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Development and Experimental Investigations of a Fiber Optic Color Sensing Probe

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Fiber optic sensors offer several potential benefits over the conventional sensors. Intensity based fiber optic sensors are conceptually simple, ruggedized and cost-effective as they can be implemented using less expensive multimode fibers and their assemblies and other components. The design principles relating to indigenously fabricated Y-guide probe alongwith details of the experimental set up realised for color sensing and the typical measurement data are also presented.

Introduction

Fiber optics has been one of the most exciting developments of the last decade. Although the growth in fiber optics technology has been dominated by the emergence of optical fibers for transmission of telecommunication signals, but in recent years, this field has been receiving greater attention from process engineers on the look out for better and hopefully cheaper methods of sensing chemical and physical parameters in process plants. Fiber optic sensors may go a long way towards meeting these needs due to their unique properties and distinct advantages. They have the potential to work over a wide temperature range. They are immune to RFI, EMI and toxic environments. Fiber optic sensors are in many instances passive and as a result, much more reliable than mechanical and electronic sensors. They offer increased sensitivity, large bandwidth and high data rates and possess geometric versatility. Fiber optics sensors can be easily interfaced with well- established fiber optic data links, facilitating convenient communication with control centres and enabling remote/ in-situ sensing.

A fiber optic sensor system basically consists of a light transmitter, a light receiver, optical fibers or bundles, a modulator element and a signal processing unit. Light is transferred to the measurement point (modulator) using optical fibers or bundles and such a scheme is called extrinsic modulat-ion. If the fiber itself acts as a sensitive element then it is intrinsic modulation which takes place. The main modulation mechanisms employed in fiber optic sensors for detecting physical and physiological parameters are intensity, phase, wavelength, polarisation, time of light or frequency of light. Though phase modulated (or interferometric) fiber optic sensors offer orders of magnitude increased sensitivity over the existing technologies, but for several applications extreme sensitivity is not required, and advantages of intensity sensors like simplicity of construction and compatibility with multimode fiber technology are exploited. Intensity modulation is the simplest method for optical detection which can be carried out extrinsically (reflectance/transmittance measurement) or intrinsically (measurement of attenuation of light due to microbending)[1-6]. This paper reports the design principles, indigenous development of the fiber optic Y-guide color sensor probe, experimental set up realised for color sensing using this probe and the typical results obtained.

Color Sensing Fiber Optic Probe

Design Considerations

Sensing of color is important in numerous industries, laboratories and clinical/ medical facilities. The various uses of color measurement in these areas include colorimetric assays, soil analysis (organic matter and minerals), soft drink colorimetry, boiler water analysis and turbidity applications. The utilisation of fiber optic technology for color sensing represents a major advance in visible/ near IR photometry. Unlike conventional instruments which need taking small samples of test solution in a cuvette, the developed fiber optic color sensing probe will facilitate on-line and in-situ color monitoring in various application areas.

