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Intellectual Property Rights (patents): Essentials and innovative potential in wine industry

Georgi Dimitrov¹, Mina Angelova²
University of Plovdiv Paisii Hilendarski, Plovdiv, Bulgaria
¹Faculty of Economic and Social Sciences, Specialty Business Management, Student, georgi.a.dimitrov1@gmail.com
²Department of Management and Quantitative Methods in Economics, mina.angelova@uni-plovdiv.bg

Abstract: The aim of the paper is to explore what the influence of the Intellectual Property Rights (IPRS) on the Modern economic growth is, whether there is a relationship between them, and what impact can patents have on the invention activity – positive, negative or both. It is going to explain the importance and association of technological progress with economic growth, the main goal and idea of IPRS, the way the system has been used in the period of the beginning of Modern economic growth, and research whether patents were the biggest incentive for inventors in this period as a whole and in wine industry in particular. The paper provides examples of the main European, United States and International patents available on wine production and preservation.

KEYWORDS: INTELLECTUAL PROPERTY RIGHTS (IPRS), INVENTION, PATENT, MODERN ECONOMIC GROWTH, INNOVATION

1. Introduction

The paper presents the influence of the Intellectual Property Rights system (IPRS) on the Modern economic growth and the arguments which can be viewed in this regard. The authors claim that before making an exact final statement, it is crucial first to present the main points of views and comment them.

The authors' thesis is that patents indeed are a big part of the whole technological progress and, thus, economic development, but at the same time IPRS has not been the biggest incentive and influencer of the economic growth. The main object of the research is patents and their strong influence over the motivation of the inventor. The paper is a part of a project focused on the innovation activities made by wine industry in Bulgaria. Thus the topic suggests good practices that can be used by wine specialists.

The subject of the paper is the influence of IPRS on the innovation process. The research aims to derive to the final conclusion and improve our view on the ascendancy of patent law and patents themselves.

The study is structured as follows: following the introduction in the second part is described the issue of technological progress. The third part pays attention on the Intellectual Property Rights (IPR) and their importance. This analysis paved the way for the fourth part, in which is highlighted the responsibility and the right of deciding the future of the invention. The main idea of the patents as discussed above is securing and to some extent it has a major impact on the work of an inventor and patents themselves.

The research aims to derive to the final conclusion and improve our view on the ascendancy of patent law and patents themselves.

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2. Technological Progress

One of the most important prerequisites for a consistent economic growth is the technological progress. We can use as a reference argument the Malthusian theory (T. Malthus, 1959) as it states that there cannot be an infinite rise of the population as at some point the resources would not be enough for everybody, although it has nothing to do with IPRS. But there is one way we can avoid this and it is exactly what we have done in the last 200 years – progress in technology, because of which we can still live a normal life despite the formidable rise of our population since then. Similarly, but not exactly, this is the case with the direct proportional relationship between technologies and economic growth.

If there is no technological progress, economic growth will remain constant at some point. The argument to this statement is based upon the fact that technology influences production, life, business, etc. And as we know, production is on the basis of wealth. Hence, difference in productivity creates difference in wealth. One of the limited resources we have is time. The day duration stays constant and the more we produce in those hours, the more we can consume (this is how we have managed to refute the statement of Malthus to a certain extent).

To explain the phenomenon of consistent economic growth, namely that in each year the economy produces more than it produced in the former year, Robert Solow (1956), who later received a Noble prize for his contribution, introduced technological progress into his model. The development of technology increases the supply of effective labor, because by using technology the productivity of labor increases (or at least this should be the main goal of the progress). Technology prevents the decline of marginal returns to capital.

Instead of assuming that technology automatically influences the economy for no clear reason, Solow suggested that innovation can be stimulated. But here is where another question pops up – is IPRS the main stimulant for innovation? In the next paragraphs we will try to give arguments over the basic hypotheses that IPRS have influence over the innovation process and the economic growth as a whole and in wine industry in particular.

3. Intellectual Property Rights: History and Importance

Whenever people think about IPRS itself, it is about all the positive sides and the mainstream idea of the system. It is true that to some extent it has a major impact on the work of an inventor (whether it is negative or positive) and it is of great importance to the whole activity. We can use the following example as it is an exact way to describe what an ordinary opinion of a person, who hasn’t made a vast research on the topic about the process, is – if we accept the inventor and his motivation as an engine, then the patent is the fuel to the engine. Moreover, it’s goal is to give meaning to the work of a genius and as Abraham Lincoln stated the US patent system “added the fuel of interest to the fire of genius, in the discovery and production of new and useful things”. (Lincoln 1858, cited in Andrews, 2017).

As we can see the idea and the basic opinion of people to patents is mostly positive. But is the patent itself so crucial to the period of modern economic growth (the beginning) and to the process of inventing, or is it just a small piece of the big puzzle? Is the effect large enough to account for a decent part of the increase and acceleration of technological progress?

This is a vast topic to which there are a lot of views. All the opinions have to be taken into account as they all have their strong arguments. Thus, we can make a better and correct conclusion. The main idea of the patents as discussed above is securing and motivating inventors, but just as many other positive policies, it can be used in an unfavourable way as well.

Many believe that we can support the statement that IPRS made at least some contribution to inventive activity and one of their arguments is that patenting became more common after 1760, exactly when England began to industrialize. Figure 1 shows the
As we can see, the number of patents filed in Britain each year, seem to track the Industrial Revolution. But the problem here is that we cannot take this information as an evidence for the fact that patents have such a big influence – more information is needed to prove that patents had such a big role in stimulating the processes that lead to modern economic growth.

It is important to mention that Britain’s patent system was not new and had many aspects in it that needed to be changed. For example, the US patent system was totally renewed when they declared independence. The British IPRS hadn’t been renewed until 1852 when the big reform took place. This is why the graph is showing the number of patents until 1851 – we would like to observe the period of the First Industrial Revolution and the old patent system. Then, filing and taking out a patent was very expensive and time-consuming. For England alone the patent fee was 100£, but for the Kingdom as a whole it was 350£, without taking into account all the other costs (e.g. travelling, time, etc.). Based on the statement of Joel Mokyr (2009), he gives an example with candidate-patentee Samuel Taylor, who spent 125£ on filing a patent in 1772, and in addition had to be in London for 6 months away from his home and business. As a multiple of average earnings, the value of 125 in 1800 would equate to around 130 000£ today, and around 95 000£ in 1850. The inventor was responsible for the physical transmission of their petition through every step.

