ICIC Express Letters
Part B: Applications
Volume **8**, Number **6**, June **2017**

ICIC International ©2017 ISSN 2185-2766
pp. **971–979**

THE EMPIRICAL RESEARCH ON PATENT-BASED MODELS OF TECHNOLOGY ENTROPY: A CASE OF CARBON CAPTURE TECHNOLOGY

Jianhua Hou

College of Marxism
Dalian University
No. 10, Xuefu Avenue, Jinzhou New District, Dalian 116622, P. R. China
houjianhua@dlu.edu.cn

Received November 2016; accepted February 2017

Abstract. *Entropy is one of the essential parameters in measuring disorder degree of the system. Technology entropy, therefore, is developed to represent a certain technology system's disorder degree in a particular time. With analysis of entropy and life cycle, criterions related to technology entropy, this paper was put forward to analyze and dispose the judgment of technology entropy increment based on the properties of technology system. We constructed the patent-based model of technology entropy which can be used to monitor the technology development trend. This method was verified effective, scientific and practical via the case study of carbon capture technology.*
Keywords: Technology entropy, Patent-based models, Carbon capture technology, Technology monitoring

1. **Introduction.** Entropy is an important parameter of the degree of the system disorder [1,2]. Entropy theory has been exploratory applied in sciences, social sciences and humanities since it was proposed. The technology system is characterized by synergism, self-organization, and mutability, all of which are consistent with the other systems that entropy theory applies to. For this reason, entropy theory is also applicable to the technology system. In the present study conducted at the information entropy [3], statistical entropy [4], black hole entropy [5] and so on, we introduce the technology entropy and patent-based models method using carbon capture technology as a case study. Specifically, in this research our aims are mainly including:

(1) Put forward the technology entropy analysis method and the judgment of entropy increment, and give the conditions of how different entropy increment correspond to different stages of technology life cycle;

(2) To construct the technology entropy analysis model based on the patent document data;

(3) To verify the validity of the technology entropy analysis model based on the patent document data by taking carbon capture technology as a case study.

2. **Technology Entropy Analysis Method.** Based on the thermodynamic entropy, Boltzmann entropy, and other properties of a technology system, we put forward the concept of technology entropy to describe and characterize the degree of the internal disorder of a specific technology system at a particular time. Its role is to solve the technology evolution, technology monitoring, technology evaluation and other related issues, by reflecting the trend or maturity of the evolution of a technology system.

Technology entropy is defined as:

$$dS = \frac{dQ}{T} \tag{1}$$

where dS is defined as the technology entropy increment, dQ denotes the energy received by a technology system, and T denotes the research interests on this technology. When $dS < 0$, i.e., the increase of entropy is negative, the technology system tends to grow orderly; when $dS = 0$, the technology system reaches a relative equilibrium, presenting a mature state; when $dS > 0$, i.e., the increase of entropy is positive, the technology system tends to be chaotic, beginning to decline.

There are two criteria for technology entropy. One is dS entropy increment itself, consisting of two parts: one part is the entropy increment d_eS generated by the energy exchange between the system and the outside world, and its value can be either positive or negative; the other part is the entropy increment generated within the system, i.e., entropy generation d_iS, and its value is positive. In summary, it can be expressed as follows:

$$dS = d_eS + d_iS \tag{2}$$

In the technology growth stage, as the external inputs of negative entropy flow are dominant, entropy generation within the system is relatively small, then: $d_eS < 0$, $d_iS > 0$, and $|d_eS| > |d_iS|$, so $dS < 0$, that is, the technology system evolves in an orderly direction. When the technology system evolves to a certain degree, the entropy generation within the system tends to rise, while the negative entropy flow tends to drop, and finally the two reach the equilibrium. The time period occupied by this state is the maturity stage of the technology system, and then there is $|d_eS| = |d_iS|$, $dS = d_eS + d_iS = 0$. Then technology system turns to decline stage, the external input positive entropy flow and the internal entropy generation cause chaos in the system, and the entropy value is constantly increasing. That is: $dS = d_eS + d_iS > 0$ ($d_eS > 0$, $d_iS > 0$).

The other criterion for the technology entropy is the trend value h of the technology entropy increment in the calculation formula for the technology entropy $dS = -k \cdot \ln h$. In the growth stage, the technology system evolves in an orderly direction, that is $dS < 0$, and then $h > 1$; in the mature stage, the technology system reaches an unstable equilibrium, $dS = 0$, $h = 1$; in the decline stage, the positive entropy flow breaks the equilibrium in the mature stage, driving the technology system more disorderly, $dS > 0$, $0 < h < 1$.

