Technology Forecasting of CCD and CMOS Digital Imaging Technology using TRIZ

Michael Tompkins, Tim Price, Timothy Clapp
College of Textiles, North Carolina State University, Raleigh, USA
E-mail: timothy_clapp@ncsu.edu
Ina Parker, I.P. Discovery, Inc., Cary, USA
E-mail: iparker@ip-discovery.com

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Abstract

CCD and CMOS image sensors, used in electronic devices such as digital cameras, have only recently become available to consumers. This paper describes a case study applying TRIZ to analyze the evolution of CCD and CMOS image sensors. TRIZ tools are used to determine the current state of the technology, and to predict its future development. TRIZ can be used to develop new, innovative product ideas resulting in an exemplary patent proposal, *Smoke Detector Containing a Digital Imaging Device*. With seamless expansion of technology forecasting into new product development, TRIZ can accelerate a company's product development process as a whole and therefore help the company to maintain a leading edge against the competition.

Introduction

CCD (**C**harge **C**oupled **D**evice) and CMOS (**C**omplementary **M**etal **O**xide **S**emiconductor) image sensors have been used commercially to capture digital images for over 20 years. The technology has become available and affordable to the consumer in electronic devices such as digital cameras or camera phones only recently [1].

This paper describes a case study in which TRIZ is applied to analyze the evolution of CCD and CMOS image sensors. The first goal is to determine the current state of CCD and CMOS technology, as well as to predict future developments in the technology and to deliver a long-term hypothesis where the technology is headed.

The second goal is to show how the TRIZ methodology can expand into innovative product development. Based on the evolution path predicted, TRIZ tools are used to execute new product development with CCD technology, resulting in a patentable new product idea.

TRIZ Background

TRIZ, the Theory of Inventive Problem Solving, is a methodology for problem solving and idea generation. TRIZ includes tools for problem identification, analysis, and solution, which can be applied to accelerate product development. TRIZ also offers systematic guidelines for technology forecasting [2].

TRIZ was developed by Russian scientist Genrich Altshuller in the 1940's. While working as a patent clerk, Altshuller identified patterns and similarities of patents in different technological areas. He discovered that problems, solutions, and patterns of evolution were repeated across industries [2].

TRIZ provides tools to determine the status and the future of a specific product technology. The specific tools used in this case study are *Maturity Mapping* and *System Approach* [2, 3, 4].

TRIZ also contains many tools that focus on problem solving during product development. Examples are the *40 Principles* to solve contradictions, the concept of *Ideality*, and the *Substance-Field Analysis* [2, 3].

A systematic TRIZ approach can accelerate a company's product development process as a whole. A TRIZ analysis can help management to make decisions on how to pursue a particular product development task. Should product development focus on refining an existing technology, or should the company assign more resources to research in alternative, new technological areas?

CCD and CMOS Overview

Digitization has become the predominant method of information storage and transfer worldwide. This trend is evident in images as well. Digital cameras are developed on the same premises as CDs, DVDs, MP3s and other electronic devices. All of these devices utilize the conversion of analog information to digital information [5].

Digital cameras differ from conventional cameras in that conventional cameras depend on a chemical process of light exposure to film. Digital cameras perform the same function with the use of image sensors, either CCDs or CMOSs. The image sensor consists of diodes that convert photons to electrons. Diodes are photo sites that store a specific level of electrical charge as a function of the light intensity received. Once the sensor has converted the light into an electrical charge, an **A**nalog-to-**D**igital **C**onverter, ADC, measures the electrical charge and converts it to binary information [5].

The majority of digital cameras use CCD technology, while some use CMOS. The difference between CCD and CMOS is how the value of the electric charge of each cell in the image is read. In a CCD device, the light energy is transported across the chip, converted to a voltage, and read at one corner of the array. CMOS sensors perform the conversion from light energy to a voltage at the individual pixels sites, which is then read

out. CCDs are more sensitive to light than CMOS, and create higher-quality, lower-noise images. CCDs have been mass produced for a longer period of time, so their quality has become more reliable. Most medium-to-high end cameras are based on CCDs. CMOS' manufacturing cost and energy consumption are much lower than those of CCDs, making them the sensor of choice for lower-end digital cameras [5].

Technology Evolution - TRIZ Maturity Mapping

Technology evolution follows the same *Biological S Curve* as seen in nature. Altshuller found that any system, biological or technological, goes through four stages: infancy, growth, maturity, and decline. The graph of the *Biological S Curve* developed by Altshuller is depicted in Figure 1. By determining the current state of a technology, future development can be anticipated [2, 6].

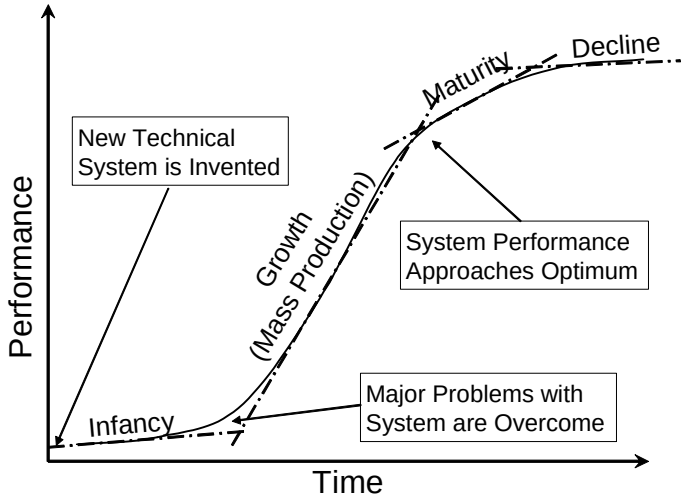

Figure 1: *Biological S Curve* [6, 7]

