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METHOD FOR FORECASTING DI BASED ON TRIZ TECHNOLOGY SYSTEM EVOLUTION THEORY

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Disruptive Innovation (DI) is an effective method for a new firm to enter mature market. According to the composing analysis of the technical system for the product, six kinds of typical state in the technical system process can be detected. In accordance with technology system evolution analysis, two kinds of evolutionary technologies — mainstream evolutionary technologies and laggard evolutionary technologies — can be detected. Then, the conditions for forecasting DI technologies are established. Based on evolution path lines of TRIZ, the potential DI can be forecasted. As a case study, the video game console system is investigated. The study shows that the adoption of TRIZ evolution theory in forecasting disruptive technologies of product is feasible.

Keywords: DI; technology system evolution; TRIZ.

1. Introduction

Disruptive Innovation (DI) is a technical innovation theory put forward by Christensen [1997], and consummated by him at last (Christensen and Bower; Christensen and Overdorf; Christensen and Raynor [1996; 2000; 2003]) DI refers to a technology, process, or business model that brings to a market, a much more affordable product or service that is much simpler to use. When these products are getting stable gradually in the low-end market and in the new market by development, they can take the place of the products in the mainstream market. Though the performance of DI products is not so good when they are introduced, they have the characteristics of cheap, simple, portable, and easy to use. This makes it possible to compete with the mature products in the mainstream market.

When Christensen studied a series of initiate DI, other scholars also studied this theory all along. Danneels [2004] thought that the concept of DI given by Christensen was not clear. People confused the difference between DI and common new technology whose performance is under that of main technologies. Govindarajan and Kopalle [2006] believed that the cases given by Christensen were all the results of the analysis after something occurred, they could not give beforehand forecasting.

Smith [2007] pointed out that the initial use of technology of modern computer game relative to imitating industry is a sort of low-end capacity for specific users. However, with the development of technologies, disruptive potential technique emerged. This kind of technique has already reached the level that is much more powerful competition ability than many main facilities. It has become the technical base of the establishment of new companies. These companies may replace the ones that adopt traditional mature technologies by means of DI. The technology of DI put forward by Chieh and Dan [2007] and others should be a noteworthy direction and it should be developed as an innovation tactic. Kohlbacher and Hang [2007] analyzed the market of the aged using the frame of DI. They pointed out that the market supplied important commercial opportunities. To sum up, the technology of DI has become the important investigative direction in this field.

The research based on industrial technology DI by Christensen [2000], by means of graphic method, can forecast the evolution of technology for the corporations in need. However, the forecasting process is difficult, in what way to forecast in general is not clear. A simple method is historical evolution trend analysis, but for new technology or new market, almost there are nonexistent historical data. The future direction of evolution is not clear that this method would not seem feasible. The present investigations suggest that there are two methods to support the technology forecasting. The first method is technology foresight. Doering and Parayre [2000] put forward a technology assessment procedure to collect, test, assess, and present for many times. This procedure is helpful to the assessment of the future commercial value of scientific innovation. Rowe and Wright [1999] put forth Delphi technology for the acquirement of integrated technologies and market track. The second method is technology roadmap. In recent years, technology roadmap has been made rapid progress in theory and practice, but all that are from the sustaining technology. Walsh [2004] corrected the traditional technology roadmap by using disruptive technology, constructed a commercial model of disruptive technology roadmap and forecasted the development trend of nanotechnology.

TRIZ is the Russian acronym for the Theory of Inventive Problem Solving Altshuller [1999]. It mostly includes the forecast of technology maturity, technology evolution, the contradiction solution, effect, standard solution, and the Algorithm for the Solution of Inventive Problems (ARIZ from the Russian abbreviation) etc. The computer-aided innovation (CAI) software Kohn *et al.* [2005] based on TRIZ has been developed recently. All kinds of methods in TRIZ can be used either separately or together, so that different problems in invention can be solved Tan [2004].

This paper is based on the technical evolution theory in TRIZ, discussed the forecasting process and method of DI and established the process model. It offers a support in both theory and methods for forecasting a DI technology.

2. Theoretical Background

2.1. *Principle of DI*

Christensen divides innovation into sustaining innovation and DI. The former is similar to incremental innovation (II); it carries out the benefit of enterprises based on improvements of products in market. The latter is different from radical innovation (RI). Although both of them have the characteristic of disruption, DI has slower affection on current enterprises and it is also systematic Christensen [1997]. The initial stage of disruptive technology is not a good solution relative to the existing technology, but technology can meet the need of part of the market that current enterprises neglect or think it worthless. Fig. 1 shows the principle of DI.

Initially, the technology of DI is developed to meet the demands of low-end users and these demands will not attract the leading firms, but new enterprises that collect money within a short time and meet the needs of low-ends established their companies based on the DI. The lower technology that low-end market needs may contains mass potentials. When these potentials have been developed, the new arrivals will acquire new improvements in the value chain. They will achieve the improvements made by the technology of DI just as depicted in Fig. 1 in. New techniques and the enterprises that have those techniques will become a menace to current enterprises or leading firms. As a result, the enterprises that collect money within a short time replace current enterprises, and then DI is achieved.

Innovations on technology evolution path are divided into two types in general, sustaining innovation and DI. Sustaining innovations are divided into II and RI. As shown in Fig. 2, sustaining innovation and DI constitute the whole product technology evolution path. Obviously, the DI technology can be forecasted according to the evolution line of product.

The manufacturers of most products have established a trajectory of technological improvement over time. When a trajectory of improvement has been established, those mainstream firms occupy the markets and master advanced technology of product and there are a few chances for the comer entering this market. Therefore,

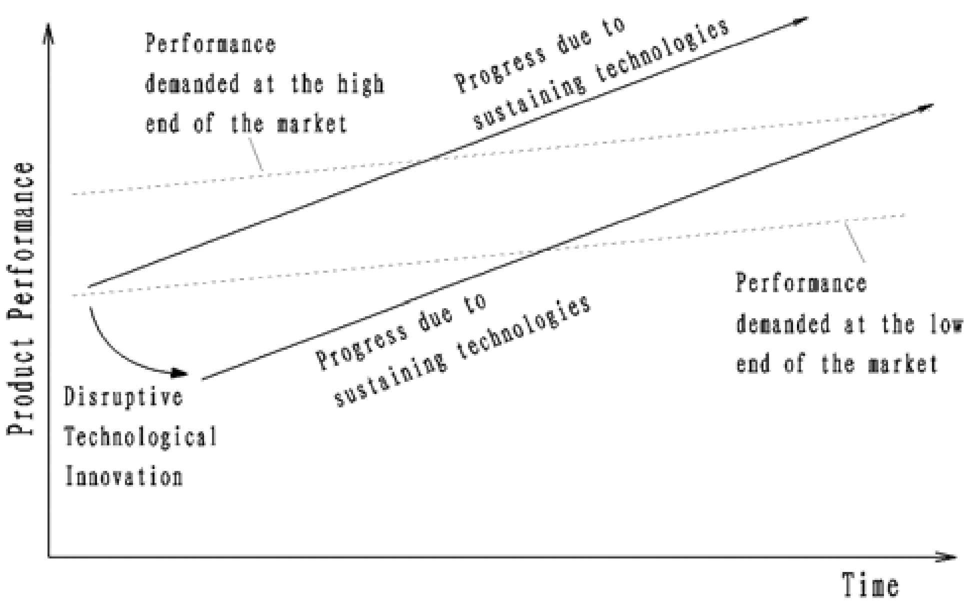

Fig. 1. The impact of sustaining and DI by Christensen [1997].

