STOCHASTIC PREDICTION WITH PARTICLE SWARM OPTIMIZATION

by

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DEDICATION PAGE

To my parents Murugesan S P & Senthamarai Murugesan,

To my brother Prabhu Murugesan,

- for their unconditional support and affection.

To Kiruthika for her trust in me to start our future together.

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ABSTRACT

Scientific research involves random processes which are complex and unpredictable in nature. Higher the understanding of the randomness in the research field the better understanding of the process and more accurate the results. Optical electronics has its fair share of random processes that remain unexplained till date. The stochastic nature in the process such as spontaneous emission, polarization effects, Phase noises, non-linearity in losses are still unexplained. These processes contribute to the degradation of optical devices which could be avoided with a better knowledge of the unpredictable nature involved in these processes.

This research is an attempt to study the interaction of random parameters incorporated within Particle Swarm Optimization (PSO) algorithm by using it as a standalone algorithm for prediction and estimation. PSO has been used in almost all possible fields of research due to its versatility, superior accuracy over other optimization algorithms and high convergence ratio with optimal initiation parameters.

Through this research a new multidimensional model of PSO is proposed. This model uses the random factors involved in the environment as a parameter in the algorithm. PSO has been combined with factors influencing randomness in the environment to analyze, predict the possible outcomes in the future. The model has been tested for accuracy, adaptability and consistency. The foreign exchange market is used as a test environment. Possible applications and future work are also discussed.

LIST OF ABBREVIATIONS USED

ABBREVATIONS

PSO	Particle Swarm Optimization
ANN	Artificial Neural Networks
NN	Neural Networks
EC	Evolutionary Computation
AIS	Artificial Immune System
FS	Fuzzy Systems
SI	Swarm Intelligence
GA	Genetic Algorithms
GP	Genetic Programming
EP	Evolutionary Programming
ES	Evolution Strategies
ACO	Ant Colony Optimization
FOREX	Foreign Exchange
OTC	Over The Counter
USD	United states Dollar
EURO	European Dollar
CAD	Canadian Dollar
GBP	British Pound
CHF	Swiss Franc
JPY	Japanese Yen
AUD	Australian Dollar

NZD	Newzeland Dollar
BOT	Balance Of Trade
CPI	Consumer Price Index
FXR	Foreign Exchange Reserve
GDP	Gross Domestic Product
IFR	Inflation Rate
IR	Interest Rate

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CHAPTER 1 INTRODUCTION

Researching on the unknown has been of keen interest to humans, as this forms the base of all development that the human race has encountered so far. From the discovery of fire to sending people to Mars, the inquisitive nature of human kind forms the fundamental stone of all the Inventions, Discoveries, Development and Existence of the human race. Even in all the discoveries that the human race has made so far, there are about a lot of unexplained processes which are random/chaotic. Our inquisitive nature keeps us going over all the obstacles. There are two ways of handling the unknown, overcoming this unknown by alternate methods/improvements in the systems or analyzing the random process itself to master it. This research work is one such attempt to aid the study of random processes.

Randomness involved in various fields of research is given high priority due to its complexity and significance as it's unpredictable. A better understanding of the randomness in the research leads to a better understanding of the process and more accurate results. Researchers have been trying to develop tools and algorithms to statistically evaluate the randomness in various process. This eventually will help us explain the existence, study the pattern, control the process and avoid any consequences. Understanding the randomness involved in various fields of research is given higher importance.

In every field of Engineering, random processes are abundant and large amounts of effort is put in to study these processes. Research on such processes focusses mainly on understanding the root cause of the process and eliminating the randomness in the process. Optical electronics has its fair share of random processes that remain unconquered till date. The stochastic nature in processes such as spontaneous emission, Stimulated emission, speckle in lasers, polarization effects, phase noises, non-linearity in losses is still unexplained [1] [2]. These processes contribute to the degradation of optical devices which could be avoided with a better understanding of the randomness involved in these processes [1].

This research work aims at using evolutionary computation techniques specifically Particle Swarm Optimization (PSO) to study these stochastic processes. The use of evolutionary computation techniques to study stochastic processes is justified by the fact that these techniques are widely used in recent years to study and optimize various processes in engineering and computer science [3].

To study the stochastic behavior in Photonics using evolutionary computation techniques (PSO), we need to test the algorithm for its limitations, adaptability, robustness, complexity, accuracy, efficiency and reliability. A preliminary investigation of this technique in a stochastic environment showed signs of a promising new field of research in explaining random processes [1]. This demands for an extensive study of the characteristics of this algorithm before it could be applied to Photonics.

1.1 Research Aim

To understand and study the characteristics of PSO in using it for a dynamic stochastic environment, we need to test the algorithm in an environment which is controlled by various factors. These factors all should behave randomly and the environment should exhibit total randomness in its behavior. This should provide a detailed understanding of the various aspects of PSO that would strongly support the fact that PSO could be used as a standalone algorithm for complex dynamic stochastic environments. This is a relatively unknown field of study with very initial literature to support. This study would include trial and error attempts of various combinations of PSO parameters which prove successful in supporting our study. This study would also include a method of self-evaluation or correction method of computation within the PSO technique.

1.2 Research Objective

The objective of this research is to test PSO in the complex stochastic environments to predict the nature of the random processes. Working towards this includes a detailed study of the random factors involved in the environment, statistical evaluation of these factors and use them as random factors in PSO. Various combinations of PSO parameters have to try to find optimal convergence of this algorithm in suck a complex and dynamic environment. This will also include an error evaluation technique, innovative methods of using the randomness involved in PSO to arrive at a set of outputs so that we get closer to testing the PSO algorithm for accuracy. This algorithm will be tested with various scenarios with a similar set of parameters to understand the adaptability, complexity and efficiency of this algorithm in dynamic stochastic environments with similar factors resulting from a totally different scope.

1.3 Research Contribution

One of the major contributions to this relatively new field of is the use of PSO as a stand-alone algorithm for prediction in a complex stochastic environment. The use of multiple random factors leads to randomizing the existing test environment which is a new approach. The use of an error evaluation and minimization technique based on previous predictions is a new addition to conventional PSO technique. Innovative methods of using the randomness involved in PSO to arrive at a set of outputs is also new in the PSO technique. The major contribution is that this would take us a big step closer to implementing this algorithm for stochastic problems in Photonics.

1.4 Organization of the Thesis

This thesis is organized as follows, Chapter 2 talks about random processes in Photonics. Chapter 3 explains Computational intelligence and the reason behind using PSO. Chapter 4 explains PSO technique and its parameters. Chapter 5 explains the proposed Model Chapter 6 explains implementing the PSO algorithm in a stochastic environment. Chapter 7 contains the procedure for training, prediction and analysis of training results. Chapter 8 presents the prediction results along with its analysis & evaluation. Chapter 9 is comprised of conclusion, recommendations for future work.

CHAPTER 2 STOCHASTIC PROCESSES IN PHOTONICS

Optical fiber technology paved way for high speed communication systems with increased bandwidth, higher efficiency and cost effectiveness. This has led to a huge increase in demand for Ultra-fast optical devices. This is a multi-billion dollar industry, attracting a lot of research for further development [4]. Optical fiber electronics or Photonics has its fair share of stochastic processes. The exponential growth in this industry has attracted extensive research to study the various nonlinear optical phenomena which limit the efficiency of these communication systems. Much of the research focuses on finding alternative techniques to compensate for degrading effects in optical communication systems like stimulated emission, spontaneous emission, Quantum/phase/shot Noise, Speckles in lasers. Various conventional numerical modelling techniques used to explain these processes have difficulties and limitations in simulating these processes [5]. Some of these stochastic processes are explained in the following sections.

2.1 Spontaneous Emission

Spontaneous emission is the process in which an electron in excited state **E2** decays to the ground State **E1** by emission of a photon of energy **ħv** without the influence of any external field or photon after a certain interval of time. This photon propagates in some random direction [6]. Figure 1 explains the spontaneous emission process[7].

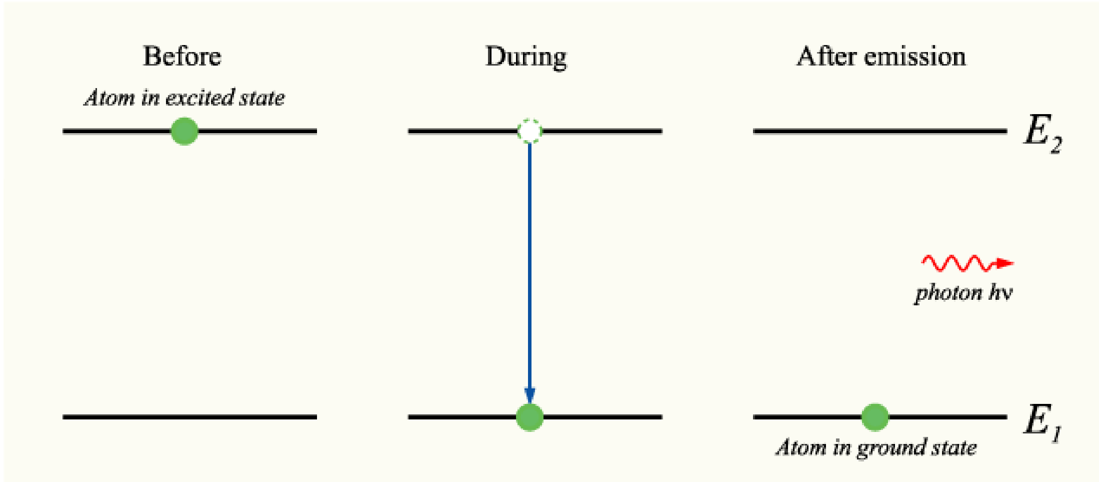

Figure 1 Spontaneous Emission

The rate of spontaneous emission, the time interval for which electron stays in excited state are determined by various factors like configuration of the atom, electric field distribution in the medium. The rate of spontaneous emission is highly stochastic in nature and is dependent on the electric dipole moment associated with the transition between excited to ground energy level. The electric dipole moment is a vector with phase direction associated with the energy levels. The phase direction which determines the nature of interaction between the system and electromagnetic wave of specific polarization. Its direction also gives the polarization of the electron transition from excited to lower energy level. As the spontaneous emission in polarization is stochastic, a detailed study of this stochastic process would pave way for enhanced and efficient ways to control or reduce this type of emission [1].

2.2 Stimulated Emission

Stimulated emission is the process in which an electron decays from excited state E2 to ground state E1 stimulated by an incident photon of energy **ħv.** This decay process further emits a photon of energy **ħv** [6]**.** The incident photon is not lost, but it helps in generating another photon, both of which are of the same frequency, phase, direction and polarization. Figure 2 explains stimulated emission process [7].

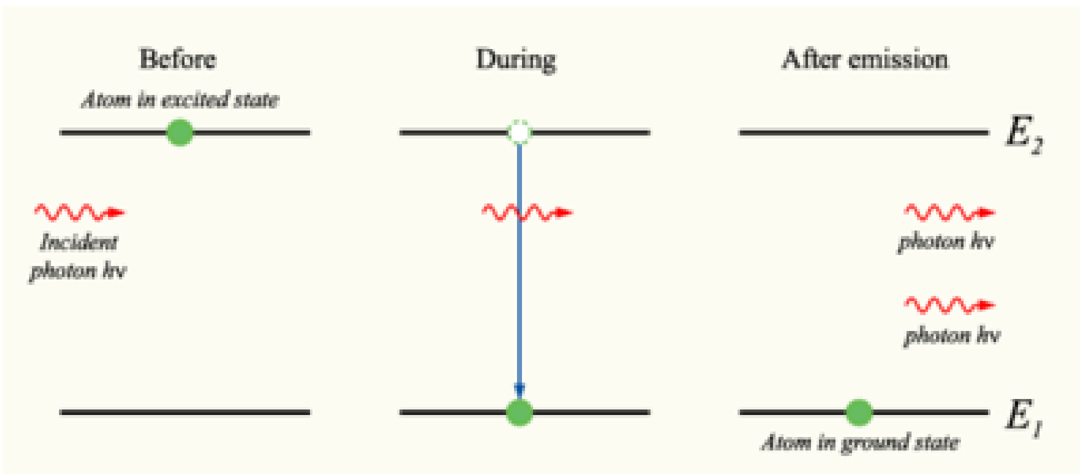

Figure 2 Stimulated emission

The incident photon and emitted photon, exhibit coherent behavior when they have identical direction, phase and frequency. This leads to optical amplification during which the characteristics of many emitted photos can differ because of Quantum effects. The atoms in laser medium are at generally at constant temperature, which in turn leads to difference in wavelength of photons emitted by electrons due to the Doppler Effect. These processes exhibit a highly stochastic nature. The performance of these processes plays an important role in designing optical devices. Hence a detailed study of this stochastic process would result in better optical devices.

2.3 Quantum /Phase/Shot Noise

In optical fiber communication systems, the fluctuations associated with the atomic or quantum properties of a physical quantity are called Quantum noise. It is also referred to as shot noise as most systems use amplitude modulation. In some lasers, the uncertainties in electric field result in a combination of fluctuations in both amplitude and phase information. Hence, it's also referred to as Phase noise [8] [9]. Figure 3 shows the Intensity noise spectrum of a solid-state laser [10].

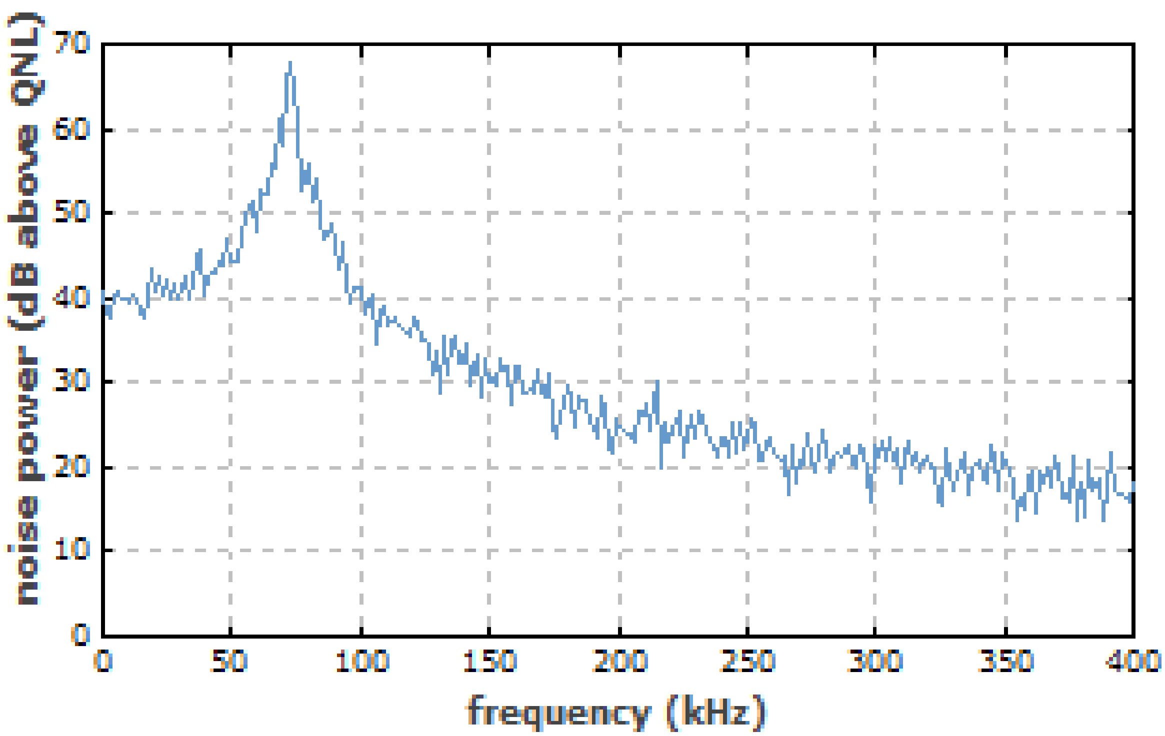

Figure 3 Intensity noise spectrum of a solid-state laser

Some Typical effects of this quantum noise are [11]

a. Excess noise in optical amplifiers (Amplifier Noise)
b. Spontaneous emission of excited atoms
c. Spontaneous Raman scattering
d. Parametric fluorescence
e. Partition noise occurring at beam splitters

Quantum noise is a result of various random factors like

a. Nonlinearities in Fibers,
b. Reservoir effects like Raman scattering
c. Use of amplifiers
d. Use of filters

All these factors contribute towards quantum noise and thus it's very stochastic in nature. Various mathematical models used to analyze Quantum noise had limitations due to the number and nature of photons involved [12]. Hence a newer multidimensional approach to explain the stochastic nature of Quantum noise is essential. If developed, this would be a major milestone in the design of high speed switching devices and optical fiber communication system.

2.4 Speckles in Lasers

Optically rough surface when illuminated with a highly coherent light source like a laser, the scattered pattern makes the surface appear as a fine granular structure with alternately bright and dark spots. A similar phenomenon is observed when coherent light travels through a medium with varying refractive index. This phenomenon is called as Speckle in Lasers. This is also considered as noise, as the variations in the surface or the medium result in a random distribution of dark and bright spots of different shapes [13], [14]. When a laser light the change in Speckle pattern associated with changes to the illuminated surface is called as Dynamic Speckle [14], [15]. This activity is also used to measure activity in a few applications, example Optical mouse. A typical speckle pattern is shown in Figure 4 [16].

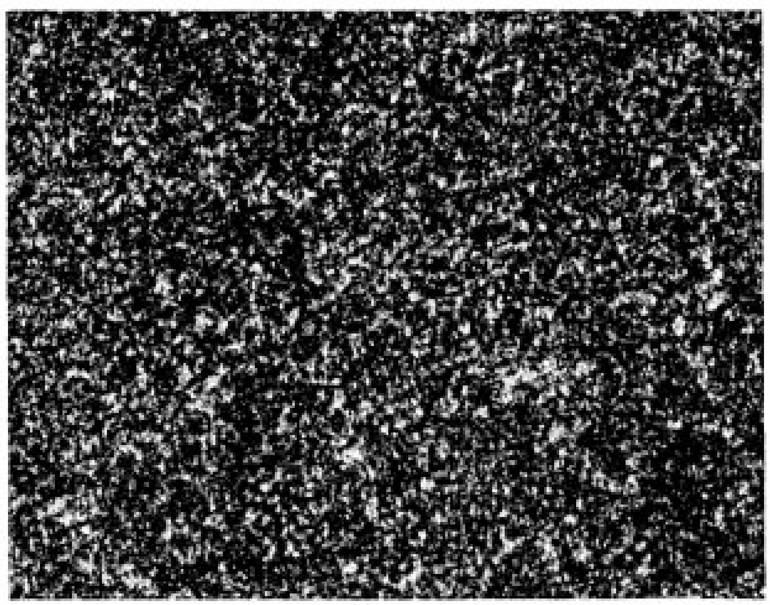

Figure 4 Speckle pattern

The same phenomenon observed in biological materials is called a Bio Speckle [17]. This property has been found useful in various applications. All the Methods of analysis for speckles recommended for further analysis due to its stochastic nature [18]–[20]. Hence a new Multidimensional stochastic approach could yield a better analysis.

CHAPTER 3 COMPUTATIONAL INTELLIGENCE

Intelligence is defined as the ability to reason, to think and to understand and profit from the experience. Creativity, skill, consciousness, emotion and intuition are also considered to be aspects of intelligence. It defines the ability to learn, adapt and survive changes both internal and external. For long intelligence was considered to be a process of the human brain. In mid-1900's Alan Turing camp up with the idea of machines that could mimic the thought process in Human brains. Turing strongly believed that there was nothing a human brain could do that a well-designed machine could not do. This paved way to a new field of intelligent computing systems. Since then various computational intelligence techniques have been proposed, accepted and have even successfully solved many complex computational issues. Enormous success has been achieved in various fields of engineering through these biological or natural intelligence based research leading computationally intelligent system [21]. This is an evolving field with new ideas, methods and applications [22] . The five main paradigms of the computational intelligence area are

i. Artificial Neural Networks (ANN)
ii. Evolutionary Computation (EC)
iii. Artificial Immune System (AIS)
iv. Fuzzy Systems (FS)
v. Swarm Intelligence (SI)

3.1 Artificial Neural Networks (NN)

Artificial neural networks are intelligent computing systems which are based on the human brain. It's estimated that the human brain has 10-500 billion neurons, which are grouped into 1000 different main modules, each comprising of approximately 500 neural networks [21]. Artificial neural networks are an algorithmic modelling of neural systems similar to that of a biological human brain. They are designed to exhibit abilities similar to that biological neurons in the human brain. Figure 5, 6 show the structure of a biological neuron and the process flow in an artificial neuron[21].

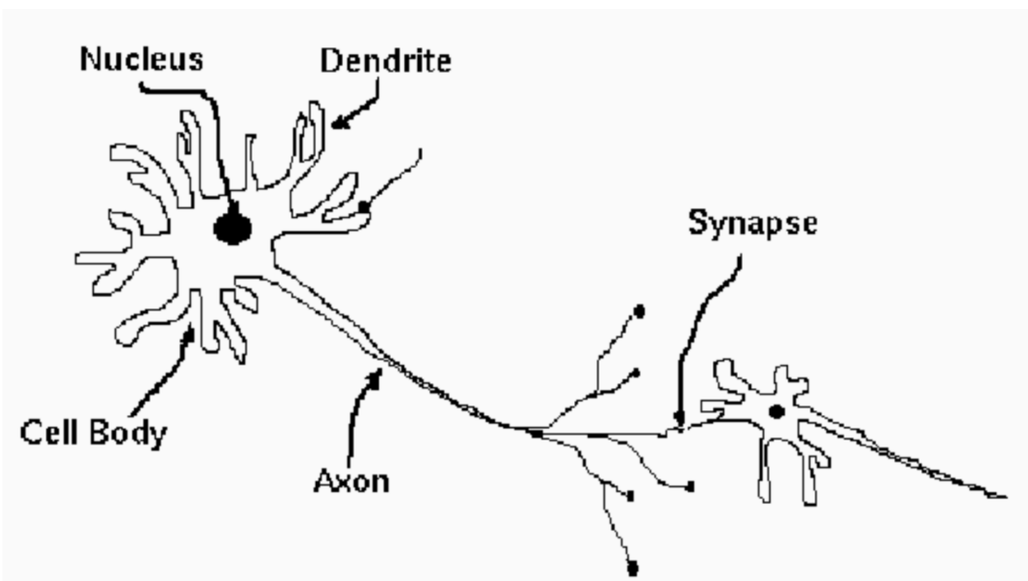

Figure 5 Biological Neuron

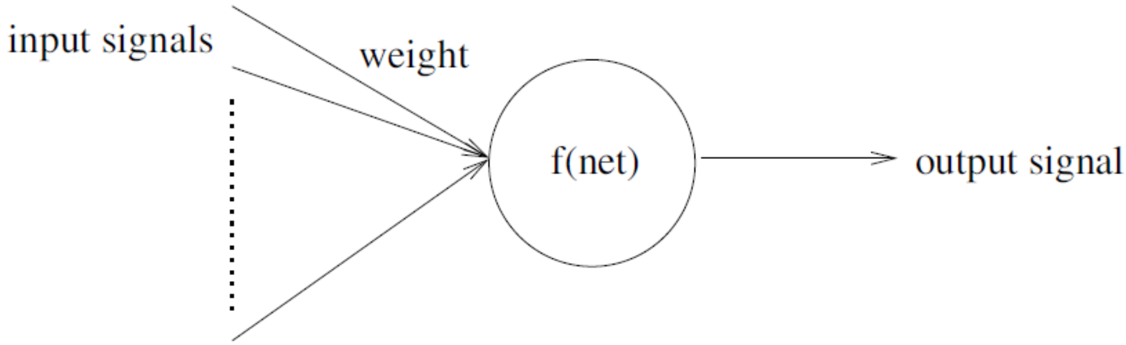

Figure 6 Artificial Neuron

The conduction of neural signals in the human brain in mimicked to provide a process flow to an artificial neuron. Each artificial neuron has a specific task defined in the function and its analogues to a miniature processing unit. A network of theses artificial neurons arranged in layers or groups performing a specific or set of tasks is called as an Artificial Neural Network (ANN). Based on the layering or arrangement of neurons ANN's have been grouped into

- Single Layer NNs
- Multilayer Feedforward NNs
- Temporal NNs
- Self Organizing NNs
- Combined Supervised or Unsupervised NNs

Artificial neural networks are used in various applications including data mining, image processing, robotics, diagnosis of diseases, forecasting etc.