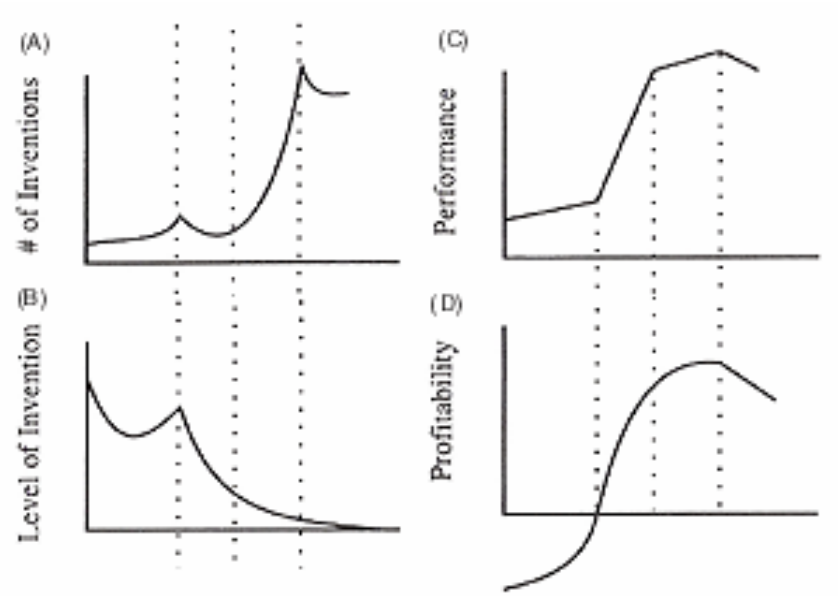

Figure 2: TRIZ Descriptive Curves for Technology Evolution [6]

In order to determine at which stage of the Biological S-Curve a current technology is located, Altshuller developed four descriptive curves, as shown in Figure 2: (A) Number of inventions or patents over time, (B) Level of inventiveness over time, (C) Performance over time, and (D) Profitability over time. The dotted vertical lines in the graphs of Figure 2 divide each of the curves into the four stages of the *Biological S-Curve*.

The infancy stage includes the initial concept and development to commercial viability of a technology, and is characterized by a small number of highly innovative patents. Once the product is on the market, the growth stage starts. As resources are focused on stablizing commercial production quality, there is a slight lull in the number of patented improvements. A significant increase in the number of patents follows as competitors try to improve their individual products, hoping to gain an edge on the technology and the favor of the consumer [2, 6].

The performance graph (C) indicates that in the infancy stage, even slight increase in actual performance can be achieved only with great effort of innovation. The focus of development in this stage is to get the product running and out on the market. During the growth stage, manufacturing cost, efficiency, and increased performance start to become issues once the product is commercially available. In order to maintain competitiveness in a rising market, price has to decrease and performance has to increase continually, reflected by the steep rise in the performance graph during the growth stage.

Maturity Mapping of CCS and CMOS Technology

As a basis for the technology forecasting of CCD and CMOS image sensors, a comprehensive patent search was conducted. Various combinations of search terms were used. Initial searches were based on combinations of *CCD*, *CMOS*, *Image Sensor*, *Semiconductor*, *Pixel* and *Charge*, resulting in a data base of approximately 150 patents during the time frame of 1976 to present [8].

Patents that truly contain a novelty relating to the CCD or CMOS sensor were identified. It became apparent that the initial invention of the CCD sensor was patented earlier than 1976. In order to include relevant patents before 1976, patents were also analyzed and traced back in terms of their references as well as their referred patents. As a result, a list of 130 patents containing novelties in CCD and CMOS technology was compiled, as attached in Appendix I.

The first criterion according to Altshuller's descriptive curves for maturity mapping is *Number of Inventions Over Time*. Figure 4 shows the accumulative *Number of Patents Over Time* for CCD and CMOS technology. Individual data are depicted as histogram in green columns. An averaged, smoothed curve of the data is shown as blue line. The averaged cumulative curve fits almost perfectly to Altshuller's corresponding descriptive curve, which is overlaid as thick black curve. The number of inventions in CCD and CMOS technology peaked around 2002 –2003. The industry has already started to see a decline in the number of inventions related to CCD and CMOS imaging chips.

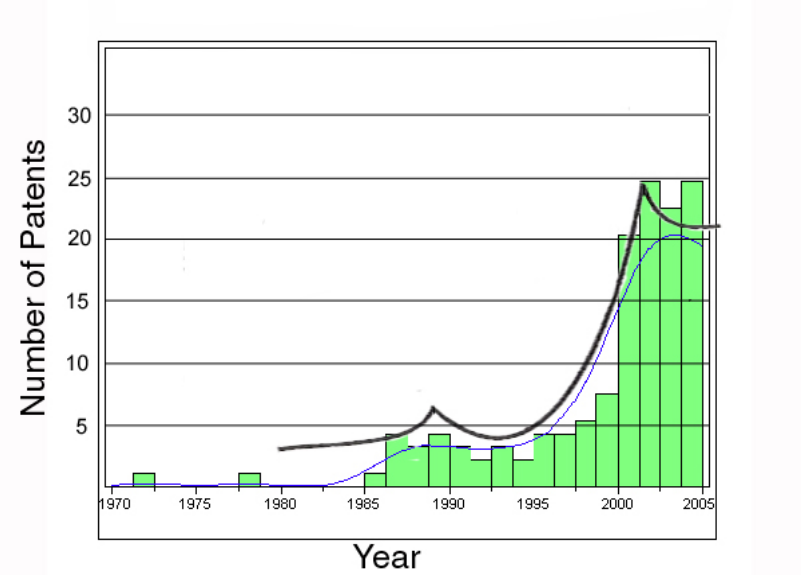

Figure 4: Number of Patents Over Time Comparison – CCD / CMOS Technology and Altshuller's Descriptive Curve

In order to generate the descriptive graph for *Level of Inventiveness*, the patents were assessed quantitatively based on Altshuller's *Five Levels of Inventiveness*. Each patent was analyzed in terms of five different criteria:

A) Field of invention vs. field of problem
B) Solution mechanism
C) Characteristics of the system
D) Effects or principles leading to the invention
E) Existence of contradictions

Each criterion is categorized at a level between one and five, five being the most inventive. The final rating of inventiveness or innovation rating as plotted in Figure 5 is calculated as the average of the rating in each category. A concise table depicting the rating criteria is attached as Appendix II.