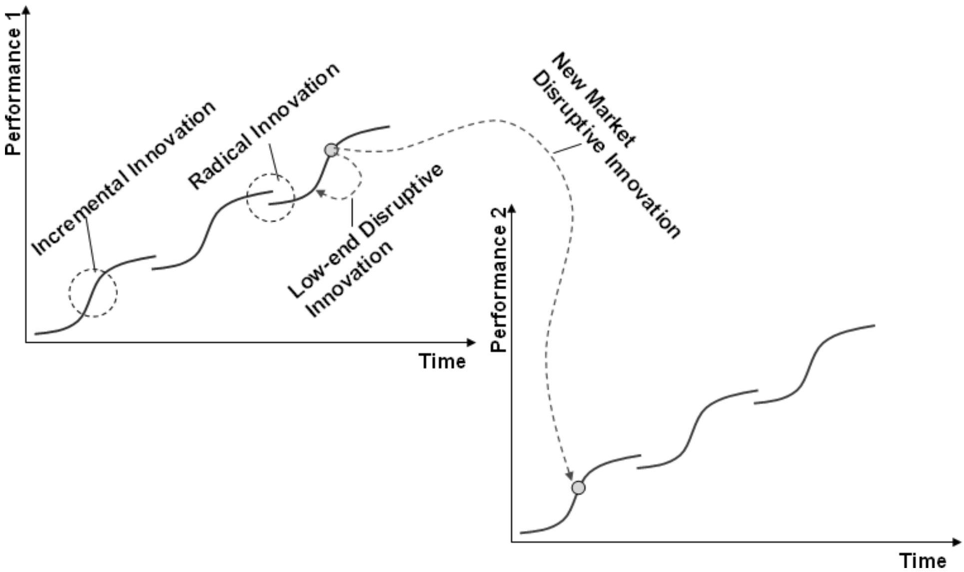

Fig. 2. The DI during the process of S curve evolution.

the new firm has to develop new product using lower technologies, current trajectory is broken.

The produce of the disruptive technology is the origin of DI, but Christensen himself is devoted to the research of commercial models of DI, market, management, and so forth. The technologies of DI in many cases described by him are already existed. His main research direction is the implements of DI based on these technologies. In addition, he did not do much about the technology of DI, especially the produce of this type of technology. Some scholars and firms doubt the concept of disruption too. As the cases Christensen used are the events already happened so its course is provided with chanciness or depended upon the gnosis that firms have. Therefore, the theory of DI is difficult to be used for technical forecasting of DI. Hence, in order to consummate the theory of DI, it is urgent to develop the technologies of DI in this field.

2.2. *Theory of technical systems evolution*

Technology is in the state of evolving. Technical evolution is affected by many elements, such as new concepts, power of the market, the status of politics, and the tradition of culture. These elements can only have an effect on the pace of technical evolution, but they cannot greatly change the direction of technical evolution. All the originators in the world as a whole cannot be controlled or regulated. Most of their activities are separate from each other. They usually do not know other people are working over the development of technology or products that are the same or similar to theirs and their objectives seem stochastic. However, whether a new technology or a new product can be accepted by the society depends upon whether the technology or the product meets the current law of technology evolution. G. S.

Altshuller, who is the founder of TRIZ, and his staff found the laws of the technical evolution in different areas are same by means of the analysis of many patents. We can forecast developmental trend of technology in the future voluntarily if we predominate these laws and we can design the products for tomorrow.

The technology evolution theory in TRIZ reflects the technical systems, the composing elements, the important, steady-going, and repeated reciprocity in evolution between the systems and the environment. Fey and Rivin [2005] reduce the technical evolution laws to nine points as follows:

(1) Law of increasing degree of ideality,
(2) Law of nonuniform evolution of sub-systems,
(3) Law of increasing dynamism,
(4) Law of transition to higher-level systems,
(5) Law of transition to micro-levels,
(6) Law of shorting of energy flow path,
(7) Law of completion,
(8) Law of increasing controllability, and
(9) Law of harmonization of rhythms.

Laws of technical system evolution give us directions of evolution, but they did not show us the details of each direction. There are many technical evolution paths under every law and the technologies evolution line is made up of different stations that indicate the process and they also offered the function of technical forecasting.

The evolution path of different products are different, for example, reducing cost, increasing function, improving reliability, reducing pollution, and so forth are all the possible directions of evolution. Low cost, high function, high reliability, and no pollution are the directions of evolution on condition that all products are regarded as an integrated system. The ultimate state of products evolution is called Ideal Final Result (IFR) Savransky [2000]. Therefore, every product is evolving toward its IFR state. Increasing the ideal level of the products ceaselessly is the objective of the innovation of the products. There are a few existed products that achieve IFR. Evolving toward the direction of IFR is the development direction of almost all the products in the future.

Figure 3 shows a product technology evolution path model. The model consists of n states from the initial state to the top state and these states may be classified by their position in the evolution path. Among them, the state i represents current state and state 1 is known as initial state. From the state i to the state n is early technology evolution path; therefore, they are known technical states. The following evolution path is from the state i to the state n, which is unknown technical state needed to be forecasted.

3. Methodology

3.1. *The bifurcation points of disruptive technologies*

In the whole technology evolution process of the product leading to IFR direction, the sustaining innovation and the DI are carried on in turn, where the DI divides into

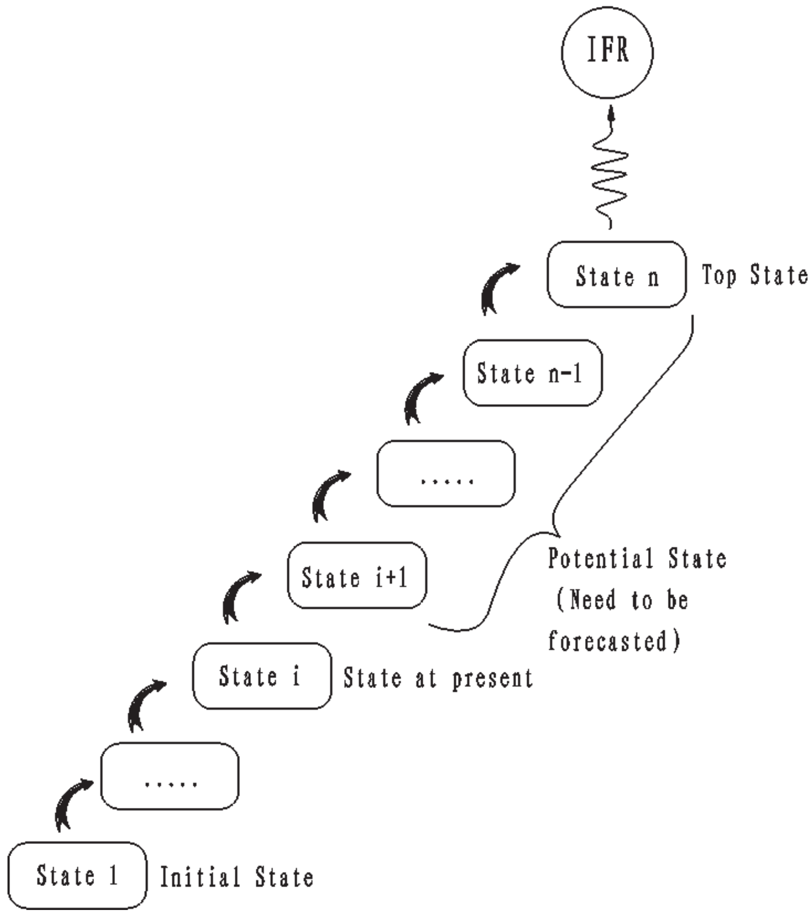

Fig. 3. Technological system evolution model.