3.2 Evolutionary Computation (EC)

Biological evolution is the process in which characteristics of parents are inherited by off springs and offsprings with desirable characteristics survive. The basic concept is survival of the fittest. Techniques using the concept of evolution to solve complex problems are grouped under evolutionary computation [22]. These are algorithms based on a population of Individuals. Each individual is defined by a chromosome, which has a specific set of characteristics. Each characteristic of an individual is called as Gene and the individual value of a gene is called an Alle. The combination of one or more characteristics of two or more individuals is called crossover which results in offspring. Off springs produced contain characteristic of both or all parents. These characteristics could be all good, bad or different combinations of both. This determines their survival, which is evaluated by a function or set of functions that determine the eligibility to survive and reproduce. Offsprings that inherit good characteristics survive and reproduce again. Some individuals in a population may incur changes to their genes which is termed as mutation. Evolutionary computation algorithms are grouped into

- Genetic algorithms (GA)
- Genetic programming (GP)
- Evolutionary programming (EP)
- Evolution Strategies (ES)
- Differential evolution
- Cultural evolution
- Coevolution

All of the above mentioned techniques are based on the simple concept of evolution with little or big variation in the algorithm process flow. Algorithms based on evolutionary computation techniques have been found very useful in real world applications for data mining, fault diagnosis, classification, clustering, scheduling and time series approximation.

3.3 Artificial Immune System (AIS)

The human immune system is a set of cells and molecules that work along with other systems like neural or endocrine to protect & prevent the human body from harmful microorganisms or particles and diseases. The harmful microorganisms like viruses, bacteria are known as pathogens. The immune system detects such pathogens or unwanted particles with the help of a specific set of molecules on their surface called antigens. These antigens in turn trigger the immune system to work on eliminating these pathogens or unwanted particles. The human immune system exhibits many characteristics such as uniqueness, autonomous, recognition of foreigners, distributed detection, and noise tolerance. Based on this concept of biological immune systems a new field of computational paradigm was established in the late 1990s [23]. This was called artificial immune system (AIS). Based on the nature of the AIS, they are modeled into four categories [21]

- Classical View
- Clonal Selection Theory
- Danger Theory
- Network Theory

Some examples of AIS based algorithms are [24]

- Negative selection algorithm
- Clonal selection algorithm
- Immune networks
- Dendritic cell algorithm

These systems have been found to have an amazing pattern matching ability which is used in detection of abnormalities, pattern recognition, classification tasks. Some of the practical applications of AIS are in computer virus detection, fraud detection and information processing.

3.4 Fuzzy Systems (FS)

Fuzzy systems are a unique computational technique which operates on the concept of traditional set theory. This is based on the concept that human reasoning is not always exactly similar to the binary system of 1or 0 which literally translates to yes or no. These systems are designed to use approximation in human behavior in solving complex problems. This approximate reasoning in these systems is determined by fuzzy sets and fuzzy logic. The major feature of fuzzy systems is its ability to realize a complex nonlinear input–output relation as a synthesis of multiple simple input–output relations [25]. Fuzzy systems are used extensively in vehicle transmission systems, automotive braking systems, Control systems, home appliances, controlling traffic signals [21].

3.5 Swarm Intelligence (SI)

Swarm intelligence is a computational technique based on the collective behavior of individuals in a social group. The collective behavior is attributed to the interaction between individuals with thin the group. The group is referred to a Swarm. The typical swarm is characterized by the following properties [26]:

- Swarm consists of many individuals
- The individuals are relatively homogeneous (i.e., they are either all identical or they belong to a few typologies).
- The interactions among the individuals are based on simple behavioral rules that exploit only local information that the individuals exchange directly or via the environment.
- The overall behavior of the system results from the interactions of individuals with each other and with their environment, that is, the group behavior self-organizes.

There are various examples of collective behavior of individuals that are natural.

- Nesting behavior of termites – Figure 7 [27].

Figure 7 Termite Mound

- Clustering of ants – Figure 8 [28]

Figure 8 Cluster of Ants

- Flocking of Birds – Figure 9 [7]

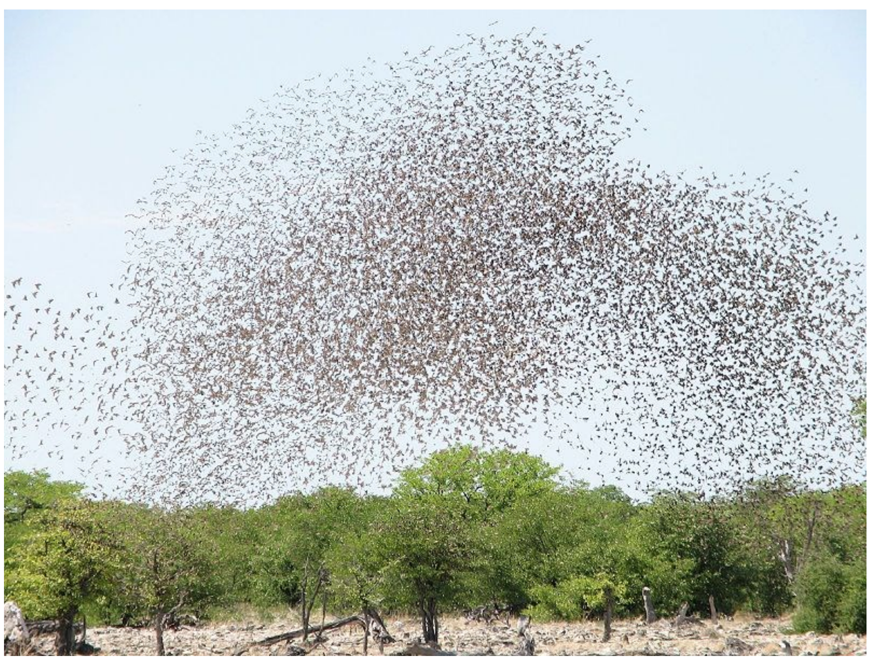

Figure 9 Flocking of Birds

- Schooling of Fish – Figure 10 [29]

Figure 10 Schooling of Fish

- Swarming of Bees – Figure 11 & Figure 12 [7]

Figure 11 Bee Hive

Figure 12 Swarming of Bees

Even though these examples have biological or structural differences, they share common properties, recognized as the five basic principles of swarm intelligence [3]:

1. **Proximity:** Ability to perform space and time computations.

2. **Quality:** Ability to respond to environmental quality factors.

3. **Diverse response:** Ability to produce a plurality of different responses.

4. **Stability:** Ability to retain robust behaviors under mild environmental changes.

5. **Adaptability:** Ability to change behavior when it is dictated by external factors.

These properties have amazed naturalists and scientists since the inception of the thought that biological groups solve complex natural problems through collective behavior. These are useful in solving many complex scientific problems which led to the development of some of these efficient algorithms and optimization techniques. Some examples of swarm intelligence based computational methods are...

- Ant colony optimization (ACO)
- Bees algorithm
- Cuckoo search
- Particle swarm optimization (PSO)

Our next chapter would be a detailed explanation of why particle swarm optimization could be the opt method for solving the stochastic phenomena in Photonics.

CHAPTER 4 PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is an evolutionary computation technique developed by Kennedy and Eberhart in 1995 [30]. Kennedy and Eberhart were inspired by the social behavior of flocking of birds and came up with this algorithm. This algorithm is often explained with the following example of how a swarm of bees search an area for flowers. The goal of a bee swarm is to find the best location of flowers in a specific region. Each bee goes around the region looking for the highest concentration of flowers. During the search it has a memory of its path and the concentration of flowers in the spots that it covered. They communicate their findings with other bees during the search. Thus, each bee has a knowledge about the search path and concentration of flowers encountered by its neighbors. So during the search if any one bee finds a new spot with a high concentration of flowers, all the bees are inclined towards that location concluding their search.

Kennedy and Eberhart were able to transcend this natural phenomena into an algorithm which could be used to solve optimization problems. Every optimization problem has numerous possible solutions which are termed as feasible solutions. Out of all the feasible solutions the solution that fits the required constraints in the best possible way is termed as the optimal solution. The required constraints are usually modelled into a mathematical function called the fitness function. This determines the optimal solution. The optimal solution could be the minimum or maximum value of the function, this is determined by the problem at hand.

Particle swarm optimization algorithm follows the similar principle of bees searching for highest concentration of flowers. The individuals in the algorithm are called as particles. The particles move around the search space looking for the optimal solution determined by the fitness function. Particles interact with one another in a predefined search space while learning from their own experience and the experience of others, gradually move towards the goal. Some of the advantages of PSO are

- Simple optimization method, easy to model and code.
- It's an evolutionary algorithm that reacts to changes in the search space.
- Dynamic in nature and converges fast.
- Recommended for complex dynamic stochastic optimization problems.

As a relatively new optimization technique that emerged within the last 20 years, PSO has grown in the past several years, and over 600 papers related to PSO has been published[31]. Figure 13 shows the number of research papers on PSO published till 2006 by IEEE Explore.

Year	IEEE Xplore
1995	(0)
1996	(0)
1997	(2)
1998	(3)
1999	(6)
2000	(10)
2001	(13)
2002	(36)
2003	(86)
2004	(270)
2005	(425)
2006	(687)

Figure 13 PSO research papers by year

The simple computational efficiency of PSO and its nature to solve complex problem has made PSO one of the widely used optimization techniques for various applications.

Table 1 shows the number of applications in various fields of engineering where PSO has been used [32].

Application	Year														Total
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
Electrical Engineering															
Electricity generation and power systems	-	-	-	-	1	3	6	11	9	11	25	64	45	36	211
Design and control of neural networks	-	-	1	-	-	3	2	4	2	11	14	27	32	32	128
Control applications	-	-	-	-	-	-	1	3	3	8	18	41	24	30	128
Design and control of fuzzy systems	-	-	-	-	-	-	1	1	3	7	14	18	17	24	85
Electronics and electromagnetic	-	-	-	-	-	-	-	1	6	15	13	15	12	14	76
Design and optimization of communication networks	-	-	-	-	-	-	-	-	-	9	16	21	11	19	76
Image and sound analysis	-	-	-	-	-	-	-	-	2	5	3	10	21	11	52
Antenna design	-	-	-	-	-	-	-	-	2	2	12	12	12	11	51
Design and restructure of electricity networks and economic load dispatching	-	-	-	-	-	-	1	1	4	4	3	16	12	-	41
Sensor networks	-	-	-	-	-	-	-	1	1	2	5	6	12	13	40
Design and optimization of electric motors	-	-	-	-	-	-	-	-	3	1	-	9	6	4	23
Design and control of fuzzy-neural networks	-	-	-	1	-	-	-	-	1	1	2	3	6	6	20
Filter design	-	-	-	-	-	-	-	-	-	-	-	9	4	4	17
Unit commitment		-	-	-	-	-	-	-	1	-	3	6	3	2	15
Fault detection and recovery	-	-	-	-	-	-	-	-	1	1	-	8	1	2	13
Computer Science and Engineering															
Visualization and computer graphics	-	-	-	-	-	-	-	-	2	-	6	4	1	7	20
Making music and games	-	-	-	-	-	-	-	-	1	2	3	3	1	1	11
Mechanical Engineering															
Robotics	-	-	-	-	-	-	-	1	1	5	9	22	19	17	74
Dynamic systems	-	-	-	-	-	-	1	-	2	4	2	4	1	4	18
Industrial Engineering															
Scheduling	-	-	-	-	-	-	-	-	3	4	3	22	19	25	76
Sequencing	-	-	-	-	-	-	-	-	-	1	12	-	2	3	18
Forecasting	-	-	-	-	-	-	-	-	1	2	3	8	11	8	33
Maintenance planning	-	-	-	-	-	-	-	-	-	-	-	1	2	5	8
Job and resource allocation	-	-	-	-	-	-	-	-	-	-	-	-	3	4	7
Supply chain management	-	-	-	-	-	-	-	-	-	-	-	1	1	3	5
Civil Engineering															
Civil engineering	-	-	-	-	-	-	-	-	-	-	-	4	-	1	5
Traffic management	-	-	-	-	-	-	-	-	1	-	-	1	1	2	5
Chemical Engineering															
Chemical process	-	-	-	-	-	-	-	-	1	-	4	4	2	4	15
Mathematics															
Data mining	-	-	-	-	-	1	-	2	4	14	18	33	35	48	155
Multi objective optimization	-	-	-	-	-	-	-	2	4	4	16	16	30	25	97
Optimization of constrained problems	-	-	-	-	-	-	-	2	1	4	2	7	16	6	38
Multi model function	-	-	-	-	-	-	-	-	3	2	1	3	6	4	19
Modeling	-	-	-	-	-	-	-	-	-	4	4	1	5	5	19
Traveling salesman problem	-	-	-	-	-	-	-	-	1	3	4	-	-	2	10
Combinational optimization	-	-	-	-	-	-	-	-	-	-	1	-	1	2	4
Other Applications															
Miscellaneous	-	-	-	1	1	-	-	1	4	5	5	11	15	11	54
Economical and financial applications	-	-	-	-	-	-	1	2	-	5	8	13	3	11	43
Biological and medical applications	-	-	-	-	1	-	-	-	1	5	1	10	2	8	28
System identification	-	-	-	-	-	-	-	-	-	2	1	9	8	6	26
Materials engineering	-	-	-	-	-	-	-	-	1	3	3	1	2	2	12
Security and military applications	-	-	-	-	-	-	-	-	-	-	-	2	-	1	3
Total	0	0	1	2	3	7	13	32	69	146	234	445	404	423	1779

Table 1 Applications of PSO Over years

The aggregation chart of applications that used PSO over the years is shown in Figure 14 [32] .

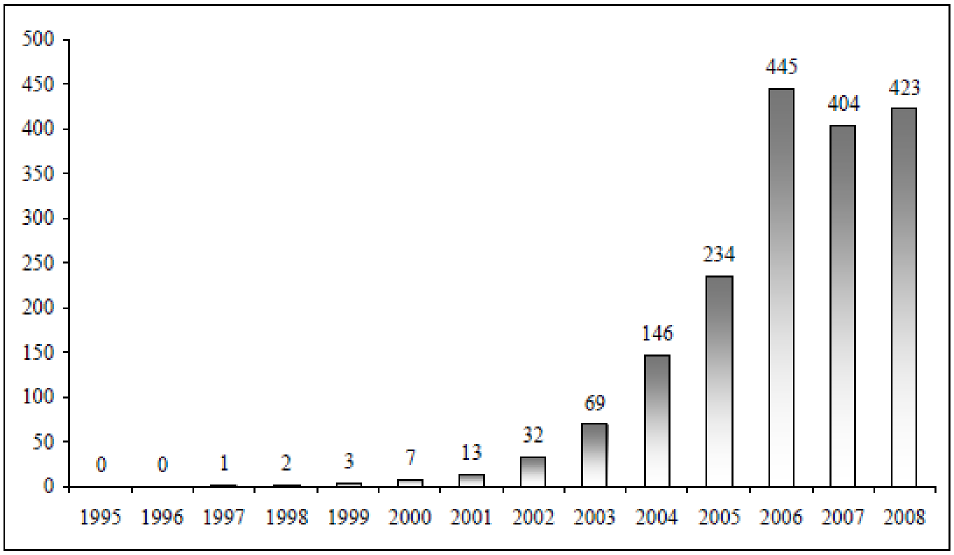

Figure 14 Aggregation chart of applications using PSO

4.1 Parameters of PSO Algorithm

One of the biggest tasks in implementing PSO is understanding the parameters involved in the algorithm and relating them to the problem that being optimized. The various parameters are explained.

4.1.1 Particle / Agent

Each individual in the swarm is a particle or agent and they all act individually as well as collectively to find the global best solution. They also interact between each other and accelerate towards their personal and global best position and also check their position with the other particles.

4.1.2 Search Space

The search region in which the particle moves around looking for the optimal solution. It's also referred to as neighborhood size. The definition of search space boundaries plays an important role in the convergence of the algorithm. The size of the search space determines the proximity, interaction and influence of particles on one another.

4.1.3 Position

Position refers to the location of particle in the search space. The search space in the examples here are two dimensional as in equations, but it could be N dimensional depending on the complexity of the search space. The solution to any search space (set of values to be optimized) is determined by the position. The Gbest and Pbest are actually positions which physically relate to the required solution for the problem.

4.1.4 Fitness Function

Fitness is the function that gives accuracy and feasibility for the position of a particle. The fitness function would determine the physical value of the problem by evaluating the position of the particle in the search space. This plays an important role in any scenario as it defines the scenario, its constraints. The fitness functions are stochastic and complex in case of dynamic cases.

4.1.5 Velocity

Velocity refers to the direction towards which the particle moves. The velocity is always controlled in order to guide the movement of the particle in the search space. Velocity is affected by and dependant on the other parameters such as Pbest, Gbest, constants C1 & C2, Random numbers R1 & R2.

4.1.6 Population

This is the number of particles that have been initialized in the search space. The population size varies for different application. In some cases smaller populations have been found to give better results. PSO has been known to have a better convergence and performance for population size ranging 100 from previous work [1], [2]. But this again is application specific.

4.1.7 Personal best - Pbest

Personal best the best position of an individual particle during its movement in the search space. Whenever a particle finds a new higher value than its personal best, the personal best value gets replaced by the high value and this becomes the new personal best.

4.1.8 Global best - Gbest

The global best corresponds to the best of the best positions of all particles in the swarm. Whenever a new higher value Pbest is found, it's compared with the Gbest and the highest of this becomes the new Gbest. The Gbest at the end of the iterations represents the optimized solution.

4.1.9 Random numbers R1 & R2 (0 – 1)

The random numbers were introduced in the equation to simulate the unpredictable component of the natural swarm behavior. The values of these have been always different for different. The random numbers are usually positive values ranging from 0-1. In some cases random numbers range from -1 to +1. These are also dynamically assigned during each iteration to get the optimal solution. In most cases Rand function in Matlab is used to generate random numbers.

4.1.10 Acceleration constants C1 & C2

These are the factors that determine the relative pull of Global best and local best values. Acceleration constants control the cooperative nature of all particles during the search. C1 determines how much each particle influenced by its own memory and C2 determines how much each particle is influenced by the swarm. An increase in C1 increases the exploration of the search space for Personal best of each particle and increasing C2 encourages the exploitation of the search space for the Global best. A balance of C1 & C2 makes sure that the particles search for personal best values considering the overall goal of finding Gbest. C1 and C2 have been determined by trial and error methods and their values have been different in different scenarios.

4.1.11 Iterations T max

This defines the number of times particles move around the search space. At the end of every iteration the particle's position is evaluated for its value and Pbest Gbest values are calculated. Less iterations might terminate the algorithm before the optimal solution and too may iterations can cause the particles to go out of the search space and cause unnecessary computational complexity. In some cases, number of iterations have been used as a terminating condition for the algorithm.

4.2 Modelling PSO Algorithm

The basic PSO algorithm was initially formed by Dr. Eberhart & Dr. Kennedy modelled based on the behavior of bees [30]. The bees are referred to as particles and the region in which they search for flowers (optimal solution) is termed as the search space. Population determines the count of particles in the search space. Each position in the search space corresponds to a particular value, which evaluated by the fitness function gives the solution for the problem. The fitness function determines the solution to the problem and this could be maximum, minimum or any function depending on the problem.

The number of iterations controls the number of times the particles move from one position to the other. Personal best–Pbest is the highest value for the fitness function encountered by a particle during its search and Global best-Gbest is the highest value of the fitness function among all the particles in the population. Random numbers R1, R2 are used to introduce randomness in the search for a solution similar to the natural bee swarm. The social constants C1 & C2 are used to reflect the social interaction of bees in the search space. The velocity and direction of each particle at any given point of time in the search space is determined by the Velocity equation (Eqn 1)

$$\mathbf{V_t = V_{t-1} + C_1 R_1 (P_{t-1} - X_{t-1}) + C_2 R_2 (G_{t-1} - X_{t-1})} \qquad \text{(Eqn 1)}$$

Where Vt and Xt represent the current calculated velocity and position parameters of the particle. $\mathbf{V_{t-1}}$ and $\mathbf{X_{t-1}}$ are the previous velocity and position of the particle. $\mathbf{P_{t-1}}$ represents the previous best position of the particle and $\mathbf{G_{t-1}}$ represents the best position in the entire swarm. The term $\mathbf{C_1 R_1 (P_{t-1} - X_{t-1})}$ is called the cognitive component.

This component controls the memory of the past positions during the particles search. Third term $C_2 R_2 (G_{t-1} - X_{t-1})$ is called the social component which is responsible for controlling the particle to work towards the optimal goal of the population

The next position of the particle is determined by the position equation (Eqn. 2)

$$X_t = X_{t-1} + V_t \qquad \text{(Eqn 2)}$$

The values of cognitive constants C1 and C2 vary depending on the application. Based on several trial and error experiments, it was recommended to (0.7,0.8) [33]. The values of Random numbers range from 0-1. The values for Iterations, number of particles are determined by trial and error methods. In some cases methods with fewer particles gave better results than a large swarm of particles. The same follows for iterations too

To control the convergence of particles and the explore the entire search space, a new factor Inertia Weight **w** was introduced to the basic velocity Equation (Eqn 1) by Dr. Eberhart and Shi in 1997 [34]. This gives a trade-off between local, global search and acts as a balancing factor. The inertia constant could be a positive number or a linear positive function. The new modified PSO velocity equation (Eqn 3) with inertia term

$$V_t = w*V_{t-1} + C_1 R_1 (P_{t-1} - X_{t-1}) + C_2 R_2 (G_{t-1} - X_{t-1}) \qquad \text{(Eqn 3)}$$

Where **w** is the inertia weight term. It was suggested to linearly decrease the inertia weight, but in some cases a randomized inertia weight is also used [33]. The values were suggested to be decreased from 1.4 to 0.4. But in most optimization problems the inertia weight value linearly decreasing from 0.9 to 0.4 seems to prove better results as this balances the local and global search throughout the algorithm. The value of Inertia at any iteration that is linearly through the PSO algorithm is defined and controlled by the following equation (Eqn 4)

$$\mathbf{W\ (t) = Wup - (Wup - Wlow / Tmax) * T} \qquad \text{(Eqn 4)}$$

Where **Tmax**- Maximum number of Iterations, **T** – Current iteration step count, **Wup** and **Wlow** are the upper limits of inertia weight. The value of inertia is extremely important for the algorithm to converge.

Even with a controlled inertia, the particles tend to go out of search space due to large velocities in some cases. To control this a velocity clamping factor was introduced. The two important factors in any particle's movement in the search space are exploration and exploitation. Exploration is the particles tendency to search new regions and exploitation is the tendency to search within the region where the particle encountered a previous best. Velocity clamping factor controls the global exploration part of the particle's movement so that it remains within the boundary space. The velocity of a particle at any point is controlled by the following equation (Eqn 5).

$$\mathbf{V_t = \{V_t} \text{ if } \mathbf{V_t \leq V_{max}}, \mathbf{V_{max}} \text{ if } \mathbf{V_t \geq V_{max}\}} \qquad \text{(Eqn 5)}$$

Where $\mathbf{V_{max}}$ is the maximum velocity that a particle can have. Vmax is determined by Equation (Eqn 6). $\mathbf{D_{max}}$ and $\mathbf{D_{min}}$ are the maximum & minimum values for the dimension D and Vmax can have the highest value of the dimension.

$$\mathbf{V_{max} = \delta\ (D_{max} - D_{min})} \qquad \text{(Eqn 6)}$$

Velocity clamping confines the particle's movement from one position to another and the maximum velocity should be dependent on all the dimensions in the search space.

Ideally the search for optimal solution is terminated when the best possible values for fitness function. In some cases the algorithm has been set to terminate after the maximum number of iterations or terminate when no improvement in Gbest value is obtained after a certain number of iterations [21]. Few other conditions like swarm radius approaching zero, fitness function slope is approximately zero have also been used to terminate the search in the algorithm. The algorithm could result in a sub-optimal solution when terminated fast or could result in computational complexity if not terminated when the particles have exhausted the search region.

Particle swarm optimization algorithm has been successful in a lot of applications and it's considered to be one of the best optimization tools available. There is not a strong mathematical explanation on how the algorithm works. Several attempts have been made to explain the backbone of this algorithm, but none of them have emerged as a successful mathematical model [35].

One of the major advantages of PSO algorithm is that it could be modified based on the requirements and nature of the environment. Based on initial velocity and position equations, various methods have been developed. Some of the frequently used methods of PSO are as follows.

The figure 15 shows the various classifications and methods of PSO developed in recent years [32].