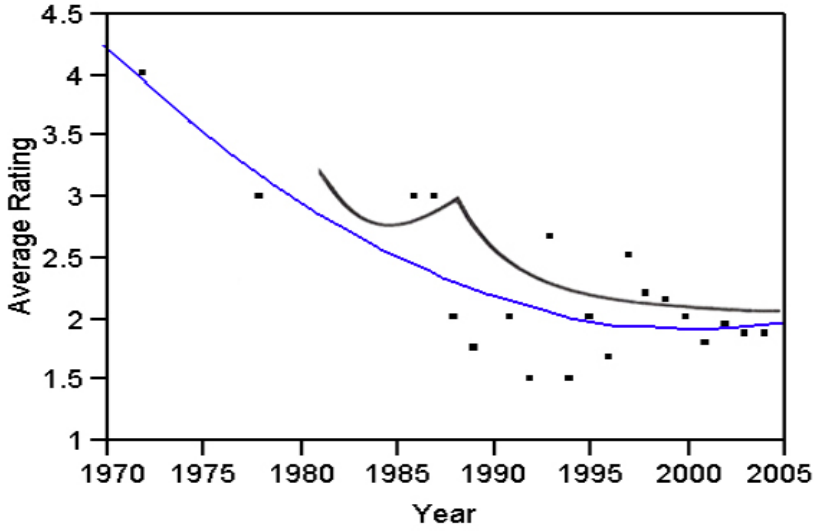

Figure 5: Level of Inventiveness Comparison – CCD / CMOS Technology and Altshuller's Descriptive Curve

The individual points in Figure 6 show the average rating of all patents filed in each year. The continuous graph depicts the smoothed accumulative average of the innovation level of all patents analyzed.

By overlaying the graph that results from the patent search for CCD / CMOS technology with Altshuller's corresponding descriptive curve, it can be seen that the plot most closely matches the area of the curve towards the end of the evolutionary cycle. This is in accordance with the findings for *Number of Patents Over Time*, showing that the evolution of CCD and CMOS technology is nearing the end of its evolution.

Altshuller's third descriptive evolutionary curve characterizes the technology's performance. As objective, measurable performance characteristic for CCDs, the number of pixels per US Dollar was chosen. Data is available from 1986 until 2004 [1]. The number of pixels has increased and the price has decreased exponentially over the past twenty years, as depicted in Figure 6. Overlaying the graph with Altshuller's descriptive curve for *Performance Over Time* shows a fit of the curve starting in the infancy stage to the end of the growth phase.

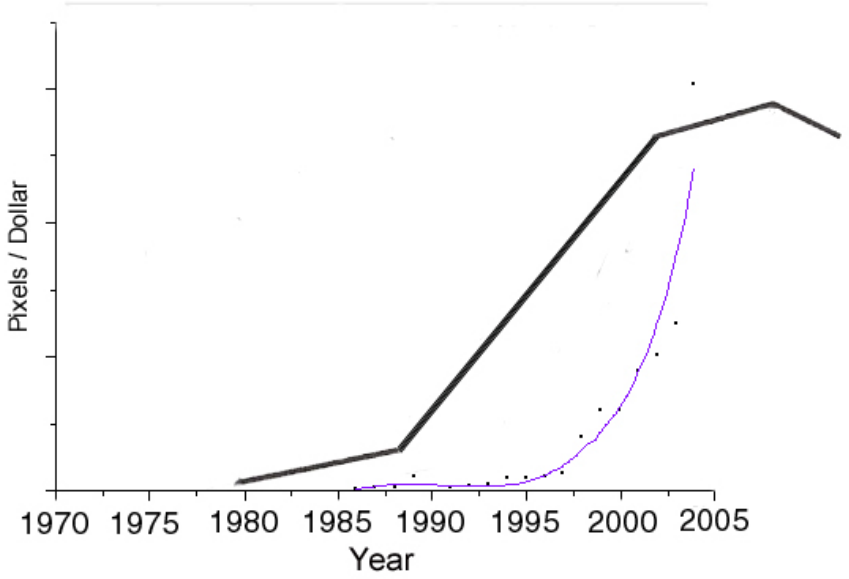

Figure 6: Performance Comparison – CCD / CMOS Technology and Altshuller's Descriptive Curve

Figure 7 shows the alignment of all three descriptive curves according to the evolutionary stages defined by Altshuller. The red boxes mark the part of the curves corresponding to the current state of the technology, from year 2000 to present. This comparison shows that CCD and CMOS technology is in the mature stage of its evolution.

While economic success can still be achieved by optimizing existing components and systems, and cutting manufacturing cost by streamlining existing production processes, profit margins will erode. Efforts and resources must be focused on developing new technology, and independent, new components, products and systems, in order to maintain a leading edge against the competition. Based on these findings, the following sections of this paper describe an approach to new product development using TRIZ tools.