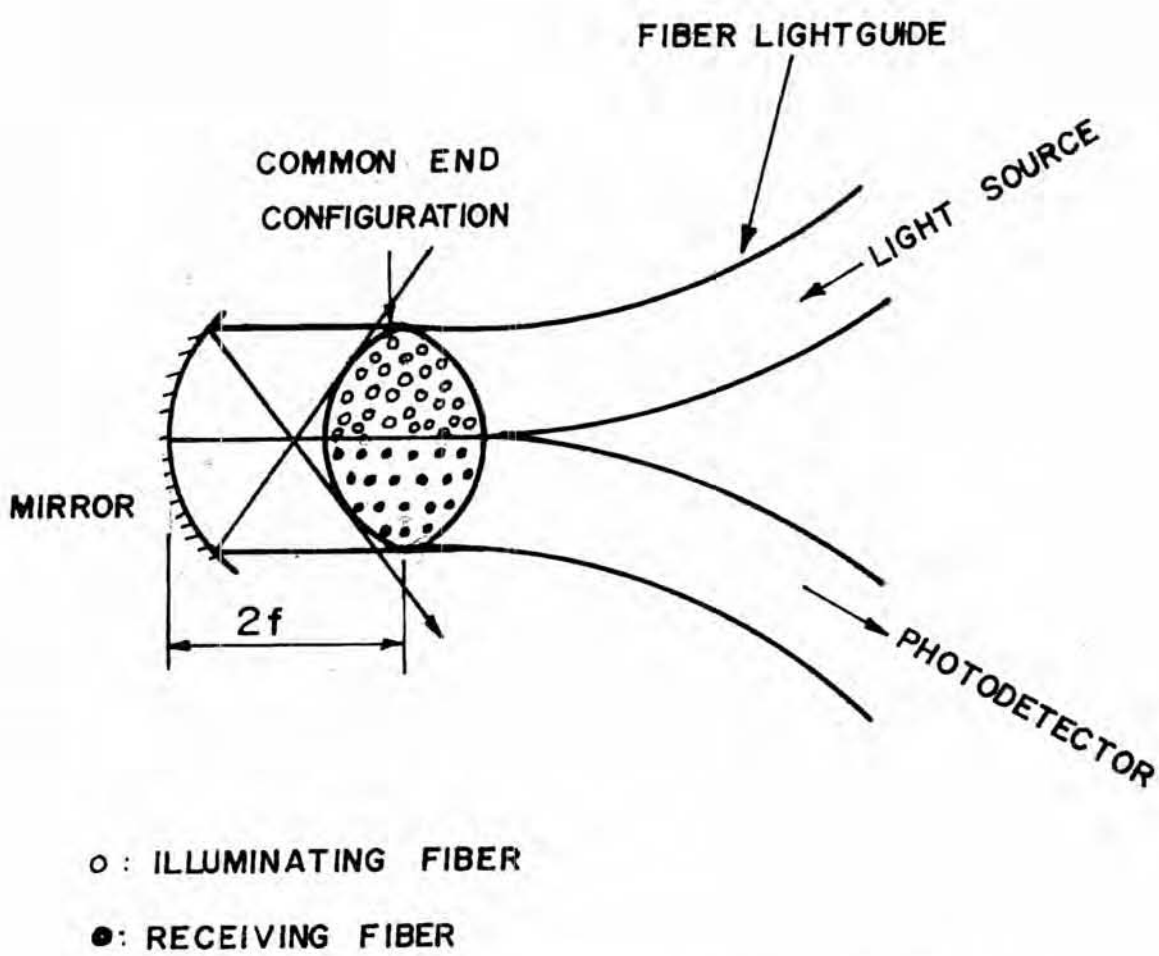

Figure 1 — Coupling of light rays at the common end of semi- circular type color sensing probe.

The fiber Y-guides are in general of three types namely, random, semi circular and concentric-transmit-inside depending on the arrangement of the fibers at the common end[7]. The common end configuration of the Y-guide for this probe was selected of semi circle type as this end is located at a separation of 2f from a concave mirror, where f denotes the focal length of the mirror. In this way, the semi-circular cross-section of the transmitting bundle is imaged on to the receiving semi-circular bundle of the same size thus providing an efficient coupling of light rays as shown in Figure 1. The probe is of about half a meter length and optical glass fibers fabricated on an indigenously designed and built fiber drawing machine[8] were used for developing this probe. The fibers are encased in a crush-resistant flexible metallic sleeving for protection. Figure 2 gives the photograph of the Y guide probe developed in the laboratory while Figure 3 indicates the photograph of the fiber drawing machine designed and built at CSIO.

Figure 2 — Photograph of fiber Y-guide probe developed at CSIO.

Experimental Arrangements for Sensing Color Using Fiber Optic Probe

Figures 4 and 5 show the schematic and the photograph respectively of the experimental arrangement realised in the laboratory for sensing color. Light from a

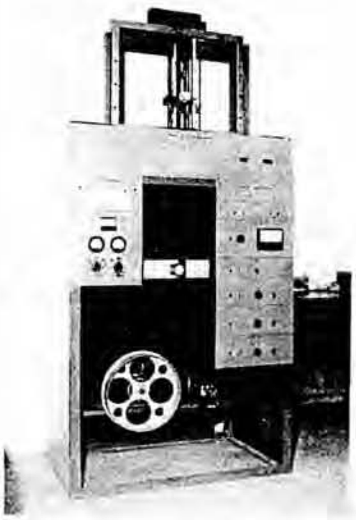

Figure 3 - Photograph of the fiber drawing machine designed and built at CSIO.