Moreover, the attitude of judges for example in this period was hostile as they considered patentees as monopolists. It is more than obvious that the whole process of filing a patent was not either easy or pleasant and because of this it has been described as “tortuous labyrinth” by Charles Dickens (1850).

However, a work suggests that the British patent system was adaptable, and that important changes really occurred to improve the whole process that a patentee had to go through (in terms of accessibility, enforceability) during the eighteenth and early nineteenth centuries (Cornish, 2010; Gubby, 2012; Bottomley, 2014). One of these improvements was the appearance of patent agents in the third quarter of the eighteenth century. This was a step of development as by employing an agent, it was no longer necessary for the inventor to transmit his petition through the different points, offices in person, and since then there was actually very little they had to do to reach the point of filing the patent. Most agents would have maintained contacts with manufacturers or investors for the benefit of their clients.

It was only around 1830, when an apparent change in the attitudes towards patentees occurred. Judicial hostility as mentioned above was replaced by a growing appreciation of the role of a patent in encouraging invention.

After the patent system was reformed in 1852, there was a sharp increase in the number of patents filed. We can derive to the fact that the whole process was problematic to the inventors.

4. Having the right of deciding the future of your invention?

Another argument that supporters of the IPRS have is that it gives the inventor the right of deciding the future of his invention. In theory, by allowing them to exclude other parties from using their invention, patents help inventors to make a return for their time and capital, invested for the inventing process, and thus incentivize the development of new technology. But did this really have such a significant impact on the development of Modern Economic Growth?

During the Industrial Revolution, inventors were able to enforce this exclusion on potential competitors. The problem here, however, is whether they could actually benefit from their inventions and use the patents to make their returns.

Even today the start of the manufacturing of an invention is a time and capital consuming process. As we saw above, agents made the links between the inventor, investor and manufacturer. But this means that the profits from their invention are not going to be fully for them. The reasons for this are:

1. Many inventors were not able to commercialize their inventions themselves this is why would either license or sell their patent. They could realize returns without going into business.
2. Some sold a portion of their patent as a part of a partnership agreement. This is how they would commercialize the invention without sufficient capital.

Of course, there were many inventors during the Industrial Revolution that failed to put their product on the market and ended their days in poverty – John Kay, James Hargreaves and Richard Trevithick. Cases like these have always questioned IPRS and its efficiency. Moreover, many of the important inventors of the Industrial Revolution viewed the patent system in a negative way and preferred not to use it. The ethics and understandings of these inventors were totally different. They stated that their motivation does not come from the materialistic side of the process. It comes from their dedication and passion to the invention activity as Claude Berthollet (Grand, 1976) wrote to James Watt – “When one loves science, one had little need for fortune which would only risk one’s happiness”. The same goes for the technological field as most of the engineers, Watt being an exception, were against the filing of patents.

Patents are not the only incentives for inventors, though. For example prizes in some cases could be decisive, especially in the famous case of the marine chronometer: the prize was given to all people who participated in the invention and improvement to the invention, and not only to the inventor John Harrison. The understanding of society was that if they wanted technological progress, the whole invention activity should be more financially attractive no matter whether there were patents or not. In some areas technological advancement was not so competitive, unlike the consequences of the patent system.

We could still argue further with the statement that only IPRS stimulated technological progress in the beginning of the period of Modern economic growth. It is a known fact that development in technology is a continuous process and for the faster and easier development, inventors need to build up on the technology that has been made until this very moment. But to do so they needed to have a license or to buy information of the patent holder. It was discussed above that when a patent was filed, the patentee would be given a period of 14 years (and in some cases the time could be prolonged, e.g. Watt’s famous patent from 1769 to 1800) to put his invention on the market and make a return for his work. Therefore, it was highly difficult and expensive for other inventors to take the risk of investing in the knowledge without being sure that improvements could really be made. More information to the public was needed so that an improvement to products could be made and not thinking of new and similar products.
The process of building up on an invention in a free and united thinking market was termed by Robert C. Allen (1983) as “collective invention” – the main actors in technological innovation freely sharing information and claiming no ownership as the goal was development. Within the technical committees of the Society of Arts, for example, people shared ideas and “sharpened minds” with the others that were engaged in similar occupations and, thus, the process of innovation was faster. The example which Robert Allen gives in his paper is about the changes in the blast furnace practice that were developed in England’s Cleveland district between 1850 and 1875. Two major improvements were made, respectively in the height and temperature of the furnace by different parties, and in the end they were combined so that all could benefit from the innovative method. However, there are many examples of how innovation has been suppressed because of this law. One of them is the above-mentioned – the patent of James Watt, which is said to have been used for suppressing competition and keeping monopoly on the production and market of steam engines. Watt would always count on patents and this way the improvement to his steam engine would be left to no one except for him. Even when the Hornblower engine was put into production in the 1790s, Watt and his partner Mathew Boulton used the full force of the legal system to stop it.

After the expiration of Watt’s patents there was an explosion in the production and efficiency of engines and this is a key argument that patents in some cases suppressed invention activity. It was then when steam power came as the driving force of Industrial Revolution. Crucial inventions such as the steam train, the steam boat and the steam jenny came into usage. One of the key innovations was the high-pressure steam engine. Most of them were available by 1804. But not before Watt’s patent expired as none of the inventors wanted to face the same fate as Jonathan Hornblower.

One last example we would like to give is with Ireland, which possessed a patent system that derived directly from the one in England, yet it saw very little inventive activity in the eighteenth and nineteenth centuries (Bottomley, 2013) and remained an extremely poor and agrarian society – tragically evidenced by the Great Famine of 1845-1849. So society and the quality of life do matter and not only IPRS.

5. Patents in Wine Industry

Many authors investigate the patents established in wine industry based on the specifics of the product focusing on the essentials that different varieties of grapes, strains of yeasts, and technologies produce different types of wine. The well-known variations result from the very complex interactions between the biochemical development of the fruit, reactions involved in fermentation, and human intervention in the overall process. The researchers state that the final product may contain tens of thousands of chemical compounds in amounts varying from a few percent to a few parts per billion.