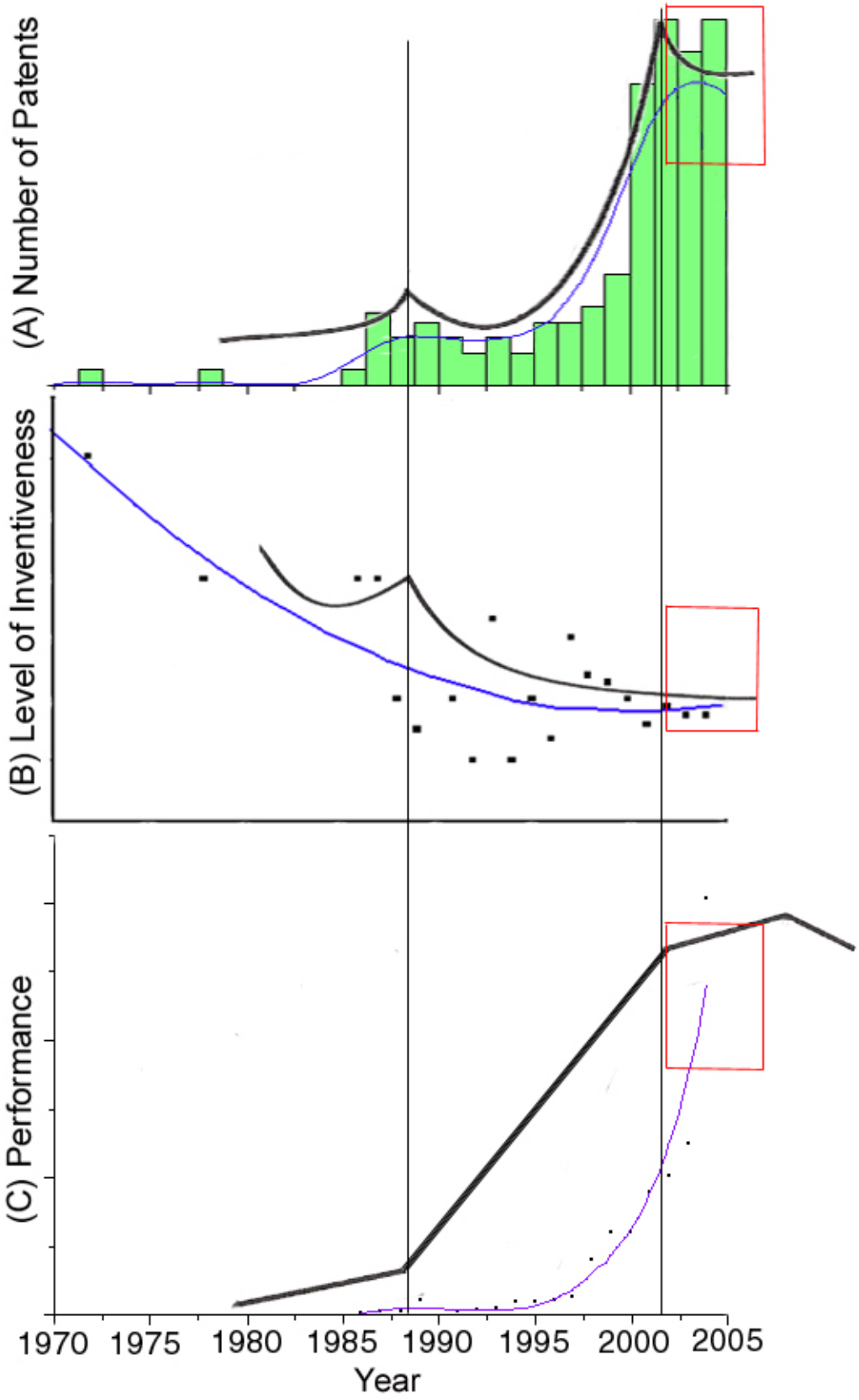

Figure 7: Comparison of Three Descriptive Curves [2]

Development of the Digital Imaging Chip – TRIZ System Matrix

With the extensive patent search, a comprehensive knowledge of CCD and CMOS technology, including its benefits and drawbacks, was gained. After determining the mature status of the technology, TRIZ analysis was seamlessly expanded into new product development. A good tool to start product development by gaining an overview of potential paths is the TRIZ *System Matrix*. The technology is visualized in a three-by-three matrix, with different time levels in the horizontal direction, and different detail levels in the vertical direction. The three time levels analyzed are past, present and future, while the three different detail levels are labeled as *Supersystem*, *System*, and *Subsystem* [4].

The *System Matrix* is of practical help to the development engineer because it forces questions like:

- What parts are missing, or what are the challenges to be overcome to make an ideal *System* (= perfect imaging sensor) or ideal *Supersystem* (= perfect camera)?
- Which are the *Subsystems* holding back new development, and what are their shortcomings?
- What were parts and characteristics of CCDs and CMOS in the past, what are the current parts and characteristics, and what are possible parts and desirable characteristic relevant for the future?
- What are desirable characteristics of the camera as *Supersystem*, how could the CCD or CMOS contribute to achieve these, or what would an alternative sensor need to be like to make a better camera?
- Are there other *Supersystems* that could use CCD or CMOS?

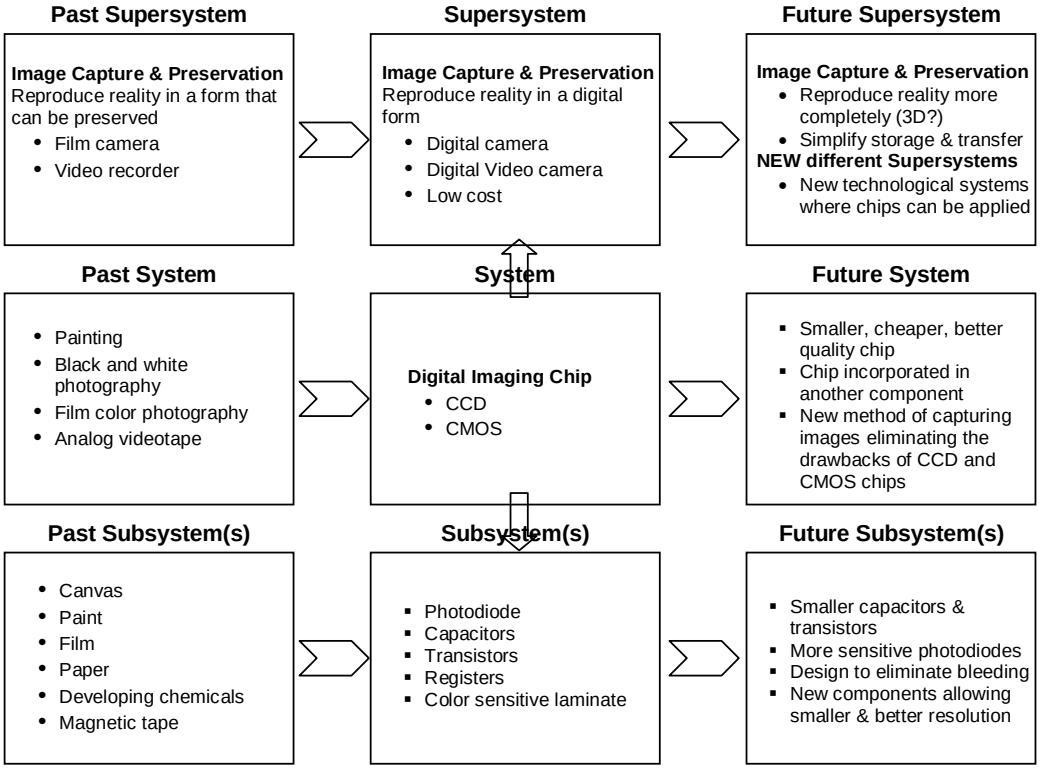

Figure 8: CCD / CMOS System Matrix [4]

The TRIZ *System Matrix* for CCD or CMOS imaging sensors is shown in Figure 8. It can be seen that at all three detail levels, future development is focused on faster performance, lower price and better quality. This means that components of CCD or CMOS sensors as well as the *Supersystem* Camera are at the same maturity level as the sensors themselves.
In the following case study for a new, innovative product development, CCD technology is applied in a novel *Supersystem* – the Smoke Detector.

