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Implementation of genetic algorithm in an embedded microcontroller-based polarization control system

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ABSTRACT

Implementation of genetic algorithm in a PIC32MX microcontroller-based polarization control system is proposed and demonstrated. The controller measures the signal intensity that is used to estimate the genetic value. This process is controlled by the genetic algorithm rather than referring to the Look-Up-Table as implemented in existing solutions. To reach optimum performance, the code is optimized by using the best genetic parameters so that the fastest execution time can be achieved. An ability of genetic algorithm to work efficiently in polarization control system possesses many advantages including easy code construction, low memory consumption and fast control speed. Genetic algorithm is intelligent enough to be used for endless polarization stabilization and in the worst case, able to stabilize the polarization changes in 300 μs. In the best case the response time can reach 17 μs.

1. Introduction

In coherent optical communication systems, polarization matching between the transmitted and received signal must be guaranteed. The challenge comes due to instability of the polarization when light propagates along the standard single mode fiber (SSMF) (Prat et al., 1995). There have been many technologies proposed to solve this problem, such as polarization controller (Noé et al., 1988), polarization diversity (Okoshi, 1985), polarization scrambling (Hodgkinson et al., 1987) and polarization switching (Habbab and Cimini, Jr, 1988). Among these techniques, polarization controller (PC) is preferable due to bit rate independency and simple receiver configuration (Shimizu et al., 1991). Optimum performance of transmission system requires endless and fast response polarization controller to track polarization variation without any interruption (Hidayat, 2008). In high-speed transmission, even a short time of undesired polarization mismatch may cause loss of data. The first electro-optic endless polarization control uses an analogue electronic feedback loop. The response time of the control loop is about 150 ms (Heismann & Whalen, 1991). Another technology involves an electro-optic polarization transformer with a simple electronic feedback circuit. The response time of the polarization trajectory is about 20 ms, which is better than the previous one (Heismann & Whalen, 1992). For improving control speed, many algorithms have been proposed for polarization controller, which were developed with sophisticated programming and high complexity (Hidayat, 2008).

In this paper, we propose a new control algorithm for polarization control system based on genetic algorithm (GA). We use and develop the intelligent algorithm to achieve better performance with minimum cost. The code construction of the algorithm is simple and consumes low size of memory besides providing fast speed. To our knowledge, this is the first report on the implementation of GA with embedded microcontroller to realize automatic polarization control system.

2. Principle of operation

The overview of an optical transmission link with a polarization control system is depicted in Fig. 1. An automatic polarization control system is located after the link and before the receiver to recover the polarization state of the launched signal. Two photodiodes (PD) are used, where PD_1 is used for receiving the signal and PD_2 for feeding the information to the control system. In this paper the control system works simply based on the aim to minimize the optical power received by PD_2. The objective is to assure that the

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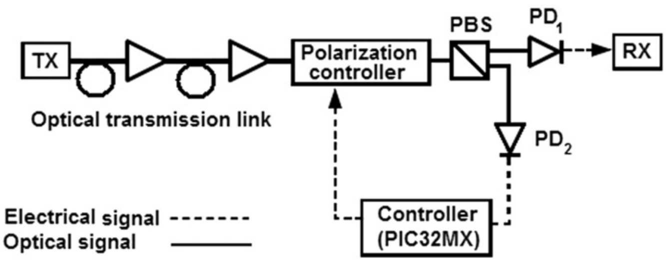

Fig. 1. Overview of an optical transmission link with a polarization control system.

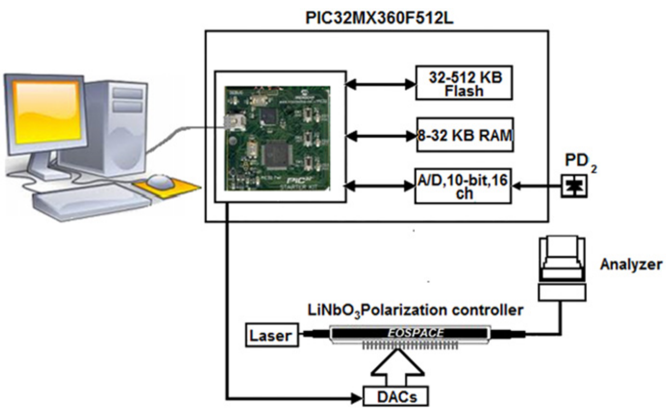

Fig. 2. Schematic diagram of polarization control setup.

received signal with random polarization state is transformed into a highly polarized signal with stable polarization state. The signal going to both PDs is isolated based on the principal state of polarization (PSP) by using a Polarization Beam Splitter (PBS). Minimizing the signal to PD_2 means that all signals are directed at PD_1. This means that the received signal is highly polarized and the launched polarization state is recovered.

