Role of Distributed Optical Fiber Sensors for FPGA Based implementation of pulse coding technique –An overview

Yelkal Mulualem #1(*)
#1(* corresponding author) Department of Information Technology, CNCS, University of Gondar Ethiopia .
{ye_mu79@yahoo.com}

M.Mohamed Sirajudeen#2
Department of Information Technology, CNCS, University of Gondar, Ethiopia.{mdsirajudeen1@gmail.com}

ABSTRACT

Over the last few years fiber sensing technology has been rapidly progressing for a wide range of industrial applications in strategic sectors such as energy, transportation and security, also including civil and structural engineering, geothermal and environmental monitoring. Advanced control electronics play a key role in such developments, allowing for significant performance improvement in the sensor systems. In this research paper to discuss the role of distributed optical fiber sensors in the implementation of FBGA based implementation of pulse coding technique. The proposed technique allows for a significant signal to noise ratio enhancement and consequent sensing range extension, allowing for temperature measurement over several tens of kilometres with meter scale spatial resolution.
Keywords: Fiber, Sensor, Optical, Signal and Pulse Coding.

I. INTRODUCTION

The field of fiber optic sensing has seen rapid growth in the past three decades since its first developments in the mid 1970s. Its principles and applications are extremely diversified and numerous mechanisms are demonstrated for the measurement of a variety of physical parameters, such as temperature, pressure, strain, electromagnetic (EM) field, flow, vibration, and chemicals. It has also become attractive for biomedical and biochemical detection [5]. Fiber optic sensors are well known for their intrinsic immunity to EM interference, electrical passivity, high resolution and large dynamic range, and play important role where electronic/semiconductor sensors cannot be apply, such as in electrical hostile, high temperature or highly corrosive environments.[1][4].
Fibre-based Distributed Temperature Sensor (DTS) have applications in a wide range of industrial sector which includes real-time monitoring of industrial processes, health monitoring of industrial and civil infrastructures, etc. Such industrial and civil infrastructures range from oil and gas production to delivery pipelines, from electric power generation to transmission and distribution networks, and from large bridges, dams to even commercial and residential buildings. The monitoring of these structures usually requires the sensors and measurement devices to be able to cover as large area with limited maintenance, low cost per measurement point, and capability of operation in harsh environments. Many different kinds of electrical and optical sensors have been investigated to meet the requirement of such applications. Optical fiber sensors, which have characteristic advantages including intrinsic immunity to electromagnetic interference, high sensitivity, high accuracy, small size, capability of remote operation and survivability in harsh environment, have attracted tremendous research interests for infrastructure monitoring. [2]

In general, the use of Optical fiber sensors has been demonstrated for the detection of a large variety of physical, chemical and biomedical parameters. Most physical properties, including displacement, rotation, temperature, strain, pressure, flow, electrical field, magnetic field etc, can be sensed with optical fibers. Temperature and strain are among the parameters mostly desired in quasi-distributed and fully distributed sensing applications such as industrial process monitoring and civil structure health monitoring. Optical fiber sensors can be configured as a fully distributed sensing mode for temperature and strain measurement, where the measurends can be accessed at any location along a single fiber with a certain spatial resolution [6][7].

This is a unique and powerful characteristic of optical fiber sensors. Common distributed sensing technologies use Rayleigh, Raman, or Brillouin scattering to determine the parameters of interest by measuring the intensity or the frequency of the scattered light. In such applications, the location of the measurends is often determined by the fight time of light pulses and the spatial resolution is determined by the width of light pulses, typically 10ns for a spatial resolution of 1m. Spontaneous Raman scattering effect is commonly exploited to implement

Fibre based distributed temperature sensor (DTS) systems. In Raman-based schemes, the ratio of Raman anti-Stokes (AS) line to Stokes line intensities is usually used for temperature monitoring, since it allows for measurements which are independent of local fibre loss effects and power fluctuations of the laser sources.
The main issue to face in long-range RDTS design is the low (limited) signal to-noise ratio (SNR) due to the weakness of the backscattered Stoke and Anti Stoke traces which generally exhibit optical power levels lower than a few tens of nW. Therefore, the integration of the scattered signal over a relative long time period is necessary to obtain reasonable measurement accuracy [3].