New Product Development for the Digital Imaging Chip using TRIZ

The following sections of this paper illustrate how TRIZ tools can be used to aid the development process, starting with an innovative idea, and resulting in a patentable product solution. The innovative product to be developed is a Smoke Detector containing a CCD image sensor.

TRIZ Ideality

One TRIZ tool suitable for product development is the concept of *Ideality*. The desire is to create the best system possible – the *Ideal System*. An *Ideal System* provides the desired function without any harmful effects or drawbacks. The degree of ideality in the TRIZ sense is a measure of how good a systems or product solution is. TRIZ *Ideality* is defined as

$$Ideality = \frac{Useful\ Effects}{Harmful\ Effects}$$

Useful Effects are features and functions that improve the product, its performance, quality, reliability etc. *Harmful Effects* include cost, pollution, energy consumed, etc.

In the case of the Smoke Detector, the existing system is a detector installed in a room that triggers an acoustical or remote alarm if smoke particles are detected in the air.

The useful functions of the existing system are
a) detection of smoke particles in the air and
b) triggering alarm.

A potential harmful effect of the existing system is false alarm (e.g. smoke detector is triggered by cooking fumes).

In order to develop the existing system towards an *Ideal System*, the useful functions can be increased:
a) detection of smoke particles in the air, complemented by a visual image of where and how dense the smoke is in the room

b) delivery of a visual image of the room to aid fire extinction and rescue (determine if and where people are trapped, assess condition of the room, locate safe entry ways to better prepare rescue personnel and to increase their safety)
c) delivery of a visual image to find the source and root cause of the smoke/fire (could be used for developing better security measures for appliances, for insurance purposes etc.)

By implementing an image sensor in the smoke detector, harmful effects could also be reduced:

a) reduction of false alarms triggered (if smoke is detected, the room can be searched visually for false triggers such as cooking fumes)
b) reduction of risk of physical harm to rescue personnel / firefighters (firefighers know what to expect before they get into the room, they are better prepared to avoid injury, and don't need to waste valuable time searching for entry ways or victims to be rescued)

The key to develop a system towards *Ideality* is to add new functions and reduce harmful effects by utilizing existing resources, such as the materials and fields of the system itself. In the case of the smoke detector, the existing field that is available as resource and has not been used with conventional smoke detectors is the visual image of the room. Using CCD technology, this system resource can be exploited to add additional functionality to the smoke detector. Implementing CCD and digital camera technology into the smoke detector will allow an image of the room to be captured without a person being present in the room.

TRIZ Substance-Field Analysis

Substance-Field (Su-Field) Analysis is another TRIZ tool that can be applied to new product development. *Su-Field Analysis* visualizes systems and the relationship between their substances, fields, functions and objectives in a simple graphic. Substances in the TRIZ sense represent objects that have a function. A generic *Su-Field Model* is shown in Figure 9.

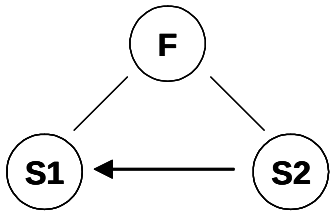

Figure 9: Simple Su-Field Model [6]

The object S2 is acting upon the object S1 through the field F. F can represent a variety of measures, such as energy fields, chemical reactions, or physical effects. S1 is the object that delivers the desired function of the system. *Su-Field Analysis* is helpful in visualizing, detecting, and repairing an incomplete system, an ineffective system, or a complete system that create harmful effects [6].

In order to improve the system *Smoke Detector* using *Su-Field Analysis*, the basic problem was identified as the system being ineffective. Conventional smoke detectors only trigger a smoke alarm. They are missing essential functions to help fire extinction or rescue, since they do not render any information about the actual situation of the place where the smoke particles are detected.

As first step in the *Su-Field Analysis*, elements of the existing system were identified:
Object S1: Smoke Detector
System Function to be delivered by Object S1:
Provide reliable smoke alarm and image of the place where smoke is detected
Object S2 acting on Object S1:
Smoke Particles
Field F: Electrical field – Smoke is detected by a) ionization of air particles or b) photoelectric analysis of air samples [9].

The second step is to construct the Su-Field Model, as shown in Figure 10.

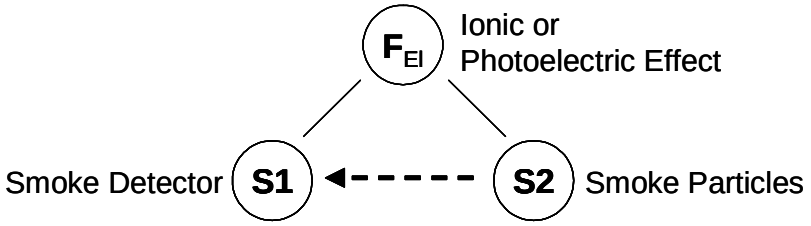

Figure 10: Su-Field Model of Existing System *Smoke Detector*

The dashed arrow indicates an incomplete desired effect, resulting in the system function delivered by the smoke detector to be ineffective. The smoke detector only alarms when smoke is in the room, but does not give any information about the severity or kind of situation. To resolve the incomplete desired effect, another field available in the system can be exploited by introducing an additional Object S3, Visual Image. The improved, complete system is shown in Figure 11.