Baiano et al. (2013) report a detailed description of patents dealing with vine, microorganisms, additive, methods and apparatus, sensors usable to monitor the process, serving of wine, packaging, storage, and preservation. The review presents a summary of the main European, United States and International patents available on wine production and preservation. They describe the purpose of patents in wine industry and different patents varieties, i.e. patents in vine like Chardonnay II0V1-S, etc.; in microorganisms - for instance the European Patent EP 0226328 A3, WO 175774 A1 , etc.; additive - the patent WO 119572 A2, EP 1964913 A1, WO 172147 A1, etc. In this context, their conclusion states that to obtain and to keep the highest censorial properties by the others that were engaged in similar occupations and, thus, the process of innovation was faster. The example which Robert Allen gives in his paper is about the changes in the blast furnace practice that were developed in England’s Cleveland district between 1850 and 1875. Two major improvements were made, respectively in the height and temperature of the furnace by different parties, and in the end they were combined so that all could benefit from the innovative method.

Another lesson that can be learned from the patent explosion is the rise of patent warfare. The question is basic in discussions and researches in USA stated that after the law changed on business-method patents, financial companies had to start dealing with patent-enforcement entities and numerous and continual threat letters of patent infringement, continually obtaining advice from counsel in order to deflect a finding of willful patent infringement if the companies were ultimately sued. Furthermore, and most relevant to wine, many of the larger patent-enforcement entities are universities.Universities are seeking to make money from their novel research and have not been hesitant to sue for patent infringement. In the wine industry, one of the largest U.S. patent holders is the University of California, Davis, which holds patents in many aspects of wine production, including patents on unique types of grapes themselves. The University of California and UC Board of Regents are no strangers to patent infringement cases in federal court in other technologies.

When most people think of patents, they think of new machines, new medicines, or improved manufacturing processes. Based upon the report of Brian Kaider who is a principal of an intellectual property law firm (called Kaider Law), these inventions are protected by “utility patents.” Some people may also be familiar with “design patents,” which protect a novel ornamental design. But, there is a third class of patents with which most people are unfamiliar, “plant patents.” As the name suggests, plant patents protect new plant varieties, such as a new strain of wine grape vine. Plant patents are a useful tool to protect new varieties of grape vines.

Growers should be aware not only of the ability to protect their discoveries, but of the basic requirements to obtain patent protection and the actions that may potentially jeopardize their opportunities to seek protection. A knowledgeable patent attorney, engaged early in the process, can help to identify those new varieties that are eligible for a plant patent and to avoid waiving potential patent rights.

6. Conclusion

Technological progress was and is a key factor for the development of an economy, and inventions and innovations are a crucial part. As we saw throughout the paper, patents are not the only incentives for inventive activity. Even if they were, they can be used both in a way that stimulates technological progress or suppresses it as it is with the example of Watt.

The role of IPRS in the period of the beginning of Modern economic growth was, to some extent, to promote ownership. Based on the economic researches, we tend to see patents as one of the most important factor of the process but when it comes to an inventor and more specifically the inventors from the specified period mentioned above – they were not motivated primarily by the desire to maximize profits. Of course, that does not mean that money is not an important figure for them, but their goals and priorities were on a higher scale.

To sum up, no matter whether the influence of IPRS was positive or negative in some cases, the role of it was evident and it changed the way people thought when it came to inventions. This is a topic for discussion, and as always there were different opinions of inventors of the system. The most important part, however, was that patents did not have that big of an influence in this period but they are as important as any other incentives. And although most parts of the paper are not in favour of the statement that IPRS had a big influence on the period of Modern Economic Growth, we would like to end with the following quote of Mark Twain: “A country without a patent office and good patent laws is just a crab, and can’t travel any way but sideways and backwards.”

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In the latter cases, the SPIMs is constructed of a high-conductivity material, such as the die-cast copper, which benefits the motor's efficiency, but deteriorates its starting performance. Thus, the aim of this work is to investigate if the use of die-cast magnesium alloys, which present lower electrical conductivity and cost than the corresponding ones of copper, could lead to the development of topologies with enhanced efficiency and starting capability. To make this happen, the authors proceeded to several investigations regarding the rotor slot configuration and the selection of the proper windings turns ratio along with the run-capacitor value. The derived topologies satisfied all the set requirements and have been proven to be advantageous over the die-cast rotor SPIMs by considering several operational characteristics.

Keywords: Electrical Machine Design and Manufacturing, High Performance, Industrial Standards, Magnesium Alloys, Premium Efficiency, Single-Phase Induction Motor

1. Introduction

The single-phase induction motors are widely used in several household and industrial applications, where the three-phase supply is not available. Their application field range is quite extensive and involves among others: refrigerators, fans, centrifugal machines, compressors, heating-circulating pumps, etc. Their horsepower ranges from 0.25 to 3.0 HP and millions of them are produced every year. Moreover, many types of them, such as split-phase, capacitor-start/induction-run, shaded pole, capacitor-start/induction-run and capacitor-run SPIMs are available. Among the above topologies, the last one gains increased research and industrial interest, as it exhibits low manufacturing cost, high power factor and simple structure. It consists of a main and an auxiliary winding which is connected in parallel with the first one. A run-capacitor is permanently connected to the auxiliary winding, while a squirrel-cage configuration is adopted for the rotor. Despite the aforementioned advantages, the efficiency of the run-capacitor SPIMs is relatively low. The ordinary efficiency of commercial SPIMs varies from 64% up to 74.5% according to the data retrieved from the catalogues of plenty SPIMs manufacturers. The recent industrial efficiency standards published by the International Electrotechnical Commission (IEC) and the National Electrical Manufacturers Association (NEMA) impose that the commercial SPIMs have to comply with the specifications set by the energy class IE3 (premium efficiency).

