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# A NOVEL APPROACH FOR PATTERN RECOGNITION BY USING NETWORK AND THEORY OF COMPLEXITY

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**Abstract:** *In this article we present new method for pattern recognition and calculating all closeness centralization of network created with connection maximum value of 3D graph of hardenend specimens. Intelligent systems are a new wave of the embedded and real-time systems that are highly connected, with a massive processing power and performing complex applications. We use a method which combines an intelligent genetic algorithm and multiple regression to predict all closeness centralization of network created with connection maximum value of 3D graph of hardened specimens. With method of intelligent system, genetic programming and multiple regression we increase production of process of laser hardening, because we decrease time of process and increase topographical property of materials.*

**Key words:** *Image processing, intelligent system, visibility graphs, fractal dimension, network theory,*

**Novi pristup za prepoznavanje uzorka korišćenjem mreže i teorije kompleksnosti.** *U ovom članku predstavljamo novu metodu za prepoznavanje uzoraka i izračunavanje bliske centralizacije mreže stvorene sa maksimalnom vrednošću pozvezano sa 3D grafikom čvrstih primeraka. Inteligentni sistemi su novi talas ugrađenih i real-time sistema koji su visoko povezani, sa masovnom procesnom snagom i izvođenjem složenih aplikacija. Koristimo metodu koja kombinuje inteligentni genetski algoritam i višestruku regresiju kako bi se predvidela sva centralizovana mreža stvorena sa maksimalnom vrijednošću od 3D grafika čvrstih primeraka. Sa metodom inteligentnog sistema, genetičkog programiranja i višestruke regresije povećavamo proizvodnju procesa laserskog očvršćavanja, jer smanjujemo vreme procesa i povećavamo topografsku strukturu materijala.*

**Ključne reči:** *Obrada slike, inteligentni sistem, grafovi vidljivosti, fraktalna dimenzija, teorija mreže*

## 1. INTRODUCTION

Process of robot laser hardening is presented in many articles [1-3]. Laser Hardening offers customers an excellent alternative to induction and flame hardening. With laser precision and robotic control, laser hardening can be applied to complex surfaces while achieving repeatable hardness and case depth. The surface finish after laser hardening is excellent and in some cases requires no finishing work. The process is used exclusively on ferrous materials containing a minimum of 0.20% carbon. The laser acts as a local heat source quickly bringing the surface up to a desired temperature. A fractal [4] is a never-ending pattern. Fractals are infinitely complex patterns that are self-similar across different scales. They are created by repeating a simple process over and over in an ongoing feedback loop. Driven by recursion, fractals are images of dynamic systems – the pictures of Chaos. Geometrically, they exist in between our familiar dimensions. Fractal patterns are extremely familiar, since nature is full of fractals. For instance: trees, rivers, coastlines, mountains, clouds, seashells, hurricanes, etc. Network theory [5] provides a set of techniques for analysing graphs. Complex systems network theory provides techniques for analysing structure in asystem of interacting agents, representedas a network. Applying network theory to a system means using a graph-theoretic representation. Pattern reconition [6] is a branch of machine learning that emphasizes the recognition of data patterns or data regularities in a given scenario. It is a subdivision of machine learning and it should not be confused with actual machine learning study. The aim of this study is to calculate all closeness centralization of network created with connection maximum value of 3D graph and complexity of robot laser hardenend specimens.

## 2. MATERIALS PREPARATION AND METHODS

The study was undertaken using tool steel standard label EN100083 − 1.We hardened this specimens with robot laser cell with speed $v \in [2, 5]$ mm/s and temperature $T \in [1000, 1400]$ °C. On Fig. 1 is presented robot laser hardened specimen. On Fig. 2 is presented fractal structure of robot laser hardened specimen.