new-market disruptions and low-end disruptions. The former prevents the product technology system evolution unbalance caused by long-term sustaining innovation and the latter avoids the long-term sustaining innovation leading to user's demand surplus. Just these two DI and the sustaining innovation cooperation impel the product to develop to the IFR direction.

The evolution of real systems is associated with a mix of regular, deterministic, and highly predictable events along with events that are random, stochastic, haphazard, difficult-to-predict, etc. A small influence often produces enormous (and unexpected) results, while in other situations extensive efforts produce an inadequate outcome Zlotin and Zusman [2004–2005]. Figure 4 shows bifurcation points on the technological evolution path. A main characteristic on the bifurcation points is that their properties will change under the influence of processes taking place within them. Unfortunately, only on the evolutionary line area between two adjacent bifurcation points technologies can be forecasted analytically, and a large number cannot be forecasted.

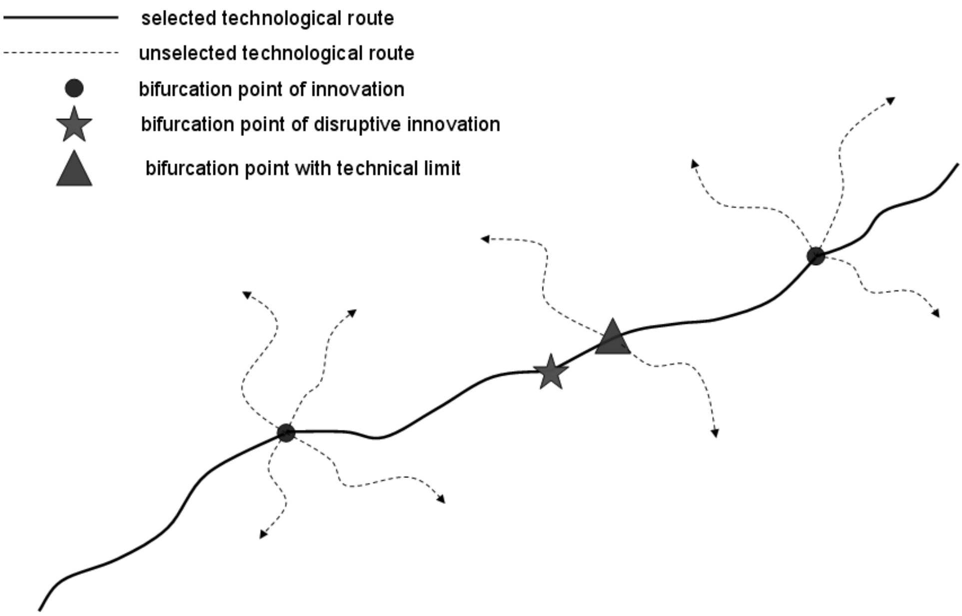

Fig. 4. Bifurcation points on the technological evolution path.

When a low-end DI occurs, the technological evolution appears as countermarch. As shown in Fig. 5, b to a is the process of the low-end DI.

When a new-market DI occurs, the technological evolution appears as bifurcate charactertics. As shown in Fig. 6, b to c′ is the process of the new-market DI.

Mixed DI is the combination of the former two DI and possesses the advantages of both of them. When a mixed DI occurs, the technological evolution appears as both countermarch and bifurcate charactertics. As shown in Fig. 7, b to a to c′ is the process of the mixed DI.

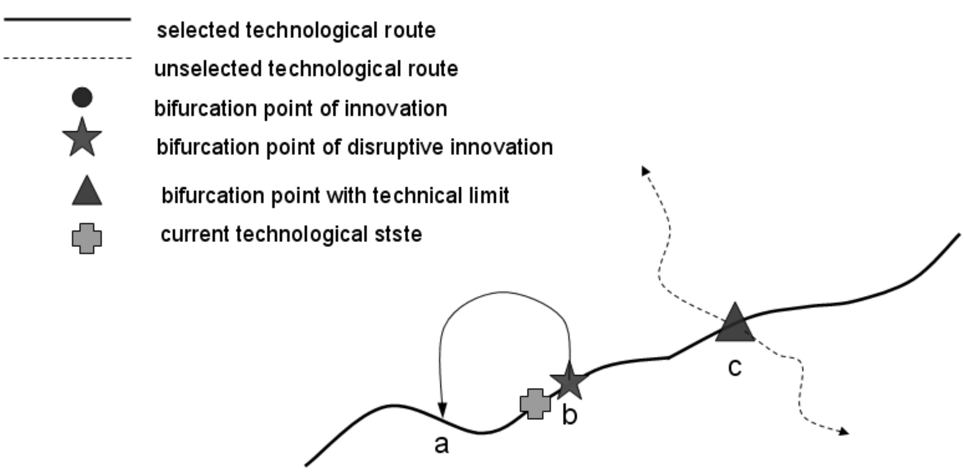

Fig. 5. Bifurcation points of low-end DI on the technological evolution path.

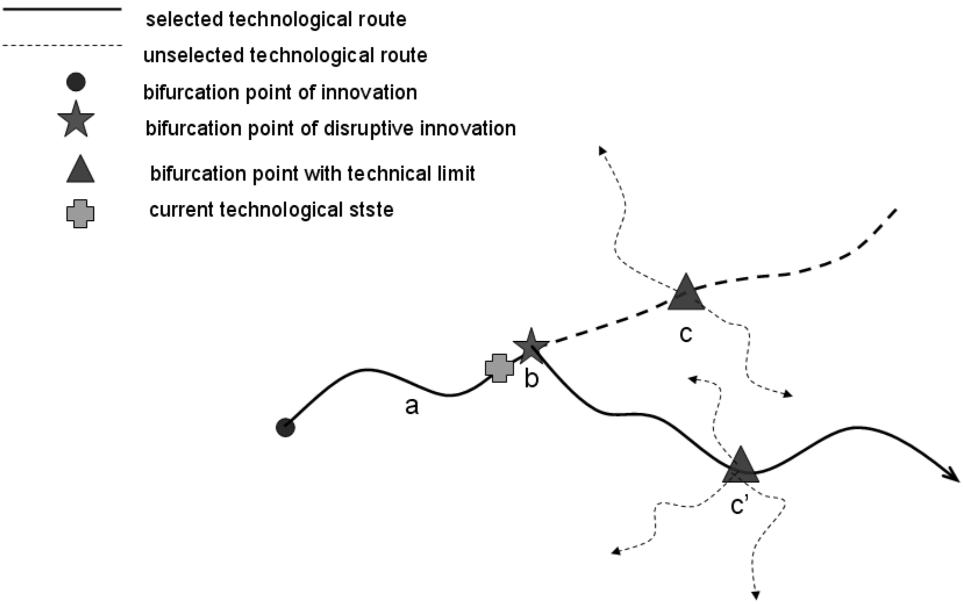

Fig. 6. Bifurcation points of new-market DI on the technological evolution path.