Aiming to meet this goal the researchers have focused on: a) the proper selection of improved equivalent circuits and analytical equations [1], b) the optimal design of rotor slot topology [2], c) the proper selection of the capacitor value and its optimal placement [3], d) the development of new configurations [4] and e) the incorporation of new materials for the manufacturing of the stator and rotor core [5] and rotor's squirrel cage [6]. It has been proven that the rotor topology and its material has great impact on the SPIM performance. In the last few decades the aluminum was the most commonly used material for the squirrel-cage rotor construction due to its low cost. Next, the aluminum was replaced by the die-cast copper. The specific material presents high conductivity (up to 57 MS/m) and thus results to lower rotor bar ohmic losses and temperature and extended life expectancy [7]. However, its high melting point and consequently the high cost of die-cast processing are always important disadvantages.

A material with lower melting point, but also lower conductivity (up to 20 M/S) is the magnesium. The die-cast magnesium alloys have gained more popularity is recent years, as they present high strength at light weight, good environmental corrosion resistance and better castability over the aluminum and copper [8]. In these alloys the magnesium is combined with other metals, such as silicon, zinc and manganese in order to acquire greater stability and improved mechanical properties. According to the conventional wisdom a squirrel-cage rotor made by magnesium can only benefit the motor's starting capability, as its resistance will be high. Thus, lower efficiency ratings are expected compared to the corresponding ones achieved when a copper rotor is used. This is true, but only when the rotor slot topology and the rest motor's design parameters remain constant.

Taking the above into consideration, the authors present here an overall design methodology for the development of die-cast magnesium rotor SPIMs with both enhanced efficiency and starting performance. To make this happen, several investigations are conducted regarding the effect of important design parameters, such as the rotor bars slot cross-sectional area, the run-capacitor value and the auxiliary to main windings turns ratio on SPIM operational characteristics. The final topologies are compared to those with copper rotors. The post-processing analysis of the results reveals that the magnesium alloys are a realistic and attractive alternative for the construction of SPIM squirrel-cage rotors.

2. Proposed Design Methodology

The perspective of developing high performance magnesium rotor SPIMs is examined for the case of a 4-poles motor with 24 stator slots and 30 rotor bars. Its output power is equal to 1.0 HP. The geometrical representations of the considered stator, rotor and end-ring topology are depicted in Fig. 1. A semi-closed trapezoidal rotor slot configuration has been selected, as it is also frequently chosen by the manufacturers. According to the IE3 class specifications, the motor's efficiency (η) has to be higher than 82.5% and its starting to nominal torque ratio (T/TN) has to be at least equal to 0.35. The rest operational characteristics of the motor under study and the relative constraints are summarized in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output power (rated), P&lt;sub&gt;r&lt;/sub&gt;</td>
<td>750 W</td>
</tr>
<tr>
<td>Output torque (rated), T&lt;sub&gt;r&lt;/sub&gt;</td>
<td>≥ 4.8 Nm</td>
</tr>
<tr>
<td>Speed (rated), n&lt;sub&gt;r&lt;/sub&gt;</td>
<td>≥ 1420 rpm</td>
</tr>
<tr>
<td>Line current (rated), I&lt;sub&gt;r&lt;/sub&gt;</td>
<td>≤ 5.0 A</td>
</tr>
<tr>
<td>Power factor, cosφ</td>
<td>≥ 0.9</td>
</tr>
<tr>
<td>Efficiency, η</td>
<td>≥ 82.5 %</td>
</tr>
<tr>
<td>Starting to nominal torque, T/T&lt;sub&gt;N&lt;/sub&gt;</td>
<td>≥ 0.35</td>
</tr>
<tr>
<td>Starting to nominal current, I&lt;sub&gt;r&lt;/sub&gt;/I&lt;sub&gt;N&lt;/sub&gt;</td>
<td>≤ 8.0</td>
</tr>
<tr>
<td>Supply voltage, U&lt;sub&gt;r&lt;/sub&gt;</td>
<td>230 V</td>
</tr>
<tr>
<td>Supply frequency, f</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Number of poles, Zp</td>
<td>4</td>
</tr>
<tr>
<td>Net mass, M</td>
<td>≤ 14.0 kg</td>
</tr>
</tbody>
</table>
The adopted design strategy combines both the classical SPIM methodology and the modifications described in [6] (a work also made by the authors). In that work, the authors proposed the enlargement of the SPIM axial length in order to enhance the motor's efficiency. Following the directions provided there the basic motor's design parameters can be obtained. Further information regarding their analytical calculation is given in [9]. Next, three crucial characteristics have to be determined. The first one is the rotor bar slot cross-sectional area \( A_{\text{bar}} \), which can be estimated as in Eq. (1), where \( k_{\text{bar}} \) is the slot area factor, \( Q_{\text{run}} \) is the stator slots number and \( Q_{\text{bar}} \) is the rotor bars number. Except from \( k_{\text{bar}} \) all the other parameters are determined in previous steps of the classical design methodology. The designer has to assign a value to \( k_{\text{bar}} \) based on his own experience. Regarding this quantity only some general rules are available in [9], where it is suggested to choose a value between 0.35 and 0.6. The authors decided to expand the above variation range from 0.2 to 0.6 with a step of 0.225, as two materials with different conductivity are going to be used. The rotor bar topology modification along with the variation of slot area factor is illustrated in Fig. 2.

\[
A_{\text{bar}} = k_{\text{bar}} \frac{A_Q}{Q_{\text{run}}} (1)
\]

![Fig. 2 The rotor bar slot cross-section variation as a function of \( k_{\text{bar}} \).](image)

The next two design variables that will be considered under investigation are the auxiliary to main winding turns ratio \( (a) \) and the run-capacitor value \( (C_{\text{run}}) \). The first one relates the auxiliary winding turns number \( (N_a) \) with main winding turns number \( (N_m) \). The \( N_a \) can be obtained through Eq. (2), where \( E_m \) is the main winding induced voltage (typically equal to 0.96 of the supply voltage \( U_{\text{in}} \), \( k_{\text{fl}} \) is the magnetic flux correction factor and \( B_g \) is the airgap flux density, \( D \) is airgap diameter, \( L \) is the motor's axial length, \( f \) is the supply frequency, \( 2p \) is the poles number and \( k_n \) is the winding factor. The \( B_g \) and \( k_{\text{fl}} \) are considered equal to 0.7 and 0.9 respectively for small induction motors. The turns ratio value usually ranges from 1.0 to 2.0, but its value can be lower than 1.0 when a capacitor of high value is used for \( C_{\text{run}} \). The \( C_{\text{run}} \) can be calculated by using Eq. (4), where a value has to be assigned to the motor's rated current \( I_s \) taking into consideration the desirable efficiency. For commercial SPIMs with the same output power the \( C_{\text{run}} \) varies from 18 uF to 30 uF.

