ICIC Express Letters
Volume **10**, Number **8**, August **2016**

 ISSN 1881-803X
pp. **1943–1950**

RESEARCH OF CRIME INVERSION FUZZY NEURAL NETWORK BASED ON FACTOR SPACE

Ping He[1] and Kaiqi Zou[2]

[1]Department of Information
Liaoning Police College
No. 260, Yingping Road, Dalian 116036, P. R. China
heping2000@163.com

[2]Information Engineering Institute
Dalian University
No. 10, Xuefu Ave., Dalian 116622, P. R. China
zoukq@vip.sina.com

Received January 2016; accepted April 2016

Abstract. *The objective of this paper is to define fuzzy inversion neural network (FINN) for crime modeling system and define analysis method and data required for crime analysis which is the focus of the research. As a benchmark, to better understand crime analysis, crime system modeling is defined and how it has evolved over time. Crime analysis and its factors are discussed in detail and examples of how countries or regions such as Dalian, China, are using Crime Modeling Analysis System (CMAS) to help them in crime management and control are given. The quantitative analysis of the crime simulations shows that the FINN presents the best scores. However, the important result is that the fuzzy perception seems to behave more adequately in the environment, in the sense that it presents an apparently more natural, coherent and realistic behavior.*
Keywords: Crime fuzzy neural network, Fuzzy inversion neural network, Fuzzy perception, Factors analysis, Crime simulations

1. **Introduction.** In recent years, the fuzzy modeling approach of crime systems was proposed to deal with the uncertainty [1]. However, this approach lacks an effective learning algorithm to refine the membership functions to minimize output errors. Another approach using neural networks has been proposed [2]. This approach is capable of learning and can obtain high-precision results. However, it usually encounters problems of slow convergence and low understandability of the associated numerical weights. In fact, the fuzzy neural network (FNN) modeling of crime analysis has attracted a lot of attention [3-6]. This approach involves two major phases, crime type identification and identification of crime factors (crime system parameter). Fuzzy sets and neural network techniques are usually adopted in the two phases. Consequently, FNN modeling possesses the advantages of both modeling approaches. In the type identification phase, the fuzzy rules of crime system are developed from the given set of large data based on input-output training.

In this paper, we found that the crime modeling system based on fuzzy relationship mapping inversion is an effective tool on criminal analysis. Our research goal was to use blend learning algorithms of data mapping intuition inversion (DMII) with methods dealing with uncertainty in order to induce extension rules from large data sets of crime modeling. Crime analysis and its factors are discussed in detail and factors of how countries or regions such as Dalian, China, are using Crime Modeling Analysis System (CMAS) to help them in crime management and control are given.

The paper is organized as follows. Section 2 presents basic model of crime fuzzy neural network. Section 3 discusses some concepts on fuzzy inversion neural network. Section 4

is the application of FINN in crime analysis. Section 5 is the conclusion and an outlook on future research challenges.

2. Crime Fuzzy Neural Network.

2.1. **Basic model based on crime factors space.** A macroscopic crime system model reflects situation characteristic of the whole social crime. These characteristics are decided by situation's relative variety rate, and situation relation structure that causes the variety. We know that the impact of many factors in crime, there are crime factors of social, economic, political, cultural, etc., there are individual factors, the variables involved in a complex mathematical model to create a complete almost impossible. One of the most basic autoregressive models that take into account local context is the factors spatially varying parameter model, where with a set of pre-defined factors weights it is defined as follows:

$$Y_t = \varphi(x) = \sum_{i=1}^{n} \beta_i x_{it} + \varepsilon_{it}$$

where Y_i is crime rate (or crime state) at t time, x_{it} is crime factor i at t time, β_i $(i = 1, 2, \ldots, n)$ is existence coefficient of relationship variables (weights of crime factors), and ε_{it} $(i = 1, 2, \ldots, n)$ are controlling parameter of crime situation.