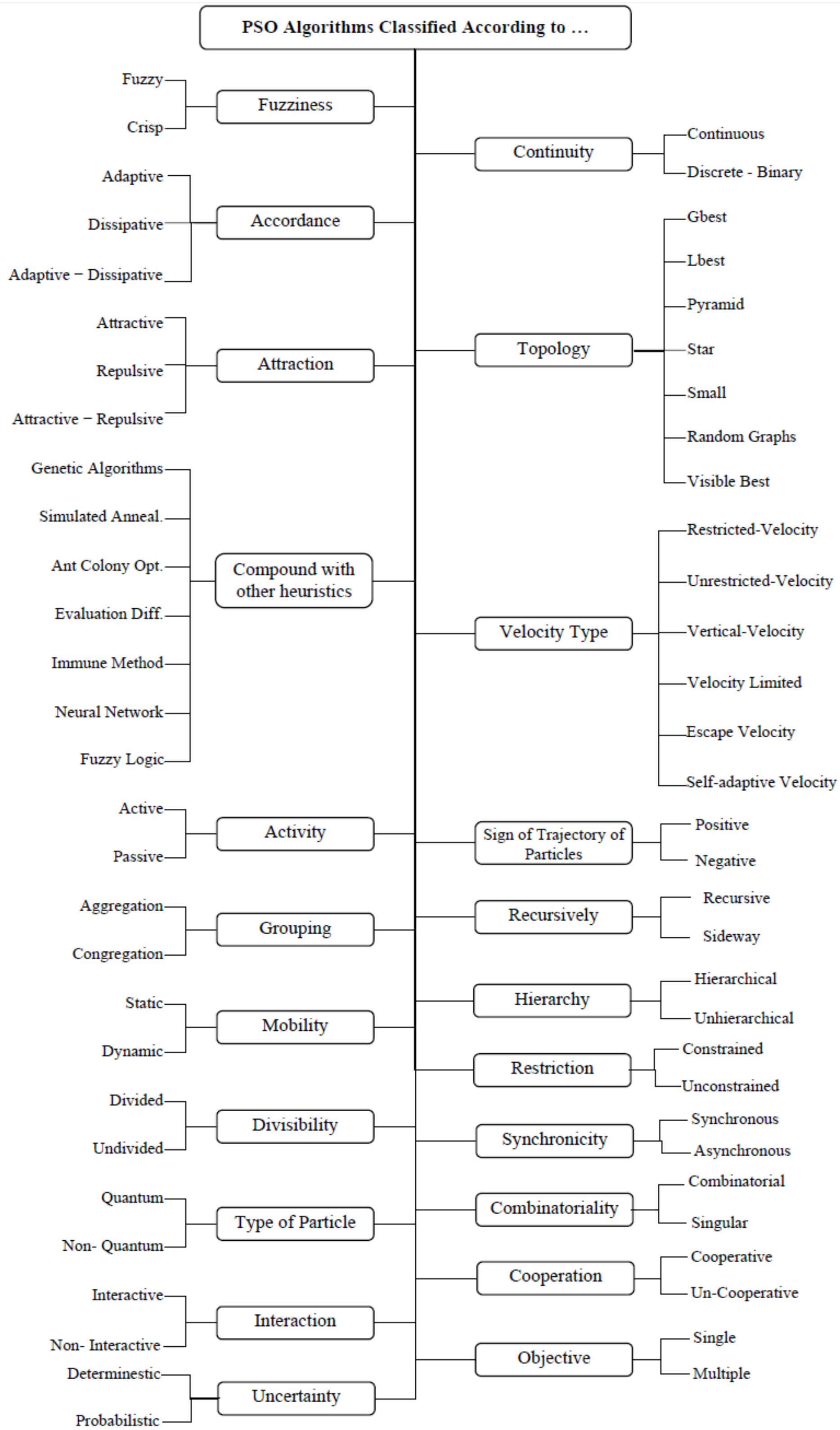

Figure 15 PSO Algorithm Methods - classification

4.3 PSO – Algorithm Flow

The general working of PSO algorithm is described in the following flowchart figure 16.

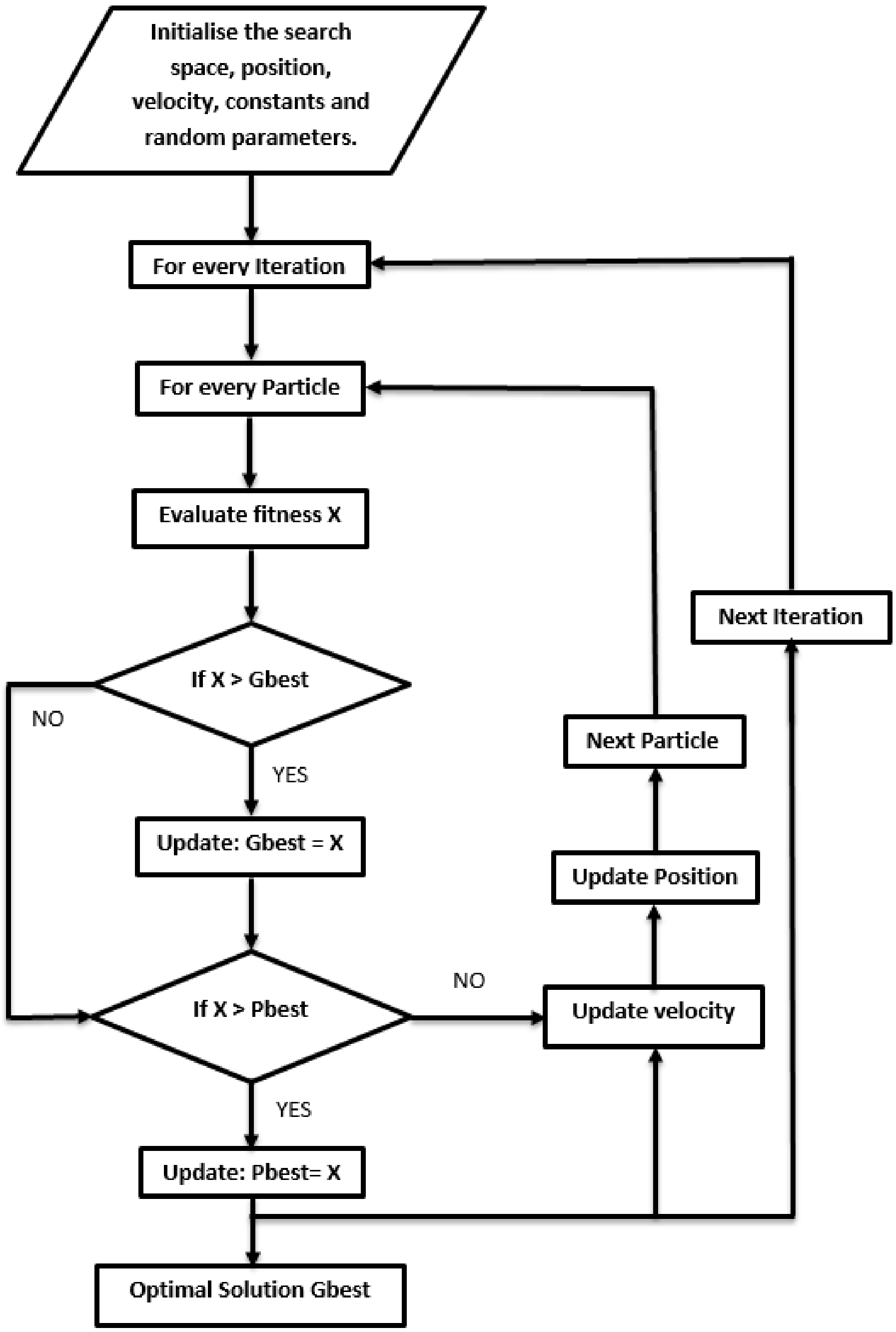

Figure 16 PSO Flowchart

The algorithm consists of the following steps:

a) The swarm or search space is initialized and each particle is initialized by assigning random position and velocity values. All parameters are initialized.

b) In every iteration, the fitness value X for each particle is calculated. This fitness value is calculated depending upon the nature of the problem by evaluating the position.

c) The fitness value X is compared with the Gbest value that is calculated within the swarm. If X is greater than Gbest, this results in new global best fitness value and the previous Gbest is updated with the new Gbest Value. Otherwise the algorithm goes to the next step.

d) The fitness value is X compared with the Pbest value of the particular particle. If X is greater than Pbest, this results in new Personal best for the Particle and the previous Pbest are updated with the new Pbest Value. Otherwise the algorithm goes to the next step.

e) The position parameter is updated which then updates the new velocity. This completes the function for one particle and all particles follow the same loop process.

f) Once all the particles have completed the search, it’s the end of the first iteration.

g) The same loop goes on till all the iterations are completed or the optimal solution is obtained. The terminating conditions are provided in the iteration loop.

4.4 Why PSO?

PSO has proven to be one of the most effective optimization methods over its counterpart like Genetic algorithm [36]. Its a simple computation method based on the social behavior of bees. The time consumption for the algorithm to complete is very less. This algorithm has been recommended for complex stochastic problem like the one that this research is based on. Also PSO can be modified to suit any number of input parameters to optimize. Various versions of PSO are available and they could be used in combination depending on the nature of our Problem. PSO has also been proven to work efficiently with other techniques like neural networks as an optimization tool. The few disadvantages of this algorithm like initialization and convergence issues could be minimized by assessing the problem in detail and translating it to PSO terms. Thus a multidimensional version of PSO could be used as a tool to understand, study and solve the random process in Photonics.

CHAPTER 5 PROPOSED MODEL

In this chapter, we would be coming up with a model to analyze the stochastic processes in Photonics. This would also include an introduction to previous work done. With PSO being our chosen method to model our stochastic phenomena, we need to analyze how to translate these processes in PSO terms. We would be designing a computation model that would be controlled by various random factors contributing to the nature of our stochastic processes. The objective is to use the social interaction factor & randomness involved in PSO to predict the possible outcomes in these stochastic processes and to come up with an optimal solution. To begin with we would be discussing on the model proposed in previous work done in this field.

5.1 Previous work

Stochastic optical phenomena have been an interesting field of research for many years now. There have been many methods proposed to overcome the limitations of these phenomena in optical fiber systems. Millions of dollars have been spent on research and in the development of infrastructure to overcome the limitations of these effects. For example, if we could analyze and control factors like shot/quantum noise, defects in fibers the loss associated with signal transmission in fibers would reduce to a great extent. The transmission distance of signals in optical fibre is greatly reduced by these losses [37]. A solution to this would, to some extent eliminate or reduce the use of optical amplifiers which have to be installed to amplify the optical signal and retransmit at specific intervals along the transmission line. The analysis of stochastic optical phenomena using particle swarm optmization technique was started by Tapan

Katwala [1] in 2007. Tapan proposed a single dimension model of PSO that could be used to study the stochastic nature of these processes and came up with an algorithm to analyse these processes. The results of his work proved that PSO could be a viable method to model theses stochastic systems. Later in 2014, Raam Bharathwaaj Chennai Jagannathan [2] proposed an multidimensional PSO model to estimate the random parametrs and consolidate the possible outcomes from this estimation . His estimation model for PSO paramets showed promise that a new multidimensional PSO model could be used to predict the nature of these random processes.

5.2 Requirements for the new Model

Based on the promising features of PSO in previous work, in this thesis a new multidimensional PSO model is proposed. Some of the requirements for this model are discussed as points in this section. The new model should address the following

i. To incorporate multiple random factors contributing to the stochastic nature of the processes

ii. Stand alone model to take advantage of its social interaction and stochastic characteristics of PSO technique

iii. The model should be able to predict the nature of these stochastic phenomena in the near future.

iv. The stochastic nature to be introduced in the algorithm through the random parameters responsible for these stochastic phenomena.

v. The model should be generic to be applied to various stochastic phenomena and adapt well to new environments.

vi. The model should be able to learn from the historic data available and should react to the changes in the stochastic environment.

vii. To include an error correction mechanism to minimize the error in prediction.

viii. To have higher accuracy and efficiency than the previous proposed models

These are some of the major factors that we are looking to achieve through this new multidimensional PSO model to be discussed in detail in the next section..

5.3 Multidimensional PSO Model

The parameters of PSO determine the new model for predicting the nature of a stochastic environment. Translating our stochastic environment into PSO terms is a very complex process and this forms the base of this algorithm. Each parameter of PSO is carefully evaluated in comparison to each characteristic of the stochastic environment. This would make sure that we translate the randomness of the factors into the algorithm. Thus we would be able to use the social interaction characteristic of the particles to predict the nature of the environment for future. To define the parameters we would use the example of losses in fiber along the transmission line. The parameters and characteristics of the new PSO model algorithm are as follows.

5.3.1 Particle/Agent

Since our model is a multidimensional model, the particle would be multidimensional. The typical structure of a particle would be an array of all the dimensions. For example [A A1 A2 A3 A4 A5 A6] where A would be the value of loss in the fiber and A1-A6 would be the factors contributing to the loss.

5.3.2 Search Space

The search region for the particle would be defined possible values of all the dimensions from the historic data available for the stochastic process. For example, to the particle defined in section 5.3.1 the search space would be matrix with 7 columns corresponding to A A1 A2 A3 A4 A5 A6 and as many rows as the rows of data available for these factors.

5.3.3 Position

Each position in the search space would resemble the structure of the particle and the value at each position would be translated into the corresponding values of the array [A A1 A2 A3 A4 A5 A6].

5.3.4 Fitness Function

The fitness function in our case would be the maximum, minimum and average change in the value of a solution to the problem. In case of optical fiber transmission line, it would be the loss associated with transmission. When a particle encounters a position, only the value of A from array [A A1 A2 A3 A4 A5 A6] would be taken into calculating the fitness. This is one of the original ideas of this method as we aim to predict the nature of the environment instead of optimizing the parameters.

5.3.5 Velocity

The velocity of the next movement of the particle would be determined by the difference in values of the array elements of the previous position and the current position. Since the difference could be either way, this direction of movement could be two ways too. This makes sure that the particles do not move in one particular direction.

5.3.6 Velocity Clamping

The velocity clamping factor is used as the particles ted to gain large values of velocity and search around or beyond the boundaries of the search space. The maximum velocity that a particle could have is defined by the difference between maximum and minimum value of each dimension of the search space defined by equation (Eqn 6).

5.3.7 Population

This multidimensional PSO model would be tested for various population sizes to find the optimal performance. We would be training and testing the algorithm with population size of 100 as suggested in [2][1].

5.3.8 Personal best - Pbest

The personal best value of the particle would be the best value for loss or Value of A in array [A A1 A2 A3 A4 A5 A6] encountered by any particle during its iteration.

5.3.9 Global best – Gbest

The global best value of the population would be the highest value for loss or Value of A in array [A A1 A2 A3 A4 A5 A6] encountered by any particle during the entire search.

5.3.10 Random numbers R1 & R2 (0 – 1)

The random numbers introduce stochastic nature into the algorithm. In this model we would be following two different approaches for generating random numbers. This is one of the original ideas of this research work.

5.3.10.1 Approach 1

In the first approach random numbers would be generated using the Rand function in Matlab. We are following this as recommended to test the performance of the algorithm.

5.3.10.2 Approach 2

The second approach the parameters from the stochastic environment would be used as random numbers. The parameter values are normalized between 0-1 and they would be used as random numbers R1 and R2. All the six parameters would be substituted for random numbers to analyze which parameter gives the better results.

Parameters are being used as random numbers because, the parameters are random in nature and they are the ones controlling the chaotic nature of our problem. Thus, substituting parameters for random variables is justified.

5.3.11 Acceleration constants C1 & C2

The acceleration constants determine the exploration and exploitation nature of the particles in the search space. For various probles analysed and optimed by different PSO techniques [32] various values for c1 & c2 have been found to lead the algorithm to better results. Also the previous works in this field suggested two different combinations of acceleration constants. [1.4, 1.4] in [1] and [0.7,0.8] in [2]. Since this algoritm has a multidimensional approach, we would be testing it for the following combinations of [C1,C2] – [2,2] , [1.4, 1.4] and [0.7,0.8]

5.3.12 Iterations T max

Number of iterations is another factor that's specific to a particular problem. This algorithm would be testeed for performance in different values of iterattion 50, 100 & 200 as suggested in [2][1]. Also in this algorithm, the iterations are used as a condition to terminate the algorithm.

5.3.13 Inertia Weight w

Inertia weight would be linearly decreased from 0.9 to 0.4 over the course of the search. This is proven to ensure that the algorithm has a balance between the concept of particles exploring and exploiting the search space [38].

These parameters have been decided after careful evaluation of a stochastic system in Photonics. This should suit all four stochastic processes discussed in chapter 2. The following section discusses a few other important characteristics involved in the proposed model.

5.4 Error Correction Technique

To maximize the efficiency of prediction by PSO, this research introduces a simple error correction mechanism. This is an original idea of this research work. It would be an additional performance factor even if the accuracy of results improves by a very small margin. In all stochastic optical systems, the fitness function is dependant of previous few instances,. For example, in a fiber transmission line the optical signal travels through a long stretch of fiber, which has a different set of parameters at each point in the fiber. So a defect in a previous position is bound to influence the strength or loss associated with the signal at the next instance. These effects are assumed to be effective only for few previous instances. Here in our scenario the error is calculated as a difference between the predicted values and actual experimentally measured value. A correction factor of 3 day moving average is to be added to the predicted value to arrive at the final predicted value of this model. This value would be evaluated against the experimental values to determine the accuracy and performance of our algorithm. The percentage error is calculated using the below formula

$$Percentage\ error = \frac{(\ Predicted\ Value - Experimental\ value)}{\text{Experimental Value}} * 100$$

An average of the percentage error for the entire prediction period is calculated. This would be the factor determining the efficiency of the algorithm.

5.5 Algorithm – Adaptability

The algorithm adaptability is the ability of the algorithm to learn from historic data during training and predict the direction of flow. This exhibits, how well the algorithm understands the stochastic nature of the environment to produce solutions in accordance with the actual experimental results. The direction of the prediction is determined by checking the increase or decrease in the values of two consecutive predictions. If this is similar in actual and predicted values for the same condition, then they follow the same direction. This confirms that our algorithm has predicted the correct direction. This would be done for the entire period of prediction and for various stochastic environments under study to check the adaptability of the algorithm to change/s in/of stochastic environment. The implementation of our new model - multidimensional PSO algorithm is discussed in the next chapter.

CHAPTER 6 ALGORITHM IMPLEMENTATION

To implement the multidimensional PSO algorithm for stochastic phenomena in optics like quantum/phase noise, speckles in lasers, experimental data of the phenomena with details of the random parameters is required. The algorithm needs to be trained in the similar environment for it to inherit the randomness in these environments to predict for the future. Experimental data of these optical phenomena required for the algorithm is not readily available. These experiments need to be conducted and data has to be collected. Such experiments involve huge infrastructure and time requirements. This is a complex process to go through, before confirming that our algorithm is capable of working in such an environment. To overcome this, it's necessary that we test our algorithm in a similar environment before proceeding to experimentally collect data for stochastic optical phenomena. Hence there is a requirement to find a similar complex stochastic environment which has various random factors controlling it.

Based on research [39] and previous work done in this field [2][1], it is suggested that Foreign exchange (FOREX) market would be the best test environment. To confirm that FOREX market would be the best test bed for our algorithm, the similarities between stochastic Optical phenomena and FOREX market has to be invstigated. A detailed study on FOREX market was done and the following section contains arguments supporting the fact that FOREX would be the best test environment for our algorithm.

6.1 FOREX Market

Foreign and Exchange abbreviated to FOREX or FX is the practice in place to exchange currencies between countries. FOREX is considered to be the largest financial market in the world with trading volumes more than $5 trillion USD daily. This volume of currency exchange is more than 3 times the total volume of all stock markets of the world combined [40].

FOREX is an over-the-counter (OTC) market unlike the other markets. Here the exchange is not controlled at a specific location [2]. The exchange is global over telephone, internet by large banks, countries, retailers and individuals who have access to the electronic marketplace. This aspect of FOREX alone makes it very ambiguous or stochastic in nature. With the rapid growth of internet FOREX trading could be done from any remote location. The FOREX market in any region follows its standard working time. For example the market in Japan is open when the market in the US is closed, but still trading occurs between US and Japanese currency.

With globalization of trade, currency exchange between countries plays an important role in the growth and development of any economy. Currencies are traded between countries for numerous reasons. The market is omnipresent and very stochastic. This argument supports the fact that FOEX is a stochastic environment which we are looking for in our test bed.

6.2 Aspects of FOREX Trading

This section analyses and compares the prediction in an optical phenomena to FOREX. In optics, we were looking to predict the nature of the stochastic process along with its random factors. In FOREX we need to establish a similar relationship to test our algorithm.

FOREX trading is the process in which one currency is bought and the other currency is sold. There are always two currencies involved in the process. The currency, which is being bought is called the target currency and the currency, which is being sold is called the base currency. The combination of a target and the base currency is called as a currency pair. Currency pair trading can also be defined in regards to the place where it is being traded from. For example, in the European market, EUR is the base currency and USD is a target currency. To express EUR in terms of USD or to exchange EUR for USD, the exchange rate is determined. The exchange rate is usually expressed as

EUR/USD = 1.12

Where EUR/USD is the currency pair traded, EUR is the base currency, USD is the target currency and 1.12 is the exchange rate for EUR to USD. This means that with 1 euro you could buy/exchange it with 1.12 USD dollars. It also refers to the fact that, a product which costs 1 EUR in European market would cost 1.12 USD in the United States market. Thus exchange rate forms the base/solution of the FOREX system. In the FOREX market, among currencies traded, 7 currencies are traded on a larger scale. These are called as major currencies.

Table 16 shows the share of major currencies in FOREX market in april of few different years [41].

Net-net basis,[1] percentage shares of average daily turnover in April[2]

Currency	1998		2001		2004		2007		2010		2013	
	Share	Rank	Share	Rank	Share	Rank	Share	Rank	Share	Rank	Share	Rank
USD	86.8	1	89.9	1	88.0	1	85.6	1	84.9	1	87.0	1
EUR	...	32	37.9	2	37.4	2	37.0	2	39.1	2	33.4	2
JPY	21.7	2	23.5	3	20.8	3	17.2	3	19.0	3	23.0	3
GBP	11.0	3	13.0	4	16.5	4	14.9	4	12.9	4	11.8	4
AUD	3.0	6	4.3	7	6.0	6	6.6	6	7.6	5	8.6	5
CHF	7.1	4	6.0	5	6.0	5	6.8	5	6.3	6	5.2	6
CAD	3.5	5	4.5	6	4.2	7	4.3	7	5.3	7	4.6	7
MXN[3]	0.5	9	0.8	14	1.1	12	1.3	12	1.3	14	2.5	8
CNY[3]	0.0	30	0.0	35	0.1	29	0.5	20	0.9	17	2.2	9
NZD[3]	0.2	17	0.6	16	1.1	13	1.9	11	1.6	10	2.0	10
SEK	0.3	11	2.5	8	2.2	8	2.7	9	2.2	9	1.8	11
RUB[3]	0.3	12	0.3	19	0.6	17	0.7	18	0.9	16	1.6	12
HKD[3]	1.0	8	2.2	9	1.8	9	2.7	8	2.4	8	1.4	13
NOK[3]	0.2	15	1.5	10	1.4	10	2.1	10	1.3	13	1.4	14
SGD[3]	1.1	7	1.1	12	0.9	14	1.2	13	1.4	12	1.4	15
TRY[3]	...	33	0.0	30	0.1	28	0.2	26	0.7	19	1.3	16
KRW[3]	0.2	18	0.8	15	1.1	11	1.2	14	1.5	11	1.2	17
ZAR[3]	0.4	10	0.9	13	0.7	16	0.9	15	0.7	20	1.1	18
BRL[3]	0.2	16	0.5	17	0.3	21	0.4	21	0.7	21	1.1	19
INR[3]	0.1	22	0.2	21	0.3	20	0.7	19	1.0	15	1.0	20
DKK[3]	0.3	14	1.2	11	0.9	15	0.8	16	0.6	22	0.8	21
PLN[3]	0.1	26	0.5	18	0.4	19	0.8	17	0.8	18	0.7	22
TWD[3]	0.1	21	0.3	20	0.4	18	0.4	22	0.5	23	0.5	23
HUF[3]	0.0	28	0.0	33	0.2	23	0.3	23	0.4	24	0.4	24
MYR[4]	0.0	27	0.1	26	0.1	30	0.1	28	0.3	25	0.4	25
CZK[4]	0.3	13	0.2	22	0.2	24	0.2	24	0.2	27	0.4	26
THB[4]	0.1	19	0.2	24	0.2	22	0.2	25	0.2	26	0.3	27
CLP[4]	0.1	24	0.2	23	0.1	25	0.1	30	0.2	29	0.3	28
ILS[4]	...	34	0.1	25	0.1	26	0.2	27	0.2	31	0.2	29
IDR[4]	0.1	25	0.0	28	0.1	27	0.1	29	0.2	30	0.2	30
PHP[4]	0.0	29	0.0	29	0.0	31	0.1	31	0.2	28	0.1	31
RON[4]	...	35	...	37	...	40	0.0	34	0.1	33	0.1	32
COP[4]	...	36	0.0	31	0.0	33	0.1	33	0.1	32	0.1	33
SAR[4]	0.1	23	0.1	27	0.0	32	0.1	32	0.1	34	0.1	34
PEN[4]	...	37	0.0	32	0.0	35	0.0	36	0.0	36	0.1	35
OTH	...		6.6		6.6		7.7		4.7		1.6	
Total	**200.0**		**200.0**		**200.0**		**200.0**		**200.0**		**200.0**	

[1] Adjusted for local and cross-border inter-dealer double-counting (ie "net-net" basis). [2] Because two currencies are involved in each transaction, the sum of the percentage shares of individual currencies totals 200% instead of 100%. [3] Turnover for years prior to 2013 may be underestimated owing to incomplete reporting of offshore trading in previous surveys. Methodological changes in the 2013 survey ensured more complete coverage of activity in emerging market and other currencies. [4] Turnover may be underestimated owing to incomplete reporting of offshore trading.