\[
N_a = \frac{2pE_m}{2\sqrt{2\pi k_{\text{fl}} B_g DLk_n f}} \quad (2)
\]

\[
N_a = aN_m \quad (3)
\]

\[
C_{\text{run}} = \frac{1}{2\pi f U_a (r^2 - 1)} \quad (4)
\]

3. Effect of \( k_{\text{bar}} \), \( C_{\text{run}} \), and \( a \)

In this Section, the effect of \( C_{\text{run}} \), \( k_{\text{bar}} \) and \( a \) on the SPIM's efficiency, power factor, starting current and starting to nominal torque ratio is presented and thoroughly discussed. By inspecting Fig. 3 we address and justify here the main findings for each quantity:

Efficiency: As the capacitance becomes higher a slight variation is observed for the motor's efficiency. The efficiency is maximized for a specific value of \( C_{\text{run}} \). In the most cases, the maximum value is achieved when the \( C_{\text{run}} \) ranges from 25 uF to 30 uF. For SPIMs with die-cast rotor the efficiency reaches its highest ratings for \( k_{\text{bar}} \) equal to 0.2. This can be justified by the fact that the stator windings copper losses increase extensively, as the rotor slot area becomes larger due to the higher absorbed line current. The above loss type is the dominant one and thus defines the efficiency trend. For the SPIMs with die-cast magnesium rotor a quite different behavior is observed for the efficiency. The highest efficiency is now achieved for \( k_{\text{bar}} = 0.475 \). Beyond and below this value the efficiency decreases. For given \( C_{\text{run}} \) and for all the examined variation range of \( k_{\text{bar}} \) the topologies with magnesium rotors present lower capacitor, stator copper and core losses. Only the rotor copper losses have been found higher for them due to the higher rotor resistance. The rotor resistance of magnesium-squirrel-cage is 3 up to 4 times higher than the corresponding one of copper squirrel-cage.

Power factor: The decrement of \( k_{\text{bar}} \) with the simultaneous increment of \( C_{\text{run}} \) benefits substantially the power factor for the case of motors with copper rotor. The obtained values range from 0.5 to 1.0. On the other hand, the power factor acquires higher values even for a high value of \( k_{\text{bar}} \) when the magnesium rotor are used. In this case, the minimum recorded value is higher than 0.88. The power factor increases as the rotor bar cross-sectional area becomes smaller. Also, acquires its maximum value for a value of \( k_{\text{bar}} \) close to 0.475 and then remains almost constant.

Starting to nominal torque ratio: All the examined models with copper rotor fulfill the minimum set requirement regarding this characteristic (i.e. \( T_{S}/T_{N} = 0.35 \)). It is observed that a higher starting torque coincides with an efficiency lower than 82.5%. When the magnesium is used, the starting torque increases significantly for low values of \( k_{\text{bar}} \), and a high value for \( C_{\text{run}} \). When \( k_{\text{bar}} = 0.2 \) the \( T_{S}/T_{N} \) ratio varies from 0.58 to 0.73, but the premium efficiency is not achieved. When the efficiency is maximized (for \( k_{\text{bar}} = 0.475 \)) the specific ratio is equal to 0.35. However, as it can be seen from the data given in Table 2, the premium efficiency can be combined with the improved starting performance when the \( k_{\text{bar}} \) takes a value between 0.375 and 0.45.
Fig. 3 Variation of efficiency, power factor, starting to nominal torque ratio, starting current and turns ratio as a function of $C_{run}$ and $k_{m}$ for:
(a) copper rotor and (b) magnesium rotor SPIM.
Starting Current: The motor's starting current decreases as the rotor bar slot cross-sectional area becomes smaller and a high value of capacitor is selected for the \( C_{\text{emp}} \). Moreover, it can be said that the topologies whose rotor is made of magnesium require a lower starting current, is required.

Aux. to main winding turns ratio: A higher value has to be assigned to the turns ratio when the rotor bar slot becomes larger aiming to satisfy the starting torque requirements. Also, as the capacitance increases the turns ratio value decreases. Comparing the SPIMs with copper and magnesium rotor, a higher number of main winding turns are required in the second case. When the efficiency is maximized, the turns ratio value ranges from 0.94 to 1.4 for the copper topologies and from 0.83 to 1.25 for the magnesium topologies.

### 3. Comparison of the final topologies and discussion

In this Section a comprehensive analysis of the derived SPIM topologies will be conducted aiming to highlight the advantages of using die-cast magnesium. As already demonstrated the SPIM configuration with copper rotor present premium efficiency only when the \( k_{\text{per}} \) is equal to 0.2 or 0.225. For the case of magnesium an efficiency higher than 82.5% is achievable for a relatively wide slot area factor variation range. In these cases both the SPIM efficiency and starting performance are enhanced. This is not feasible when the die-cast copper is used. Moreover, the performance characteristics of the configurations with the highest efficiency are summarized in Table 3 and 4. As it can be seen, the topologies with magnesium present efficiency of the same ratings with the corresponding ones of SPIM with copper rotor. When the \( C_{\text{emp}} \) is lower than 25 \( \mu \)F the difference among the achievable efficiency are negligible. For a value of \( C_{\text{emp}} \) higher than 25 \( \mu \)F the efficiency of the copper topologies is higher up to 0.7%. The performance ratings of the examined topologies are comparable even under different load conditions according to the data presented in Table 5. When the motor is unloaded, the use of magnesium seems to benefit both its efficiency and power factor. For full load and overloaded conditions the efficiency of the motor with copper rotor is superior.

Furthermore, the magnesium rotor topologies require lower starting current aiming to provide the same amount of torque during the start-up phase. The ratio \( I_{\text{per}}/I_{\text{S}} \) varies from 4.8 to 6.0 for the case of motor with magnesium. On the other hand, the corresponding ratio value for SPIM with copper rotor lies between 6.5 and 7.18. Also, the mass of magnesium motors is lower up to 0.54 kg and their manufacturing cost is lower by 9.16% up to 14.47%.