These crime factors have been put up in some space and time. Every factors variable is not only time's function, but also is crime space's function. If crime factors have relationship with time or space, we call these equations that can control their changes crime situation's partial differential equation. Generally speaking, nonlinear partial differential equation is difficult to get analytical result while it can get numerical result. However, numerical result is greatly limited. No matter how many times we calculate, it is always limited, and cannot give the whole macroscopic characteristics of crime problem. For 20 years, the study of nonlinear question has great progress. They have study methods themselves. Firstly, we change partial differential equation into corresponding non-linear ordinary differential equation by spectral expansion of higher intercept methods. Secondly, we study the equilibrium result and its stability of ordinary differential equation, study crime system track shape in the space by geometry theory and study more-equilibrium situation, fork, mutation and chaos of social crime dynamical system. To crime system's trait of self, it can study problems from some angles, and then synthesize all aspects. The result got from crime dynamical system and inference of crime qualitative analysis, must be analyzed with decision-making.

2.2. **Crime fuzzy neural network.** In the context of crime system modeling, crime fuzzy neural network (CFNN) has been playing an important role, and it is possible to find many interesting works using CFNN to deal with different problems that cannot be solved with classical simulation models and tools. CFNN [1] is based on the idea that several elements in human thinking are not exact data, but can be approximated as classes of objects in which the transition from membership to non-membership is gradual rather than abrupt, represented by membership grades in the interval $[0, 1]$. Since human reasoning sometimes does not follow the two-valued or multivolume logic, CFNN is learning system with fuzzy truths, fuzzy connectives, and fuzzy rules of inference.

Neural network is similar to a finite state machine that is non-linear dynamical system. By combining with fuzzy logic it makes a hybrid structure. And this sort of structure is very well fitted for numerical and linguistic knowledge. Building crime analysis systems (CAS) with neuro-fuzzy system gives us a new thought to develop crime pattern analysis (CPA) in cooperation with artificial intelligence, where difficulty involves in knowledge acquisition and deriving intuitive inference. Like neural networks inversion neuro-fuzzy

system gives us parallel architecture with distributive processing, system's adaptive nature for linguistics, non-linear perspective, and real time processing. Because of all these essential qualities of inversion neuro-fuzzy systems, decision making ability of CPA ameliorates. However, the cognitive process execution and associative memory for storing the serial characters are issues for CPA. Data, perception and model are the significant sources of CPA (see Figure 1).

The FNN model of crime system is the input space (crime factors space) to a desired output space (crime pattern space) to the way in which the dependent variable of crime system is a function of the independent variables in regression model. The difference is that regression model of crime system uses linear direct mapping whereas multi-layer feed-forward networks use non-linear indirect mapping.