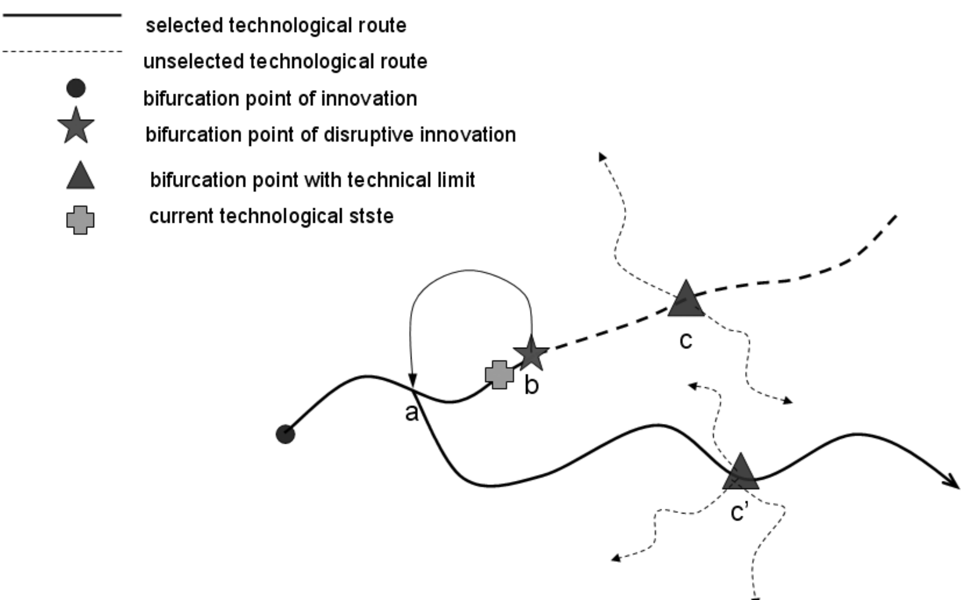

Fig. 7. Bifurcation points of mixed DI on the technological evolution path.

3.2. *Evolution analysis of the technical system for DI process*

3.2.1. *Composing analysis of the technical system for the product*

Systematology is the knowledge to research the general model, structure, and law of a system. It works over the corporate characteristic of all kinds of systems, which describes the function of a system quantificationally by means of mathematical method. Systematology is seeking and establishing the principle and fundamental and mathematical models that are the same with all systems. It is a burgeoning ology that has the character of mathematics and logic. Commonly, the entia that has holistic function and synthetical action is called a system, which is made up of interrelated, interdependent, mutual checking, and interactional alternative or process Mao [1997].

Product is the complex entia that is constitute of different components, which has holistic function and synthetical performance. The technical system that forms the product is made up of subsystems at all levels and each subsystem has integrated systems structure that can be analyzed as a whole technical system. To the decomposition of a technical system that is known, we usually use tree analytic process as is showing in the picture. In order to escape the appearance of extra hierarchies of technical system decomposition, the smallest unit in the decomposition should be the outsourcing unit that is for the manufacturing of the products. Moreover, design constraint (volume and weight, price, operation accessibility, energy consumption etc.) will be listed among all subsystems, which acts as technical subsystem for the convenience of the evolution analysis of technical system.

Figure 8 shows technical system decomposition model that faces toward the products of DI. The product technical system has a hierarchical structure and is made up of basic-functions and constraints, by means of a series of decomposition

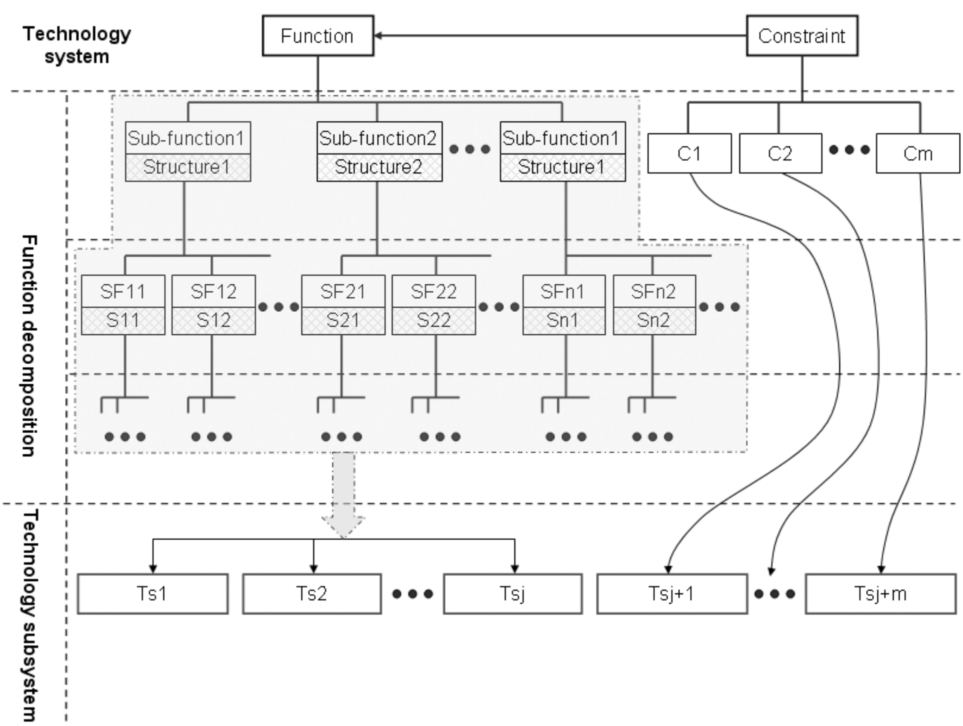

Fig. 8. Model of the technology system decomposition face to DI.

process, $j + m$ technical subsystems are produced at last. The decomposition process is discussed in the following paragraphs.

First, divide the basicfunction of the product into sub-function from technical system hierarchy, meanwhile, the constraint items that are relevant to the product should be listed as well. Please note, from the beginning of functional decomposition, the influence to the function that is brought by constraint should be considered. We may even need to add aided sub-function to meet constraint condition.

Second, all functions are decomposed with zigzagging mapping between function and structure by means of axiom design analytic process, so as to review whether the composing structure of each acquired product is the outsourcing function unit of the enterprise. Decomposition should be stopped if the composing structure of each acquired product is the outsourcing function unit of the enterprise, or else, the decomposition should continue.

Third, dividing sub-function into sub-function ceaselessly by means of homogeneous method. Then, decomposing sub-function step by step until the structure cannot be decomposed any more or they are divided into outsourcing unit. Thus, the technical system decomposition tree is acquired.