Table 2 Share of currencies in FOREX market

Since trading of a currency always relates to an other currency the total trading would be for 200 instead of 100. There are 8 major currencies that are traded widely and considered major currencies united states Dollar USD, European Dollar EURO, Canadian Dollar CAD, Great Britan Pound GBP, Swiss Franc CHF, Japanese Yen JPY, Australian Dollar AUD, Newzeland Dollar NZD. There are 7 major currency pairs that are traded globally EUR/USD, USD/JPY, GBP/USD, USD/CHF, AUD/USD, USD/CAD, NZD/USD. Each of these currency pairs are traded separately in the FOREX market. Thus, each of them is a stochastic system of its own, which is evident from their exchange rates. The exchange rates are very random in nature and they are controlled by a lot of factors which are random in nature. So by using FOREX as a test bed for our algorithm, we would be testing our algorithm to predict the currency exchange rate for each of the currency pairs. Thus we have seven independent stochastic systems which follow a similar concept of currency trading, but have a stochastic exchange rate pattern.

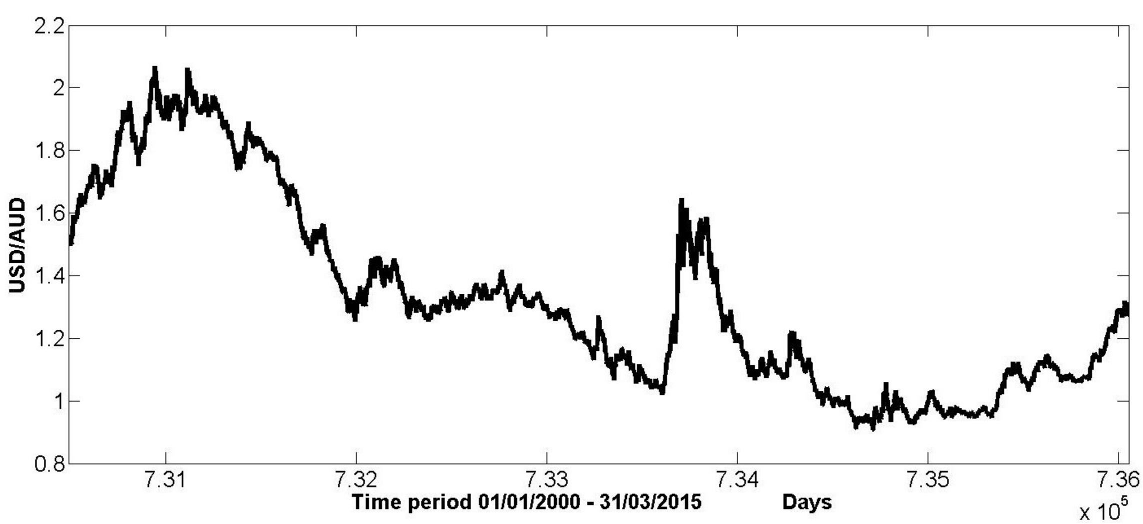

Figure 17 USD/AUD exchange rate plot

The figures 17- 23 show the currency exchange rates of these 7 major currency pairs over a period of 15 years.

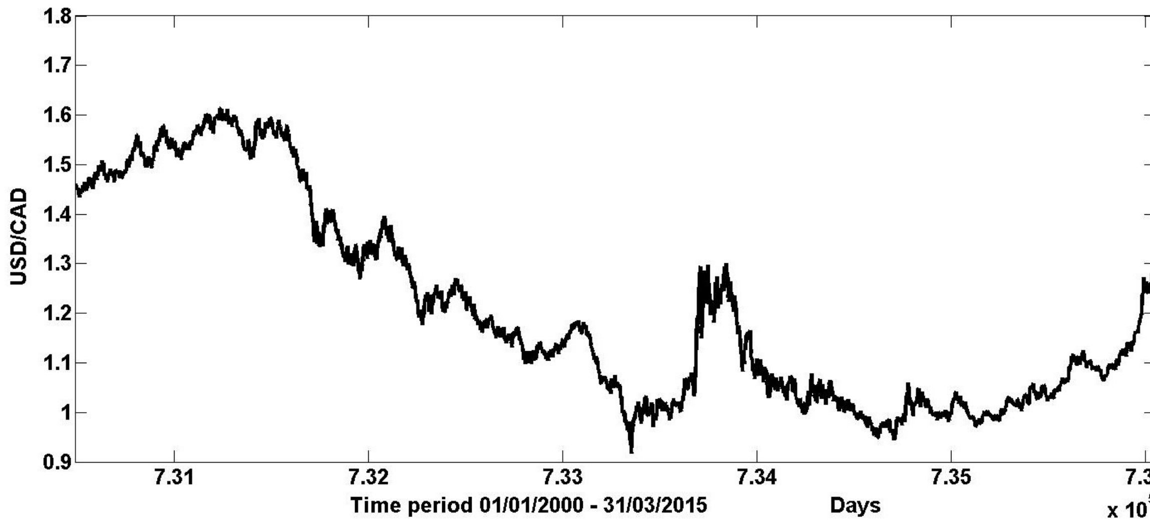

Figure 18 USD/CAD exchange rate plot

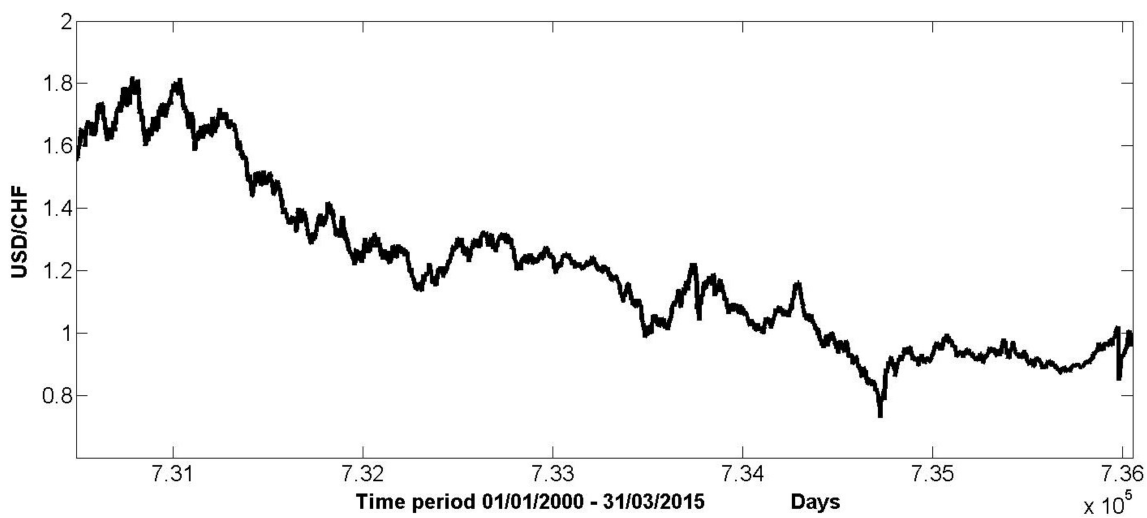

Figure 19 USD/CHF exchange rate plot

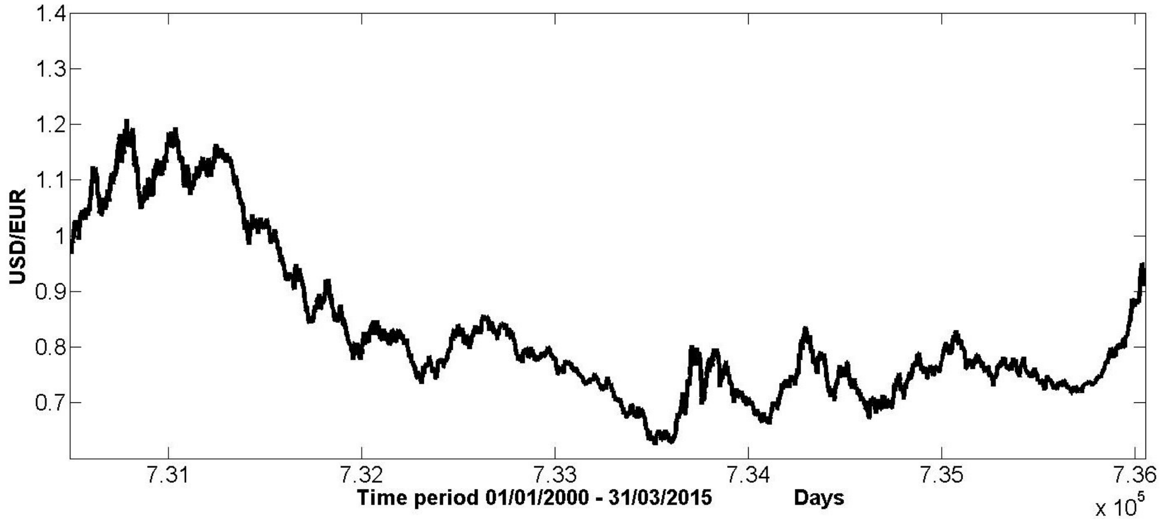

Figure 20 USD/EUR exchange rate plot

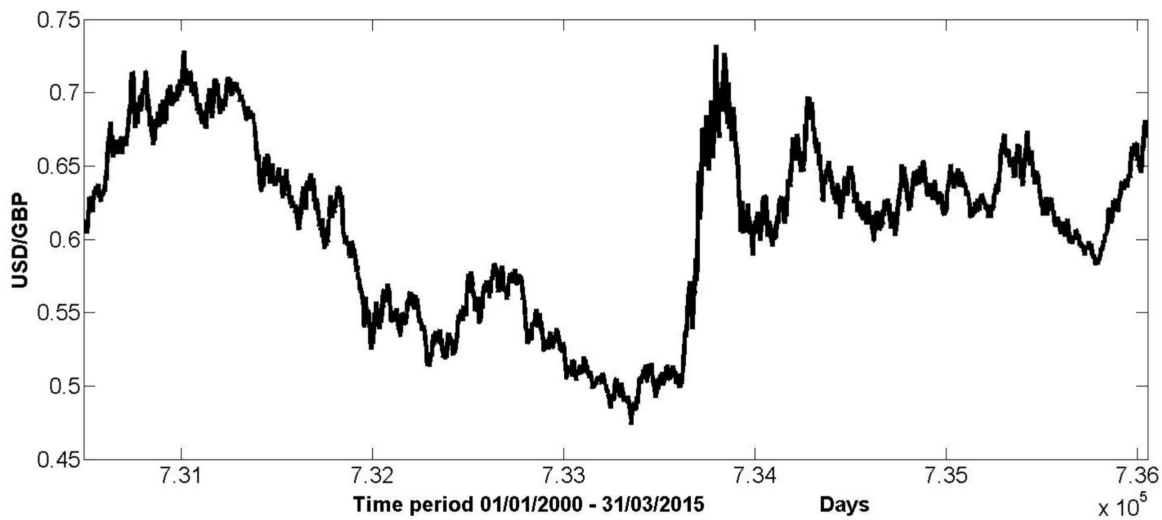

Figure 21 USD/GBP exchange rate plot

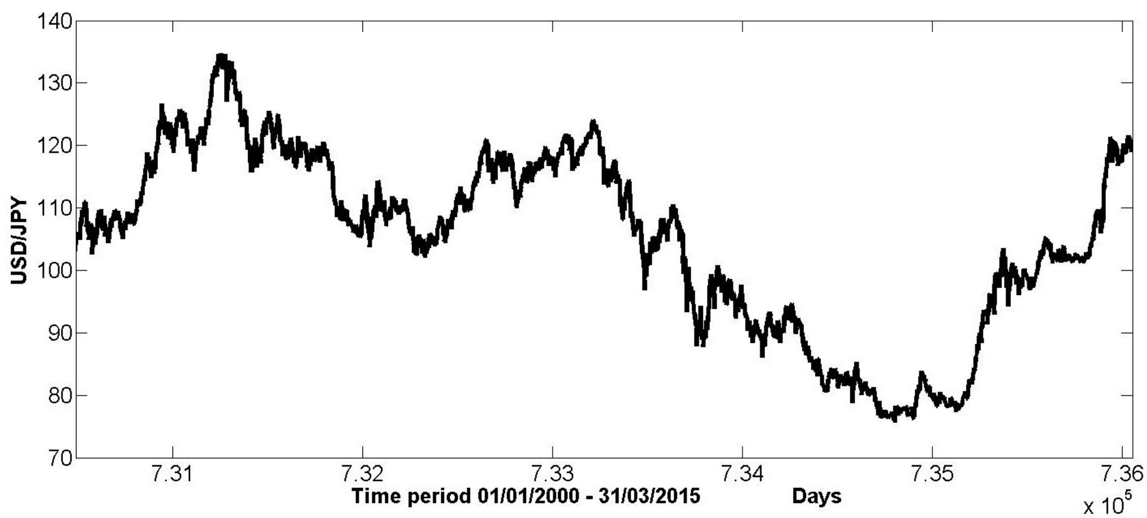

Figure 22 USD/JPY exchange rate plot

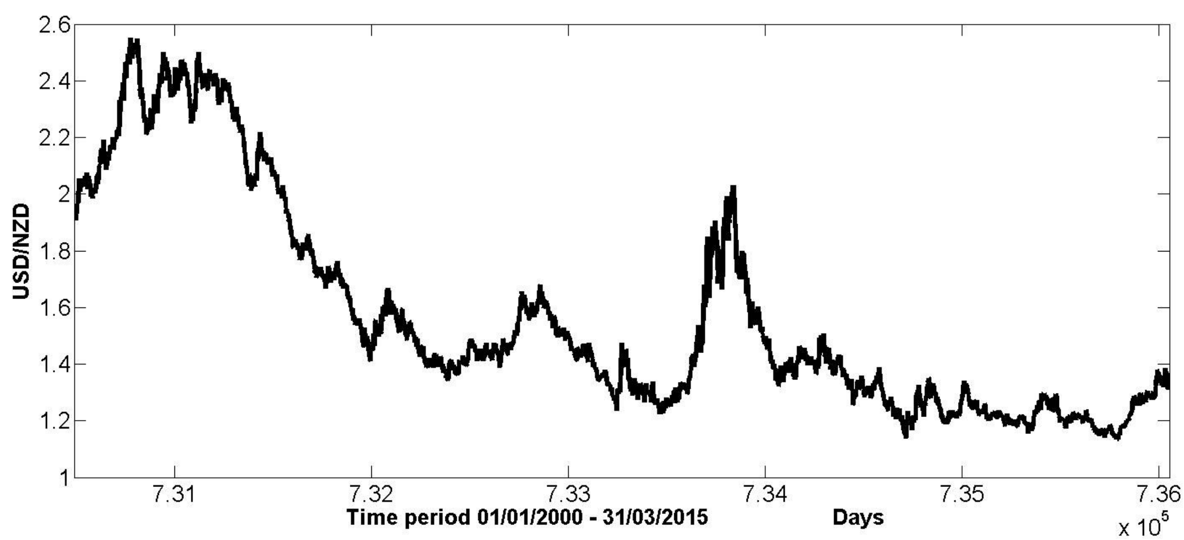

Figure 23 USD/NZD exchange rate plot

It's evident from that the exchange rates don't follow a particular pattern and exhibit stochastic behavior. Thus in the stochastic FOREX market, the algorithm would be tested to predict currency exchange rates of each currency pair independent of each other as a separate system. This would also check the adaptability of the model. The next chapter would be to discuss, analyze the random factors contributing to currency exchange rates and translating them into our algorithm.

6.3 Currency Trading – Factors

The multidimensional PSO model proposed requires random parameters contributing to the stochastic process to be added as dimensions in the search space. Similar to stochastic process in Photonics, the currency exchange rate in FOREX market is determined by a lot of factors. Since a currency pair has two currencies involved, each parameter is evaluated against the other in determining the currency exchange rate. All these parameters are random in nature and the evaluation of these parameters are an inherent aspect of the FOREX market. There are no statistical evaluation models comparing the parameters of two currencies. Thus, there is no linear relationship between these two parameters contributing to the exchange rate of a currency pair. Thus the parameters of each currency are the parameters that evaluate the various aspects of the economy to which the currency represents. For example USD/AUD is determined by the parameters of both united states and Australia economy. The parameters represent similar aspects of the country and could be compared with each other, but their ratio of influence on the currency exchange rate is totally random. Thus the FOREX market has parameters for exchange rate that are twice random as our optical stochastic system parameters. In terms of defining the parameters in our search space, we would normalize the parameters of both the currencies together. These would be used along with the currency exchange rate to form the search space. The logical explanation to normalizing a specific parameter of two currencies together is based on the fact that they represent the exact same aspect of the economies in these two countries. The major factors of each currency that contributes to the exchange rate were studied [42]. Some of the factors are discussed below along with the example of USD/CAD factors.

6.3.1 Balance of Trade - BOT

The difference between a country's import and export is called as balance of trade. A balance of trade with a particular country could be a debit/ credit with the country. This is considered to be an important factor in determining the exchange rate. The balance of trade of the United States and Canada is shown in Figure 24.

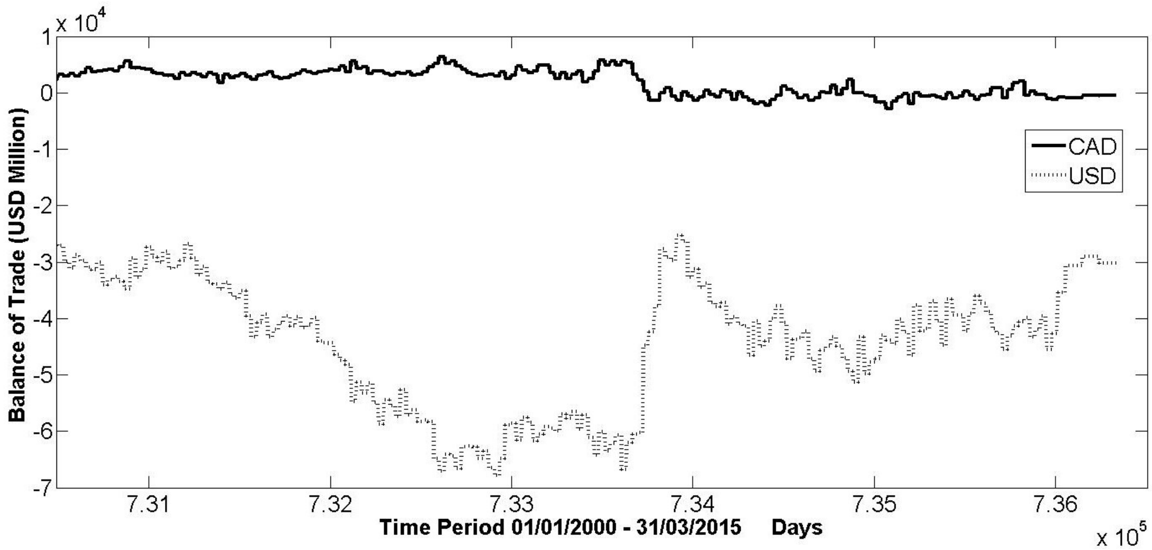

Figure 24 Balance of trade plot for United States and Canada

6.3.2 Consumer Price Index - CPI

Consumer price index is the parameter that measures the change in prices of urban consumer goods over a period of time in an economy. This factor is considered to also contribute to the exchange rate. The Consumer Price Index of United States and Canada are shown in Figure 25.

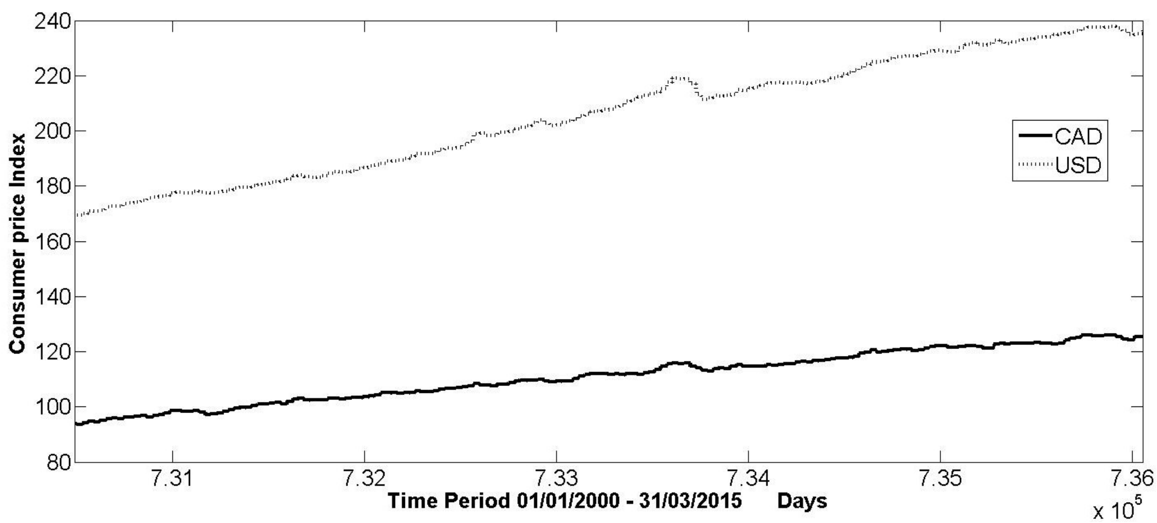

Figure 25 Consumer Price Index plot for United States and Canada

6.3.3 Foreign Exchange Reserve - FXR

This is the amount of foreign currency held by the government, banks of a country as a reserve. This is mainly done to influence the exchange rate. The foreign exchange reserve of the United States and Canada are shown in Figure 26.

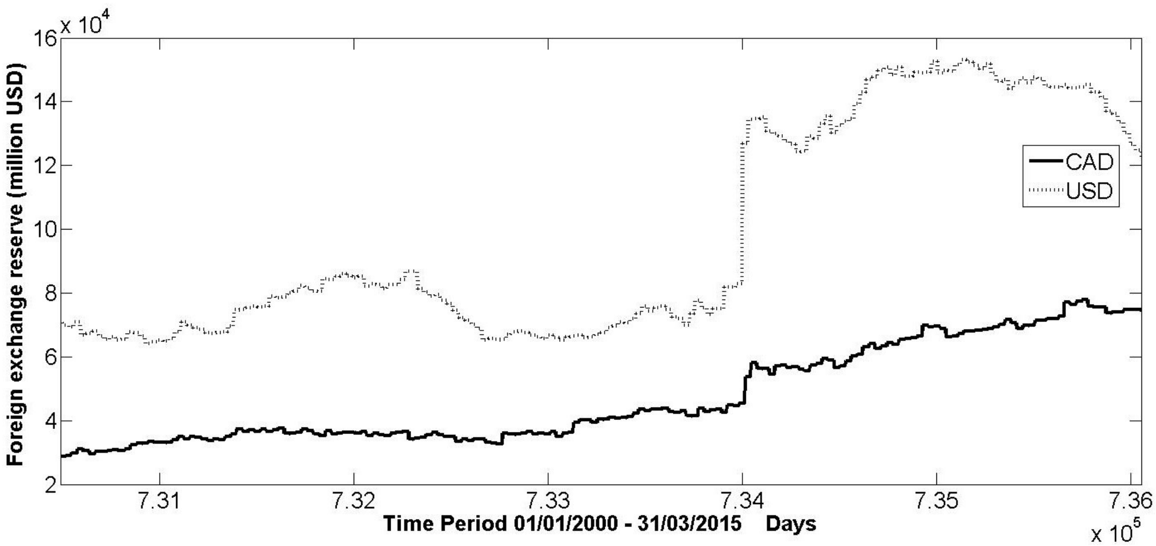

Figure 26 Foreign exchange reserve plot for United States and Canada

6.3.4 Gross domestic product (GDP) - Growth rate

The gross domestic product is the value of all the goods and services produced within a country's borders. The rate or change of GDP over a period of time (quarterly) is the GDP growth rate. This evaluates the performance of an economy and is important in deciding the exchange rate. The GDP growth rate of the United States and Canada are shown in Figure 27.

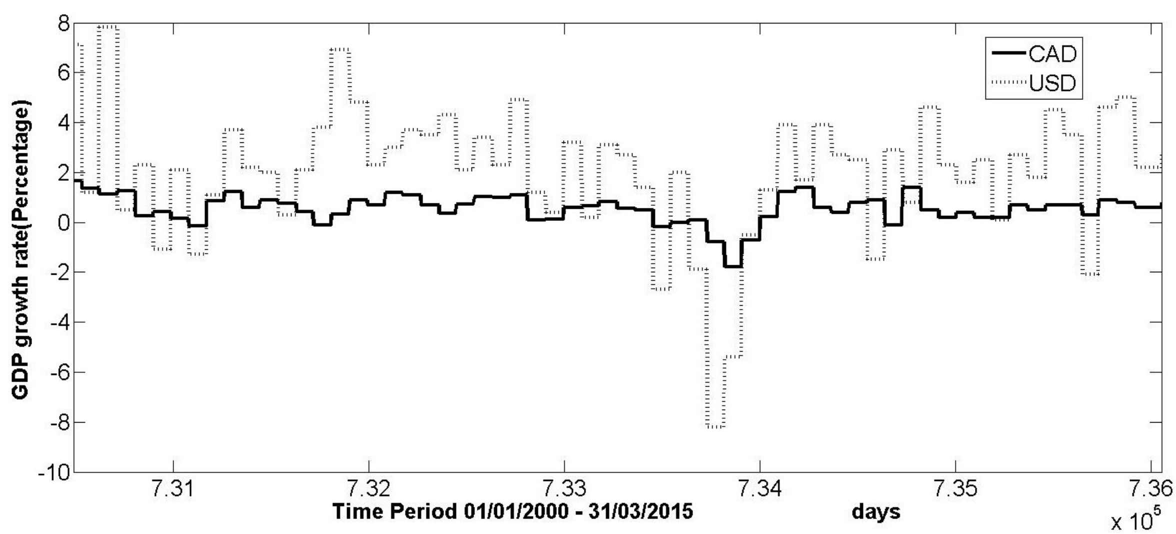

Figure 27 GDP growth rate plot for United States and Canada

6.3.5 Inflation Rate - IFR

Inflation is the increase in the price of essential commodities. The rate at which inflation increases is inflation rate. The central bank of every country tries to counteract the inflation to keep the prices minimum. This also plays an important role in the economy. The inflation rate in the United States and Canada are shown in Figure 28.