Fig. 1. Robot laser hardened specimen

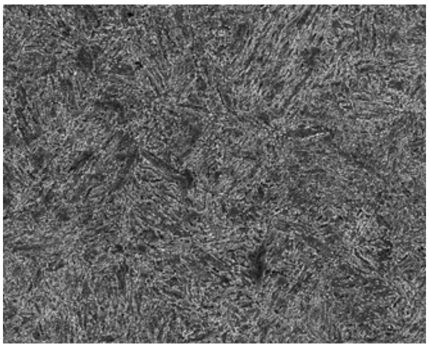

Fig. 2. Fractal structure of robot laser hardened specimen

In Imaging Science [7], image processing is any form of signal processing for which the input is an image, such as a photograph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensionalsignal and applying standard signal processing techniques to it. After hardening, we polished and etching all specimens. Detailed characterization of their microstructure before and after surface modifications was conducted using a field emission scanning electron microscope (SEM), JEOL JSM-7600F. Firstly, the SEM pictures were converted into binary images, from which we calculated the fractal dimension. Socendly, we convert SEM pictures into 3D graph, from which we connect all maximum value. After then, we calculated topological properties of network created with connection maximum value of 3D network of hardenend specimens. Fig. 3 present process of hardening, image processing, fractal dimension calculating and calculating topological properties of network created with connection maximum value of 3D network of robot laser hardened specimen.

Closeness $C_c(i)$ is based on the length of the average shortest path between a vertex and all vertices in the network. $C_c(i)$ is calculated by equation (1):

$$C_c(i) = \left[ \sum_{j=1}^{N} d(i,j) \right]^{-1} \tag{1}$$

Closeness centrality can help find good ‘broadcasters’, but in a highly connected network you will often find all nodes have a similar score. What may be more useful is using Closeness to find influencers within a single cluster in our case, elements in microstructure of robot laser hardened specimens.

An intelligent system [8] is a machine with an embedded, Internet-connected computer that has the capacity to gather and analyze data and communicate with other systems. Requirements for an intelligent system include security, connectivity, the ability to adapt according to current data and the capacity for remote monitoring and management. Essentially, an intelligent system is anything that contains a functional, although not usually general-purpose, computer with Internet connectivity.

An embedded system may be powerful and capable of complex processing and data analysis, but it is usually specialized for tasks relevant to the host machine. Intelligent systems exist all around us in point-of-sale (POS) terminals, digital televisions, traffic lights, smart meters, automobiles, digital signage and airplane controls, among a great number of other possibilities. We used an intelligent system methods, namely a genetic programming method and multiple regression for analysis of the results.

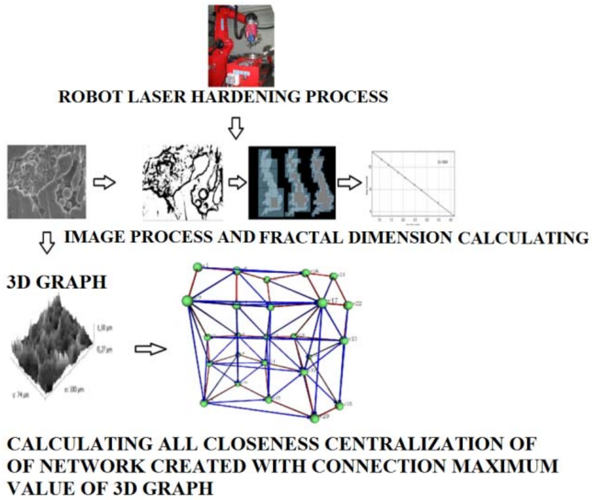


Fig. 3. Process of hardening, image processing, fractal dimension calculating and calculating all closeness centralization of robot laser hardened specimen

Genetic programming (GP) [9] is a collection of evolutionary computation techniques that allow computers to solve problems automatically. Since its inception twenty years ago, GP has been used to solve a wide range of practical problems, producing a number of human-competitive results and even patentable new inventions. Genetic programming starts with a primordial ooze of thousands of randomly created computer programs. This population of programs is progressively evolved over a series of generations. On Fig. 4 is presented model of genetic programming.

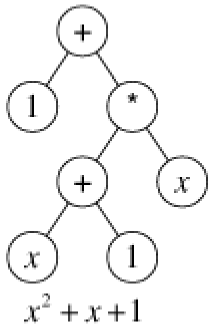


Fig. 4. Model of genetic programming

In statistics, regression analysis [10] is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. A regression model relates $Y$ to a function of X and β.

