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COURSE : SENSORS AND ACTUATORS

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TITLE : CASE STUDY ON SENSORS IN AUTOMATION AND HEALTH CARE

Case Study 1 : SENSORS IN AUTOMATION

TITLE: Acoustic Emission (AE) Sensors for Real-Time Weld Quality Monitoring in Additive Manufacturing

Introduction

Additive manufacturing has transformed modern production by enabling components with intricate geometries and lightweight designs to be built layer by layer from materials such as metals, polymers, and composites. In high-performance sectors like aerospace, metal 3D printing methods (like laser powder bed fusion) are increasingly common.
However, because the printing process involves rapid melting and solidification, even minor temperature changes can cause residual stress, leading to microscopic cracks or delamination between layers. Traditionally, manufacturers detect these issues only after production using X-ray or ultrasonic scans, which are time-consuming and expensive.

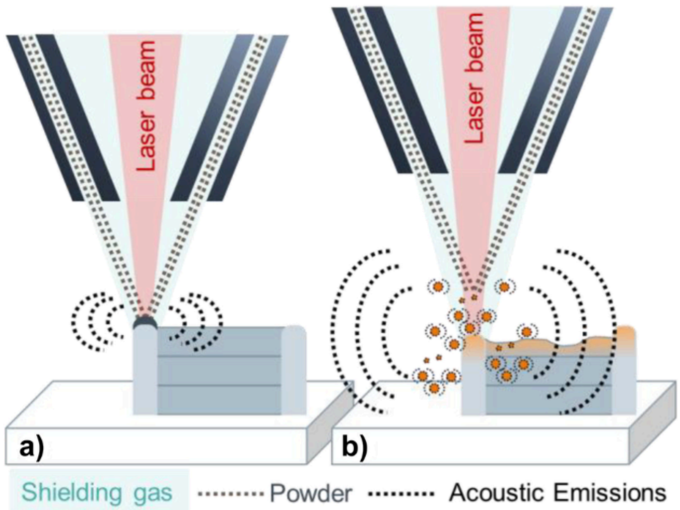
To address this, AE sensors are introduced as a non-destructive, real-time solution. By integrating AE systems directly into the printer's structure, engineers can continuously "listen" to the stress signals emitted during each layer's formation:making the machine effectively self-aware and capable of automated defect detection without human intervention.

Methodology

Acoustic Emission sensing works on a simple but powerful idea: when a material undergoes stress or micro-cracking, it releases high-frequency elastic waves (20 kHz - 1 MHz). These ultrasonic signals travel through the material and are captured by piezoelectric AE transducers attached to the printer frame or component surface.

Each AE sensor converts the mechanical wave into an electrical signal. The signals are then processed using a Digital Signal Processor (DSP) that extracts features such as amplitude, frequency, and event counts. Based on these characteristics, the system can determine whether the detected activity corresponds to harmless background noise or a genuine defect event.

A machine-learning algorithm or threshold-based automation system is used to classify the events in real time. If abnormal activity is detected, such as a sudden spike in amplitude or event rate,the system automatically halts the print or adjusts process parameters like laser power or cooling rate. This transforms the 3D printer into an intelligent automated system capable of self-correction and quality assurance.