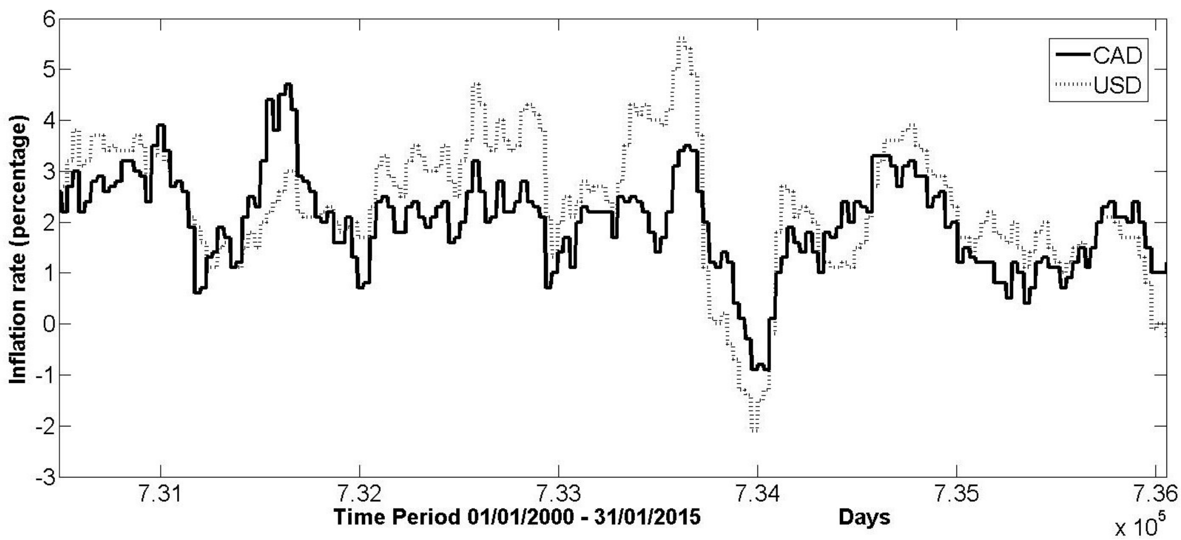

Figure 28 Inflation rate plot for United States and Canada

6.3.6 Interest Rate - IR

The amount charged, expressed as a percentage of principal, by a lender to a borrower for the use of assets [42]. The interest rates in a country for lending is controlled by the central monetary authority. The change in interest rates influences a change in currency exchange rate. Sometimes countries use the interest rate to increase the value of their currency. The interest rate of the United States and Canada are shown in Figure 29.

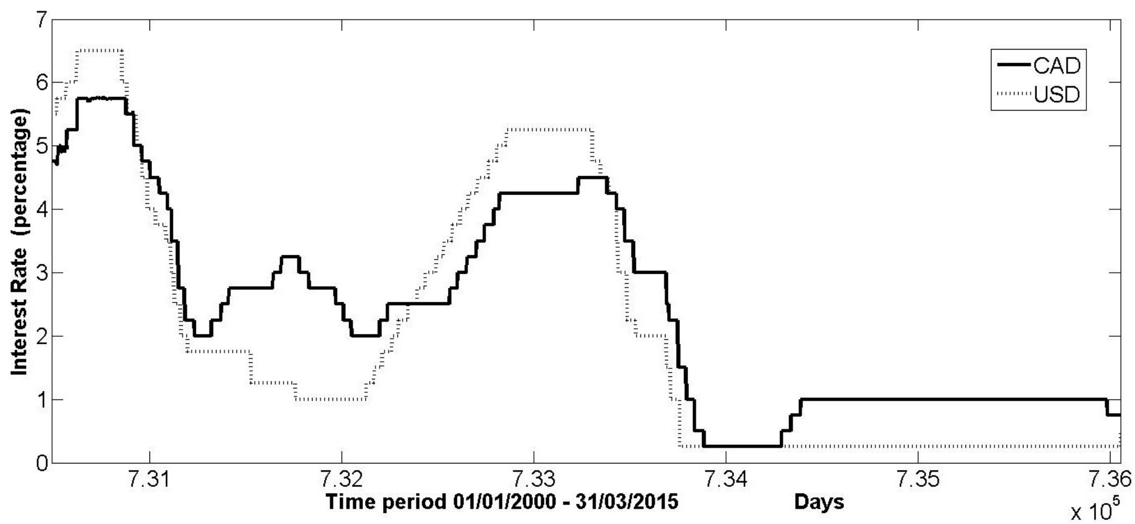

Figure 29 Interest rate plot for United States and Canada

From the figures 24-29, it's evident that the factors for both the countries are related to each other but there is no linear relationship between them. These parameters are random in nature depending on the economy of a country. Thus the factors considered in our test environment are random, which is one of the requirements to test the algorithm. These random factors will also be used in place of random numbers in the PSO velocity equation (Eqn 1) to test the performance of the algorithm.

6.4 PSO Parameters for FOREX Test Environment

The previous section of this chapter discussed on translating FOREX test environment into the multidimensional PSO algorithm. In this section, parameters of PSO defined in chapter 5 are redefined for implementation in FOREX environment

i. Velocity

The velocity would be difference in values of exchange rate, factor between the current and previous position of the particle.

ii. Position

The position of each particle in the search space is given by coordinates. These coordinates inturn translate into the values initialized in the search space. The position of any particle in FOREX environment would be an array of exchange rate and the six parameters.

iii. Particle

Each particle will assume the structure of the position array so that its movement is influenced by the exchange rate and all the six factors.

iv. Fitness Function

The fitness function would be the best value for exchange rate encountered by the swarm. In calculating the fitness we would not consider the values of factor, we would be considering only the exchange rate

v. Personal best – Pbest

The personal best value would be the highest value of exchange rate encountered by a particle during the search.

vi. Global best – Gbest

The global best value would be the highest value of exchange rate encountered by any particle in the entire swarm.

vii. Random Numbers

Two approaches were proposed in chapter 5 for assigning random values. The first approach involves Rand function in Matlab. In the second approach all the factors would be substituted for random numbers. The results from each factor would be compared to find the optimal factor to be used for prediction later.

viii. Iterations

This algorithm would be tested for performance in different values of iteration 50, 100 & 200 and the number providing better result would be used for prediction.

ix. Inertia Weight

Inertia weight would be linearly decreased from 0.9 to 0.4 over the course of the search.

x. Social constants

This algorithm will be tested i8n FOREX market for the following combinations of [C1, C2] – [2,2], [1.4, 1.4] and [0.7,0.8] and the combination producing better results during training would be used for prediction.

6.5 Data Collection

The data for exchange rate of all the currecy pairs was collected for the period from january 2000 till March 2015 [43]. The data for all the factors inflencing currency exchange rates were downloaded from an online repositry of an economic forum for the same period of time [44]. The historic data collected would be used to train the algorithm. The algorithm needs to be trained for it to understand the stochastic nature of the process and parameters. With the memory of search during training the algorithm would be used to predict for the future.

CHAPTER 7 PROCEDURE - TRAINING - PREDICTION

This chapter explains the procedure for training the algorithm, analysis and discussion of training results. With conclusions from training, the parameters and procedure for the prediction will be determined.

7.1 Trainaing Procedure

The steps for training the algorithm as follows.

1. The search space is initialized with data. Inertia weight is set to linearly decrease from 0.9 to 0.4. Velocity clamping conditions are defined with all dimensions of data. The values of random numbers are assigned using rand function and first set of social constants are assigned.
2. To start, the algorithm is initialized with 100 particles. Each particle is assigned to a random position, assuming a random initial velocity.
3. The particle is evaluated for its initial value which is set as Pbest and the Gbest value is calculated among the Pbest of all the particles.
4. A loop is run for 50 iterations during which each particle with a gains a velocity calculated by Eqn 1 and goes to a new position by Eqn 2.
5. The value for fitness function is calculated in the new position. Pbest for all particles and Gbest of the swarm is evaluated and updated. This process continues till 50 iterations are completed.

6. The algorithm produces values determined by the fitness function and are compared with actual exchange rates for error and performance.
7. The process is repeated for 100, 200 and 500 iterations. The better performing iteration is selected to go on with the next parameter optimization
8. Now with optimized iteration, the entire training is repeated for the remaining the value of acceleration constants.
9. The results are compared with actual exchange rates to find error and direction. The better performing set of social constants is selected to go on for optimizing random parameter with the factors influencing FOREX.
10. Random random parameters R1 & R2 are substituted with the normalized values of the first factor. The results are compared with actual values to compute the error, adjust with a 3 day moving, percentage error and direction.
11. A similar procedure is done for all the other factors to predict exchange rate, calculate error, percentage error, exchange rates after error correction and direction. The performance of the algorithm for all the factors is compared with results from Matlab Rand function to determine the best performing substitution for random numbers.

All the above steps are performed during training to tune the algorithm to predict exchange rates.

7.2 Training Results – Analysis

Training results for parameter optimization was carried out for all currency pairs.

7.2.1 Training results for Iterations optimization

The algorithm is tested for iterations of 50,100,200 & 500. The results are in table 8.

Currency Pair	Iterations	Average Percentage Error	Correct prediction days (30)	Correct Prediction Percentage
USD/AUD	50	8.47	11	36.67
	100	8.61	12	40.00
	200	**8.43**	**13**	**43.33**
	500	8.47	10	33.33
USD/CAD	50	9.05	15	50.00
	100	8.99	11	36.67
	200	8.99	12	40.00
	500	**9**	**19**	**63.33**
USD/CHF	50	4.61	18	60.00
	100	**4.64**	**19**	**63.33**
	200	4.69	18	60.00
	500	4.69	18	60.00
USD/EUR	50	10.78	12	40.00
	100	10.79	12	40.00
	200	**10.99**	**15**	**50.00**
	500	10.96	13	43.33
USD/GBP	50	6.98	7	23.33
	100	6.9	13	43.33
	200	6.95	14	46.67
	500	**6.87**	**17**	**56.67**
USD/JPY	50	5.89	14	46.67
	100	5.91	12	40.00
	200	**5.85**	**19**	**63.33**
	500	5.99	14	46.67
USD/NZD	50	7.79	15	50.00
	100	**7.91**	**16**	**53.33**
	200	7.9	14	46.67
	500	7.79	14	46.67

Table 3 Training results for Iterations optimization

7.2.2 Training results for Accelerations constants optimization

The algorithm is tested for three combinations of acceleration constants. The results are in table 8.

Currency Pair	Constants [C1,C2]	Average Percentage Error	Correct prediction days (30)	Correct Prediction Percentage
USD/AUD	[0.7,0.8]	8.44	13	43.33
	[1.4,1.4]	**8.44**	**18**	**60.00**
	[2,2]	8.46	16	53.33
USD/CAD	[0.7,0.8]	9.02	15	50.00
	[1.4,1.4]	**9**	**19**	**63.33**
	[2,2]	8.96	17	56.67
USD/CHF	[0.7,0.8]	4.63	13	43.33
	[1.4,1.4]	**4.65**	**19**	**63.33**
	[2,2]	4.75	15	50.00
USD/EUR	[0.7,0.8]	10.95	13	43.33
	[1.4,1.4]	**10.99**	**15**	**50.00**
	[2,2]	10.78	13	43.33
USD/GBP	[0.7,0.8]	6.95	13	43.33
	[1.4,1.4]	**6.87**	**17**	**56.67**
	[2,2]	6.99	13	43.33
USD/JPY	**[0.7,0.8]**	**5.82**	**23**	**76.67**
	[1.4,1.4]	5.85	19	63.33
	[2,2]	5.84	18	60.00
USD/NZD	[0.7,0.8]	7.75	17	56.67
	[1.4,1.4]	7.76	12	40.00
	[2,2]	**7.72**	**17**	**56.67**

Table 4 Training results for Acceleration constants optimization

7.2.3 Training results for Random parameter optimization

The algorithm is now optimized for random parameters. The algorithm is initially tested by the rand function, substituting values for random parameters. The random parameters are then substituted with normalized values of factors BOT, CPI, GDP, IFR, and IR in a random manner and tested for prediction. The results for each currency pair is summarized in Table 5 & 6.

Currency Pair	**Random variable / calculations**	**Rand()**	**BOT**	**FXR**	**GDP**	**IFR**	**IR**
USD/AUD	Average Percentage Error	**8.44**	8.34	8.46	8.45	8.45	8.48
	Correct prediction days (30)	**18**	15	17	10	14	17
	Correct Prediction Percentage	**60.00**	50.00	56.67	33.33	46.67	56.67
USD/CAD	Average Percentage Error	**9.00**	8.92	9.01	8.97	8.99	9.03
	Correct prediction days (30)	**18**	12	18	12	12	17
	Correct Prediction Percentage	**60.00**	40.00	60.00	40.00	40.00	56.67
USD/CHF	Average Percentage Error	**4.65**	4.53	4.63	4.58	4.66	4.67
	Correct prediction days (30)	**19**	12	13	20	15	13
	Correct Prediction Percentage	**63.33**	40.00	43.33	66.67	50.00	43.33
USD/EUR	Average Percentage Error	10.99	10.96	10.80	**10.77**	10.95	10.81
	Correct prediction days (30)	18	18	12	**19**	14	14
	Correct Prediction Percentage	60.00	60.00	40.00	**63.33**	46.67	46.67

Table 5 Training results for Random parameter optimization 1

Currency Pair	Random variable/ calculations	Rand()	BOT	FXR	GDP	IFR	IR
USD/GBP	Average Percentage Error	**6.87**	6.89	6.94	6.99	6.91	7.04
	Correct prediction days (30)	**17**	12	15	12	16	13
	Correct Prediction Percentage	**56.67**	40.00	50.00	40.00	53.33	43.33
USD/JPY	Average Percentage Error	5.82	**10.02**	5.99	5.90	5.83	5.99
	Correct prediction days (30)	23	**17**	14	9	20	16
	Correct Prediction Percentage	76.67	**56.67**	46.67	30.00	66.67	53.33
USD/NZD	Average Percentage Error	7.72	10.60	7.68	7.85	**7.81**	7.79
	Correct prediction days (30)	17	14	15	15	**18**	13
	Correct Prediction Percentage	56.67	46.67	50.00	50.00	**60.00**	43.33

Table 6 Training results for Random parameter optimization 2

7.3 Training Results – Summary

The algorithm is trained to optimize the initialization parameters and the optimized results for each currency pair is shown in Table 7 with correct prediction percentage and the associated average percentage error. From the results its evident that with tuning the algorithm the efficiency and prediction percentage improves. This also confirms that each system behaves separately and gives a better performance for a different set of characteristics. The error percentage is almost the same for every run of a particular pair, which confirms that the algorithm is consistent. The results also show the Error correction technique increases accuracy but decreases the efficiency of prediction direction. Thus its recommended that error correction not be used.

Currency Pair	Iterations	[C1,C2]	Random Variable	Average Percentage Error	Correct prediction days (30)	Correct Prediction Percentage
USD/AUD	200	[1.4, 1.4]	Rand	8.44	18	60.00
USD/CAD	500	[1.4, 1.4]	Rand	9	19	63.33
USD/CHF	100	[1.4, 1.4]	GDP	4.58	20	66.67
USD/EUR	200	[1.4, 1.4]	GDP	10.77	19	63.33
USD/GBP	500	[1.4, 1.4]	Rand	6.87	17	56.67
USD/JPY	200	[0.7,0.8]	Rand	5.82	23	76.67
USD/NZD	100	[2,2]	IFR	7.81	18	60.00

Table 7 Training results summary

The plot of actual exchange rate Vs predicted currency exchange rates is shown in figures 30-36 for all currency pairs. The graphs are plotted to show the direction of prediction in comparison with the direction of market data. In all the graphs the error in prediction is as shown in the tables 3-7.