Lastly, the induction of technical sub-system: we may induct the front j items of the sub-system from the function tree and they unite with the mth item to become $j + m$ item, which is the final technical system. To a fixed functional decomposition tree, the concluding outcome of technical sub-system is not unique, we will bat around this point in the next section.

To the product that has highly modularization extent, the technical system decomposition is much simpler, the decomposition could be carried out according to modules, then, the design constraint can be added solely. In this way, technical subsystem is acquired. Technical system decomposition is more complex to the products whose division of components is not clear.

3.2.2. *Evolution state of technical system for products*

The opportunity for DI technique comes from overage evolution of product performance and the appearance of new demand market and even extends to the evolution field of technical system, which actually is the opportunity brought by the unbalancing evolution of sub-system, on condition of the restriction of user requirements. Therefore, the opportunity for DI has close relationship with evolution state of technical system

As is shown in Fig. 9, we use radar chart for expressing technical system. Supposing technical evolution system Et is made up of six sub-systems, $E_t = \{E_{t1}, E_{t2}, \ldots, E_{t6}\}$, the real line areas represent for technical performance and broken line areas represent for user requirements, among others, mainstream technological evolution state (MTES) stands for the evolution state of technique which similar with the level for social mainstream science and technology. There are six kinds of typical states in the technical system process Sun [2009]:

(1) Optimal performance state (OPS). The performance of each sub-system can meet user requirements (Fig. 9(a), at this time, systemic performance could

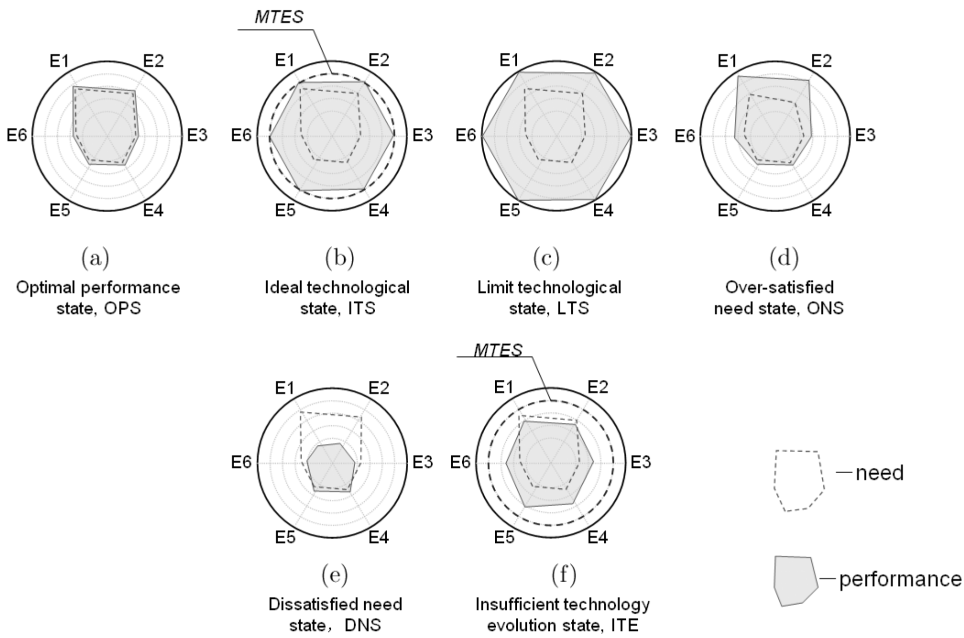

Fig. 9. States of technological system evolution.

satisfy user requirements already; moreover, the consumption of resource is at the lowest level and the price and quality of products reaches a perfect balance, this is just the state that DI dreams of.

(2) Ideal technological state (ITS). Which is shown as Fig. 9(b). The performance of each sub-system reaches the evolution state of mainstream technology. Technically, ITS is the most reasonable advanced state for current products, but ITS cannot come into reality in real technical system of products for the coherence of performance of technical sub-system and the cost restriction caused by cutthroat competition.

(3) Limit technological state (LTS). The performance of each sub-system reaches its technical terminal (Fig. 9(c)), LTS is the object of sustainable innovation. In the process of sustainable innovation, enterprises could only improve all performance indexes at their best, which is far from user requirements, so as to win in the fierce market competition. Meanwhile, LTS cannot come into reality in real technical system of products too, as the coherence of performance of technical sub-system and the cost restriction.

(4) Over-satisfied need state (ONS). The performance of some sub-systems is obviously over user requirements (Fig. 9(d)). In the process of ITS, blindly improving the performance of product that is just the hotspot of market competition will lead to ONS. ONS is always regarded as the opportunity to produce low-end disruption.

(5) Dissatisfied need state (DNS). The performance of some sub-systems of a product is below user requirements obviously, because the highly increasing of user requirements or the evolution deficiency of sub-systems of the

product (Fig. 9(e)). The pursuing of ITS and the inertia of technical development will lead to the lack of monitoring to user requirements. It may results in the low performance of some sub-systems that is below user requirements day by day. In addition, this is always regarded as the opportunity to produce new market disruption.

(6) Insufficient technology evolution state (ITES). The performance of some sub-systems is obviously below the evolution state of current mainstream technique (Fig. 9(f)). This state of sub-system has very good technical potential; the promotion of performance can be improved greatly without paying much expense.

3.2.3. *DI model of technology system evolution for product*

Technical systemic evolution appears as the resultant force of each sub-system; the process of technical systemic evolution is just the process of product innovation. Product innovation is made up of II, RI, and DI. The three innovations run through the process of technical systemic evolution. As is shown in Fig. 10, when a product is in maturity, which evolved from $S_{n-3} \Rightarrow S_{n-2} \Rightarrow S_{n-1} \Rightarrow S_n$ to current state of S_n and $E_{n1} \ll E_1$, $E_{n2} \ll E_2$, which we can conclude from S_n. Therefore, E_1 and E_2 are the hotspots in the market competition of the process for graduate product innovation. ONS has already appeared in the evolution process of product maturity. Moreover,