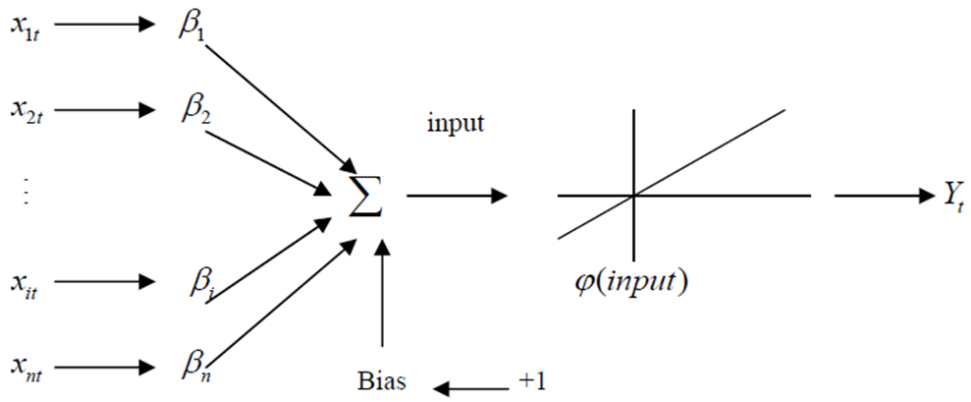

FIGURE 1. Crime fuzzy neural network

3. Fuzzy Inversion Neural Network.

3.1. Factor discovery based on object state perception.

Definition 3.1. *Let $S = (F, O, \varphi)$ be a mapping model structure of the FNN from the factor space to object relationship, and $S^* = (O^*, f^*, \varphi^{-1})$ is a perception inversion structure from trust object to factor space. If there exists a reversible and confirmable relationship mapping φ and perception inversion φ^{-1} in FNN, then the FNN with inversion network model is called fuzzy inversion neural network (FINN).*

The basic framework of Definition 3.1 is shown in Figure 2.

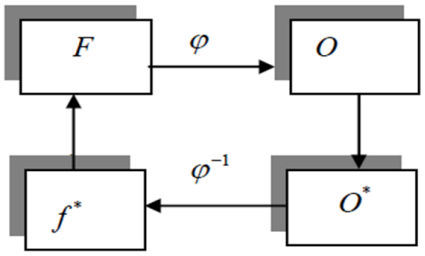

FIGURE 2. The structure of FINN

In Definition 3.1, let $F = \{x_1, x_2, \ldots, x_n\} = \{x\}$ denote the data relationship of factor space of crime system (or input space), which includes the crime state factor space to be determined. If $\varphi(x) = \sum_{i=1}^{n} \beta_i x_{it} + \varepsilon_{it}$ (crime state mapping) denotes a kind of mapping with data set of fuzzy neural network, then the crime state Y (or object O) can be

determined by $\varphi(x)$. In fact, the fuzzy neural network output Y (object data) is incomplete; thus, a trusted network output Y can be decided by perception mapping (P). If trusted Y^* can be decided, then the corresponding trust crime factor X^* can be decided by $\varphi^{-1}(x)$ with perception mapping (intuition learning), where $\varphi^{-1}(x) = \psi(Y^*) = X^*$, $Y^* = \{y_1^*, y_2^*, \ldots, y_m^*\}$ and y_i^* $(i = 1, 2, \ldots, m)$ is fuzzy perception to crime state (or crime rate). Thus, the role of $\varphi^{-1}(x)$ is to be discovery crime factors as well as the influence degree of the crime factors through fuzzy perception of the crime rate in different periods. This is the basic framework of factor inversion neural network of crime state as shown in Figure 3.

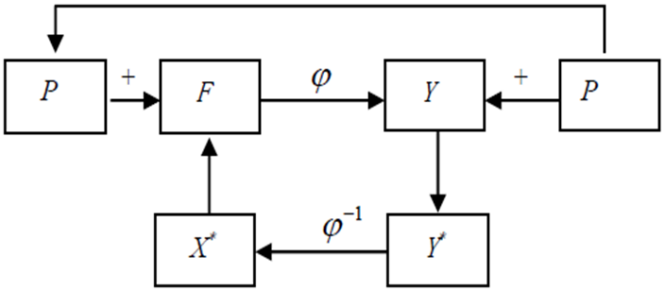

FIGURE 3. Confirmative factor inversion structure

3.2. **System framework of FINN.** Neural network is similar to a finite state machine that is non-linear dynamical system. By combining with fuzzy logic it makes a hybrid structure. And this sort of structure is very well fitted for numerical and perception of intuition. Building crime analysis systems with FINN gives us a new thought to develop crime reasoning system in cooperation with artificial intelligence, where difficulty involves in perception information acquisition and deriving intelligent inference. FINN system gives us parallel architecture with distributive processing, system's adaptive nature for linguistics, intuitive perception perspective, and real time processing. Data, intuition and model are the significant sources of crime reasoning system. Figure 4 shows the proposed model of research framework of FINN associated with the perception learning of the intuition for intelligent inference and data mining (see Figure 4).