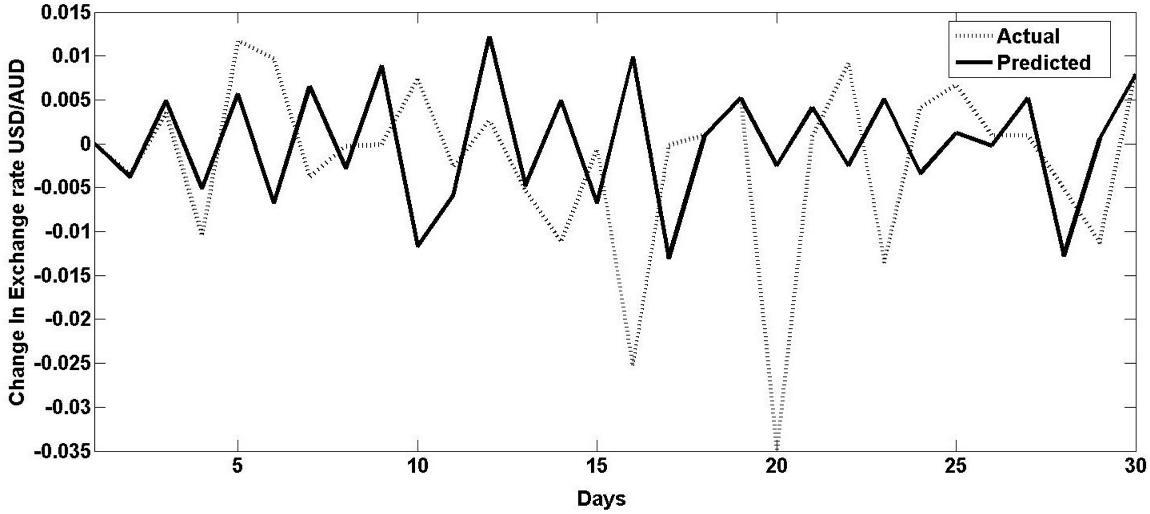

Figure 30 USD/AUD Training Prediction

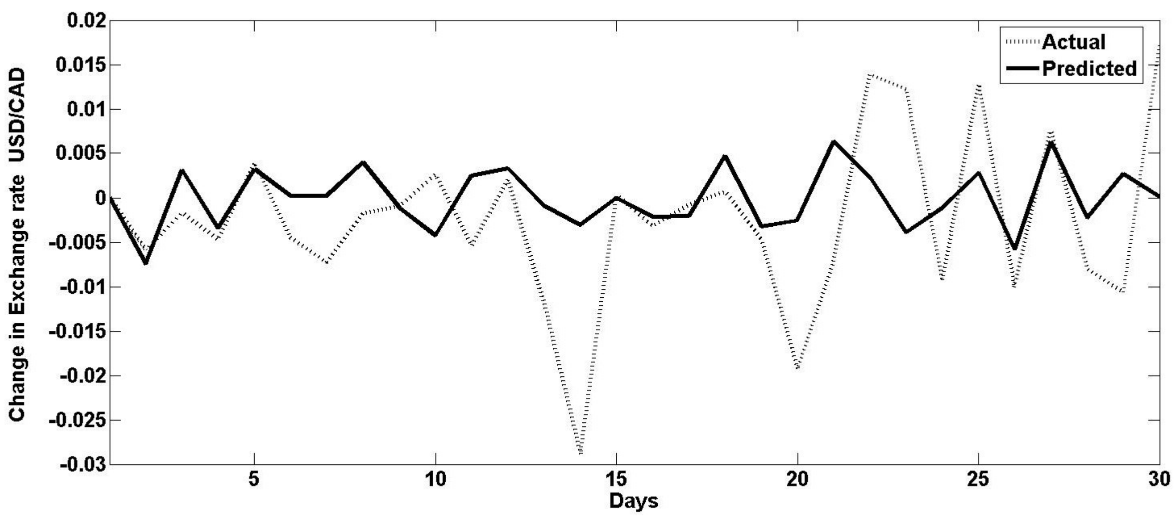

Figure 31 USD/CAD Training Prediction

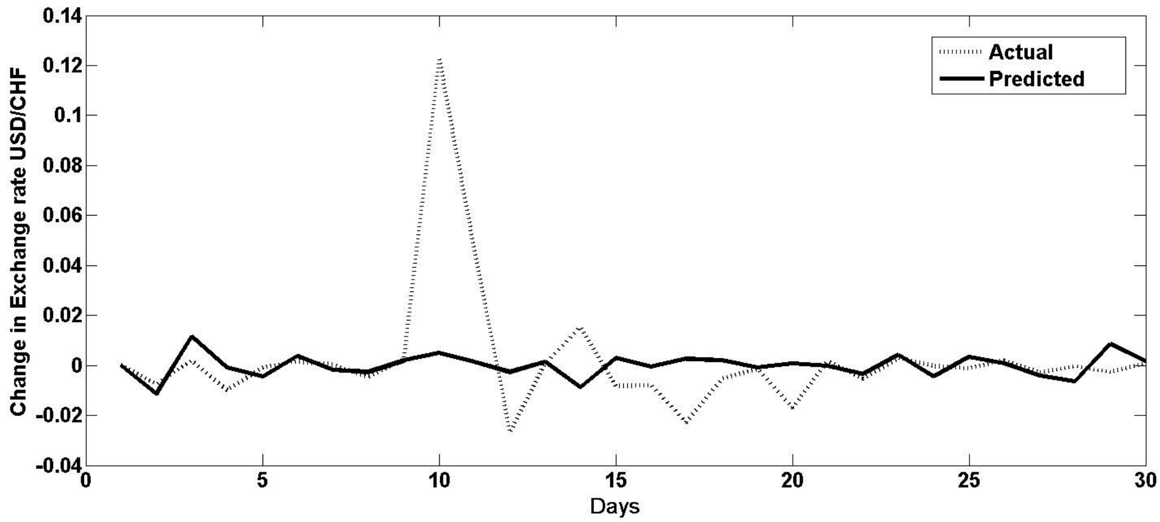

Figure 32 USD/CHF Training Prediction

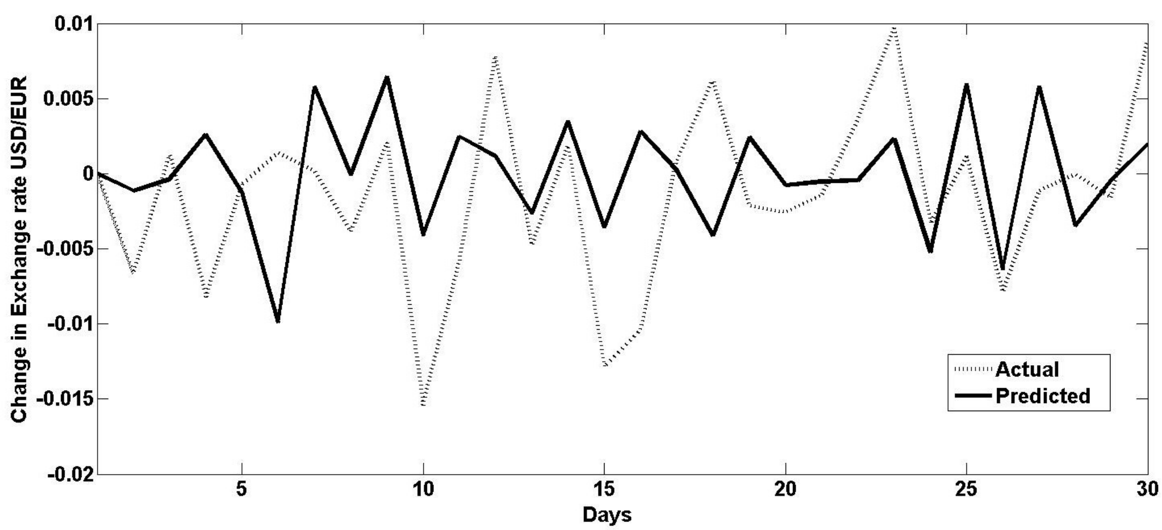

Figure 33 USD/EUR Training Prediction

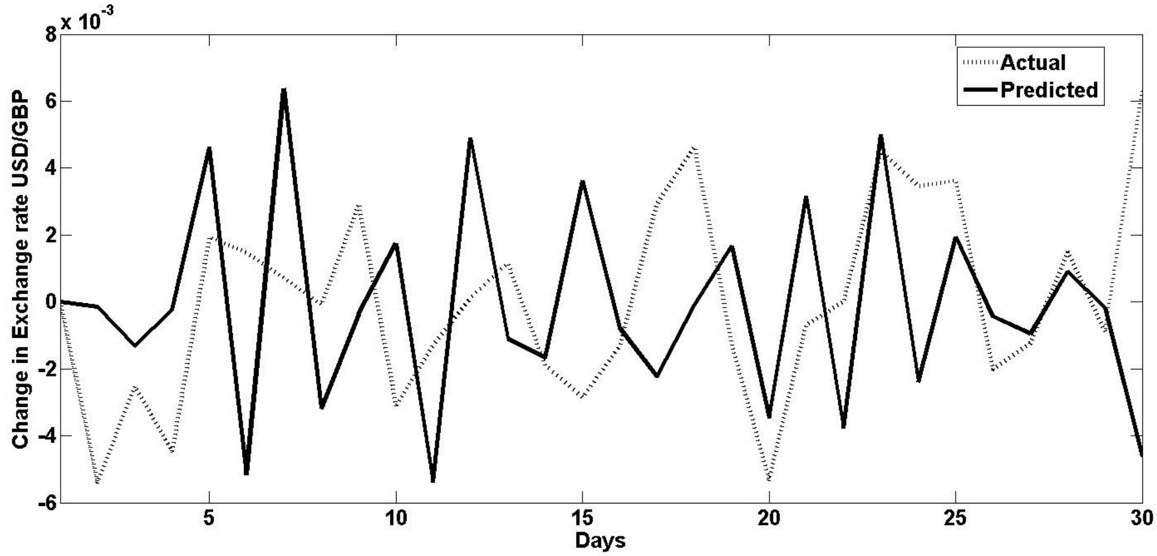

Figure 34 USD/GBP Training Prediction

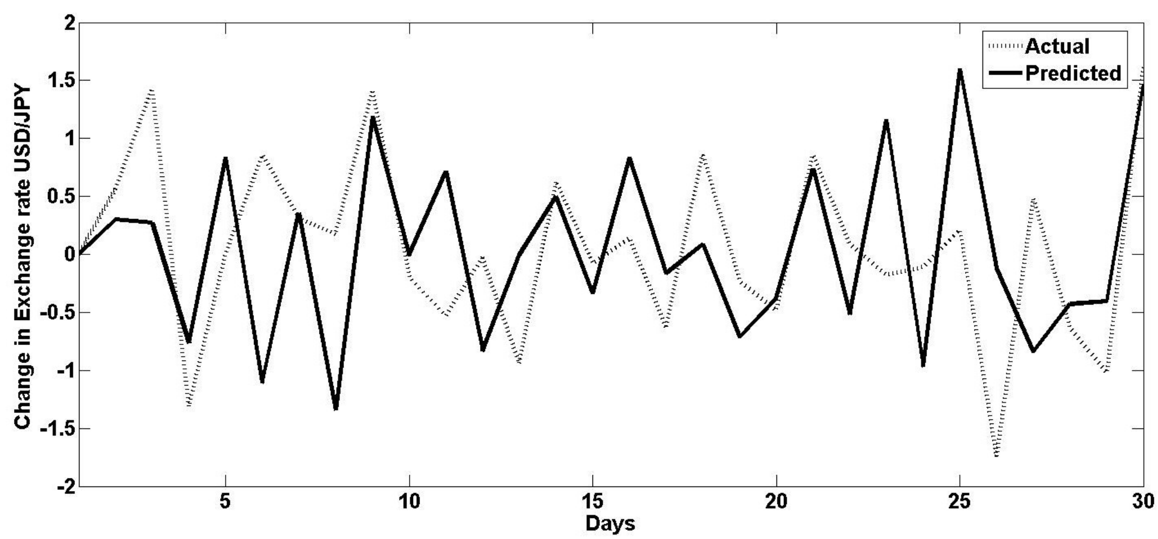

Figure 35 USD/JPY Training Prediction

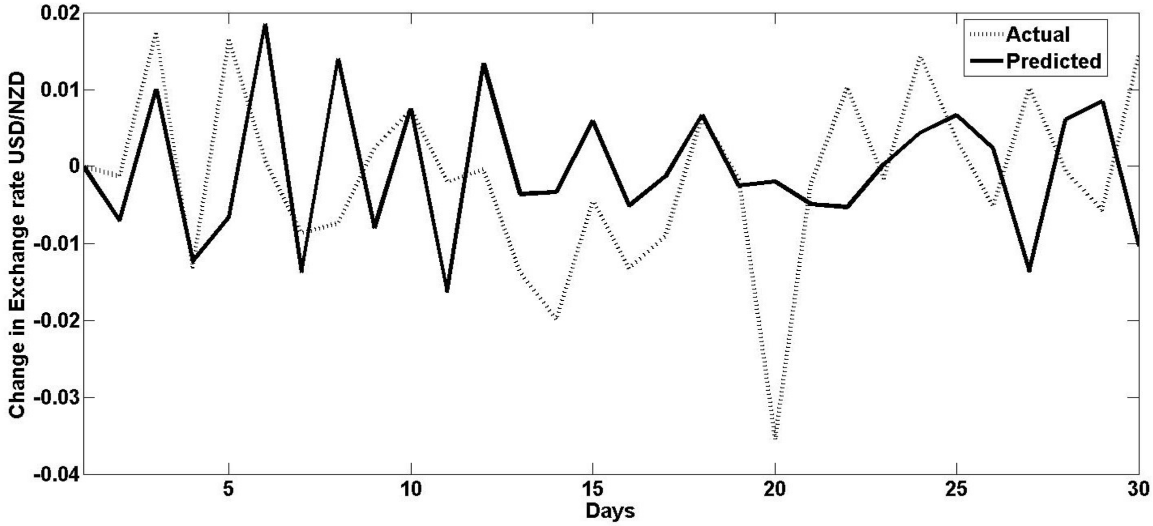

Figure 36   USD/NZD Training Prediction

7.4 Procedure for Testing Precdiction

During testing, the algorithm is again optimized for all the initialization parameters iterations, acceleration constants and better performing random values if there is a change in the search space. The algorithm will be implemented to predict exchange rates for the unknown future. The algorithm is set to predict for a specific number of days in the future depending on the availability of actual data/forecast data to compare and evaluate performance. The number of prediction days could also be set constant. The optimization procedure is similar to training and the prediction procedure ig given below

1. The search space is initialized with data. Inertia weight is set to linearly decrease from 0.9 to 0.4. Velocity clamping conditions are defined for all dimensions of data. The values for random numbers and acceleration constants are assigned.

2. To start, the algorithm is initialized with optimized particles. Each particle is assigned to a random position, assuming a random initial velocity.
3. The particle is evaluated for its initial value which is set as Pbest and the Gbest value is calculated among the Pbest of all the particles.
4. A loop is run for optimized iterations during which each particle with a gains a velocity calculated by Eqn 1 and goes to a new position by Eqn 2.
5. The value for fitness function is calculated in the new position. Pbest for all particles and Gbest of the swarm is evaluated and updated. This process continues till all iterations are completed.
6. The algorithm produces values determined by the fitness function and compare with actual exchange rates for calculating error, adjusted exchange rates with 3 day moving average and direction of the prediction.
7. The process is repeated for all currency pairs independent of each other so that there is no influence of the previous currency.

CHAPTER 8 RESULTS & SUMMARY

The results of the prediction are analyzed and the performance of the algorithm is discussed in the this chapter.

8.1 Prediction Testing Results - Analysis

The algorithm is tested to predict exchange rates for 21 days. The results are compared with the actual values. The actual values are not available in the search region for particles. The predicted values are evaluated for error, average percentage error, direction of prediction and percentage of prediction direction. These are calculated in comparison with the actual exchange rate data/forecast exchange rate data. The graphs are plotted to show the direction of prediction in comparision with the direction of market data. In all the graphs the error in prediction is less than 5 % as shown in the tables 8 – 15. The results for each currency pair is discussed in the following sections.

8.1.1 Prediction test results for Iterations

The algorithm is tested for iterations of 50,100,200 & 500. The results are summarized in table 8. The plot of predicted values and actual values for USD/CAD for various iterations is plotted in Fig 37-40. Each currency pair acts as a separate stochastic system. The optimized iterations are different in case of each system.

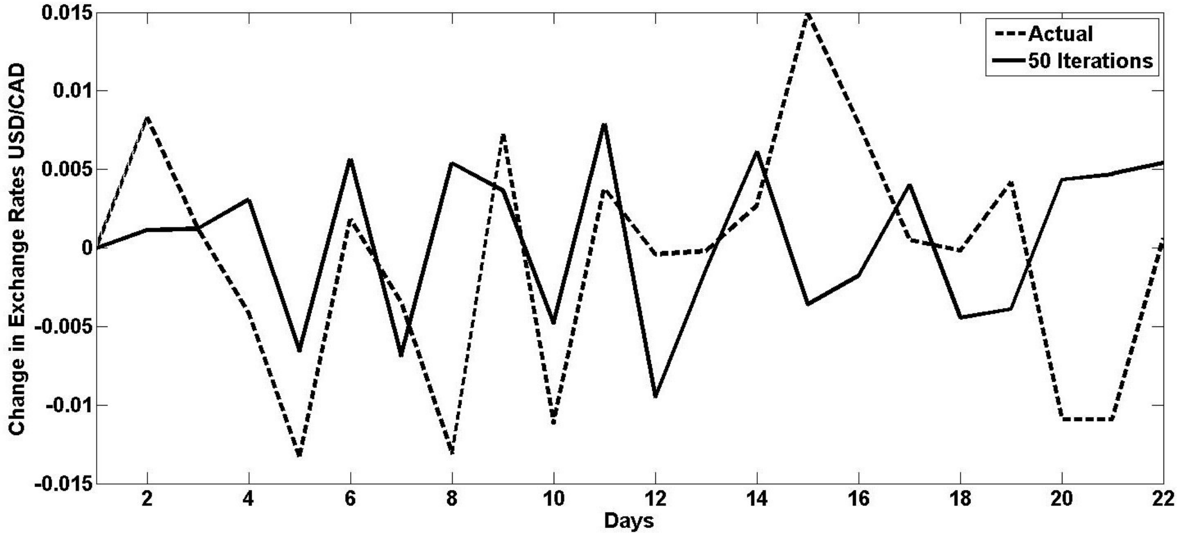

Figure 37 USD/CAD Prediction Test results for 50 Iterations

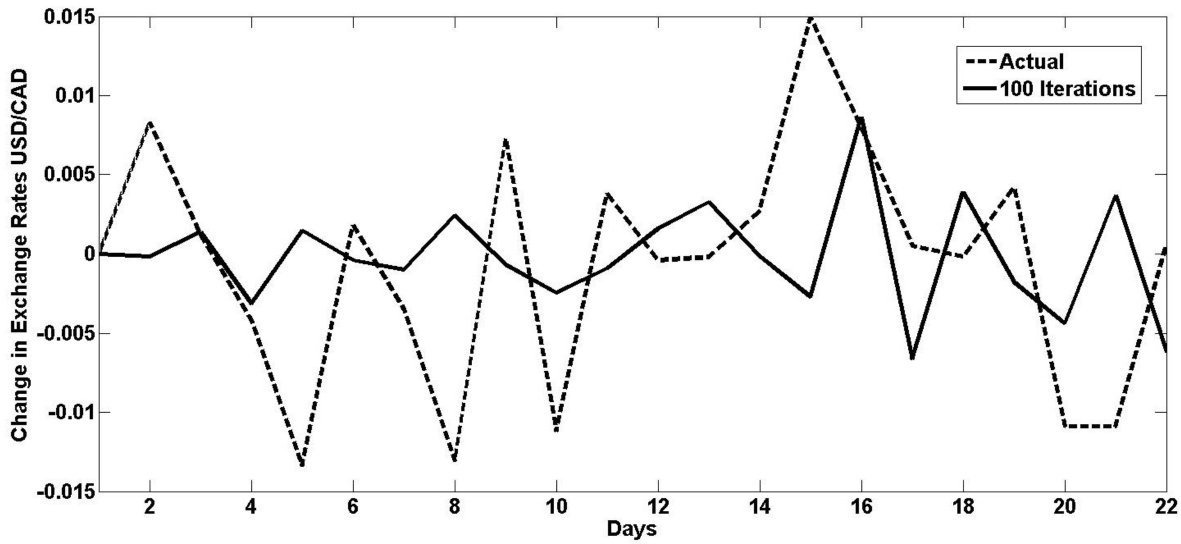

Figure 38 USD/CAD Prediction Test results for 100 Iterations

Currency Pair	Iterations	Average Percentage Error	Correct prediction days (30)	Correct Prediction Percentage
USD/AUD	50	8.47	11	36.67
	100	**8.61**	**12**	**40.00**
	200	8.43	13	43.33
	500	8.47	10	33.33
USD/CAD	50	9.05	15	50.00
	100	8.99	11	36.67
	200	8.99	12	40.00
	500	**9**	**19**	**63.33**
USD/CHF	50	4.61	18	60.00
	100	**4.64**	**19**	**63.33**
	200	4.69	18	60.00
	500	4.69	18	60.00
USD/EUR	50	10.78	12	40.00
	100	10.79	12	40.00
	200	**10.99**	**15**	**50.00**
	500	10.96	13	43.33
USD/GBP	50	6.98	7	23.33
	100	6.9	13	43.33
	200	6.95	14	46.67
	500	**6.87**	**17**	**56.67**
USD/JPY	50	5.89	14	46.67
	100	5.91	12	40.00
	200	**5.85**	**19**	**63.33**
	500	5.99	14	46.67
USD/NZD	50	7.79	15	50.00
	100	**7.91**	**16**	**53.33**
	200	7.9	14	46.67
	500	7.79	14	46.67

Table 8 Prediction test results for Iterations

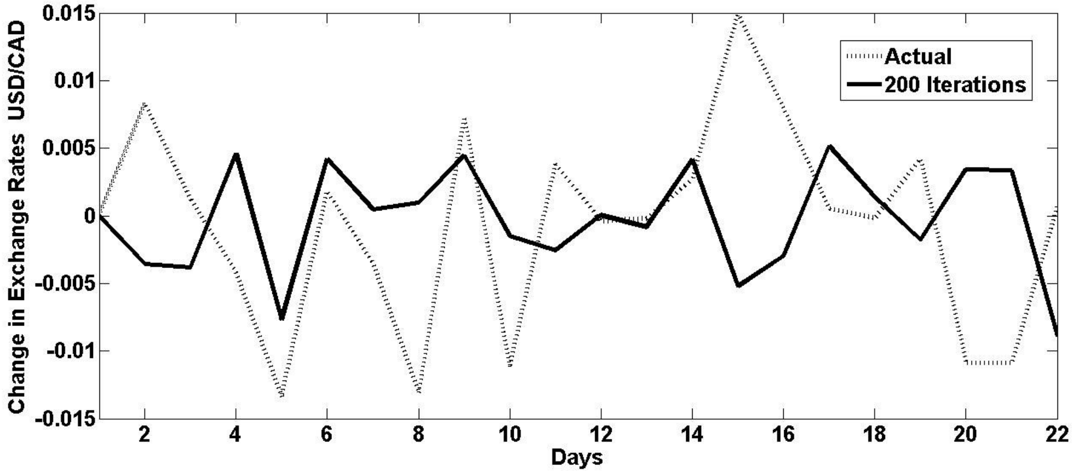

Figure 39 USD/CAD Prediction Test results for 200 Iterations

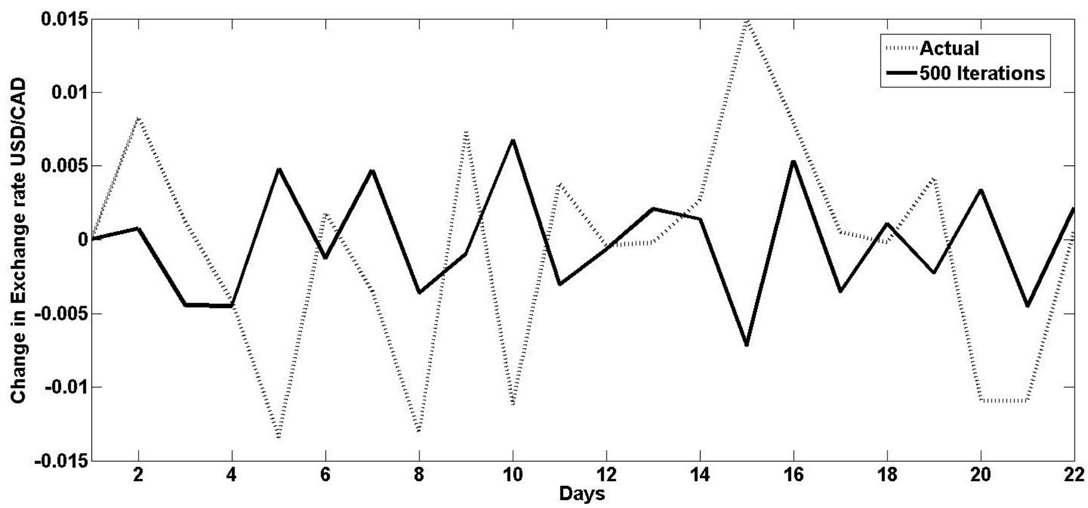

Figure 40 USD/CAD Prediction Test results for 500 Iterations

8.1.2 Prediction test results for acceleration constants

The Algorithm is optimized for acceleration constants. The results are summarized in table 9 and figures 41-43 contain the plots for actual exchange rates vs predicted exchanges rates of USD/CAD for various combinations of acceleration constants.

Currency Pair	**Constants [C1,C2]**	**Average Percentage Error**	**Correct prediction days (30)**	**Correct Prediction Percentage**
USD/AUD	[0.7,0.8]	8.44	13	43.33
	[1.4,1.4]	**8.44**	**18**	**60.00**
	[2,2]	8.46	16	53.33
USD/CAD	[0.7,0.8]	9.02	15	50.00
	[1.4,1.4]	**9**	**19**	**63.33**
	[2,2]	8.96	17	56.67
USD/CHF	[0.7,0.8]	4.63	13	43.33
	[1.4,1.4]	**4.65**	**19**	**63.33**
	[2,2]	4.75	15	50.00
USD/EUR	[0.7,0.8]	10.95	13	43.33
	[1.4,1.4]	**10.99**	**15**	**50.00**
	[2,2]	10.78	13	43.33
USD/GBP	[0.7,0.8]	6.95	13	43.33
	[1.4,1.4]	**6.87**	**17**	**56.67**
	[2,2]	6.99	13	43.33
USD/JPY	**[0.7,0.8]**	**5.82**	**23**	**76.67**
	[1.4,1.4]	5.85	19	63.33
	[2,2]	5.84	18	60.00
USD/NZD	[0.7,0.8]	7.75	17	56.67
	[1.4,1.4]	7.76	12	40.00
	[2,2]	**7.72**	**17**	**56.67**

Table 9 Prediction test results for acceleration constants

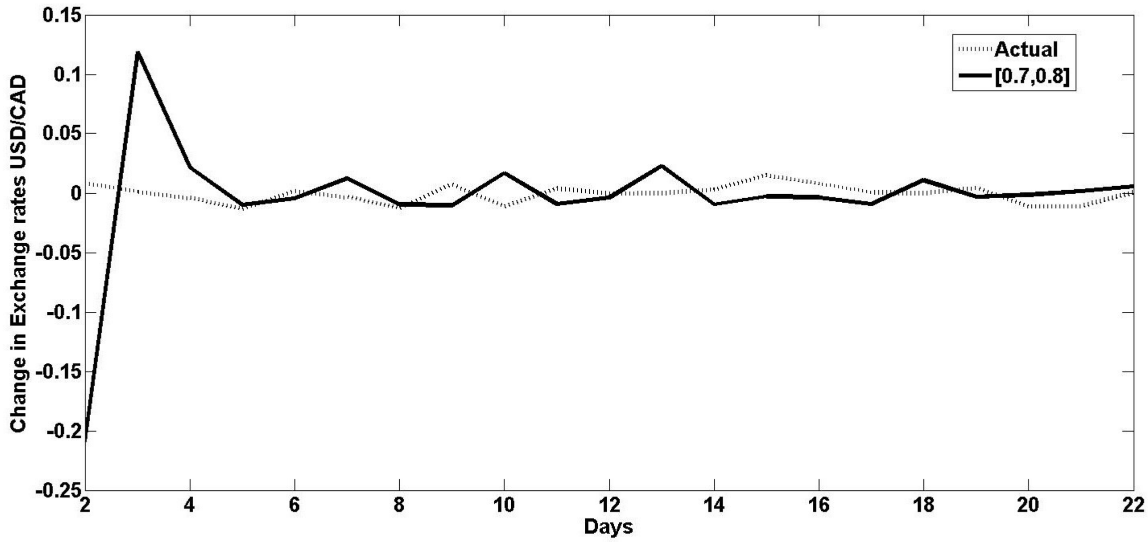

Figure 41 USD/CAD Prediction test results for acceleration constants [0.7,0.8]

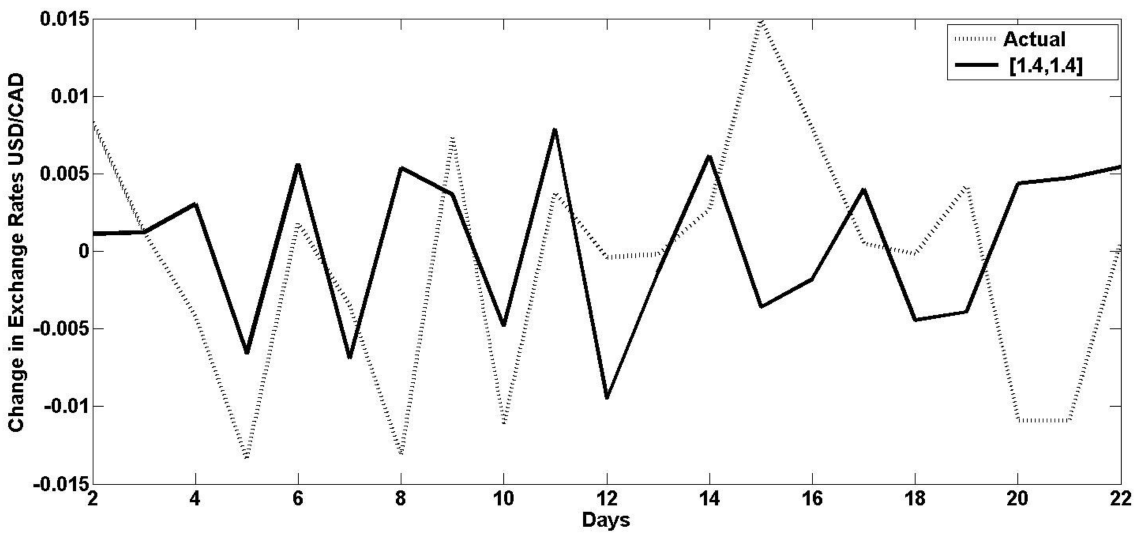

Figure 42 USD/CAD Prediction test results for acceleration constants [1.4,1.4]

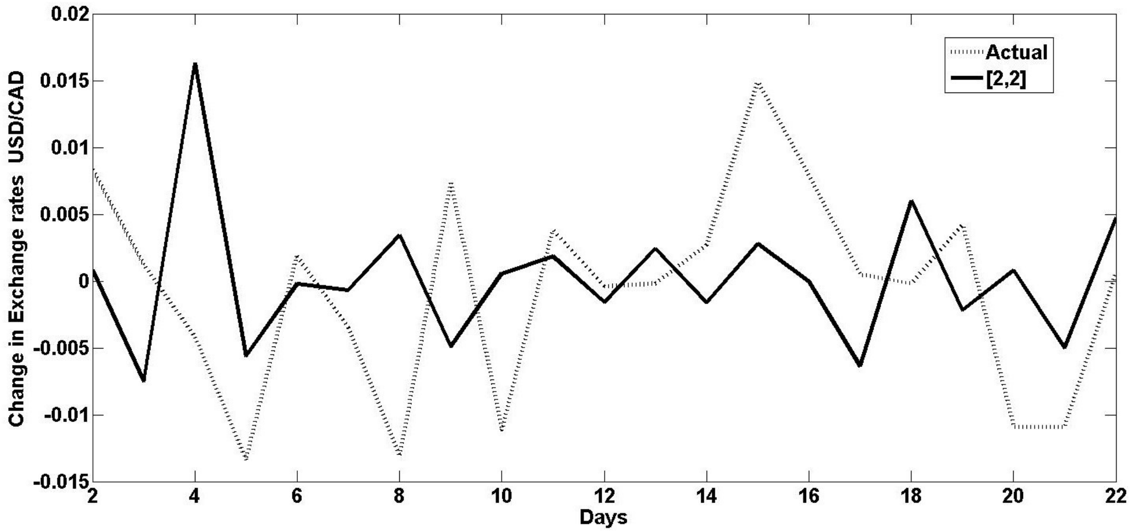

Figure 43 USD/CAD Prediction test results for acceleration constants [2,2]

8.1.3 Prediction test results for random parameters

The algorithm is now optimized for random parameters. The algorithm is initially tested with Rand function, substituting values for random parameters. The random parameters are then substituted with normalized values of factors BOT, CPI, GDP, IFR, and IR in a random manner and tested for prediction. The results for each currency pair is summarized in Table 10 & 11. Figures 44-49 show the plot of actual exchange rates vs Predicted exchange rates for USD/CAD for various combinations of factors substituted for random numbers.