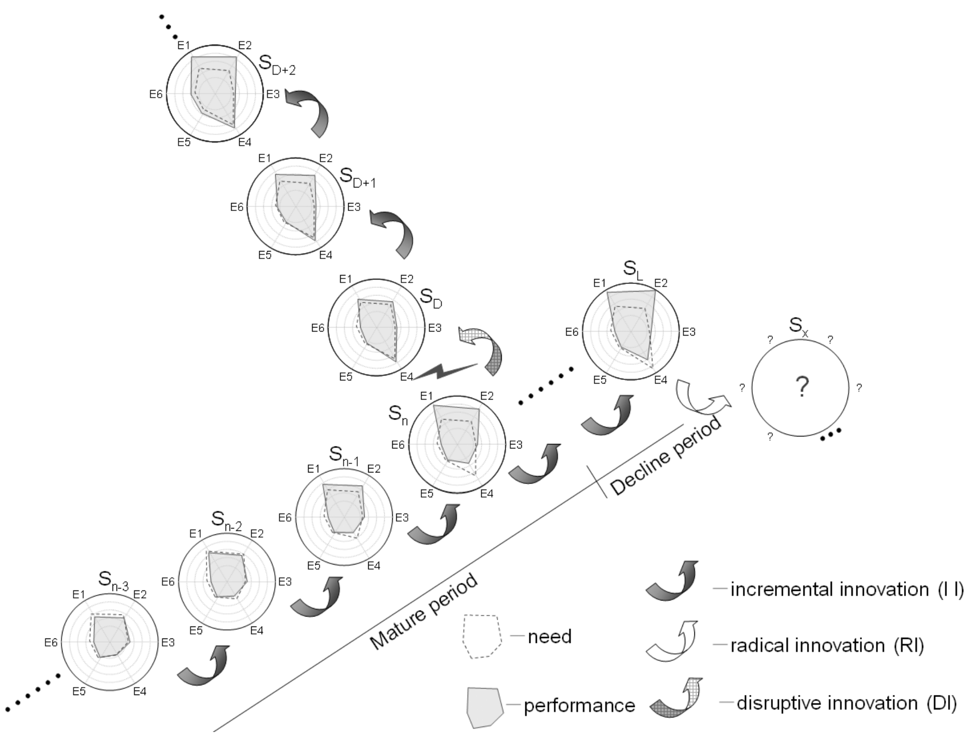

Fig. 10. Technological system evolution and innovation model.

user requirement to E_{n4}, which is the requirement to sub-system E_4, is always increasing. However, E_4 is not increasing accordingly and this result in $E_{n4} \gg E_4$ when the evolution comes to current state of S_n, so DNS appears in technical systemic evolution.

S_n has two evolution potential states that are as follows, according to the definition of state S_n above:

(1) Embranchment potential of II Evolution: The characteristic of II is going in for continuing improvement of critical performance in the market. In other words, the performances of sub-systems E_1 and E_2 need to be advanced, in order to compete with other enterprises. Until the performance reaches technical high-point S_L by means of RI, systemic evolution reaches S_x, which is the start point of curve S.

(2) Embranchment potential of DI: The unbalance of sub-system evolution will bring DI opportunity for a system; we may use two different kinds of DI strategy:

  (i) Low-end Market DI: Decreasing the performance of sub-systems E_1 and E_2, making it just meets user requirements. At this moment, in the potential state S_D, $E_{n1} \approx E_1$, $E_{n2} \approx E_2$; A part of product cost can be saved because of the knock-down of E_1 and E_2. Therefore, the price of the product could be reduced, so low-end market disruption that is for certain users can be realized.

  (ii) New market DI: Adding the performance of sub-system E_4, which is for meeting user requirements. The adding of sub-system E_4 means the reinforcement of sub-systemic function of products. Thus, products may enter to the user group who are interested in this sub-systemic function and new market DI can be achieved.

The demand evolution is corresponds with the technical evolution. The emergence of mainstream evolution technology is because the dominant markets are wild about the sustaining innovation, but this kind of innovation comes from a supposition on user's demand evolution. The fanaticism of sustaining innovation leads to the user's demand unbalance and surplus, which results in low-end disruption.

Figure 11 shows the flowchart of DI based on technological system evolution. First, selecting a product to perform DI according to self-condition and the situation of market. Second, technology maturity mapping by the patent analysis and market analysis. Here, we get the system's technical composition. After analyzing each sub-technology evolution path by using the TRIZ principle, we obtain the radical mainstream innovation technology and the relative lag evolution technology. In existence mainstream evolution technology, if there has the user's demand surplus phenomenon, we should identify the existence contradiction between the product technology system and the mainstream evolution technology, reduce the mainstream technology rank, and strengthen the technology conflict with the product. Finally, the low-end disruption innovation product forms. In the existence lag evolution technology, we should investigate if there has such technology that it can be used conveniently for these who lack of the technology and are not too wealthy. This

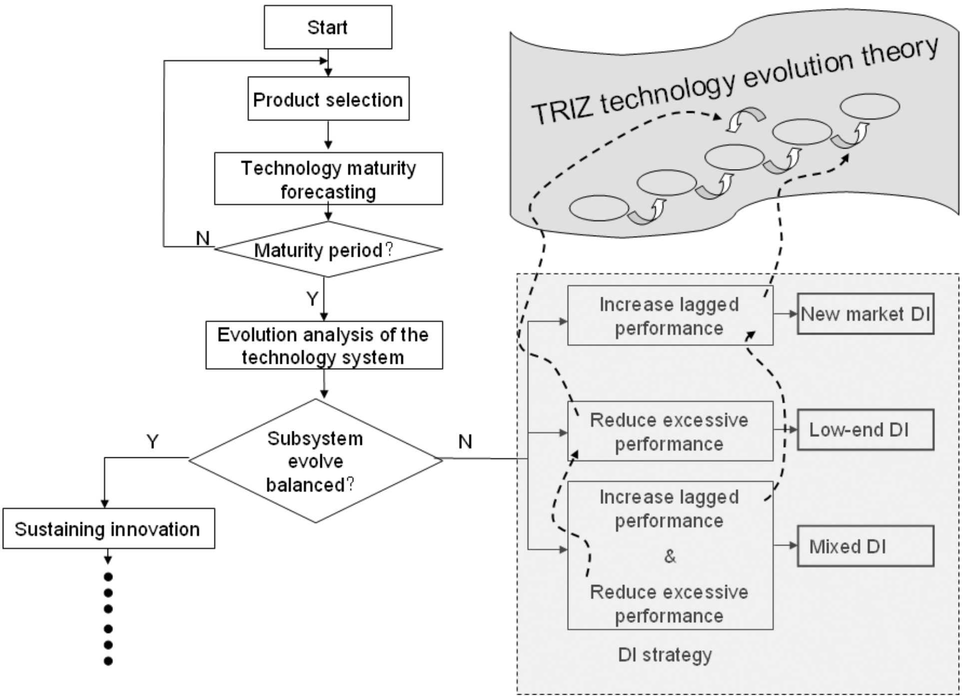

Fig. 11. The flowchart of DI based on technological system evolution.

kind of technology is the potential new-market disruptive technology. Forecasting this technology by using the TRIZ evolution path can realize the new-market DI technology.

4. Case Study

Video Game Technology has progressed tremendously since the dawn of its existence. The first video game system was made over three decades ago. That is many of years to cover Ref. [22]. In this paper, we will discuss how video game consoles have evolved over the years.

In this final segment of our in-depth look at the evolution of game consoles, we cast our attention on the ever-present video game controller. Compared with the CPU and picture quality, the game controller is easy to be disregarded. However, the controller plays a great part in the game, which makes the game more fun and enjoyable. Therefore, with that, we should look into the development of game controllers: in the process, we discovered an evolution as rich and varied as the one experienced by game consoles themselves.