3. **Patent-Based Model of Technology Entropy.** According to Equation (2), where dS denotes the system's total entropy changes; d_eS denotes the entropy increment caused by interactions between the system and the outside world, i.e., the entropy flow, and its value can be either positive or negative; d_iS denotes the entropy increment generated by irreversible factors within the system, i.e., the entropy generation, and this term is always positive. To simplify the research, the following assumptions were made.

Assumptions: 1) All external factors are acting on the technology system through the patent, that is, there is a mapping relationship, which ideally makes the patent become the only way for the system to technologically exchange with the outside world; 2) if and only if the patent fails, the patent will automatically withdraw from technology system in the form of entropy generation; 3) the patents of different sources and different types contribute differently to the technology system, and their contributions can be measured; 4) the number of patent applications can be used as a measure of research intensity [6-8].

Based on the above assumptions, one can identify the order parameters of a certain technology system: within a certain time frame, the number of Type 1 patent applications is dN_1, and the number of Type 1 published ones is dn_1; within a certain time frame, the number of Type 2 patent applications is dN_2, and the number of Type 2 published ones is dn_2; $\ldots$; within a certain time frame, the number of Type i patent applications is dN_i, and the number of Type i published ones is dn_i. The patents can be classified according to their sources or types.

According to the definition of entropy, d_eS can be similarly expressed as

$$d_eS = d_eS_A + d_eS_B \tag{3}$$

where d_eS_A denotes the entropy introduced by the authorized patent into the system since it makes the system "orderly" and has a positive effect, this part of the entropy is negative entropy, and its value is always negative; d_eS_B denotes the entropy changes caused by the unpublished patent in the system. These patents enter the technology system during application, but soon withdraw from it. On the whole, they increase the chaos in the technology system, and their values should be positive. It can be seen by juxtaposing the two that, when the negative entropy introduced by the authorized patents is greater than the increase of entropy caused by the unpublished patents, the entropy flow is generally manifested as entropy reduction, and the system tends to be orderly; when the negative entropy introduced by the authorized patents is less than the increase of entropy caused by the unpublished patents, the entropy flow is generally manifested as the increase of entropy, and system tends to be chaotic; when the negative entropy introduced by the authorized patents is equal to the increase of entropy caused by the unpublished patents, the effect of the entropy flow on the system is zero.

The numbers of patent applications and published patents of various types per unit time are respectively defined as dN_{1-0}, dN_{2-0}, $\ldots$, dN_{i-0}, and dn_{1-0}, dn_{2-0}, $\ldots$, dn_{i-0}. Let T_0 be the research intensity of one technology source in the base year, and then

$$T_0 = 1 + \sum_{k=1}^{i} x_k dn_{k-0} \tag{4}$$

where x_1, x_2, $\ldots$, x_i denote the intensity coefficients of various types of patents. In this paper, it is defined that when the inputs of dn_{1-0}, dn_{2-0}, $\ldots$, dn_{i-0} are all zero, the value of T_0 is 1, and then T_0 is an actual number that is always not less than 1. According to the definition of entropy $dS = \frac{dQ}{T}$, there is:

$$d_eS_A = -\frac{\sum_{k=1}^{i} \alpha_k dN_{k-0}}{T_0} \tag{5}$$

where α_1, α_2, $\ldots$, α_i respectively denote the contributions made by each type of patents to the technological development in the base year, as a weight coefficient. The patent types with generally higher levels contribute more to the technological development, leading to greater value of α; and vice versa.

Similarly, it can be calculated as

$$d_eS_B = \frac{\sum_{k=1}^{i} (1 - \varepsilon_k)\alpha_k dn_{k-(0-\tau_k)}}{T_0} \tag{6}$$

where ε_1, ε_2, $\ldots$, ε_i respectively denotes the average authorization rate of each patent type; τ_1, τ_2, $\ldots$, τ_i respectively denotes the average application period of each patent type; $dn_{1-(0-\tau_1)}$, $dn_{2-(0-\tau_2)}$, $\ldots$, $dn_{i-(0-\tau_i)}$ respectively denotes the number of applications of each patent type in τ_1, τ_2, $\ldots$, τ_i years before the base year. This is because there is a review cycle of patents from application to pending to authorization. A patent can be considered being into the technology system since pending, and it will withdraw from the technology system after review and fail to be authorized. For this reason, the patent withdrawn in the base year should be applied before the average review cycle, and thus it is unreasonable to use the number of applications in the base year for the measurement here. This approach not only improves the accuracy of patent measurement, but also strengthens the logical connection between adjacent time nodes, thereby enhancing the integrity of the research.