Crime fuzzy neural networks (CFNNs) are non-linear models that aim to describe the input-output relationship of a real criminal system using a family of linguistic If-then constructions and the learning mechanisms of FNN. Among the several methods available for fuzzy inference, we adopt in this work the crime modeling method [1], where each fuzzy rule represents a local model of the real criminal system under consideration.

The kth rule of a crime state with inversion input vector $Y^* = \{y_1^*, y_2^*, \cdots, y_k^*\}$ and output $Y = \{y_1, y_2, \cdots, y_n\}$ presents the crime rate: If $(y_1$ is $y_1^*)$ and $\ldots$ and $(y_n$ is $y_k^*)$ then $X^* = \psi_k(y^*)$, where the linguistic terms y_k^* $(i = 1, 2, \cdots, k)$ in the rule antecedents represent fuzzy sets with membership functions μ_k which are used to partition the domains of the inversion input variables into overlapping regions.

$TY^* = \{< y, \mu_{TY^*}(y) > | y \in Y\}$, where $\mu_{TY^*}(y)$ denotes respectively the degree of the trusted membership of the Y in the set TY^*, and

$$\mu_{TY^*}(y) = \sum_{i=1}^{n} I_{Y^*}^i(y)\mu_{Y^*}(y) + \varepsilon(y^*)$$

For a given inversion input $Y^* = \{y_1^*, y_2^*, \cdots, y_k^*\}$, the degree of fulfillment of the kth rule evaluates the compatibility of the output Y with the rule antecedent and determines the contribution of the rule's response $y = \varphi(x_1, \cdots, x_n)$ and $x^* = \psi(y_1^*, \cdots, y_k^*)$ to the overall model's output and input. The degree of firing of kth rule is expressed as the influence degree of the crime factors $\beta_L(x_1, \cdots, x_n) = T\left(\mu_{y^*}(y_1), \cdots, \mu_{y^*}(y_n)\right)$.