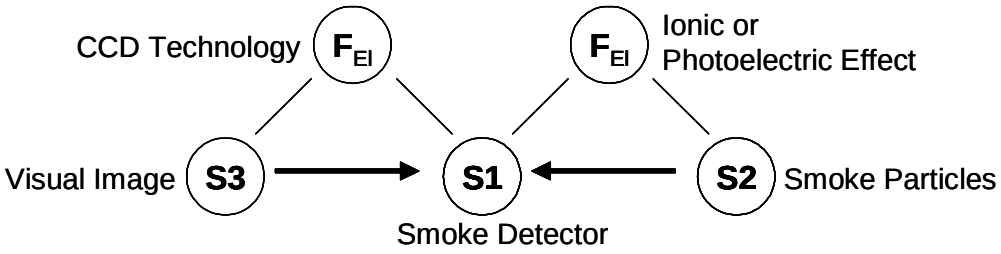

Figure 11: Su-Field Model of New, Complete System *Smoke Detector*

Since the system now provides the desired effect, the analysis is complete. If the system were still ineffective, other TRIZ tools, such as *Contradiction Matrix* or *Many Little People Modeling* could be used to generate further innovative solution ideas.

New Product Development - Patent Proposal Example

In order to secure the results of innovative product development, and to prepare the product for commercial success, the rights to the product must be established. One way to successfully complete the product development is to obtain a patent on the innovative product. The following section gives an example how a patent could be written as a result of product development using TRIZ.

Smoke Detector Containing a Digital Imaging Device

ABSTRACT

The claim of this invention is a smoke detector, which contains a CCD or CMOS digital imaging chip, along with a panoramic lens facilitating the most comprehensive view of the room in which the detector is placed. Also claimed is an infrastructure, which allows the smoke detector to be either wire- or wirelessly-connected to an external monitor.

BACKGROUND OF THE INVENTION

The invention described below incorporates a standard smoke detector. Smoke detectors are used to detect the presence of fire, alerting the inhabitant to extinguish the fire or leave the premises. Smoke detectors are able to sense multiple types of smoke, and emit an audible and/or visible alarm if smoke is detected. Typical smoke detectors use either ionic or photoelectric effects to detect smoke particles in the surrounding air [9]. Usually, the sensitivity of the smoke detector to particle size, frequency and type is adjustable. One problem with these existing systems is that, depending on the chosen sensitivity, false alarms may be triggered, or smoke or fire may be detected at a delayed time. Furthermore, these conventional devices do not allow for any assessment of the situation before a human actually enters the problem area.

CCD and CMOS chips are used in digital imaging applications, from high resolution digital cameras, to low resolution cameras in cellular phones. Low resolution color or black and white chips are cheap and easy to obtain. CCD and CMOS chips contain an array of photodiodes, each representing a pixel, and supporting circuitry to convert the analog signals from the photodiodes into a digital image.

There is need for a smoke detector that provides a simple way to detect fire and smoke, then assess the situation and potential danger in the specific area. The alarm triggered by the detector needs to allow for instant assessment of the condition of the room, in order to insure maximum safety of persons on the premises.

SUMMARY OF INVENTION

The present invention incorporates an image sensor with a smoke detector, allowing the room to be previewed to assess danger and the presence of victims. The image sensor uses CCD or CMOS imaging technology, and a panoramic lens, allowing the most complete view of the room. There will be either a wireless or wired infrastructure facilitating connectivity to emergency personnel.

The smoke detector will also incorporate a visible signal, in the form of a strobe. This will serve to illuminate the room, ensuring a properly lighted image. The smoke detectors will be installed in the places smoke detectors are typically installed. With a unit in each room, emergency personnel will be able to quickly scan through the building and determine where victims are trapped, and what areas are safe enough to attempt rescue.

Conclusions

By means of a case study, it was shown how TRIZ can be used to determine the evolutionary status of a specific technology, and how TRIZ can then help to accelerate new product development based on the maturity status determined.

Digital imaging technology using CCD and CMOS chips was analyzed, and the maturity of the technology was mapped in the areas of *Number of Patents per Year*, *Inventiveness* of the patents, and *Performance*. In all areas, the technology is in the mature stage and nearing the end of its evolutionary cycle. While there is still room for optimization and improvements in existing technology, companies must focus on developing new technologies, and advance new technologies for commercialization. One way to keep an edge against the competition, and to compensate for the declining economic success of the existing mature technology, is to find innovative, new Supersystems where the existing technology has not yet been applied, and can be of major advantage.

This paper shows how the TRIZ analysis can lead to innovative product development, resulting in a patent in a new technological field, which will allow for continued commercial success of the existing mature technology of CCD and CMOS.

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Appendix I – Patent Database for "CCD"