In addition to the entropy flow existing outside the system, entropy generation may also be generated by irreversible factors inside the system. Under different conditions, entropy generation can be calculated differently, but the basic idea is to calculate the irreversible loss within the system. Specific to the technology system represented by the patent, the reasons causing entropy generation can be simplified as the invalidation of patent. On the one hand, the invalid patent still belong to the original technology system, generating impacts within the system, and the process of "invalidation" is extremely irreversible; on the other hand, the invalid patent and unauthorized patent are essentially different, as the former has become a component of the system and plays a long-term substantial role, while the latter merely enters and leaves the system in the form of entropy flow, without playing a substantial role within the system. Hence, only the former is the driving force for generating entropy generation within the system. Based on the above analysis and the assumptions at the beginning of this section, for the technology system represented by patent, entropy generation can be calculated as follows:

$$d_iS = \frac{\sum_{k=1}^{i} \alpha_k dN_{k-(0-t_k)}}{T_0} \tag{7}$$

where t_1, t_2, ..., t_i respectively denotes the term of validity of each patent type.

The total entropy change in the technology system can be expressed as,

$$dS = d_eS + d_iS = \left(-\frac{\sum_{k=1}^{i} \alpha_k dN_{k-0}}{1 + \sum_{k=1}^{i} x_k dn_{k-0}} + \frac{\sum_{k=1}^{i} (1-\varepsilon_k)\alpha_k dn_{k-(0-\tau_k)}}{1 + \sum_{k=1}^{i} x_k dn_{k-0}} \right) + \frac{\sum_{k=1}^{i} \alpha_k dN_{k-(0-t_k)}}{1 + \sum_{k=1}^{i} x_k dn_{k-0}} \tag{8}$$

When $dS < 0$, the technology system evolves in an orderly direction, that is, in the growth stage; when $dS = 0$, the technology system reaches an unstable equilibrium, that is, in the maturity stage; when $dS > 0$, positive entropy flow breaks the equilibrium in the maturity stage, making the technology system more disorderly, that is, in the decay stage.

According to the definition of Boltzmann entropy $S = k \ln H$, in the growth stage, the technology system evolves in an orderly direction, that is, $dS < 0$, and then $h > 1$; in the maturity stage, the technology system reaches an unstable equilibrium, $dS = 0$, $h = 1$; in the decay stage, positive entropy flow breaks the equilibrium in the maturity stage, making the technology system more disorderly, $dS > 0$, $0 < h < 1$.

4. Technology Monitoring of Carbon Capture Technology.

In this study, relying on the China national patent information service platform of SIPO, the patent abstracts were searched with "carbon dioxide and (adsorption or absorption or capture)" as the element, and 2861 entries of data were obtained. Moreover, technology entropy analysis was carried out on 2716 entries of patent information applied from 1985 to 2013, thereby accurately and objectively monitoring the carbon capture technology.

4.1. Technology entropy analysis of carbon capture technology.

In order to macroscopically sort out the development of carbon capture technology in China, here the patent model is used for technology entropy analysis.

As only a one-dimensional form was adopted, the original model can be simplified as

$$T_0 = 1 + xdn_{1-0} \tag{9}$$

$$dS = d_eS + d_iS = \frac{-\alpha dN + (1-\varepsilon)\alpha dn_{1-(0-\tau_1)}}{T_0} + \frac{\alpha dN_{1-(0-t_1)}}{T_0} \tag{10}$$

where x denotes the intensity coefficient of the patents, and it is 1; α denotes the contribution of the patent to technological development in the base year – due to a lack of comparison – and it is also 1; ε denotes the average authorized rate of patents, τ_1 denotes the average application period of patents, and all of them are calculated from the patent application and pending data published by SIPO.

Based on the calculated results of T_0, in this study, technology entropy analysis was carried out on the low-speed blossoming phase and the high-speed jumping phase (as shown in Figure 1).

According to Figure 2, although carbon capture technology underwent a low-speed blossoming phase (1996-2005), it is generally manifested as the obviously increased number of patent and the approximate linear growth of research intensity. However, in fact, internal shock of the technology system occurs at this phase. In 1996, the patent inputs higher than the previous years provided excessive negative entropy for the technology system of carbon capture, and the orderly perturbation was introduced into the technology system. However, the initial input of negative entropy is still small, not enough to produce macro-movement, plus the technology system has its own self-organization, manifested as offsetting the external influences, so the huge entropy generation started to appear around 1999. However, the slow enhancing negative entropy flow was not enough to offset the influence, making the technology system tend to be stable equilibrium, manifested as degradation of the system.