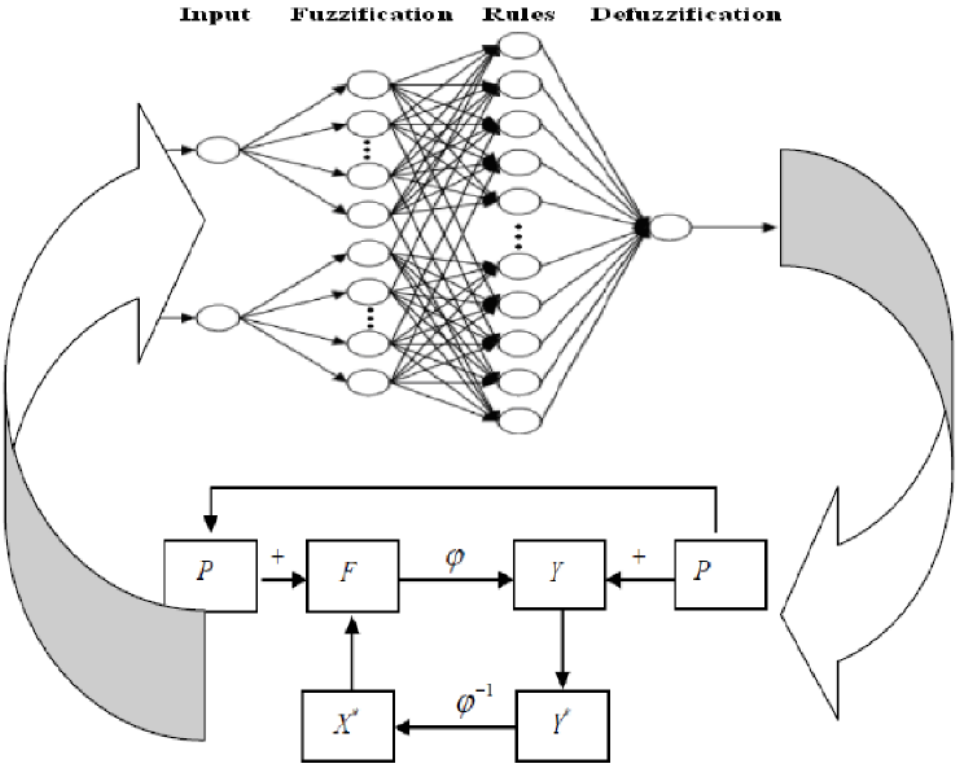

FIGURE 4. System framework of FINN based on fuzzy perception

4. **Crime Analysis.** A macroscopic crime system model reflects situation characteristic of the whole social crime. These characteristics are decided by situation's relative variety rate, and situation relation structure that cause the variety. If crime system's situation variables $X^* = \psi_k(y^*) = X_{1t}, X_{2t}, \cdots, X_{5t}$ are described by 5 controlling parameters ε_{it} $(i = 1, 2, 3, 4, 5)$, we have

$$Y_t = \sum_{i=1}^{5} \beta_i X_{it} + \varepsilon_{it}$$

In the crime pattern analysis, the effective choosing situation variable has pivotal effect on reflecting social crime truly, and describing social stability and development. The main sign of human social development lies in the economy increase and consumption level. In economy study, if we are lack of the analysis of crime factors, our result of economy analysis will be short of reliability. During every study, there are many influential factors forming crime system, such as economy factor, education factor, social ethos, law factor, people relationship and management factor. Because these factors lie in different situations, traits of crime system are different. The social stability and development can effectively choose controlling parameter, for example unemployment rate, income difference relative quantity, controlling proportion of social informal groups, management efficiency of public and education quality [8-11]. The crime data of 20 years is shown in Table 1.

In crime analysis of Dalian Policeman Department (DPD) in China, an officer can acquire crime data leads that fall into a number of different categories and work together to create the 'story' that describes the crime. In the categorization of crime analysis reports, we chose to break down the search terms into six search objects: person, address, organization/business, vehicle, crime type and weapon.

For this study, the specific group from DPD targeted to participate was made up of crime analysts, who investigate high-profile cases as well as create statistical reports on criminal activities. The analysts are the department's most technology savvy user group and are accustomed to using a number of different data sources. Eleven crime analysts and

TABLE 1. 1993-2012 crime statistics data

N	Crime rate (Y_t)	Police efficiency (x_1)	GDP Per capita (x_2)	Educational status (x_3)	Population density (x_4)	Gini Coefficient (x_5)
1993	639.5609	0.45	1423	0.22	413.5185	0.29
1994	652.5675	0.42	1487	0.24	415.8668	0.29
1995	676.4070	0.47	1534	0.23	419.1992	0.31
1996	691.6834	0.52	1787	0.25	422.7266	0.31
1997	699.9800	0.51	1856	0.26	425.2153	0.32
1998	717.6092	0.53	1925	0.27	427.3921	0.33
1999	726.1099	0.56	2031	0.29	429.7489	0.33
2000	760.6705	0.54	2212	0.28	432.0333	0.35
2001	794.3057	0.50	2303	0.31	433.6836	0.35
2002	824.1940	0.48	2447	0.33	438.5872	0.36
2003	845.1829	0.49	2700	0.36	441.0857	0.36
2004	852.5065	0.52	3056	0.35	443.7241	0.36
2005	878.8844	0.50	3529	0.37	445.4914	0.37
2006	907.8857	0.54	4100	0.38	446.6431	0.37
2007	913.5331	0.52	4700	0.41	449.6104	0.39
2008	943.9222	0.56	5453	0.43	454.9775	0.39
2009	978.3541	0.58	7067	0.45	459.8323	0.40
2010	1000.1294	0.59	9099	0.49	463.9593	0.42
2011	1037.1664	0.65	10515	0.52	465.0969	0.43
2012	1065.9342	0.67	10765	0.55	466.9775	0.46