Number	Title	Rating	Date Issued	Filed
6,831,689	Optical imager using a method for adaptive real-time expanding of the dynamic range	3	2004	2004
6,825,879	Solid-state image sensing device and method of driving the same	2	2004	2004 1999
6,818,962	Image sensor having integrated thin film infrared filter	2	2004	2004
6,818,934	Image sensor having micro-lens array separated with trench structures and method of making	2	2004	2004
6,818,933	CMOS image sensors	2	2004	2004
6,809,768	Double slope pixel sensor and array	3	2004	2004
6,806,514	Modular digital pixel sensor system	2	2004	2004
6,803,952	Signal readout circuit of an amplification type solid-state imaging device	1	2004	2004 2000
6,801,345	Color image sensor and image reading apparatus	2	2004	2004
6,801,258	CMOS integration sensor with fully differential column readout circuit for light adaptive imaging	3	2004	2004
6,774,420	Image sensor	2	2004	2004
6,762,401	CMOS image sensor capable of increasing fill factor and driving method thereof	2	2004	2004
6,759,262	Image sensor with pixel isolation system and manufacturing method therefor	2	2004	2004
6,740,915	CMOS imager cell having a buried contact	2	2004	2004
6,737,719	Image sensor having combination color filter and concave-shaped micro-lenses	2	2004	2004
6,724,022	Solid-state imaging device	2	2004	2004
6,721,010	Method and structure for accelerating image-sensing speed of a CCD image-sensing device	1	2004	2004 2000
6,721,008	Integrated CMOS active pixel digital camera	2	2004	2004 1998
6,710,804	CMOS active pixel image sensor with extended dynamic range and sensitivity	1	2004	2004 2000
6,704,050	Active-pixel image sensing device with linear mode voltage to current conversion	1	2004	2004 1999
6,697,114	Triple slope pixel sensor and arry	2	2004	2004 1999
6,680,498	CMOS image sensor with extended dynamic range	1	2004	2004 2002
6,674,471	Solid-state imaging device and method for driving the same	1	2004	2004 1999
6,657,178	Electron bombarded passive pixel sensor imaging	3	2003	2003
6,656,777	Solid state imaging device, method of manufacturing the same, and solid state imaging system	1	2003	2003 2002
6,654,057	Active pixel sensor with a diagonal active area	1	2003	2003 1999
6,649,993	Simplified upper electrode contact structure for PIN diode active pixel sensor	1	2003	2003 2001
6,649,950	Active pixel having reduced dark current in a CMOS image sensor	1	2003	2003 2002
6,638,786	Image sensor having large micro-lenses at the peripheral regions	2	2003	2003 2002
6,627,929	Solid state CCD image sensor having a light shielding layer	2	2003	2003 2001
6,603,513	Using a single control line to provide select and reset signals to image sensors in two rows of a digital imaging device	2	2003	2003 1999
6,600,172	Image sensor and method of fabricating the same	2	2003	2003 2000
6,590,610	Digital double sampling in time integrating pixel sensors	2	2003	2003 2001
6,580,454	CMOS active pixel sensor having in-pixel local exposure control	2	2003	2003 1998
6,580,106	CMOS image sensor with complete pixel reset without kTC noise generation	2	2003	2003 2002
6,552,745	CMOS active pixel with memory for imaging sensors	2	2003	2003 1998
6,552,322	Shared photodetector pixel image sensor	2	2003	2003 2001
6,549,684	Image sensor having an array with integrated control circuitry which includes constantly-illuminated photodiodes	2	2003	2003 1997
6,545,302	Image sensor capable of decreasing leakage current between diodes and method for fabricating the same	2	2003	2003 2001
6,521,926	Mos type image sensor	2	2003	2003 2000
6,518,115	CMOS image sensor and method for fabricating the same	2	2003	2003 2001
6,515,702	Active pixel image sensor with a winner-take-all mode of operation	2	2003	2003 1998
6,504,196	CMOS imager and method of formation	2	2003	2003 2001
6,504,195	Alternate method for photodiode formation in CMOS image sensors	2	2003	2003 2000
6,501,065	Image sensor using a thin film photodiode above active CMOS circuitry	2	2002	2002 1999
6,486,912	Image sensor with sampling control system	2	2002	2002 1998
6,486,504	CMOS image sensor with extended dynamic range	2	2002	2002 1999
6,486,503	Active pixel sensor array with electronic shuttering	3	2002	2002 1997
6,476,372	CMOS active pixel sensor using native transistors	2	2002	2002 2001
6,469,290	Solid-state image pickup apparatus in compliance with the arrangement of complementary color filter	2	2002	2002 2001
6,466,266	Active pixel sensor with shared row timing signals	2	2002	2002 1998
6,462,365	Active pixel having reduced dark current in a CMOS image sensor	2	2002	2002 2001
6,452,633	Exposure control in electronic cameras by detecting overflow from active pixels	2	2002	2002 1998
6,452,243	Solid state image sensor and method for fabricating the same	2	2002	2002 1999
6,448,104	CMOS type solid imaging device	1	2002	2002 1999
6,433,369	Solid state imaging device for achieving enhanced zooming characteristics and method of making the	1	2002	2002 2001
6,429,038	Solid-state imaging device and method of manufacturing the same	1	2002	2002 1996
6,423,994	Active pixel sensor with inter-pixel function sharing	2	2002	2002 1905
6,423,993	Solid-state image-sensing device and method for producing the same	2	2002	2002 2000
6,423,958	Solid state imaging device and method of driving the same	1	2002	2002 2000
6,400,824	Semiconductor imaging sensor with on-chip encryption	3	2002	2002 1997
6,396,539	CMOS imaging device with integrated defective pixel correction circuitry	2	2002	2002 1998
6,380,568	CMOS image sensor and method for fabricating the same	2	2002	2002 2000
6,365,926	CMOS active pixel with scavenging diode	2	2002	2002 2000
6,344,877	Image sensor with dummy pixel or dummy pixel array	3	2002	2002 1997
6,344,670	Solid-state sensor and system	2	2002	2002 2001
6,339,213	Solid state imaging device and method for driving the same	2	2002	2002 1998
6,300,157	Solid state image sensor and method for fabricating the same	2	2001	2001 1998