Y=(X, β), where

the unknown parameters, denoted as β, which may represent a scalar or a vector. The independent variables, X. The dependent variable, $Y$.

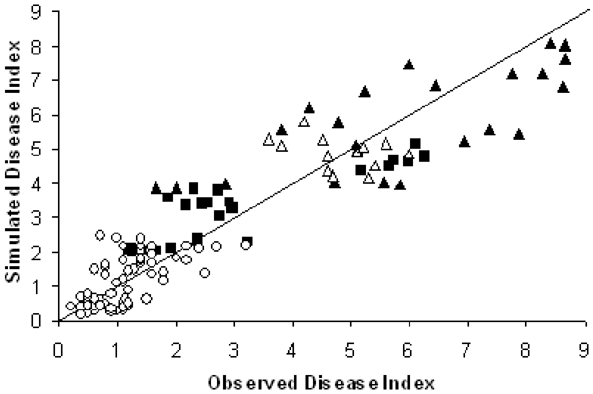


Fig. 5. Model of multiple Regression

## 3. RESULTS AND DISCUSSION

In Table 1, the parameters of hardened specimens that impact on all Closeness Centralization of network created with connection maximum value of 3D graph of hardenend specimens are presented. We mark specimens from P1 to P21. Parameter X1 presents the parameter of temperature in degree of Celsius [C], X2 presents the speed of hardening [mm/s] and X3 presents fractal dimension in 2D space. The last parameter Y is the measured surface of all Closeness Centralization of network created with connection maximum value of 3D graph of hardenend specimens. Table 2 presents experimental and prediction data regarding the surface volume of laser hardened robot specimens. In Table 2 present symbol S name of specimens, E experimental data, R prediction with regression and GP prediction with genetic programming. In Table 1, we can see that specimen P6 has the maximal complexity, 1.9784. The measured and predicted surface hardness of robot laser hardened specimens is shown in the graph in Fig. 7. The genetic programming model is presented on Fig. 6. Under Table 1 is presented model of regression. The regression model presents a 46,59% deviation from the measured data, which is less than the genetic programming model, which presents a 44,08% deviation.

$$Y = 0.0000621453 \times x_1 + 0.019336 \times x_3 + \frac{x_3^2 \times (x_1 \times x_2 - 167.74 \times x_3^2 - 8.5785 \times x_3^3)}{-116.57 \times x_1 + \frac{x_1}{x_3} - 167.74 \times x_3^2 - 8578.5 \times x_3^3} + \frac{\times x_1 \times x_4}{-8578.5 + x_1 - 176319 \times x_3^3 - 8578.5 \times x_3^5}$$

Fig. 6. Model of genetic programming

| S | $X_1$ | $X_2$ | $X_3$ | Y |
|---|---|---|---|---|
| P1 | 1000,0 | 2,0 | 1,9135 | 0,144331 |
| P2 | 1000,0 | 3,0 | 1,9595 | 0,106186 |
| P3 | 1000,0 | 4,0 | 1,9474 | 0,130929 |
| P4 | 1000,0 | 5,0 | 1,9384 | 0,11598 |
| P5 | 1400,0 | 2,0 | 1,9225 | 0,118042 |
| P6 | 1400,0 | 3,0 | 1,9784 | 0,099485 |
| P7 | 1400,0 | 4,0 | 1,9540 | 0,068042 |
| P8 | 1400,0 | 5,0 | 1,9776 | 0,108248 |
| P9 | 1000,0 | 2,0 | 1,9720 | 0,123712 |
| P10 | 1000,0 | 3,0 | 1,8580 | 0,141753 |
| P11 | 1000,0 | 4,0 | 1,9781 | 0,147939 |
| P12 | 1000,0 | 5,0 | 1,9410 | 0,122166 |
| P13 | 1400,0 | 2,0 | 1,9781 | 0,135568 |
| P14 | 1400,0 | 3,0 | 1,5810 | 0,113918 |
| P15 | 1400,0 | 4,0 | 1,9650 | 0,10464 |
| P16 | 1400,0 | 5,0 | 1,8113 | 0,400518 |
| P17 | 800,0 | 0,0 | 1,9669 | 0,078866 |
| P18 | 1400,0 | 0,0 | 1,9753 | 0,163918 |
| P19 | 2000,0 | 0,0 | 1,9706 | 0,190207 |
| P20 | 950,0 | 0,0 | 1,9631 | 0,36495 |
| P21 | 850,0 | 0,0 | 1,9537 | 0,22629 |