II. RELATED WORK

A distributed temperature sensors (DTS) systems is an optoelectronic device which is able to measure the continuous temperature pro le along the whole length of an optical fibre which acts itself as sensing elements. First DTS prototypes were built about 30 years ago. However, the major technological progress occurred in the last few years in the field of optical and electronic devices has brought the performance of distributed temperature sensors (DTS) systems to such a high level that they are used or required for industrial applications. A distributed optical fiber sensor offers the unique characteristic of being able to measure physical parameters along the whole fiber length, allowing the measurements of thousands of points using a single transducer. [4]

There are two major classification of optical fiber sensing systems that measure space mapped parameters such as temperature and strain. One category is intrinsic distributed sensing in which optical fibers are used for both sensing and light guiding. [14] [6] Intrinsic distributed sensing technologies usually use Rayleigh, Raman, and Brillouin scattering phenomena in optical fiber to determine the parameters of interest along the fiber. The measurands can be determined at any location with a certain spatial resolution. The other category is quasi-distributed sensing in which multiple point sensors are multiplexed in various topology and multiplexing schemes.

An intrinsic distributed sensing system allows the environmental parameters to be measured at any point along the length of the fiber with a certain spatial resolution. It is also called a fully distributed sensing system [7]. Usually, communication grade fiber, which has no discontinuous points, can be used to measure the field over kilometres with a spatial resolution interval from centimetres to meters. Common measurands include distributed temperature and strain along the fiber [7].
The main advantage of this kind of sensors is that the optical fiber is the actual temperature probe. Focusing on Raman based DTS systems, the fibre can be properly laid in contact with the object to be monitored, so that the thermal profile along the object length, surface or volume can be determined without the need for complex arrays of discrete sensors. Moreover, the fibre is immune to EM noise and made of dielectric material, so that it can be safely used in electrically noisy environments.

A high accuracy of temperature determination is achieved over great distances. Typically a DTS system can measure the temperature with a spatial resolution down to 1 m with accuracy within 1C at a resolution of 0.01C. Measurement distances greater than 30 km can be archived and some advanced systems can provide even better spatial resolutions. Thanks to these parameters, they are used for instance to monitor gas or oil pipelines, high voltage underground or sub-marine power cables, nuclear or chemical plant processes, civil infrastructures such as railway or road tunnels, bridges or dikes, and also for aeronautic applications.

III. RESULTANT OBSERVATIONS

The Basic operating principle of distributed temperature sensors (DTS) systems is based on the Optical Time Domain Refctometry (OTDR): a laser pulse is launched into the probing fiber and the temperature dependent backscattered lights are acquired as a function of time. These light components can be guided by different physical phenomena, namely the Raman scattering and the Brillouin scattering [9]. For the following observed information play an important role to achieve the FPGA based implementation of pulse coding techniques for Distributed Temperature Sensors.

A. The Raman Effect:

Backscatter phenomena that occur inside the optical fiber are due to the interaction between the photons of the launched laser pulse and the optical fiber itself. As shown in Figure 1, the light backscattered by an optical fiber segment without any defects or normal characteristics is spectrally decomposed in to three distinct peaks corresponding to three different physical phenomena [11].

Basically the classification is based on the relation between the frequencies of backscattered and incident photons [14]. If these frequencies are equal (i.e. Rayleigh scattering), the phenomenon is called an elastic process, whereas if they are different, the molecule is left in a different quantum state (i.e. Raman and Brillouin Scattering), and process is called an inelastic scattering. Elastic processes are usually grouped under the name of Rayleigh scattering, whereas inelastic ones such as Raman or Brillouin scattering are indicated with the name of the particular physical effect on which they are based.