6,297,070	Active pixel sensor integrated with a pinned photodiode	1	2001	2001	1999
6,285,018	Electron bombarded active pixel sensor	2	2001	2001	1999
6,255,640	Solid-state image sensing device and method for manufacturing solid-state image sensing device	1	2001	2001	1999
6,218,656	Photodiode active pixel sensor with shared reset signal row select	2	2001	2001	1998
6,211,509	Solid-state image sensor	2	2001	2001	1991
6,175,383	Method and apparatus of high dynamic range image sensor with individual pixel reset	2	2001	2001	1996
6,169,576	Solid state image sensing device having variable resolution and color linear image sensor having	2	2001	2001	1997
6,169,318	CMOS imager with improved sensitivity	2	2001	2001	1998
6,160,281	Active pixel sensor with inter-pixel function sharing	2	2000	2000	1997
6,150,676	MOS type image sensor	2	2000	2000	1999
6,107,655	Active pixel image sensor with shared amplifier read-out	2	2000	2000	1999
6,100,551	Active pixel sensor integrated with a pinned photodiode	1	2000	2000	1998
6,084,259	Photodiode having charge transfer function and image sensor using the same	2	2000	2000	1999
6,081,018	Solid state image sensor	2	2000	2000	1999
6,069,374	CCD type solid state imaging device	2	2000	2000	1997
6,051,447	Partially pinned photodiode for solid state image sensors	2	2000	2000	1998
6,046,466	Solid-state imaging device	3	2000	2000	1998
6,040,593	Image sensor having self-aligned silicide layer	2	2000	2000	1999
5,969,759	Solid state image sensing device	2	1999	1999	1996
5,952,645	Light-sensing array with wedge-like reflective optical concentrators	1	1999	1999	1996
5,930,591	High resolution, low voltage flat-panel radiation imaging sensors	3	1999	1999	1997
5,929,432	Solid state image sensing device and image sensor using the same	2	1999	1999	1997
5,904,493	Active pixel sensor integrated with a pinned photodiode	3	1999	1999	1996
5,892,253	Active pixel sensor cell with balanced blue response and reduced noise	2	1999	1999	1997
5,870,142	Image sensor, image reading device, and image reading method	2	1999	1999	1996
5,828,091	Interline charge coupled device solid state image sensor	3	1998	1998	1997
5,804,844	Solid-state imager with container LOD implant	2	1998	1998	1997
5,767,901	Color linear image sensor	2	1998	1998	1996
5,721,425	Active pixel sensor cell that reduces the effect of 1/f noise, increases the voltage range of the cell, and	2	1998	1998	1996
5,710,446	Active pixel sensor cell that utilizes a parasitic transistor to reset the photodiode of the cell	2	1998	1998	1996
5,637,893	Interline-transfer CCD image sensor and method for fabricating the same	2	1997	1997	1996
5,625,210	Active pixel sensor integrated with a pinned photodiode	3	1997	1997	1995
5,614,744	CMOS-based, low leakage active pixel array with anti-blooming isolation	2	1997	1997	1995
5,612,555	Full frame solid-state image sensor with altered accumulation potential and method for forming same	3	1997	1997	1995
5,578,842	Charge coupled device image sensor	2	1996	1996	1995
5,576,561	Radiation-tolerant imaging device	1	1996	1996	1994
5,566,103	Optical system having an analog image memory, an analog refresh circuit, and analog converters	2	1996	1996	1994
5,436,476	CCD image sensor with active transistor pixel	2	1995	1995	1993
5,337,340	Charge multiplying detector (CMD) suitable for small pixel CCD image sensors	2	1994	1994	1993
5,293,237	CCD image sensing device having a p-well region with a high impurity concentration	1	1994	1994	1992
5,262,871	Multiple resolution image sensor	3	1993	1993	1989
5,182,647	High resolution charge-coupled device (CCD) camera system	3	1993	1993	1990
5,182,647	High resolution charge-coupled device (CCD) camera system	2	1993	1993	1990
5,151,587	Image sensor having an array of operative and dummy bipolar transistors and pairs of pixel selecting	2	1992	1992	1991
5,151,587	Image sensor having an array of operative and dummy bipolar transistors and pairs of pixel selecting	1	1992	1992	1991
5,063,449	Solid-state image sensor employing a gate and diode for bias charge injection	3	1991	1991	1989
5,063,449	Solid-state image sensor employing a gate and diode for bias charge injection	1	1991	1991	1989
5,060,038	Charge sweep solid-state image sensor	2	1991	1991	1905
4,878,121	Image sensor array for still camera imaging with multiplexer for separating interlaced fields	2	1989	1989	1987
4,875,101	Solid state photovoltaic imaging device with excess charge eliminator	1	1989	1989	1987
4,858,022	Contact-type linear image sensor	2	1989	1989	1987
4,798,958	CCD imaging sensors	2	1989	1989	1987
4,764,814	Solid-state imaging device with reset pulse selector	1	1988	1988	1987
4,746,984	Solid state image sensor with lateral-type stactic induction transistors	2	1988	1988	1986
4,734,774	CCD imager video output defect compensation	3	1988	1988	1984
4,684,992	Solid state image sensor having means to reset and clear static induction transistor photoelements	2	1987	1987	1985
4,677,453	Solid state image sensor	2	1987	1987	1985
4,663,535	Color image sensor	4	1987	1987	1985
4,654,536	Contact color image sensor	4	1987	1987	1984
4,586,084	Solid state image sensor	3	1986	1986	1985
4,085,456	Charge transfer imaging devices	3	1978	1978	1972
3,654,499	Charge coupled memory with storage sites	4	1972	1972	1970

Appendix II – Altshuller's *Five Levels of Inventiveness*

Level of Innovation	1	2	3	4	5
	Apparent / Conventional Solution 32% (1964-1974) *(trivial non-inventive inv.)*	**Small Invention Inside Paradigm** 45% (1964-1974) *(common invention)*	**Substantial Invention Inside Technology** 18% (1964-1974) ***(average, solid invention)***	**Invention Outside Technology** 4% (1964 - 1974) ***(macro inventions)***	**Discovery** 1% (1964 – 1974) *(major invention & new science)*
Field of Solution	Problem & solution methods **within one professional field**		Problem & solution methods belong to **same technology**	Other science field, **outside technology** involving completely different principle	**Outside** contemporary **scientific knowledge**
Solution Mechanism	**Obvious** (undisguised) solutions from a few clear options	Solution **not obvious** to untrained person – possible give-up	Technology of other industries **beyond accepted ideas & principles** ⇒ paradigm shift in industry	**New generation of design** using science not technology	**New phenomenon** discovered & applied to inventive problem
Characteristics of System	**Existing system** not substantially changed	**Existing system** slightly changed	**Existing system** essentially improved	Synthesis of **a new technical system**	**New technical systems**, industries & design products
Effects / principles leading to solution	Enhanced features - **good engineering**	**New features** ⇒ improvements, but obvious compromise	Combination of several physical effects, 'tricky' methods, **ingenious use of well-known physical phenomena**	**Physical effects & phenomena previously little known**	Solution methods **beyond the scope of modern science**
Existence of Contradictions	Contradictions **not identified & resolved**	System inherent contradiction **reduced, but not eliminated**	Contradiction **resolved within existing system**, often through introduction of entirely new element	Contradictions **eliminated since non-existent** in NEW system	**No** contradictions
Examples	Increasing wall thickness to create greater insulation	Adjustable steering columns increases range of body types able to drive comfortably	Replacing standard transmission of a car with an automatic transmission	Using material with thermal memory for key rings that open in hot water	Laser, Transistor

[1] Yuri Salamatov. "TRIZ: The Right Solution at the Right Time" Insytec B.V., The Netherlands, 1999, ISBN 90-804680-1-0

[2] John Terninko, Alla Zusman, Boris Zlotin. "STEP-by-STEP TRIZ: Creative Innovative Solution Concepts" Responsible Management Inc., Nottingham, New Hampshire, USA, 1996