Table 1. Parameters and hardness of hardened specimens

**Model of regression**

$$Y = -1.878887319 \times 10^{-6} \times X_1 - 1.011752794 \times 10^{-2} \times X_2 - 1.589400828 \times 10^{-1} \times X_3 + 4.884547217 \times 10^{-1}$$

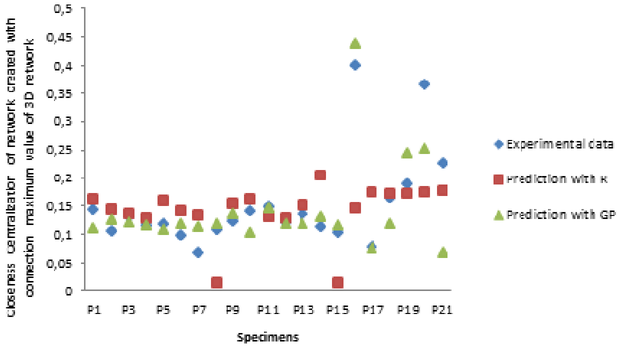


Fig. 7. The measured and predicted volume of robot laser hardened specimens

| S | E | R | GP |
|---|---|---|---|
| P1 | 0,144331 | 0,16220893 | 0,110789 |
| P2 | 0,106186 | 0,1447801583 | 0,126788 |
| P3 | 0,130929 | 0,1365858053 | 0,120523 |
| P4 | 0,11598 | 0,1278987382 | 0,117159 |
| P5 | 0,118042 | 0,1600269144 | 0,10754 |
| P6 | 0,099485 | 0,1410246358 | 0,117765 |

| | | | |
|---|---|---|---|
| P7 | 0,068042 | 0,1347852459 | 0,11406 |
| P8 | 0,108248 | 0,0120916732 | 0,117655 |
| P9 | 0,123712 | 0,1529109352 | 0,137313 |
| P10 | 0,141753 | 0,1609125767 | 0,102627 |
| P11 | 0,147939 | 0,1317063448 | 0,145953 |
| P12 | 0,122166 | 0,1274854939 | 0,118049 |
| P13 | 0,135568 | 0,1511898457 | 0,117765 |
| P14 | 0,113918 | 0,2041874247 | 0,12991 |
| P15 | 0,10464 | 0,0133036905 | 0,115829 |
| P16 | 0,400518 | 0,1473484678 | 0,437964 |
| P17 | 0,078866 | 0,1743323629 | 0,07673 |
| P18 | 0,163918 | 0,1718699338 | 0,117336 |
| P19 | 0,190207 | 0,1714896198[1] | 0,244429 |
| P20 | 0,36495 | 0,1746545022 | 0,252827 |
| P21 | 0,22629 | 0,1763364277 | 0,067982 |

Table 2: Experimental and prediction data

A statistically significant relationship was found between all Closeness Centralization of network created with connection maximum value of 3D graph of hardenend specimens, the parameters of the robot laser cell and image analysis with fractal geometry. In addition, image analysis of SEM images of robot laser hardened specimens is an interesting approach. This specimen we hardened with 5 mm/s at 1400° C. We use method of intelligent system to make prediction of topological properties of network created with connection maximum value of 3D network of robot laser hardened specimens. Parameter X3 (fractal dimension, complexity) has most impact on genetic programming and Regression model.

## 4. CONCLUSION

In this article we present a new method for pattern recognition by using network and theory of complexity and its application in Mechanical Engineering. The SEM pictures were converted into 3D graph, from which we calculated topological properties of network created with connection maximum value of 3D network of robot laser hardened specimen. So, we use Closeness to find influencers within a some elements in microstructure of robot laser hardened specimens. We use fractal geometry to describe complexity of robot laser hardened specimens. For prediction of topological properties of network created with connection maximum value of 3D network of robot laser hardened specimen, we use genetic algorithm and multiple regression.

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