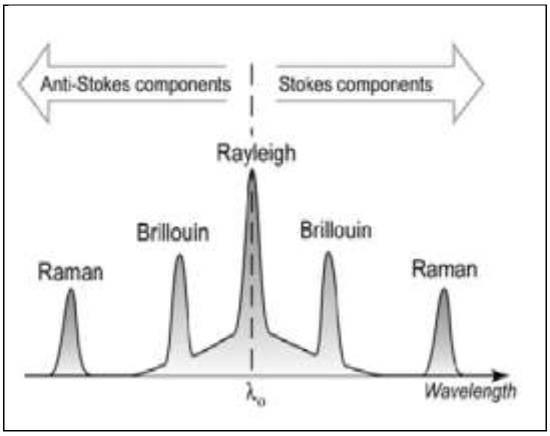

Figure 1. Backscattering Spectrum of Monochromatic wave within an optical fiber

B. Optical Time Domain Reflectometry (OTDR):

Optical Time-Domain Reflectometry (OTDR) is the most widely used technique utilized for the characterization of optical fiber links and distributed optical fiber sensors (DTS) [12][13]. The basic principle is to launch an optical pulse into an optical fiber and examine the time dependent intensity response of the reflected signal. In other words, OTDR launches short duration light pulses into a fiber and then measure, as a function of time after the launch, the optical signal returned to the instrument. As the optical pulses propagate along the fiber, they encounter reflecting and scattering sites resulting in a fraction of the signal being reflected back in the opposite direction. Rayleigh scattering and Fresnel reflection are physical causes for this behavior. By measuring the arrival time on the returning light, the locations and magnitude of the faults can be determined and the fiber link can be characterized.

In the OTDR method, light pulses are launched into the optical fiber. While light propagates in the fiber, a fraction of light scatters in a direction 180^0 to the propagation axis. This back scattering is the combination of Rayleigh scattering caused by the density and structure of material and Raman and Brillouin scattering occurred due to molecular and volumetric vibrations. The scattering sensitive to the measurand (distance, temperature, etc.) are altered at the receiver and variation in the intensity of the altered back-scattered light is determined as a fraction of the measurand. The above figure 2 shows the schematic output of the standard OTDR.

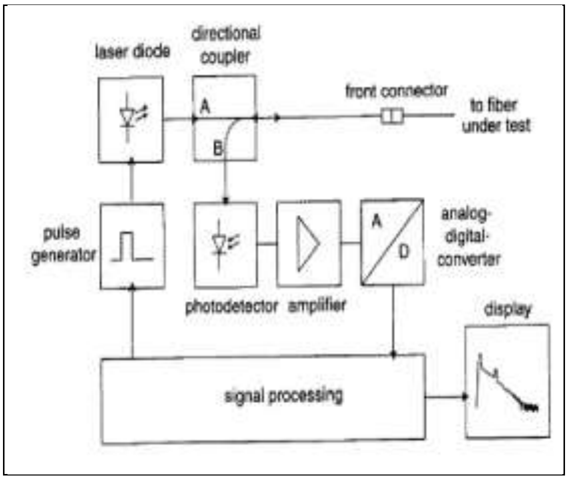

Figure 2. Block diagram of Single pulse OTDR

IV. RECOMMENDATION

This research paper discussed the role and contribution of Distributed Temperature Sensor (DTS) in the implementation of FPGA based implementation of pulse coding techniques. The main objective of the project is to develop a new FPGA architecture suitable to decode the averaged coded Stockes and Anti-Stoke sampled traces in Distributed Temperature Sensors (DTS) systems. This involves the development of an algorithm based of cyclic simplex coding technique and develop the architecture with minimum resource utilization. It will be carried out in the continuation of this work with the DTS framework along with the implementation experimental results.

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