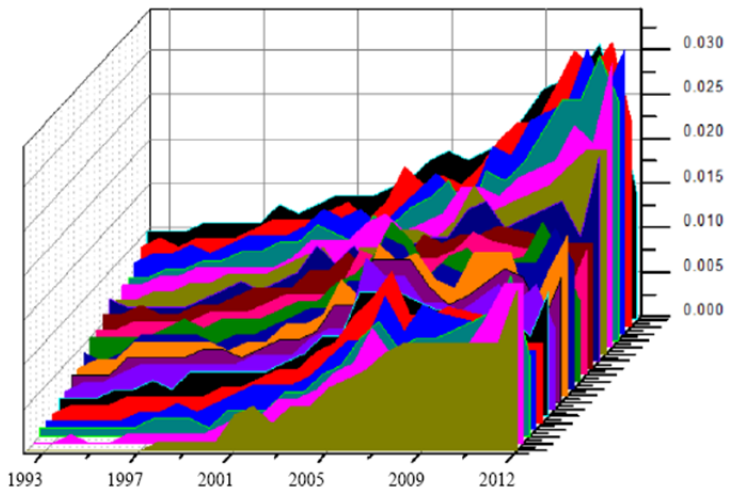

FIGURE 5. The experiment result of crime rate

one homicide detective from DPD were asked to participate in the study. The detective was also experienced in using a number of different technologies. Data collection methods employed in this study included documentation, interviews, and direct observation by both the researcher and a DPD officer working on the intuitionistic project. Documentation consisted of journals kept by each subject detailing actual search experiences.

We use the crime data used in crime analysis system to start our simulation. As a result, this crime analysis is by FINN with fuzzy perception learning for each crime factors combination. In this paper, we informally build on the factors-pattern approach for a perception-based crime rate simulation in order to analyze the level of a policing with

fuzzy perception in surviving in an environment of imperfect information. The experiment result is shown in Figure 5.

As an introduction to crime rate analysis, this section provides the definition of crime rate analysis as a general concept as well as definition of five factors of crime analysis. These definitions are meant to enhance the understanding of crime state analysis and to help create commonly understood terminology, concepts and ideas in the field of crime analysis.

Crime FINN analysis uses both data mapping and perception inversion and it also uses analytical techniques. Data mapping and perception inversion refer to non-numerical data as well as the examination and interpretation of observations for the purpose of discovering underlying meanings and pattern of relationships. Crime data are data primarily in numerical or categorical format. Mapping and inversion analysis consists of manipulations of observations for the purpose of describing and explaining the crime phenomena that those observations reflect and is primarily statistical.

5. **Conclusions.** In this paper, we get relationship structure of practical crime analysis system. This analysis's trait is that through FINN system model it makes mathematical model, gets result and infers the result qualitatively. At the same time, according to the relationship structure mapping which gets from qualitatively inferring, we establish mathematical model through all kinds of set mapping spaces suppositions. Two results will be fed back through self-organization and finally form a feasible result. Here, let us first give a set of object hypotheses that, in actual crime analysis, the police department conceives a simulation of a crime system by analysis of the crime factors, and constructs a simulated model approximate to the actual crime system. Thus, the hypotheses space can be actual crime system as objective space, and the mapping of the criminal model from the data analysis is called image space of object. If the hypotheses can be determined by the mapping relation, the objective model can be obtained by the hypotheses. And this object model is the trusted model of this crime system. This mechanism is called object-image of crime modeling system. We have discussed relevant issues of the selection of crime factors and intuition reasoning. Here, the key is the good combination of data analysis and fuzzy perception, and what methodology should be adopted to reach the goal of criminal analysis and to fully unfold the intellectual behavior of the FNN. Research shows that fuzzy inversion neural network (FINN) is an effective thrust tool to construct this intellectual behavior.

Acknowledgment. The authors are grateful for the support given by National Natural Science Foundation of China (Grant No. 61272170). We also thank reviewers for insightful and helpful suggestions.

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