### 4. Conclusions

Through the conduction of extended investigations it has been proven that the die-cast magnesium alloys are an attractive alternative for the construction of SPIM rotors from economical point of view and also by taking into consideration numerous performance indexes. When the proper design of the rotor topology is combined with the careful determination of the rest important design parameters an overall enhanced performance can be achieved.

### 5. References

The Medical Appointment Application
Enikeeva Adelya Iskanderovna
Kazan Federal University, Russia
Email: aadelyaenikeeva@mail.ru

Abstract: The main topic discussed in the report is the automation of the registry by creating a mobile application in order to improve the quality of medical care, reduce the burden on reception staff, and also save clients time

Keywords: HOSPITAL, AUTOMATION, BENEFITS OF AUTOMATION, INFORMATION SYSTEM, MOBILE APP, PERSONAL ACCOUNT, ONLINE APPOINTMENT.

1. Introduction

In recent years all over the world qualitative changes have occurred in the process of interaction between customers and service organizations. Automation of workflows has become widespread in all sectors of the service sector, customer interaction now often occurs through the Internet and mobile applications. Modern technology offers us simply unlimited possibilities. Now everyone has access to information and can control the quality of their own lives. Earlier visits to doctors were associated with long expectations, queues, carelessness on the part of staff and the need to adapt to circumstances. With the advent of the opportunity to leave a request on the organization’s website, more and more consumers are switching to this particular communication method.

However, many medical organizations continue to use only the traditional appointment method by telephone which limits their integration into modern living conditions. The conformity of communication methods to the processes taking place in society is gaining great importance. It is easier for a patient who spends a lot of time on the Internet to make an appointment with a doctor using online services than to call the same clinic. To make their services accessible, clinics meet the needs of their consumers, and the introduction of online recordings is one of these significant steps.

Medical Appointment is a mobile application design to help in patient scheduling. Patient scheduling is an integral part of daily work for healthcare professionals, from family practices to large clinics, from physician offices to hospitals. Appointments need to be coordinated and medical support staff has to be constantly aware of all new patients and doctor’s schedule

2. Prerequisites and methods for solving the problem

Currently, most people often go to the hospital on various issues. In this regard, queues are increasing, and the workload of the hospital staff, especially the reception staff, is also growing [2]. Therefore, a decision was made to automate in order to significantly increase the working capacity of employees of the medical institution and reduce the time spent in the hospital by people, future patients of the hospital, and provide a number of advantages for them.

What are the benefits of automation?

1. Automation of the registry dramatically increases the capacity of the hospital, thus there are no cases of patient leaving the queue and refusing medical services due to lengthy appointments [2].

2. Having the opportunity to make an appointment on their own, the client thereby facilitates the work of the administrator, who no longer needs to answer a series of phone calls, and the client, in turn, wait until the administrator is free.

3. Everyone has the opportunity to make an appointment with the doctor, without leaving their own home. They can perform the necessary manipulations while at work while in work, in another city or in a foreign country [2].

4. The application includes all the advantages of an online registry with an appointment with the doctor, each client will be able to create a personal account. It reflects the history of his visits, future appointments with the possibility of canceling an appointment, the results of medical research and the schedule of doctors. Also, the advantage of the application is its simplicity and ease of use, which consists in the location of all the necessary information (from the name of the doctor to the address of the clinic) in one place, accessible with one touch.

5. An online booking system works all the time. This gives freedom to potential visitors to make an appointment anytime they want [1].

All this benefits that with the introduction of the information system, patients in most cases receive a higher level of medical care.

3. Solution of the examined problem

It was decided to create a mobile application that will provide patients with a number of different possibilities. Here are some main functions.

1. Make an appointment. Patients can choose a specialist, date and time and, after entering their personal data, make an appointment. But often it’s not always possible to visit a doctor’s appointment, and calling and canceling an appointment requires a lot of effort, so the application has the ability to cancel or reschedule an appointment in just a few steps.

2. View the schedule of specific doctors. This saves a lot of time, since you don’t need to call the registry and find out all the necessary information from them.

3. See medical research results. You won’t have to spend time picking up the results in the hospital. They will be available in the application with the ability to print.

When creating a mobile application, it was important not only that it was functional, but also that it was easy to use. An app that can be easily used in a variety of situations with seamless features is generally most appealing.

In addition, it is important to create a simple intuitive registration. Today users can be quite impatient. The simpler the registration process is, the better [3]. Therefore, the best and safest method will be authorization by phone number. Authorization by phone number has several advantages. By associating a unique and valid phone number to each user account, enterprises can stop fake accounts from gaining access to a service. Once this phone number is validated — a mobile or landline number, even — this is the trusted identifier throughout the customer journey.
4. Results

1. Figure 1 shows the authorization. A patient enters his phone number, receives and enters a code that allows access to the application.

2. When making an appointment, a patient chooses a specialty (Fig. 2), a doctor (Fig. 3), date (Fig. 4) and time (Fig. 5). Next you need to enter your contact details (Fig. 6).
3. Viewing the schedule of doctors looks like this (Fig. 7).

5. Conclusion

Thus, all of the above factors make the online appointment system the most convenient. Attracting the Internet saves patients time, makes medical care affordable and timely, and increases the level of medical care. An online appointment with the clinic gives clients a sense of the availability of the services provided. The perception of the clinic as an organization, which is easy to contact at any time and get the right service, creates a positive reputation for it.