The first, the functional decomposition model of game console product is constructed, from that detailed function elements is obtained (Fig. 12). By doing so, we hope to get the branched function technological evolution of the product. Regardless of the specific technique used to create a functional model, the basis identifies when

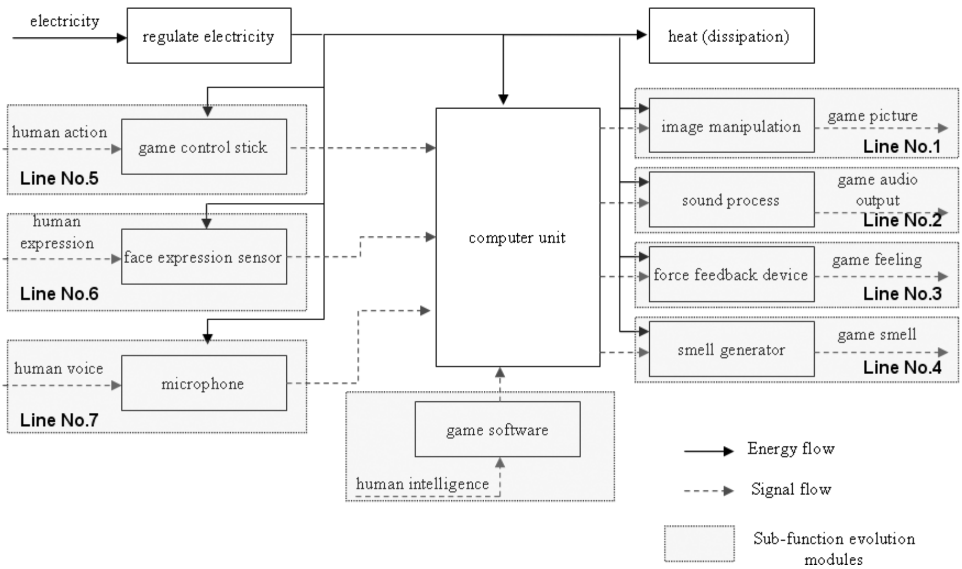

Fig. 12. Function decomposition of game console.

an overall function is decomposed to a small sub-function and provides a common level of detail.

According to the result of function decomposition, the IFR of video game console is established as shown in Fig. 13. After analyzing the video game console function in the IFR state, there are seven ideal functions in video game system, and then we can get seven technical evolution lines. According to analysis patents of video game console, every technical evolution line has been analyzed (Fig. 14). Because of the rapid development of the picture display technology, many advanced technologies were widely used for that. From the original state till now, in order to improve the

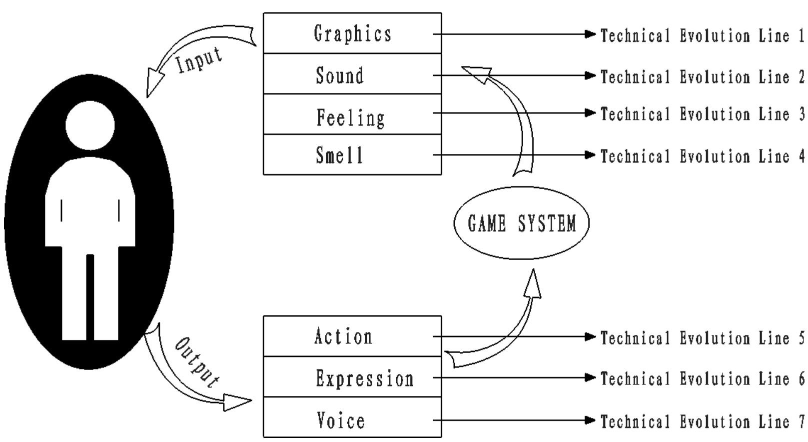

Fig. 13. IFR of video game console system.

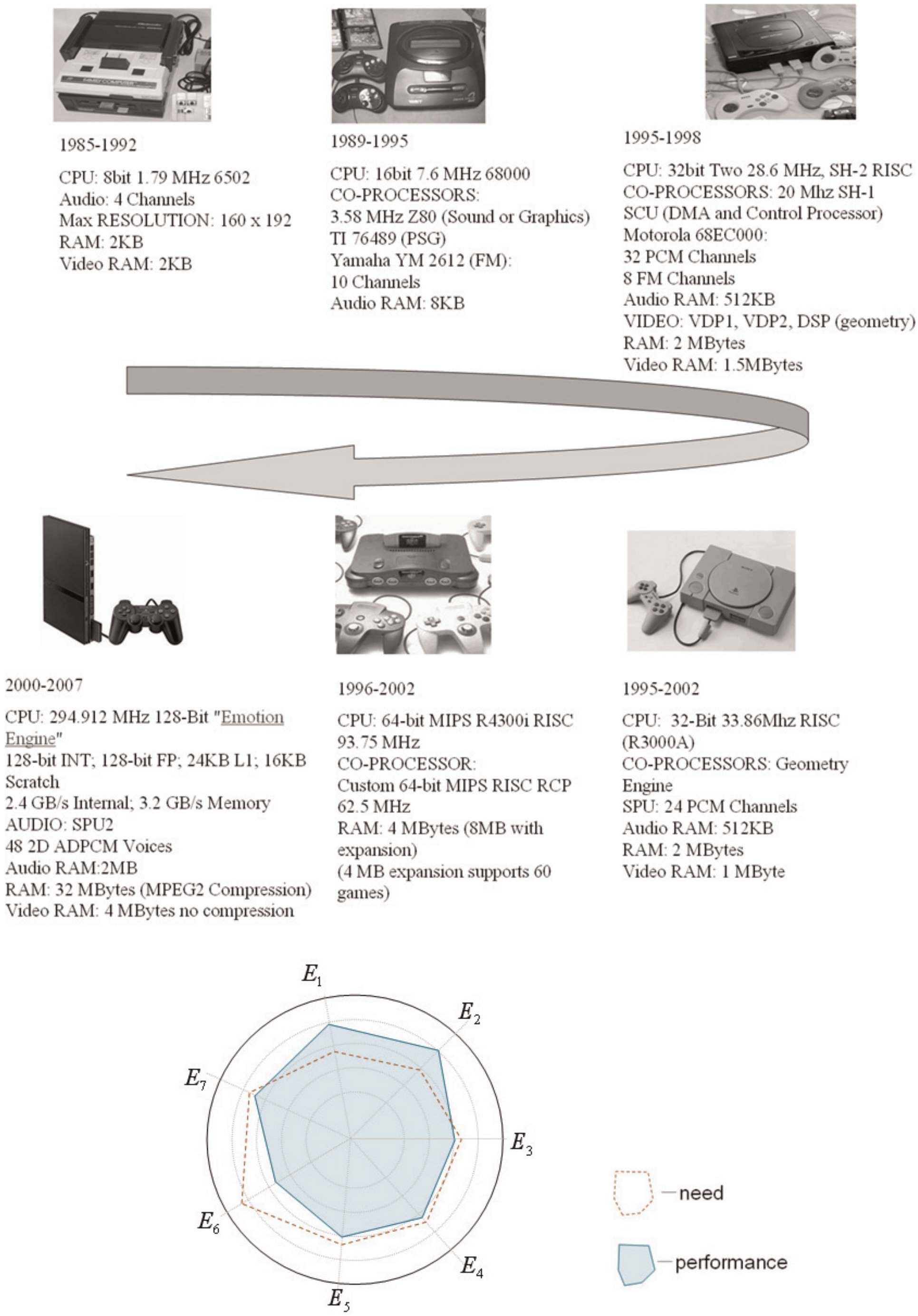

Fig. 14. Technology evolution of video game console main processor.

Table 1. The classification of technical system evolution of video game system.