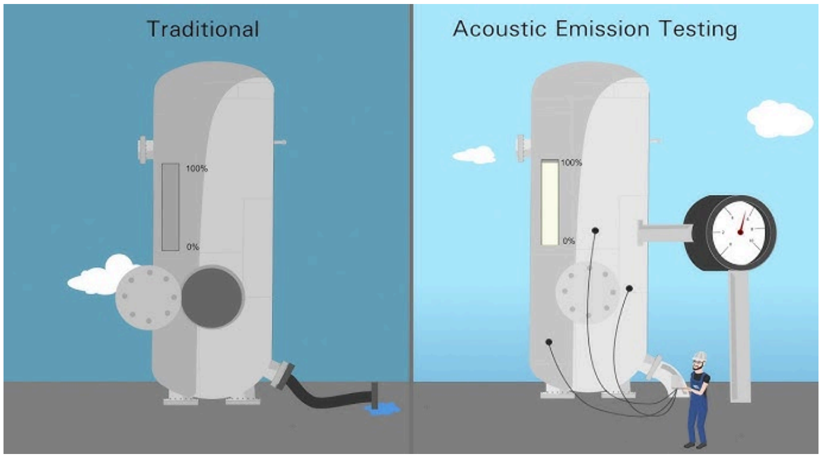


Case Study Example

In one industrial scenario, an aerospace manufacturer integrated AE sensors into a titanium-alloy 3D printing system used for jet engine components. During early experiments, conventional prints often contained micro-cracks that were invisible until post-testing. By installing three AE transducers on the build plate and connecting them to a DSP module, the company achieved continuous monitoring of stress events during layer deposition.

The AE system successfully identified high-energy acoustic bursts that correlated with micro-crack formation. Engineers could visualize the activity in real time through an automated dashboard, allowing them to stop the build immediately, modify the print settings, and resume without wasting an entire component. The adoption of AE-based monitoring reduced defect rates by over 40% and eliminated the need for multiple destructive quality checks.

This demonstrates how AE sensors introduce automation, efficiency, and predictive intelligence into manufacturing lines that previously depended on manual inspection.



Advantages

The application of AE sensors in additive manufacturing shows several advantages:

- **Early Detection:** Identifies defects as they form, not after printing.
- **Automation:** Reduces human monitoring by enabling real-time data-driven decisions.
- **Cost Reduction:** Minimizes wasted material and post-processing costs.
- **Safety:** Especially vital in aerospace, where even micro-defects can cause catastrophic failure.

While AE technology requires signal filtering and calibration to avoid false alarms, ongoing developments in AI-driven pattern recognition are enhancing accuracy. The system's ability to adaptively tune the printing parameters represents a major step toward fully automated smart manufacturing.

Conclusion

Acoustic Emission sensors are revolutionizing additive manufacturing by merging sensing, data processing, and automation into one intelligent framework. Their ability to "listen" to materials under stress enables precise, non-destructive, and instant feedback,turning ordinary 3D printers into self-monitoring systems. As industries continue to demand higher precision and lower downtime, AE-based automation stands out as a next-generation solution for real-time quality control in complex manufacturing environments.

Case Study 2 : SENSORS IN HEALTH CARE

TITLE: Microfluidic Optical Biosensors for Early Detection of Neurodegenerative Biomarkers

Introduction

Neurodegenerative diseases such as Alzheimer's are becoming increasingly common with aging populations. The main problem is that these diseases are usually diagnosed too late,after significant brain damage has already occurred. Traditional tests like MRI or PET scans are expensive and not suitable for routine screening.

To solve this, researchers are developing microfluidic optical biosensors, which are tiny lab-on-a-chip devices that can detect disease biomarkers in small samples of blood or saliva. These biosensors combine microfluidics (movement of very small fluid volumes) with optical detection (using light to sense biomolecules) to provide fast and accurate results.

This case study focuses on detecting **Amyloid-beta (Aβ)**, a key protein involved in Alzheimer's disease, using a microfluidic optical biosensor for early and accessible diagnosis.

Clinical Problem and Objective

Alzheimer's disease (AD) is characterized by the accumulation of Amyloid-beta ($A\beta_{42}$ and $A\beta_{40}$) plaques in the brain. Early detection of these proteins in blood or plasma is difficult because their concentration is extremely low often in the femtomolar range.

The objective of this case study is to describe how a microfluidic optical biosensor can detect these biomarkers efficiently. The system aims to:

- Detect Aβ in small blood samples quickly and accurately.
- Reduce diagnostic costs using low sample volumes.
- Enable portable, real-time testing for clinical and home use.