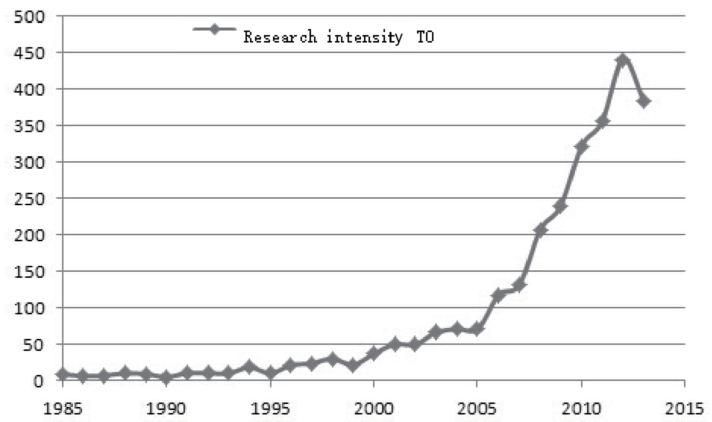


Figure 1. Research intensity T_0

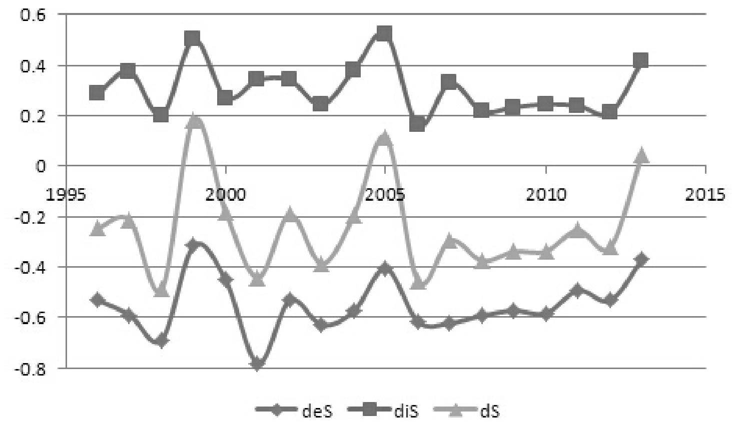


Figure 2. Trend of technology entropy of carbon capture

In this fluctuating development, the continuous input of negative entropy flow will constantly act on the entire technology, gradually leaving the system in an approximately critical state. Hence, after undergoing the fluctuations in 2005, the fluctuations in 2006 caused qualitative change of the technology system, instantly leaping into the high-speed jumping phase (2006-2013). During this period, negative entropy flow was continuously input and always greater than the entropy generation within the system, and the system developed towards the unstable equilibrium of technical maturity. However, it should be noted that in 2013, negative entropy flowing into the technology system was reduced, while the entropy generation suddenly increased, bringing the system back to the critical state of relative equilibrium.

4.2. **Dynamic evaluation of carbon capture technology.** According to the technology entropy theory, the development of technology is affected by many factors, such as policy, economy, market and so on, and its actual developing path is almost unpredictable. In this paper, therefore, starting from technology entropy, based on the available data, dynamic evaluation on the carbon capture technology in China was carried out by a single variable.

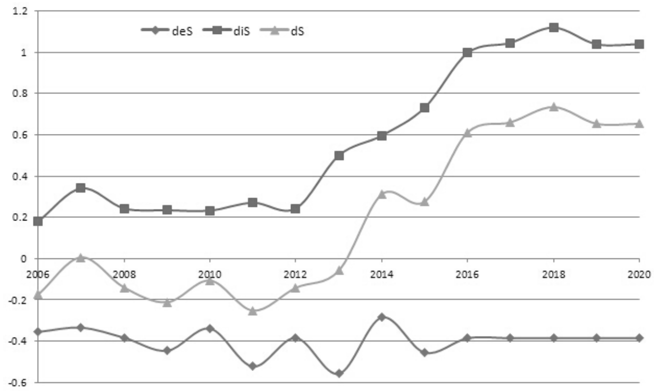
1) It is assumed that by 2020 in China, the numbers of applications and published patents related to carbon capture technology will maintain the level of 2011-2013, and its dS will develop as shown in Figure 3(a). In this case, d_eS will become steady since 2014, but d_iS will increase rapidly, and dS is always positive, leading to serious degradation of the technology system and the ultimate decline.