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Introduction of Industry 4.0 in Industrial Enterprises: Problems and Challenges

Neli Veleva
Faculty of Mechanical Engineering, Department of Industrial Management – Technical University of Varna, Bulgaria
neli_veleva@tu-varna.bg

Abstract: This publication analyzes the opportunities, problems and challenges associated with the implementation of Industry 4.0 in Bulgarian industrial enterprises in condition of a dynamic changing competitive environment and extending digitalization. An analysis is made on the base of the four fundamental principles that are used for application of solutions related to the implementation of Industry 4.0 and that influence on the organizational activities in all functional areas in the industrial enterprise. Various industrial sectors are analyzed to identify the trends, problems and challenges of the introduction of Industry 4.0 in manufacturing activities. Opportunities for improving their competitiveness are identified by means of using the principles and advantages of the modern digitalization. Up-to-date statistics and various methods for analyzing of the existing information are used. The specifics of development of the leading sectors in Bulgarian economy are identified. The results show that there is a growing number of Bulgarian industrial enterprises focused on deploying Industry 4.0 to reach new higher levels of productivity, quality and efficiency. This is a new approach in seeking favorable opportunities for their further sustainable development and competitiveness. Some fundamental problems, challenges and barriers in industrial enterprises, in the process of introduction of digitalization in the industry are discussed, which hinder the fast pace of their development. As a result of this analysis are presented some appropriate solutions.

Keywords: INDUSTRIAL PRODUCTION, INDUSTRY 4.0, DIGITALIZATION, CHALLENGES, SUSTAINABLE DEVELOPMENT.

1. Въведение

In the modern world, it is increasingly being talked about the enormous impact that digitalization is developing at an extraordinary rate, its advantages and challenges. The process itself may be called "megatrend", which causes the world to look toward new, more sophisticated levels of productivity. More and more organizations are redirecting and refining their strategies and goals toward the introduction of new generations of digital technology. Aiming at building competitiveness, today every industrial enterprise is concentrating its efforts and resources on the development and improvement of digital technologies through the implementation of Industry 4.0. The aim is to achieve higher levels of productivity, quality, efficiency, search for favorable opportunities for their further sustainable development and competitiveness.

2. Industry 4.0 - essence and characteristics

Industry 4.0 is a modern phenomenon that has many advantages but also has negative impacts. There is no one specific answer for the name "For" or "Against" Industry 4.0. Prior the introduction of Industry 4.0, every industrial enterprise must clarify the specific nature and specific characteristics contained in the concept of digitalization through its prism of reality. According to the concept of digital transformation of Bulgarian industry, "... the importance of new technologies for society and economy is determined by the definition of the term "Fourth Industrial Revolution"[2]. Based on the detailed literature review, could be done the conclusion about the majority of the Fourth Industrial Revolution. These conclusions may be presented by summaries of researchers in this field (Industry 4.0) (Table 1):

The Fourth Industrial Revolution is developing on the base of modern digitalization, combining different technologies, methods and digital solutions, which lead to significant changes in the market environment, business and society.

Table 1: Key summaries concerning the essence of the Fourth Industrial Revolution (Industry 4.0).

<table>
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<tr>
<th>Description</th>
<th>Summary</th>
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<tr>
<td>The Fourth Industrial Revolution (Industry 4.0) - The Essence</td>
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| According to the Concept for Digital Transformation of Bulgarian Industry | "Industry 4.0 is defined as part of the application of new digital technologies in the manufacturing sector and includes a wide range of technological solutions and business models"

The need to understand, use and fully implement the concept of Industry 4.0 is primarily due to the fast development of new technologies leading to the automation, modernization, refinement and digitization of the real production and business processes. In this way, each organization (industrial enterprise) manages to achieve sustainable development and growth and high levels of competitiveness.

According to the Concept for Digital Transformation of Bulgarian Industry from 2017 digitalization of the economy "... it is developing dynamically and is an important driver of innovation, competitiveness and growth ...". The Fourth Industrial Revolution is based on four basic principles that are used to implement decisions related to its implementation and that affect organizational activities in all functional areas of an industrial enterprise. These are: [2]

1. Interoperability - the ability and need of a system or product to work with other systems or products without the need for additional user action. This principle is implemented through the Internet of Things (IoT) or Internet of People (IoP);

2. Transparency – it is realized by the ability of new generations of information systems to calculate and store data in the so-called cloud structures.

3. Structuring and visualizing information in a new, comprehensible way that helps managers to make decisions about pressing issues.

4. Autonomy - technological innovations are not universally applicable, but they must be tailored to the specific functional areas of the industrial enterprise.
Applying and complying these 4 fundamental principles is a key factor in achieving the competitiveness, development, productivity and survival of any organization in today’s competitive environment.\[10\]

Industry 4.0 is a set of various activities, business models, technological and strategic decisions. E-commerce, intelligent manufacturing enterprises, cloud technologies, internet technologies, artificial intelligence, 3D printing, robotics, smart cities, smart factories are only a small part of the development of automation and real-time data exchange in manufacturing processes.

The characteristics of the Fourth Technological Revolution may be summarized as follows:

- Decision-making optimization - Big Data analysis and processing facilitates more flexible decisions when urgent problems arise;
- Resource Productivity and Resource Efficiency - The pursuit of basic strategic goals, namely producing the most output based on available resources at the lowest possible cost. In this way, optimization of production processes, reduction of costs, better use of resources and energy, reduction of harmful emissions from production and environmental protection are achieved;
- Customer/customer feedback regarding ordering, planning, manufacturing, design regarding the production of a product or service;
- Dynamic organization of production processes according to time, quality, price, risk, sustainability, resources, suppliers, customers and more.

3. Introducing Industry 4.0 into Industrial Enterprises - Essence, Problems, and Challenges

"The Industry 4.0 platform is a response to the changes in modern technology that have led to the fourth industrial revolution since the introduction of machines, production lines and IT." [1]

The introduction and implementation of this platform is not an easy process for any industrial enterprise, which is developing in the current competitive environment. In an extremely fast-paced, dynamic business environment, it is clear that there is no one-size-fits-all solution or sequence that can be applied to digitalization, both for large, small, and medium-sized industrial enterprises. Each organization is unique and each decision must be strictly individual. The desire to achieve pragmatism and adaptability on the part of enterprises is increasingly being sought, trying to achieve maximum results with limited resources and opportunities.

One of the main keys to the introduction of Industry 4.0 is the promotion of human-machine collaboration. The pace of introduction of new technologies, resources and staff qualification are also among the key factors for transition to the Fourth Industrial Revolution.