Currency Pair	Calculation	Rand()	BOT	FXR	GDP	IFR	IR
USD/AUD	Average Percentage Error	2.86	2.93	2.92	2.91	**2.88**	2.94
	Correct prediction days (21)	13	12	12	8	**14**	14
	Correct Prediction Percentage	59.09	57.14	57.14	38.10	**66.67**	66.67
USD/CAD	Average Percentage Error	**3.09**	3.16	3.11	3.11	3.16	3.15
	Correct prediction days (21)	**14**	13	10	13	12	11
	Correct Prediction Percentage	**66.67**	61.90	47.62	61.90	57.14	52.38
USD/CHF	Average Percentage Error	4.78	4.66	4.59	4.74	**4.64**	4.57
	Correct prediction days (21)	14	13	12	10	**14**	10
	Correct Prediction Percentage	66.67	61.90	57.14	47.62	**66.67**	47.62
USD/EUR	Average Percentage Error	6.66	**6.62**	6.65	6.63	6.57	6.71
	Correct prediction days (21)	13	**14**	13	8	12	14
	Correct Prediction Percentage	61.90	**66.67**	61.90	38.10	57.14	66.67

Table 10 Prediction test results for random parameters 1

Currency Pair	Calculation	Rand()	BOT	FXR	GDP	IFR	IR
USD/GBP	Average Percentage Error	2.14	**2.16**	2.15	2.14	2.11	2.11
	Correct prediction days (21)	12	**16**	8	13	11	9
	Correct Prediction Percentage	57.14	**76.19**	38.10	61.90	52.38	42.86
USD/JPY	Average Percentage Error	1.54	1.54	**1.50**	1.55	1.52	1.55
	Correct prediction days (21)	14	8	**15**	7	11	12
	Correct Prediction Percentage	66.67	38.10	**71.43**	33.33	52.38	57.14
USD/NZD	Average Percentage Error	**1.49**	1.58	1.52	1.58	1.63	1.53
	Correct prediction days (21)	**15**	10	14	11	7	10
	Correct Prediction Percentage	**71.43**	47.62	66.67	52.38	33.33	47.62

Table 11 Prediction test results for random parameters 2

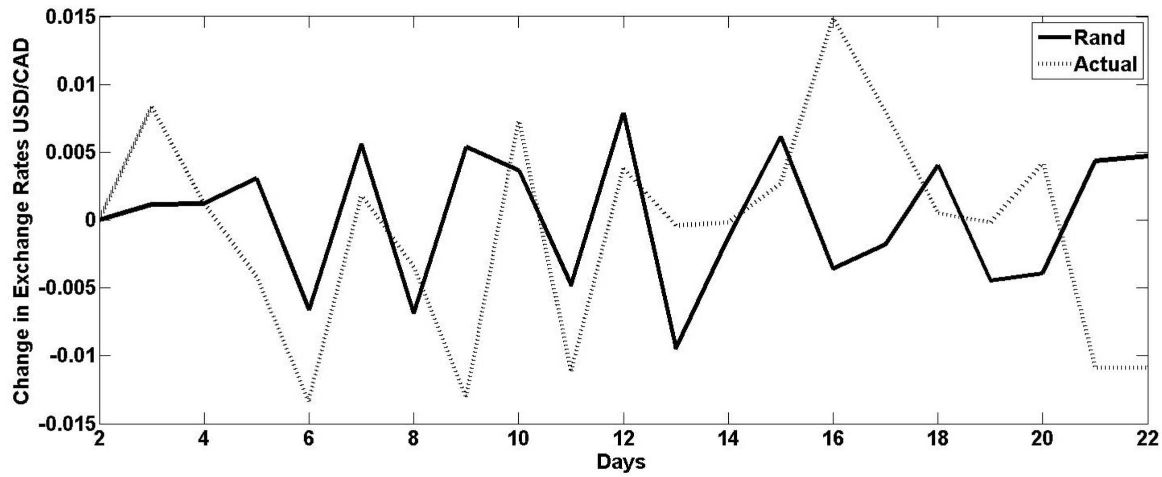

Figure 44 USD/CAD Prediction test results for Rand as random parameters

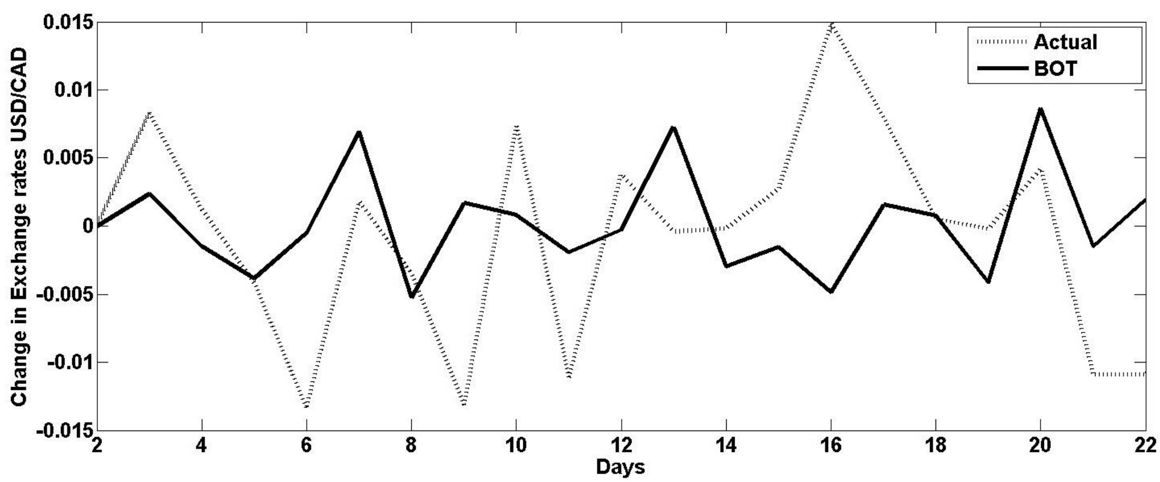

Figure 45 USD/CAD Prediction test results for BOT as random parameters

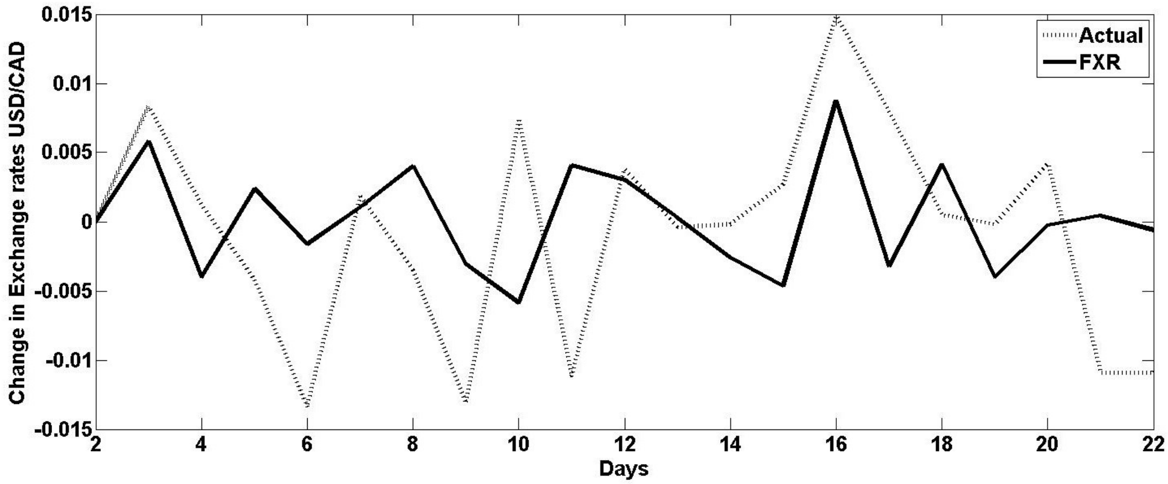

Figure 46 USD/CAD Prediction test results for FXR as random parameters

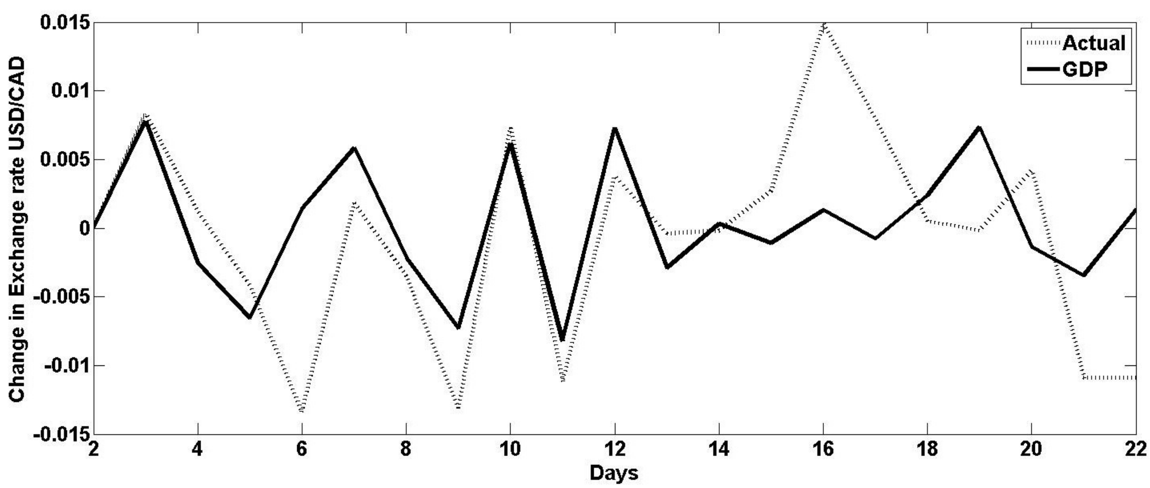

Figure 47 USD/CAD Prediction test results for GDP as random parameters

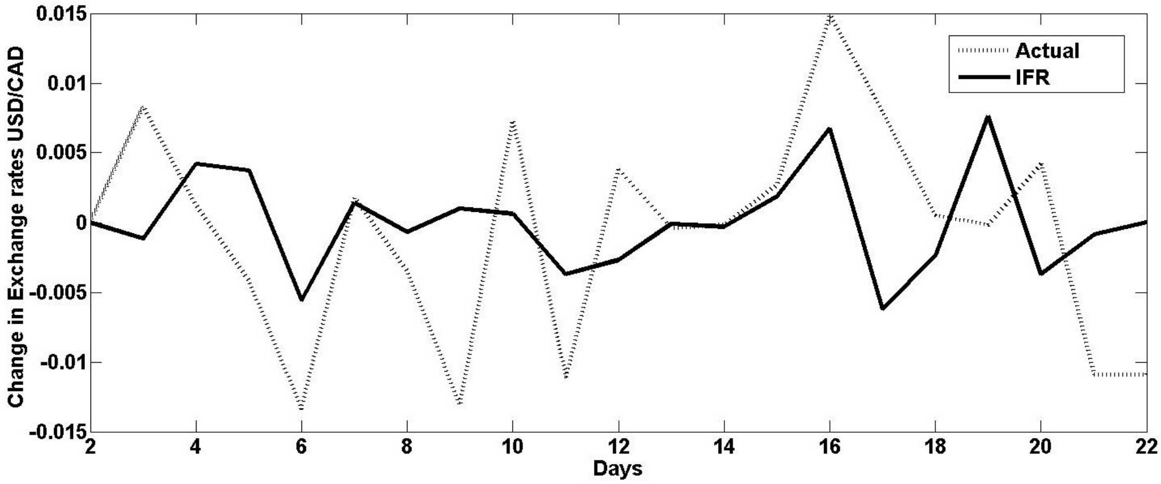

Figure 48 USD/CAD Prediction test results for IFR as random parameters

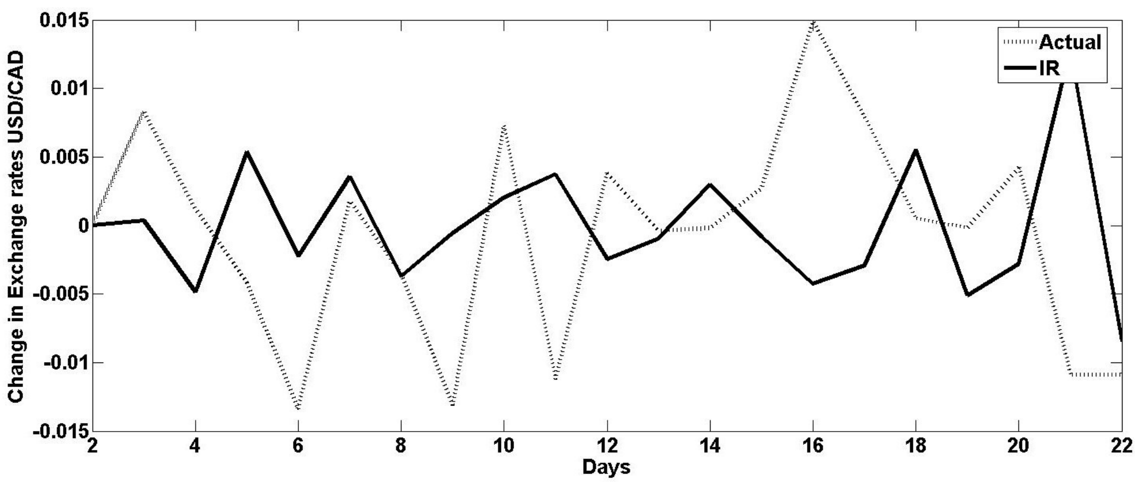

Figure 49 USD/CAD Prediction test results for IR as random parameters

8.2 Prediction Test Results

The best performing combination of parameters and the corresponding prediction rate, correct prediction percentage and the average percentage error are summarized in table 12. Figures 50,52,54,56,58,60,62 show the plot of actual exchange rates and predicted exchange rates for all currency pairs. Figures 51,53,55,57,59,61,63 show the prediction performance of this algorithm for each day.

Currency Pair	Iterations	[C1,C2]	Random Variable	Average % Error	Correct prediction days (21)	Correct Prediction %
USD/AUD	50	[1.4, 1.4]	IFR	2.88	14	66.67
USD/CAD	50	[1.4, 1.4]	Rand	3.09	14	66.67
USD/CHF	200	[1.4, 1.4]	IFR	4.64	14	66.67
USD/EUR	50	[1.4, 1.4]	BOT	6.62	14	66.67
USD/GBP	200	[1.4, 1.4]	BOT	2.16	16	76.19
USD/JPY	200	[0.7,0.8]	FXR	1.5	15	71.43
USD/NZD	50	[2,2]	Rand	1.19	15	71.43