2) The numerical relationship between the research intensity T and the number of patents was disconnected, that is, carbon capture is still highlighted but its technological achievements are not fully reflected in patent growth. Then, it is assumed that during 2014-2020, T will increase at the average growth rate of 2009-2013, and its dS will develop as shown in Figure 3(b). In this case, both d_eS and d_iS will decrease year by year, but d_eS decreases faster than d_iS; dS is always positive, and the system will quickly decay.

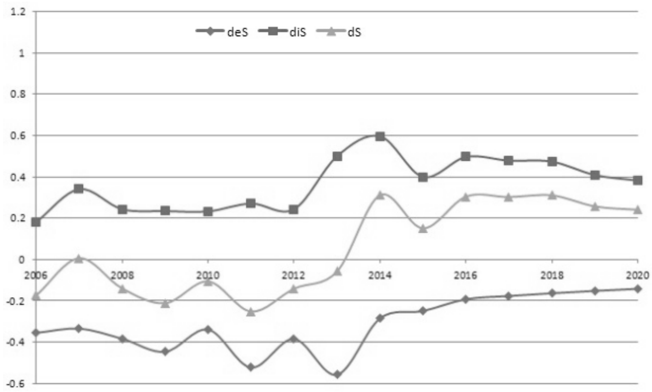
3) It is assumed that by 2020 in China, both the numbers of applications and published patents related to carbon capture technology will see liner growth at the average growth rate of 2009-2013, and the dS will develop as shown in Figure 3(c). In this case, both d_eS and d_iS will accelerate growth, and the growth rates of them are fairly close; dS will fluctuate around 0, and the technology system reenters a low-speed blossoming phase similar to that in 1996-2005, hardly achieving any substantial progress.

4) It is assumed that by 2020 in China, both the numbers of applications and published patents related to carbon capture technology will exponentially grow at the average growth rate of 2009-2013, and dS will develop as shown in Figure 3(d). In this case, both d_eS and d_iS will accelerate their growth, but d_eS grows significantly faster than d_iS; dS is negative, effectively pushing the technology towards maturity.

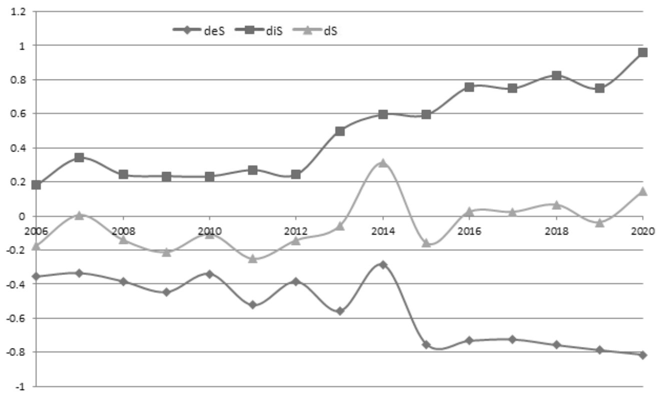
According to analysis, carbon capture technology in China is undergoing a critical period, and its development in the next few years will directly influence the growth of the entire technology system. Since the technology system itself is still in the growth stage, it may quickly degrade and even decay, if the inputs of negative entropy are lower than the entropy generation within the system. The technology accumulated over the previous decades will be dispersed into different fields, failing to form the technology system of carbon capture; however, if the inputs of negative entropy are equal to the entropy generation within the system, the system will maintain an unstable equilibrium, but still unable to reach maturity. At this point, an increasing amount of negative entropy will be needed to maintain the dissipation of the system itself, and the costs will get higher and higher. Once the negative entropy flow decreases, the system will be also faced with the risk of rapid degradation, finding itself in a situation of high input and low yield; if the inputs of negative entropy are higher than the entropy generation within



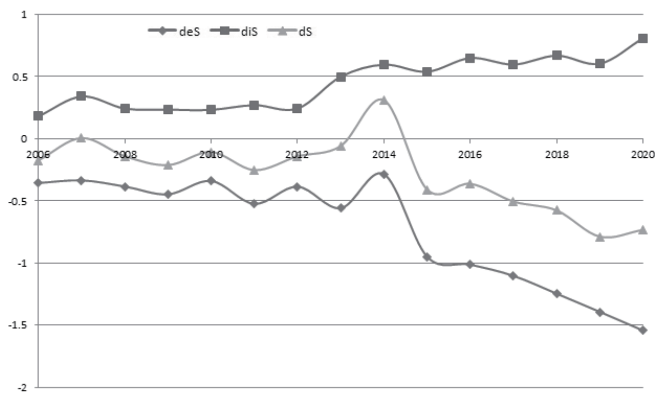
(a)