The control setup for the polarization control system is schematically shown in Fig. 2. The controller is realized by using a PIC32MX360F512L microcontroller, where the developed algorithm is embedded. This microcontroller has an onboard analog-to-digital converter (ADC). One of the ADC pins is connected to PD_2, which is used to monitor the power. The control process is started when there is power detected and stopped when the power is suppressed to a minimum value. The control signal that consists of the decision produced by the algorithm is converted to analog signal by using digital-to-analog converters (DACs). The DACs output are fed to the $LiNbO_3$ polarization controller. The monitor is used to display the status of the controller where the computer is important to retrieve additional information and changing the operation of the controller. We have developed an automatic polarization control system with an integrated-optical polarization controller in X-cut, Z-propagation $LiNbO_3$. The device consists of 8 cascaded integrated polarization transformer stages each of which can be electro-optically adjusted by applying different voltages (positive and negative voltages).

This controller has 24 pins where 8 of them are grounded. The other 16 pins are used for control purposes. According to Heismann & Whalen (1991, 1992) only three stages are sufficient to produce different states of polarization. In this paper, all eight stages are used to achieve fast operation and high accuracy (Hidayat, 2008). The value of finite word length used in our experiment is 16. This value is sufficient for GA to operate for producing different and wide range of voltages in each generation, besides optimizing the parameters to achieve desired fitness value and control speed. Therefore, 16 electrodes are used to recover the original polarization state. By changing the voltage applied to each electrode, which is determined by the control algorithm, the state of polarization is changed. Proper control of the 8 stages by GA allows for fastest endless reset-free polarization control.

3. Genetic algorithm

GA is embedded in a PIC32MX microcontroller, which acts as a brain that determines the whole operation of the system. The operation is based on the natural selection scheme and can be parameterized for solving optimization problems. GA is evolutionary algorithm that mimics the manner of natural evolution and self-adaption to solve difficult problems (Greenwood & Tyrrell, 2006). GA operates on the chromosomes. In general, chromosomes are any point that is applied to the fitness function. Fitness function is an objective function that needs to be minimized in our case. Each chromosome is assigned a "fitness score" referring to the quality of the solution offered to any given problem (Greenwood & Tyrrell, 2006). In other words, all possible solutions can be represented as a population, which is an array of chromosomes. The population size depends on the nature of the problem. In this paper, population size is recognized as an 8×16 matrix. The general form of the population matrix of GA code consists of a minimum number of 20. GA population size can be any even number that is greater than 6 because of crossover operator. In this system, to decrease the response time and number of generation, the two possible values of 12 and 8 are chosen to be evaluated. Finally the population size of 8 is chosen for less time consumption. Sixteen chromosomes in the matrix refer to the number of polarization controller pins. Different operators applied to the GA are the selection methods, crossover and mutation. The selection process creates a new generation from the current generation involving two steps. It starts with the initial population, which is randomly produced. Selection is applied to the initial population to create an intermediate population. In the intermediate population, chromosomes which are called parents that contribute to the population at the next generation are chosen. These chromosomes are selected by one of parent selection techniques, where children are produced from the parents (Greenwood & Tyrrell, 2006). Children are produced either by making random changes to a single parent (mutation) or by combining the two parents (crossover) to the intermediate population. Both operators are essential to the GA. While crossover enables the algorithm to extract the best index from different voltages and recombine them into potentially superior children (Deb et al., 2002). Mutation adds to the diversity of a population, and thus increases the chance that the algorithm will generate voltages that control the PC to reduce the intensity detected at $PD_{2.}$

The process of going from the current population to the next population constitutes one generation in the implementation of a GA (Deb et al., 2002). In the first generation, the current population is also the initial population. The new populations are generated to replace the old one. This process is repeated until desired fitness value (minimum intensity at PD_2) is detected. In this experiment, the minimum intensity at PD_2 is fixed at 0.05 V.

3.1. Genetic algorithm for polarization control system

The structure of complete control algorithm is implemented in Fig. 3, which attempted to control all interface modules such as ADC and DACs. In the ADC module, the feedback signal (that is the photo-intensity) must be detected by a photo detection circuit and then converted by an analog-to-digital converter (ADC) to the discrete binary representation. The value of photodiode voltages is checked. If it reached 0.05 V, the control stops. The driving