Table 12 Prediction test results summary

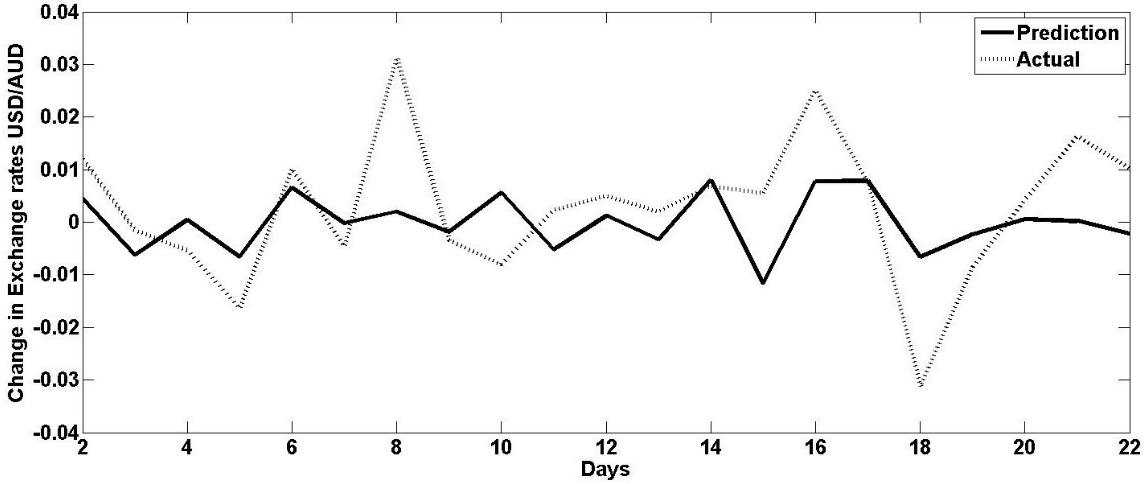

Figure 50 USD/AUD Prediction test results

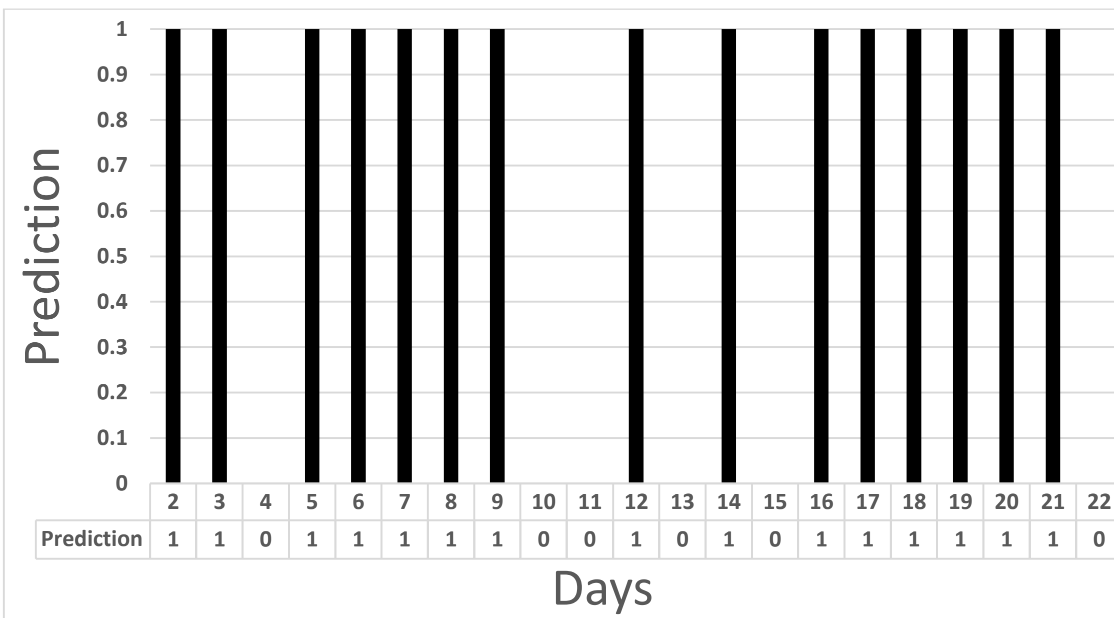

Figure 51 USD/AUD Prediction performance plot

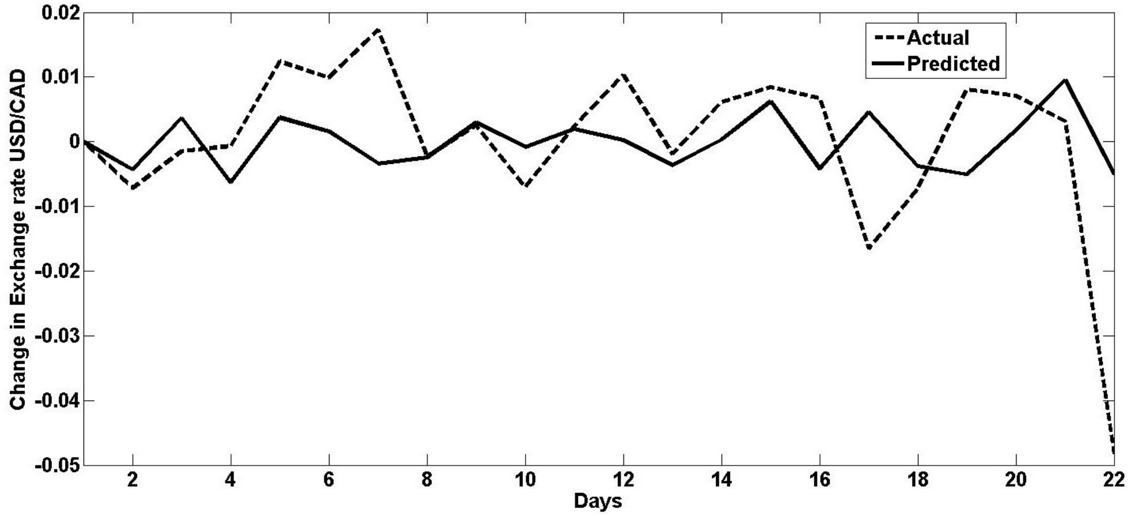

Figure 52 USD/CAD Prediction test results

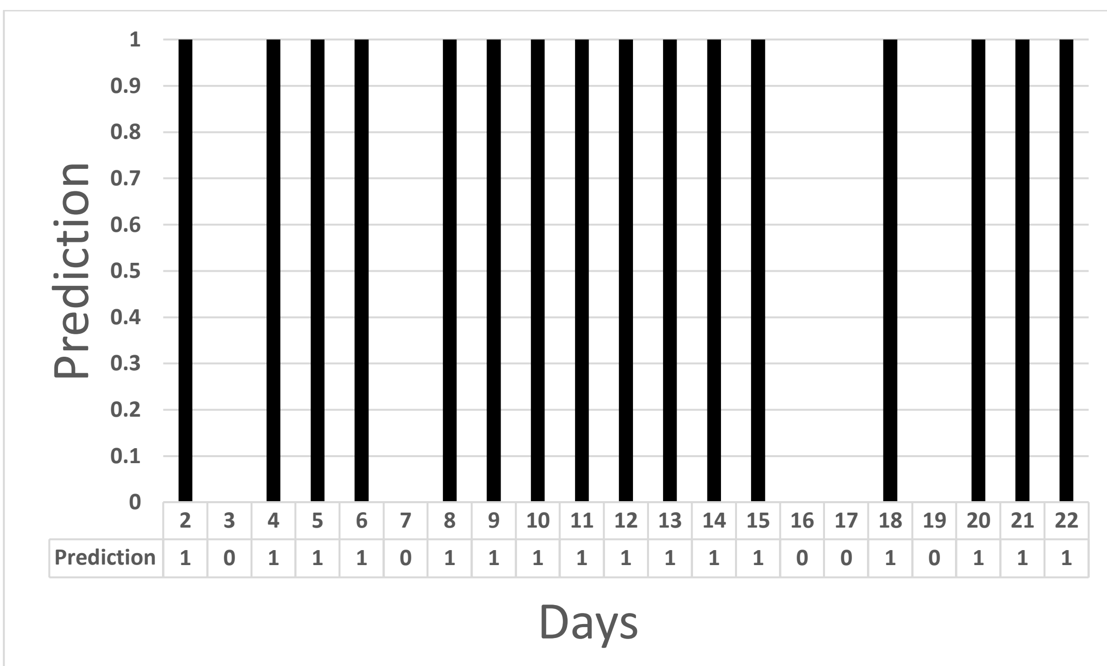

Figure 53 USD/CAD Prediction performance plot

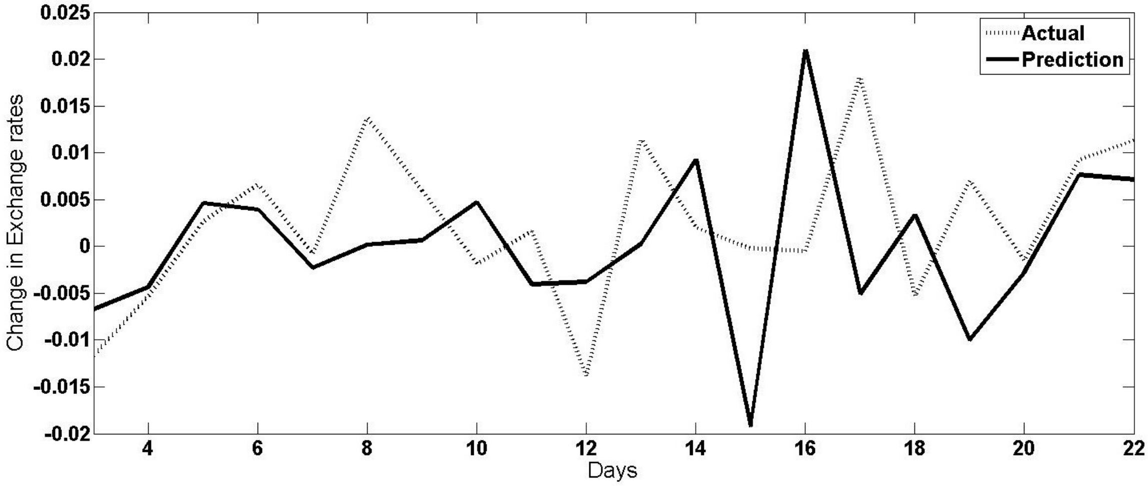

Figure 54   USD/CHF prediction test results

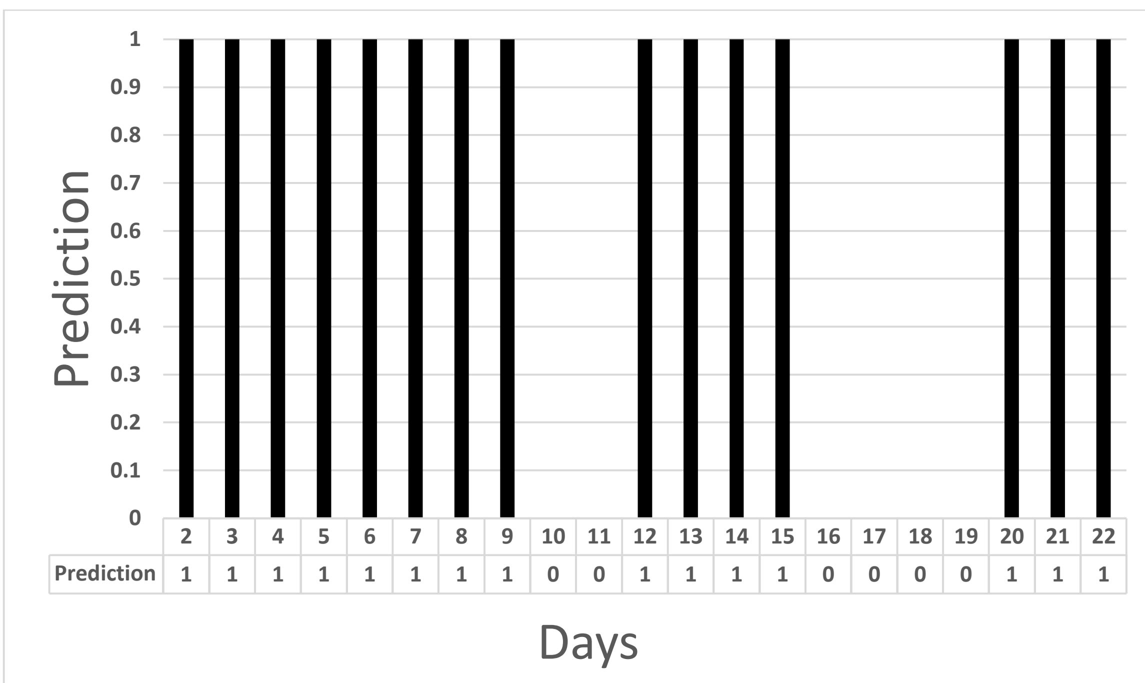

Figure 55   USD/CHF Prediction performance plot

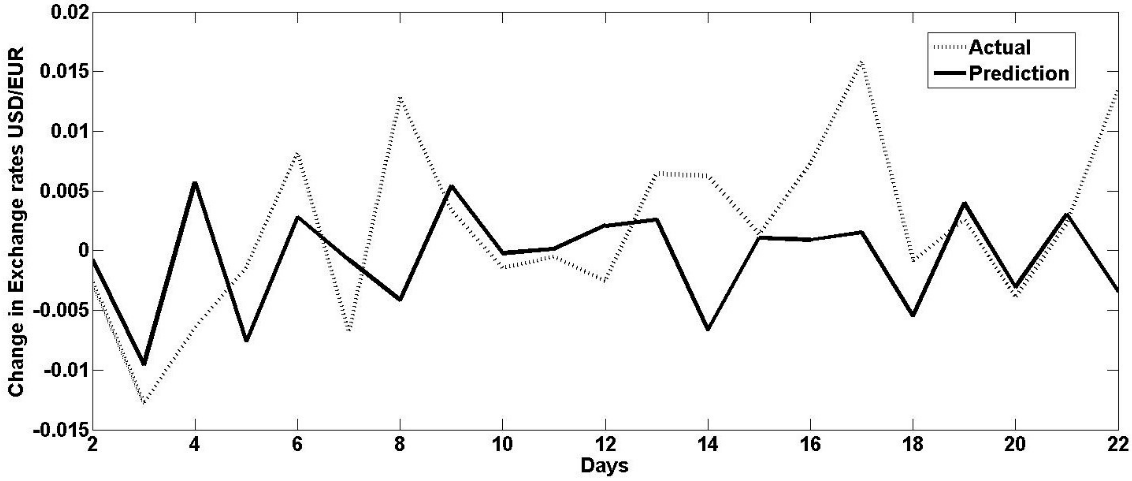

Figure 56 USD/EUR prediction test results

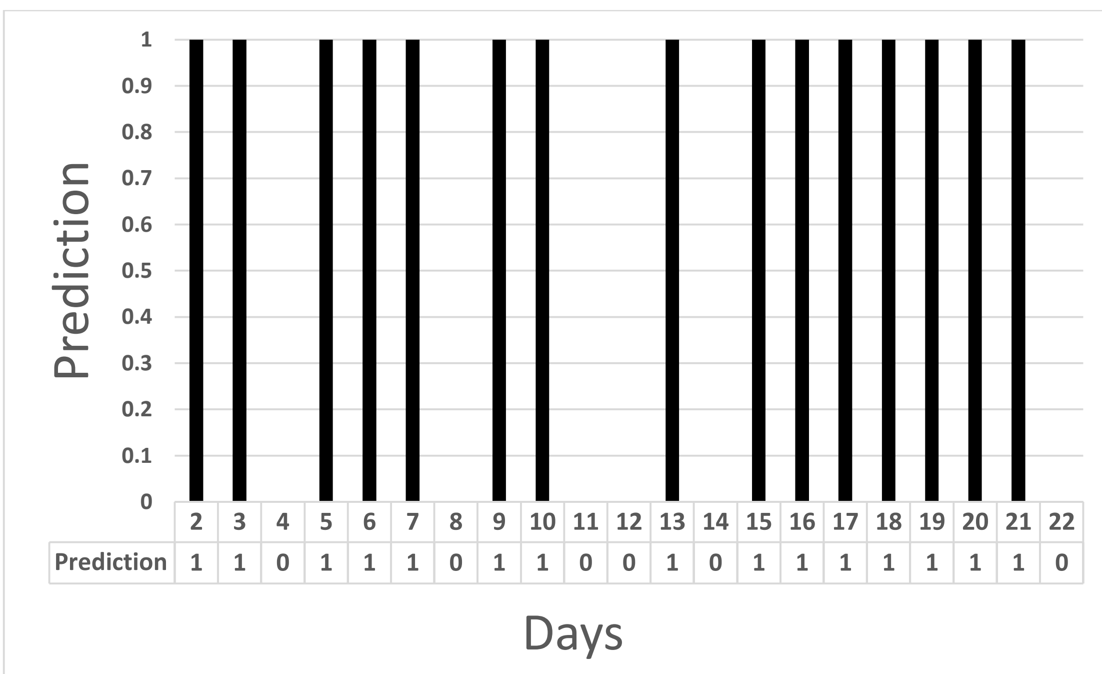

Figure 57 USD/EUR Prediction performance plot

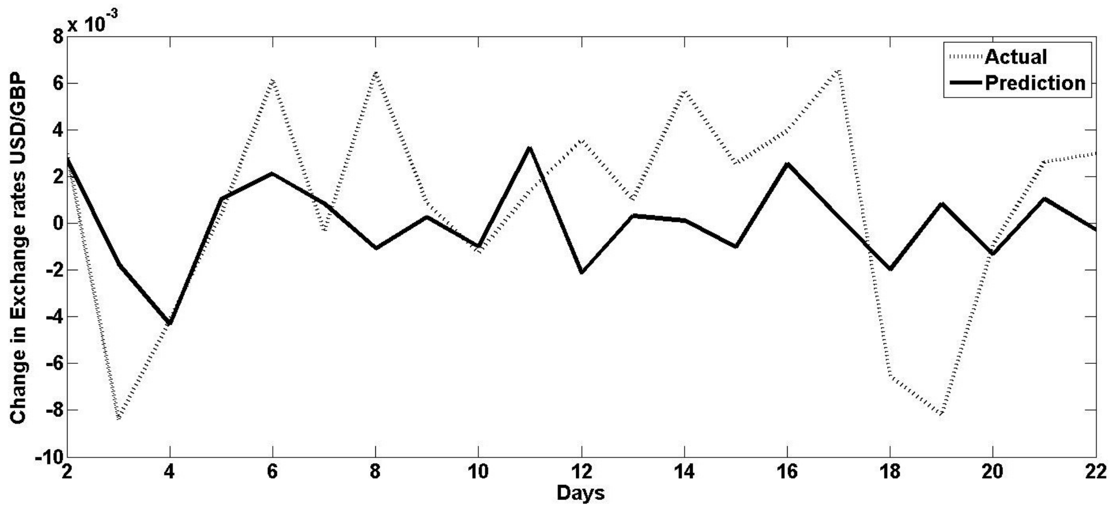

Figure 58 USD/GBP prediction test results

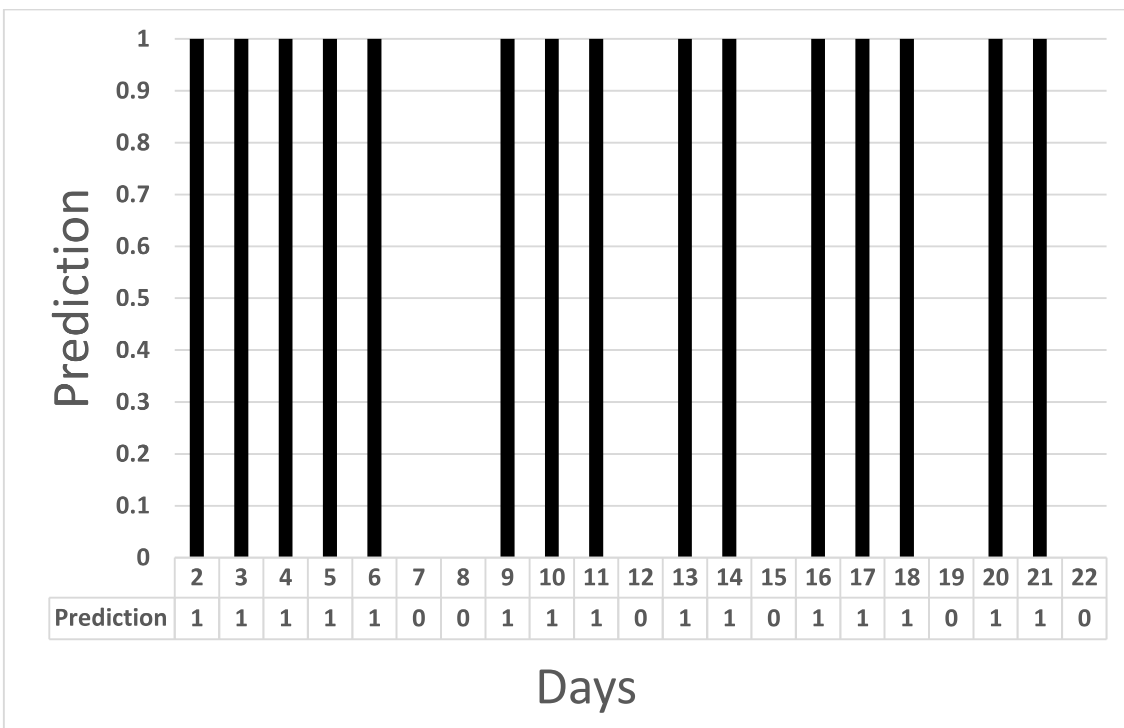

Figure 59 USD/GBP Prediction performance plot

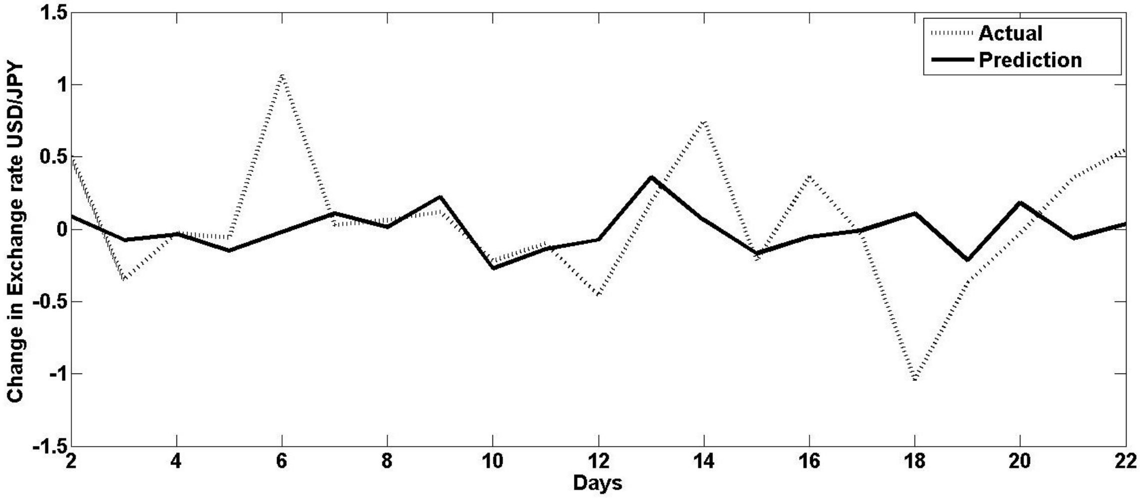

Figure 60 USD/JPY prediction test results

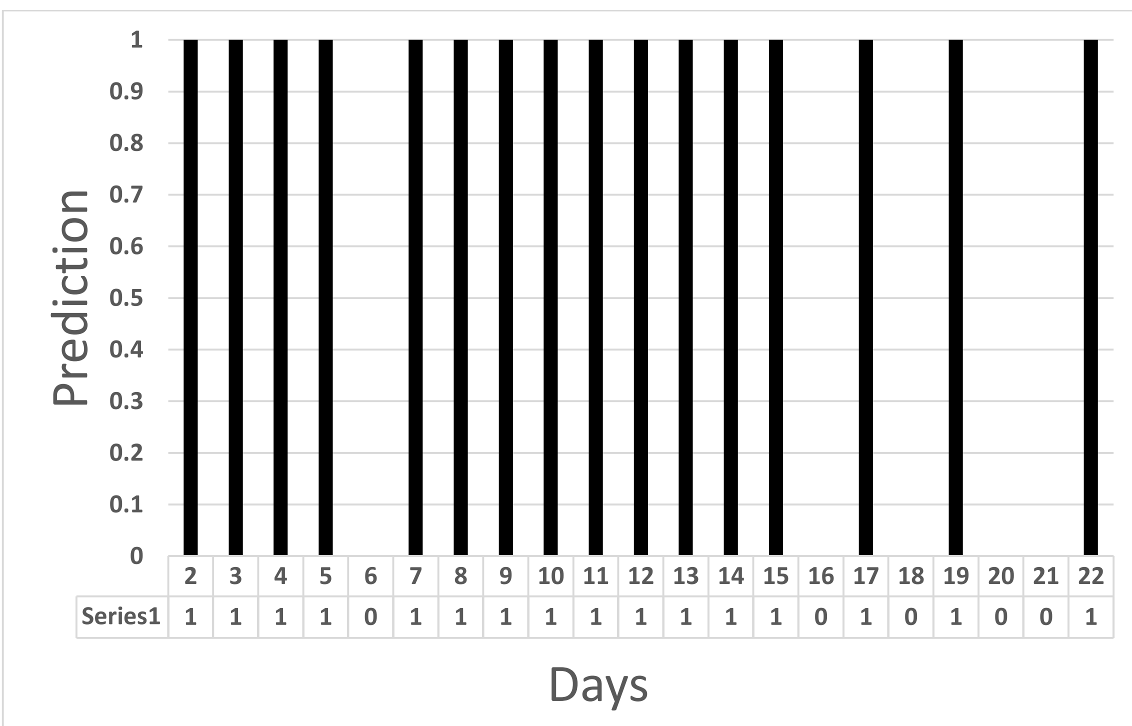

Figure 61 USD/JPY Prediction performance plot

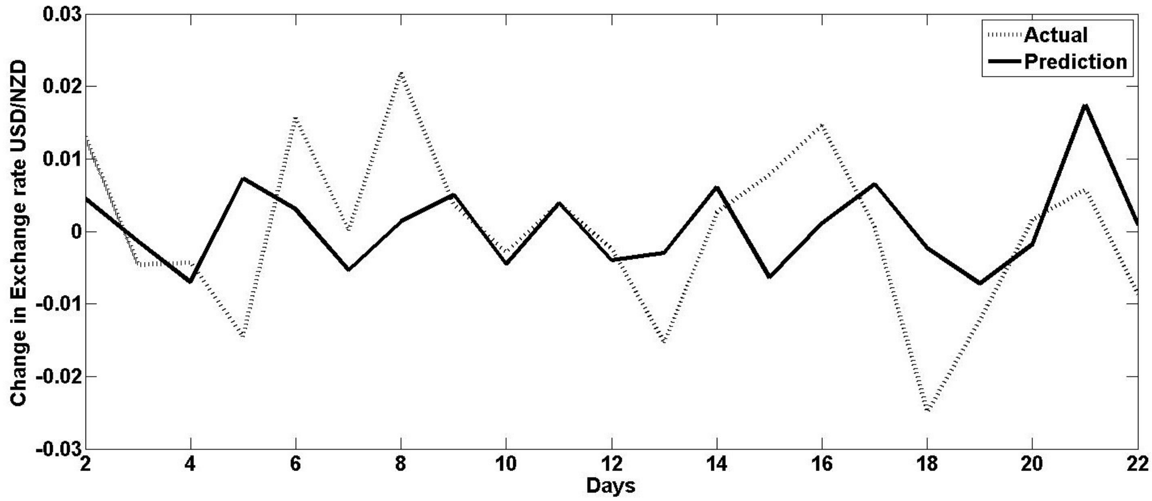

Figure 62 USD/NZD prediction test results

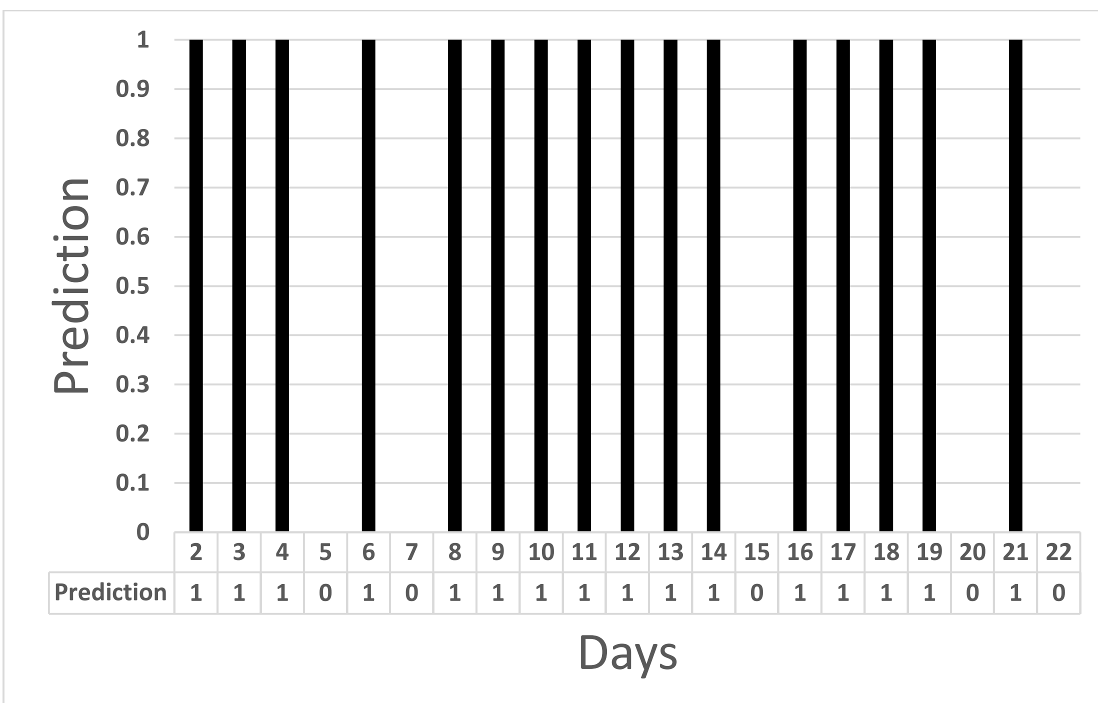

Figure 63 USD/NZD Prediction performance plot

Testing was repeated over a time period with data of the previous day updated in the search space for the consecutive days. The prediction was performed from 01/04/2015-15/04/2015 . The results of this test are summarized in Table 13.

Currency	Correct prediction days (21)	Correct Prediction Percentage	Average Percentage Error
USD/AUD	12.82	63.76	1.59
USD/CAD	13.36	66.52	1.32
USD/CHF	12.82	64.25	2.16
USD/EUR	13.00	64.93	2.97
USD/GBP	13.55	67.67	1.22
USD/JPY	13.55	67.80	0.40
USD/NZD	13.36	66.61	1.33

Table 13 Prediction results over a 15 day period - summary

The algorithm was tested repetitively 11 times for a single day to see if the prediction results are consistent. Here the database was not refreshed everytime before the run.The prediction results are shown in Table 14.

Currency	Correct prediction days (21)	Correct Prediction Percentage	Average Percentage Error
USD/AUD	9.18	43.72	1.65
USD/CAD	9.36	44.59	1.35
USD/CHF	9.82	46.75	2.40
USD/EUR	9.64	45.89	3.15
USD/GBP	10.18	48.48	1.32
USD/JPY	11.27	53.68	0.45
USD/NZD	10.73	51.08	1.27

Table 14 Repetitive prediction tests - summary

The algorithm was tested multiple times with each test independant of the other. The average results of 11 such tests are summarised in table 15.

Currency	Correct prediction days (21)	Correct Prediction Percentage	Average Percentage Error
USD/AUD	13.55	64.50	1.62
USD/CAD	14.09	67.10	1.29
USD/CHF	13.64	64.94	2.29
USD/EUR	14.09	67.10	3.14
USD/GBP	14.00	66.67	1.31
USD/JPY	14.36	68.40	0.44
USD/NZD	14.36	68.40	1.25

Table 15 Multiple prediction tests - summary

Its evident from the results that this algorithm is consitent and the proposed model does have a higher accuracy of prediction than the previous models. An average accuracy of 66.67% was obtained with the new model.

8.3 Prediction Test Results – Summary

The algorithm has been tested to predict for known values, unknown values, different periods of time and the tests were repeated to confirm the consistency of results. Here is a summary of an analysis based on the results.

- The PSO algorithm's performance is dependent on the historic data, random parameters, acceleration constants and iterations. PSO has to be tuned for optimized parameters before it is set to predict.
- The use of factors influencing the problem as random parameters did influence the performance of the algorithm. This is evident from the fact that specific factors led to a better performance than the others. The factor that changes more often yielded or guided the performance of the model.
- Each currency pair exhibited different behavior and acted as a separate system. This is contrary to the fact that they are interdependent on each other. PSO adapted to different currency pairs and showed consistency in performance.
- PSO algorithm performed better with shorter periods of data than training them with large amounts of data. This is contrary to the fact that PSO performs better with better training of the algorithm
- Percentage error in production for all currency pairs were consistent throughout the tests. This confirms the algorithm's consistency within a specific system.
- The model did learn from historic data available and predicted for the future with a higher accuracy of 66.67% for all currency pairs.

CHAPTER 9 CONCLUSION & RECOMMENDATIONS

Analysis of stochastic systems has always been a challenging and complex problem for many researchers. Numerous methods have been proposed to analyze and solve such problems. This research work used the concept of swarm intelligent PSO algorithm to predict the nature of Stochastic systems. The FOREX market was used as a test environment to evaluate the model. A number of random factors contributing to the chaotic nature of the system were studied and substituted for parameters within the model. A new modified multidimensional model was developed and tested.

The proposed model shows a higher consistency in results. The model performed consistently with a certain accuracy of prediction when tested multiple times for the same parameters. The model could predict with a an accuracy of 66.67%, which is clearly a better performance than previous models proposed. The use of random factors involved in the system within the algorithm contributed to a better prediction performance. With this, it is recommended to use random factors as random parameters within the algorithm.

The model also exhibited that the currency pairs in FOREX market behave independently of each other and they performed better with different sets of random factors. The performance and error in each system were different. Thus, from this research, we were able to propose a successful multidimensional model for analyzing and predicting complex stochastic processes.

9.1 Applications & Future Work

This model will find its best use in fields where a need for prediction is prominent in resolving a problem. Some specific fields/applications that could take advantage of this model are

- Performance prediction in engineering systems based on demands, for example Power transmission & distribution systems.
- Resource allocation systems based on usage, for example Telecommunication systems
- Financial models that involve prediction, for example FOREX Market, Stock market
- Behavioral pattern prediction models using big data.
- Disaster prediction & mangement models.

The proposed model is consistent with a good performance. Further, this model needs to be implemented for stochastic processes in optics after necessary experimentation in these systems for historic data. This model could be applied in various applications/fields mentioned earlier to predict from the historic pattern. This would be a very interesting topic to work on in the future.

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