50 W quartz halogen lamp is made incident on an optical chopper and then coupled using suitable optics into the transmitting bundle of the Y-guide probe. The probe tip is dipped into the test solution and the light reflected from the mirror and captured by the receiving fiber bundle is focussed on to a Si PIN photodetector using a lens. A complimentary filter is used before the photodetector, because color of the light absorbed is complimentary to the color of the test solution and, therefore, it is intensity of the complimentary color that varies with the concentration of the sample. The accuracy of color measurement in this set up depends on the proper selection of the complimentary filter. The photo detector output in turn is fed to a precision lock-in-amplifier which displays voltage signal corresponding to the intensity of light reaching the detector, giving an estimate of color concentration or percentage transmission of the test solution. This set up works under the linearity limit of Beer's law according to which absorbance of the light by a solution is proportional to its color concentration.

The probe design is such that tip of the probe is interchangeable. In the present case, it is made of stainless steel, while probe of suitable materials can be used with acids and other solvents. The probe is dipped into the test solution which can be in any size container - from a test tube containing 0.5 ml to a large vat or pipeline. Some of the other important features of this sensor over conventional colorimeters include, elimination of the problem of cuvette breakage and cleaning, no contamination of the sample as there is no measurable carry over

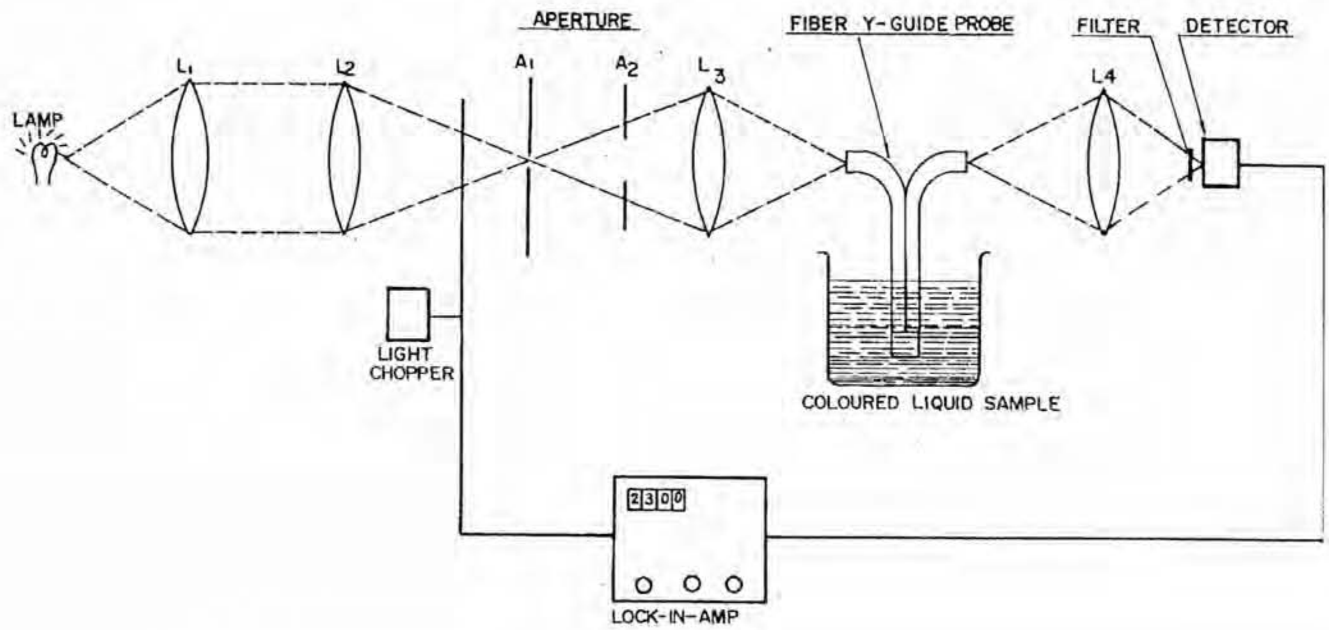

Figure 4 - Schematic of the experimental arrangement realised for color sensing.