Working Principle and Methodology

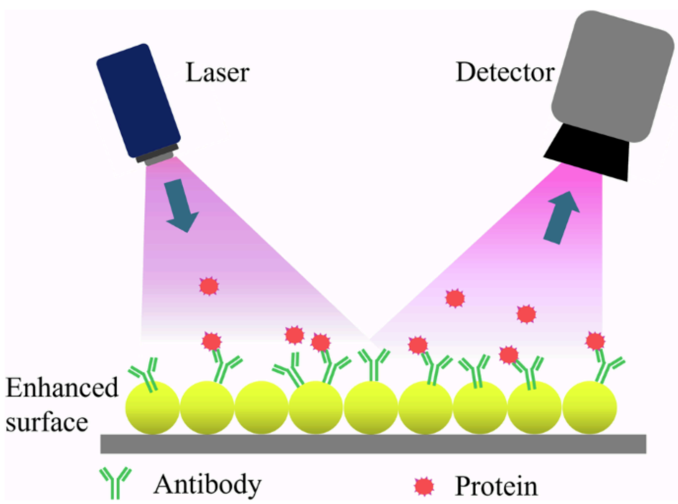
Microfluidic System

The biosensor uses a PDMS-based microfluidic chip with tiny channels that guide a small blood sample (around 5-10 μL) through the device. The chip is designed to automatically control fluid movement, reducing manual errors and contamination.

Optical Detection (Surface Plasmon Resonance - SPR)

At the base of the chip, a thin gold film is used for light sensing. When light hits this surface at a specific angle, it excites electrons called surface plasmons.
If Amyloid-beta binds to the surface, it slightly changes how the light is reflected. This shift in reflected light angle is measured -it's directly proportional to how much biomarker is present.

Because no fluorescent or chemical labels are used, this method is label-free and provides real-time results.