(b)



(c)



(d)

Figure 3. Trend of dS under different dynamic conditions

the system, the system will enter a new development process. This depends on a series of technological innovation brought about by the breakthrough of the core technology, pushing the technologies towards maturity, and the degree of its evolution will directly determine the possibility of industrialization of carbon capture technology in China.

5. **Conclusions.** 1) Technology entropy can describe and characterize the disorder of internal relations of specific technology system. Technology entropy increment can judge the different stages of technology life cycle. When $dS < 0$, $h > 1$, then technology system is in its growth stage. When $dS = 0$ ($dS \approx 0$), $h = 1$ ($h \approx 1$), then technology system tend to be in mature stage. When $dS > 0$, $0 < h < 1$, then technology system turns to decline stage.

2) Based on the patent information in the database, we construct patent-based analysis model of technology entropy as,

$$\begin{aligned} dS &= d_eS + d_iS \\ &= -\frac{\alpha_1 dN_{1-0} + \alpha_2 dN_{2-0} + \cdots + \alpha_i dN_{i-0}}{T_0} \\ &\quad + \frac{(1-\varepsilon_1)\alpha_1 dn_{1-(0-\tau_1)} + (1-\varepsilon_2)\alpha_2 dn_{2-(0-\tau_2)} + \cdots + (1-\varepsilon_i)\alpha_i dn_{i-(0-\tau_i)}}{T_0} \\ &\quad + \frac{\alpha_1 dN_{1-(0-t_1)} + \alpha_2 dN_{2-(0-t_2)} + \cdots + \alpha_i dN_{i-(0-t_i)}}{T_0} \end{aligned}$$

3) Carbon capture technology as a case study, we verified effectiveness, scientificity and practicability of patent-based analysis model of technology entropy. From 1985 to 2013, researches on carbon capture technology in China underwent the budding phase, the low-speed blossoming phase, and the high-speed jumping phase. Around 2006, on the previous basis, carbon capture technology began to develop rapidly and entered a critical period of development in 2013.

In future research, we will introduce the scientific literature indicator to the patent-based model and make further improvement of technology entropy analysis model. To analyze the evolution of technology domain based on the entropy increment of technology system and obtain the optimal scheme of technology development by calculating the marginal value of quantitative effect of different factors. At the same time, because the technology itself is greatly influenced by various factors such as market, policy, finance, this study of the technology entropy still has many deficiencies, and our research will improve and expand the indicator system and application of the technology entropy analysis method in the future.

Acknowledgment. This work is partially supported by Ministry of Education in China Project of Humanities and Social Sciences under Grant 15YJC630033.

REFERENCES

[1] M. W. Grenn, S. Sarkani and T. Mazzuchi, The requirements entropy framework in systems engineering, *Systems Engineering*, vol.17, no.4, pp.462-478, 2014.

[2] Z. Zhang, Q. Mei, J. Zhang and B. Hu, Evaluation of engineering project management system based on information entropy, *International Conference on Electric Technology & Civil Engineering*, pp.1186-1189, 2012.

[3] T. D. Pham, Image texture analysis using geostatistical information entropy, *Intelligent Systems*, pp.353-356, 2016.

[4] F. M. Al-Athari, A new secure forward digital signatures based on forecasting and statistical entropy of key exposures, *Advances in Computer Science & Engineering*, pp.479-483, 2016.

[5] P. Bargueño and E. C. Vagenas, Semiclassical corrections to black hole entropy and the generalized uncertainty principle, *Physics Letters B*, no.742, pp.15-18, 2015.

[6] H. Park, K. Kim, S. Choi and J. Yoon, A patent intelligence system for strategic technology planning, *Expert Systems with Applications*, vol.40, no.7, pp.2373-2390, 2013.
[7] T. Dereli and A. Durmusoglu, A trend-based patent alert system for technology watch, *Journal of Scientific & Industrial Research*, vol.68, no.68, pp.674-679, 2009.
[8] L. Fleming and O. Sorenson, Technology as a complex adaptive system: Evidence from patent data, *Research Policy*, vol.30, no.7, pp.1019-1039, 2001.