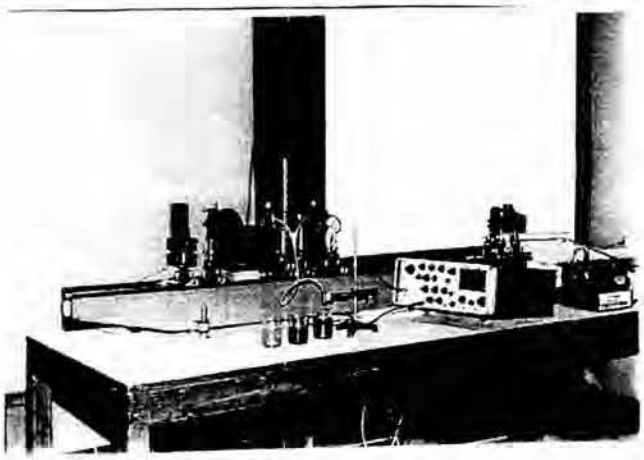

Figure 5 — Photograph of the experimental bench for color sensing.

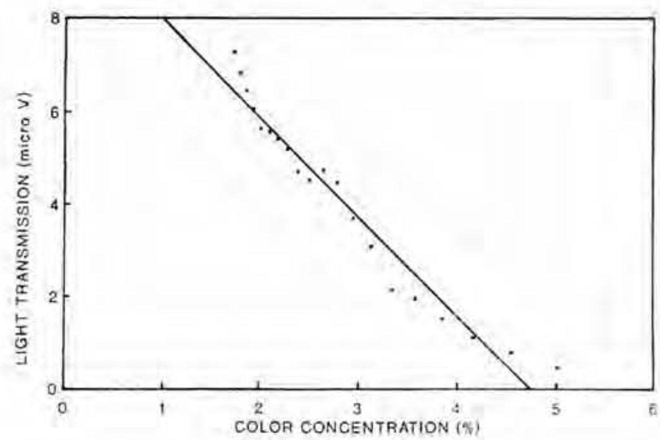

Figure 6— Variation between color concentration (per cent) and light transmittance.

Table 1— Color Measurement Data Using Fiber Optic Sensing Probe

Color Conc. (per cent)	Light Transmittance (uV)
5.0	00.46
4.54	0.79
4.16	1.10
3.84	1.50
3.57	1.95
3.33	2.14
3.12	3.09
2.94	3.70
2.77	4.47
2.63	4.74
2.50	4.52
2.38	4.71
2.27	5.20
2.17	5.42
2.08	5.56
2.00	5.64
1.92	6.06
1.85	6.46
1.78	6.83
1.72	7.26

between tests, errors due to change in turbidity and temperature substantially reduced and measurement possible at any level of ambient illumination since no extraneous light affects the probe.

Results and Discussions

Standard red color samples of known and varied concentrations were prepared using cobalt chloride and their respective light transmittance was measured employing the developed color sensing fiber optic probe. A typical set of measurements data showing the variation trend is indicated in Table 1 and the corresponding graph between color concentration percent and light transmittance is given in Figure 6. It is evident from the graph which is also the calibration chart for this set up, that concentration and transmittance follow an approximate linear relation and this is also expected according to Beer's Law of absorbance. This also indicates that the probe has performed correctly. Employing such a fiber probe, a compact on-line colorimeter can be developed for industrial and other applications.

Conclusion

The design, principles and development of fiber optic Y- guide color sensor probe, its technical features, salient aspects, limitations and experimental investigations using this probe are discussed. The probe design is so versatile that it can also be used for sensing other measurands with minor modifications.

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