in identifying tumors and edema i

iii) Monitoring of Blood Flow Used in impedance plethysmography Measures changes in blood volume

iv) Cardiac Applications Used in monitoring cardiac output Helps in heart function assessment v) Medical Instrumentation Used in ECG, EEG, and other bio-signal measurement systems Improves accuracy of physiological monitoring

Q 13: Artificial intelligence (AI) in radiotherapy Artificial intelligence (AI) in radiotherapy has become an important and transformative tool in modern cancer treatment by improving the accuracy, efficiency, and safety of radiation therapy procedures. Radiotherapy uses high-energy radiation to destroy malignant cells while sparing the surrounding healthy tissues, and even small errors in planning or delivery can lead to serious complications. AI techniques such as machine learning and deep learning are widely used in the analysis of medical images including CT, MRI, and PET scans to accurately detect tumors and delineate organs at risk. Automated tumor segmentation using AI reduces inter-observer variation and significantly shortens the time required for manual contouring. AI also plays a major role in treatment planning by optimizing radiation dose distribution, selecting appropriate beam angles, and generating high-quality treatment plans within a short time. In adaptive radiotherapy, AI continuously evaluates anatomical changes such as tumor shrinkage and patient movement during the treatment course and modifies the treatment plan to ensure precise dose delivery. Furthermore, AI assists in patient positioning and motion management by tracking real-time movements and correcting errors during irradiation. It is also used in quality assurance to detect machine faults and planning errors, thereby improving patient safety. In addition, AI helps predict treatment outcomes and radiation-induced side effects, enabling personalized treatment strategies. Thus, artificial intelligence enhances precision, reduces workload, improves treatment outcomes, and represents a major advancement in the field of radiotherapy.

Applications of AI in Radiotherapy

a) **Tumor Detection and Diagnosis**: AI-based image analysis can identify small tumors that may be missed by human radiologists, significantly improving the detection rate and reducing the risk of misdiagnosis.

b) **Automated Tumor Contouring**: Tumor contouring refers to delineating the tumor and surrounding organs in medical images. It is a critical step in treatment planning to ensure that radiation is targeted precisely at the tumor while sparing healthy tissues. AI-based models, particularly deep learning techniques, have been developed to automate this process. By learning from large datasets, these models can contour tumors with high accuracy and consistency, reducing the time clinicians spend on this task and improving interobserver agreement.

c) **Treatment Planning and Optimization**: AI enhances treatment planning by analyzing historical data and patient-specific factors to suggest the best possible radiation dose distribution. AI algorithms can optimize the placement, angle, and intensity of radiation beams to minimize damage to healthy tissues and improve tumor targeting. AI can also automate dose calculation, thus reducing human error and saving time.

d) **Predicting Treatment Outcomes**: AI systems, especially machine learning models, can predict patient outcomes based on historical data.

e) **Adaptive Radiotherapy:** In adaptive radiotherapy, AI algorithms are used to adjust the treatment plan dynamically as the tumor or patient anatomy changes over time. This is particularly useful for patients who undergo treatment over several weeks, as tumors and surrounding tissues may change in shape or position.