Classification	Sub-technology
Mainstream evolutionary technologies	Picture display technology of video game system (Line 1)
	Audio technology of video game system (Line 2)
Laggard evolutionary technologies	Action controller of video game console system (Line 5)

picture quality of video game, many advanced technologies had been adapted. For example, CPU has been developed from 8 to 128 bit and the main frequency has been improved from 4 MHz to 3.2 GHz. The audio of game system has been developed rapidly too. Compared with the improvement of the picture display technology, other features of game console such as feeling, smell, expression, and voice have little improvement all these years. Consequently, its mainstream evolutionary technologies and laggard evolutionary technologies were concluded (referred to Table 1).

The features of the mainstream evolutionary technologies have met the needs of the consumers, which possesses the feature of the technical demand surplus. In addition, laggard evolutionary technological features such as game controller, which conflict with mainstream technologies, are most probably keys to the DI. We can reduce the graphics standard and improve controller standard, thus the DI is possibly achieved.

In order to achieve DI, we can reduce the graphics standard and improve the technique of controller. It is easy to reduce the graphics standard, but how to improve game controller technology is an important problem. Searching the TRIZ technology evolution line, the technical evolution of game controller cohere with the TRIZ evolution principle 4, that is to say, the technology system transition to higher-level systems (shown in Fig. 15). According to the evolution line, from a separated 3D game controller to a disruptive product, Wii has been put forward in 2006 by Nintendo.

Figure 16 shows a whole evolution line of game console system. According to that, we can forecast a potential DI process: the first, reduce graphics standard and improve controller standard to achieve DI and occupy the market, then improve graphics technology of game console to sustain product development in the market.

Impressively, the responsive Wii controller remains satisfying to use and player's movements can become more subtle (and less energy consuming). There is also the classic controller option and the promise of myriad forthcoming controller shells. The Wii's ridiculously enjoyable titles and innovative, motion-sensitive controllers help make it feel more like a toy you will want to share with a group of players than a console you would use strictly on your own for hours on end.

Because of Wii, Nintendo has officially become the most successful next-generation game console, in terms of introduction sales volume. 600,000 units in North America helped the company to achieve a market share of about 55% in the video game console market.

To sum up, Wii is an effective DI product of game console system.

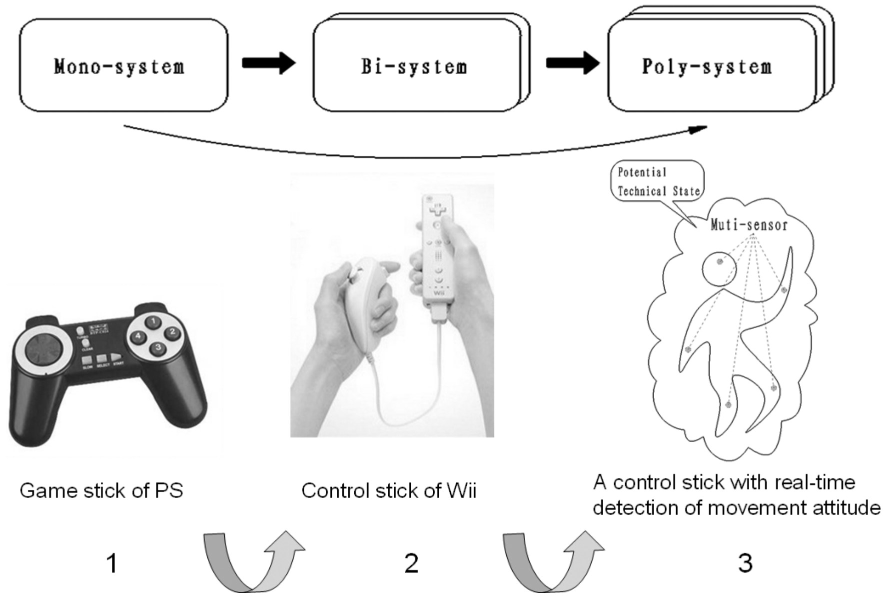

Fig. 15. Forecasting game controller technology of video game console according to TRIZ evolution theory.

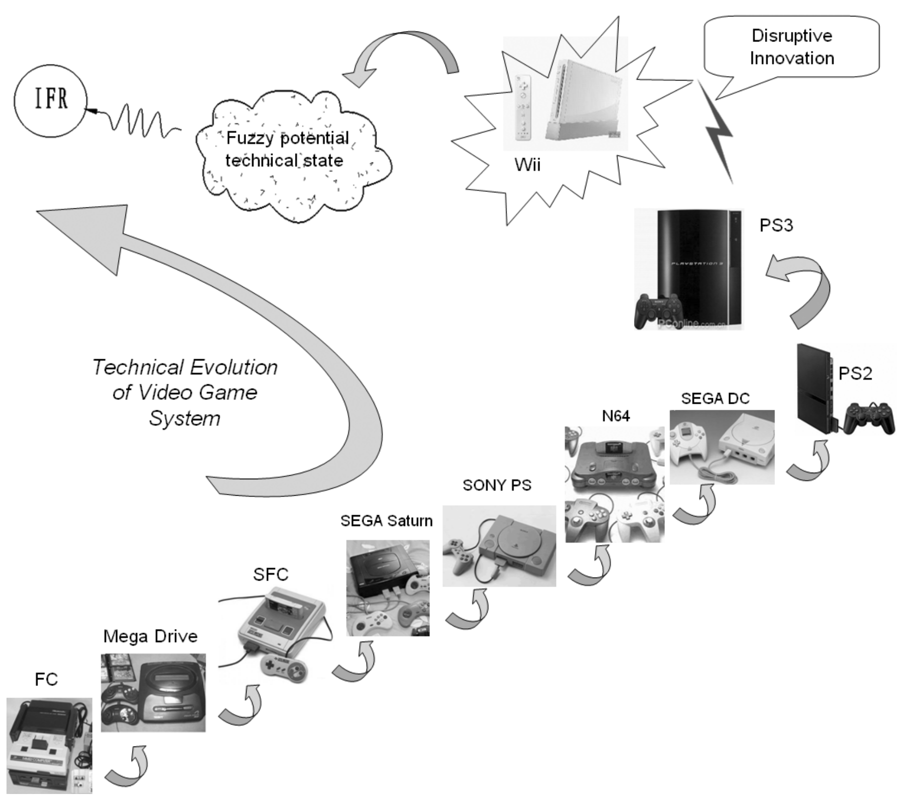

Fig. 16. Whole evolution line of video game system products.

5. Conclusions

This paper presents forecasting process and method on base of analyzing the existing evolution principle and the evolution line combined with the features of the DI. Based on analyzing the function structure of product, the technology system of goal product is decomposed into sub-systems, and the evolutional path of each technology sub-systems is generated respectively. In order to seek a method for searching DI technologies, the balance of technology evolution of each sub-systems is studied. By analyzing each sub-technology evolution path, the radical mainstream innovation technology and the relative lag evolution technology by using the TRIZ principle, it makes technical forecasting of the DI possible. The method can be used by firms to do technical system analysis on the existing productions in the market, develop new technical market, defeat competitors, and effectively prevent their mainstream products from defeating by the DI.

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