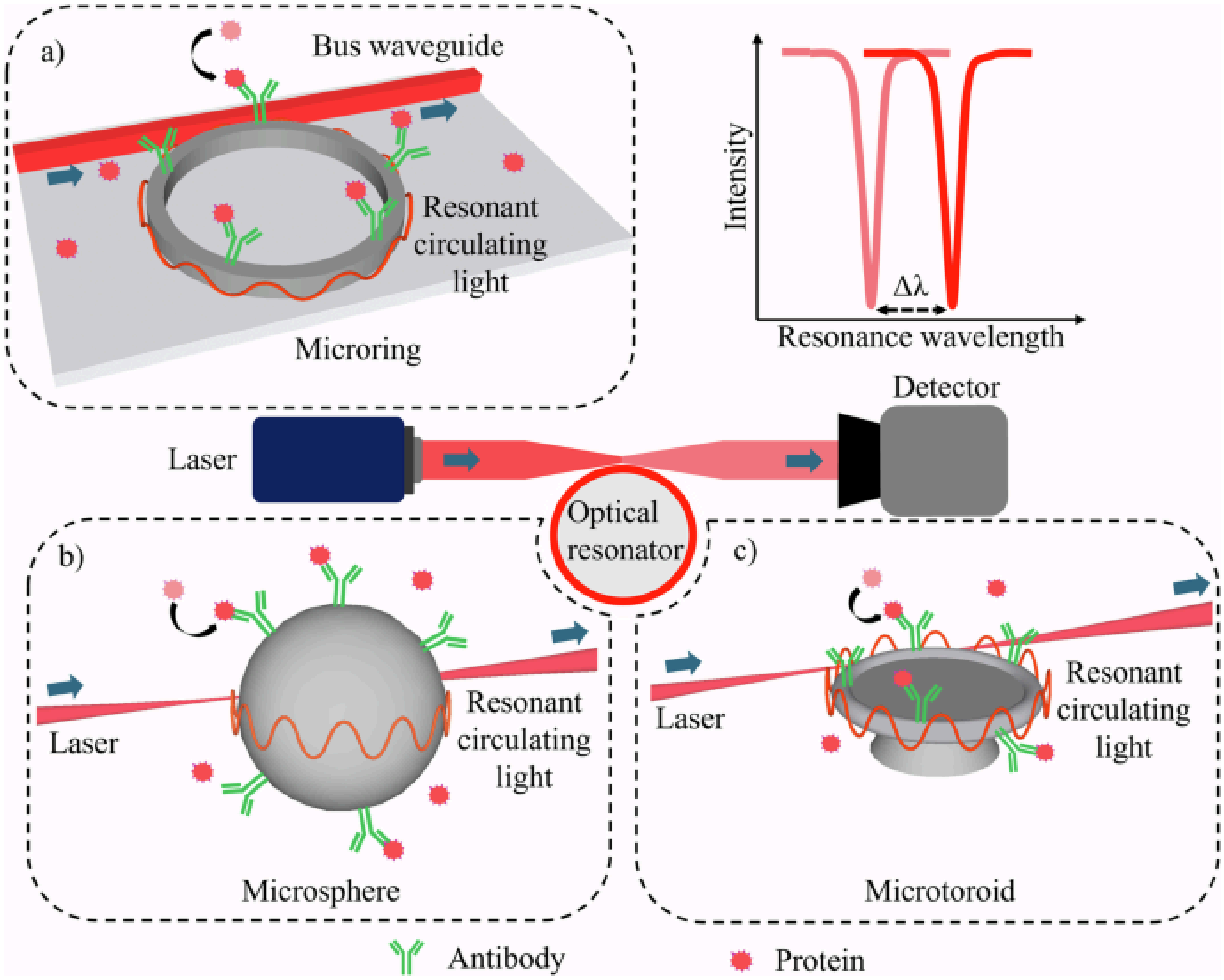


Surface Functionalization

The gold layer is coated with specific antibodies or aptamers that only bind to Amyloid-beta. When the target protein from the blood attaches to these receptors, the change in signal confirms its presence and concentration.

Data Analysis

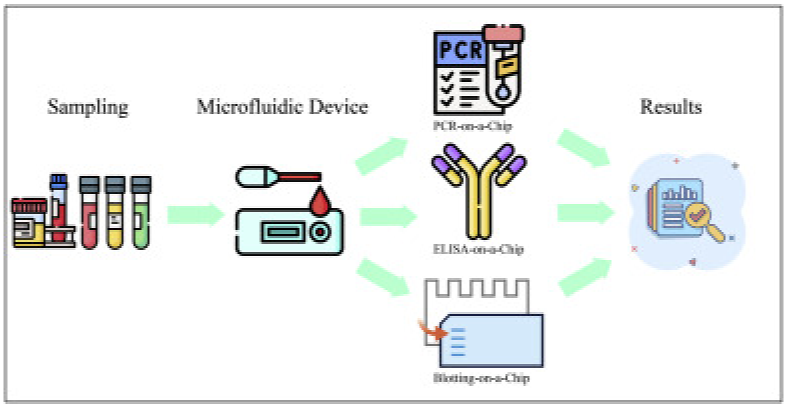
The system converts light changes into a graph called a sensorgram, showing how fast and how strongly the protein binds. These results can be processed by simple onboard software or machine-learning algorithms to classify the patient's risk level.



Advantages

The integration of microfluidics with optical biosensing enables detection of Amyloid-beta at very low concentrations, which was not possible with conventional lab methods like ELISA. The biosensor's high sensitivity, portability, and automation make it suitable for point-of-care (PoC) applications in clinics or home settings.

Additionally, the system requires only a few drops of blood, gives results within minutes, and can wirelessly transmit data to electronic medical records, making it both efficient and user-friendly.



Advantages and Future Prospects

Advantages:

- Rapid and early disease detection.
- No need for chemical labeling or bulky lab instruments.
- Portable and affordable for large-scale screening.
- Real-time data with minimal human intervention.

Future Scope:
In the future, microfluidic optical biosensors could be adapted to detect multiple biomarkers for diseases like Parkinson's and Huntington's, improving diagnosis accuracy. With advancements in nanomaterials and AI-based analysis, these biosensors could become a common part of early disease detection systems worldwide.

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