According to the Strategy for Bulgaria's Participation in the Fourth Industrial Revolution, (Industry 4.0) – 2018, [9] 4 basic strategic tasks for the introduction of Industry 4.0 can be identified and practically implemented as they are listed:

- Institutional support for the development of Industry 4.0 - identification of specific strategies, policies, programs, procedures, mechanisms and tools to support the development of Industry 4.0 in relation to the peculiarities of Bulgarian organizations and market conditions;
- Creating synergies between existing policies, programs, procedures, strategies and support mechanisms;
- Development of educational and scientific initiatives to build institutional and organizational capacity for acceptance and compliance with the requirements and prerequisites of Industry 4.0;
- Creating preliminary projects and demonstration models for visualization, analysis and implementation;

Digital education, qualifications and training in the range of the work process can be cited as major problems with implementation. Their solutions lie in providing accessible tools for employees that are used in different departments of industrial enterprises. In this way, by sharing experience and information, organizations can achieve their ultimate goals faster, pragmatically, by joining forces to implement complex solutions.

The key to the introduction of Industry 4.0 is based on the seamlessly digital knowledge transformation into everyday skills and professional qualifications - fast, pragmatic and more active. [10]

The significant role of innovation must also be noted here. To realize an innovative idea, several components are needed: creativity, entrepreneurship, freedom. [1]

In the classification of the main challenges and obstacles to the introduction of Industry 4.0 Industrial enterprises can be identified the following risks and barriers:

- Unclear economic benefits;
- Investment amount;
- Qualification and training of employees;
- Insufficient standardization and certification;
- Unclear economic conditions;
- Data security;
- Strong competition;
- Insufficient stimulation of digitalization by the state;
- Adaptation of legislation;

Some of the major benefits that any industrial enterprise could benefit after deciding to introduce and use the latest generation digital platform are:

- Increasing efficiency;
- Optimization of planning and management processes;
- Achieving resource efficiency and resource productivity;
- Maintaining competitors advantages and competitiveness in the market;
- Collection and analysis of large amounts of data through information systems;
- Cost reduction;
- Increase in turnover;
- Achieving sustainable development and growth;
- Employee-user feedback;

According to the National Statistical Institute (NSI) the results of the conducted in 2019 a survey of enterprises with 10 or more employees show that 95.7% of them use computers, and for large enterprises with 250 and more employees the relative share is 100.0%. High-speed, reliable and uninterrupted Internet access is a fundamental necessity for businesses and 93.7% of them have permanent access to the global network. To connect with Internet companies, they mainly use DSL or other fixed technology (80.5%), with 64.8% of them having the fastest fixed connection speed exceeding 30 Mbps. [11]

From the Fig. 1, it is clear that more and more organizations are using the Internet, which is directly dependent on the development and implementation of Industry 4.0 in the Bulgarian market economy. [9]

Another important factor concerning the essence of the introduction of Industry 4.0 is the provision, deployment and use of information and communication technology (ICT) in an industrial enterprise. [8]

According to NSI data, in 2019 one of five enterprises (20.1%) has employers whose primary job is to develop, manage or maintain ICT systems or software applications. In the previous 2018 10.0% of enterprises have employed or have tried to employ ICT specialists, as 41.6% of them have experienced difficulties in finding suitable staff. 10.1% of employers provide ICT training to improve the skills of their staff. Fig. 2 presents the relative share of...
enterprises that employ ICT professionals and provide training in the field of ICT by enterprise size in 2019. [11]

![Share of enterprises with Internet access by size class and economic activity in 2019](chart1.png)

**Fig. 1 Relative share of enterprises with Internet access of enterprises economic activities in 2019 by size according to NSI [11]**

![Share of enterprises employing ICT specialists and providing ICT training by size class in 2019](chart2.png)

**Fig. 2 Share of enterprises employing ICT specialists and providing ICT training by size class in 2019 according to NSI [11]**

More and more Bulgarian industrial enterprises are focusing on the implementation of Industry 4.0 to achieve higher levels of productivity, quality and efficiency. This is a new, modern approach to seeking opportunities for their further sustainable development and competitiveness. [4], [7].

4. Barriers to industrial enterprises in the process of introduction of digitalization in industry and appropriate solutions.

The barriers defined by the analysis of existing information facing industrial enterprises determined to introduce and use new generations of technology can be classified into several major groups:

- Related to policy - One of the most important barriers facing industrial organizations is the need for long-term and sustainable national and international policies that have to ensure the development of smart innovation and sustainable change.
- Related to new technologies - in this group, the main barrier is that enterprises must be uncompromisingly quickly ready to apply and use new technologies, creating innovation. Flexibility of the organization regarding to this barrier is crucial in achieving competitive positions in the face of new market conditions.

- Related to R&D. Research and development (R&D) needs adequate financial support, both from the EU and from a national perspective.
- Related to qualification - the shortage of highly qualified personnel also influences the issue of introducing and embarking on the Fourth Technological Revolution.

5. Conclusion.

Achieving resource productivity (producing as much output as possible from available resources) and resource efficiency (at the lowest possible consumption of resources for available quantities of output), individual approach to the consumer, flexibility and potential for value creation by offering new services and products, summarizes and presents how important and necessary the process of deploying Industry 4.0 in an industrial enterprise is. In this way, the key advantages considered are the challenges and benefits of implementing digitalization, defining Industry 4.0 as a powerful tool for achieving high efficiency and competitiveness of industrial enterprises in a highly competitive environment.

This research was carried out in the range of research project NP14/2019 of Department of Industrial Management at the Technical University of Varna and the research work on this problematic will continue after the project completion.

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Radical innovations as a drive of Industrial Revolutions

Emilia Ilieva Nawfal
E-mail: emmy.nawfal@gmail.com

Abstract: The purpose of this publication is to elucidate the nature of radical innovations as drives of various industrial revolutions, as well as the conditions that led to their emergence. They incorporate substantially different technologies from existing ones and meet the needs of consumers in a new way and better than the current ones. This article will discuss factors that can be used to evaluate an innovation as radical. A new view of Industrial Revolution will be presented, explaining critical factors and their relation to sectors of production. An invention may lead to the production of a new, unknown product at a certain time or to the provision of an unknown service. The use of these unfamiliar products or services on the market is characterized as a radical innovation. Relevant radical innovations in turn lead to industrial revolutions. It is argued that a paradigm shift takes place and we call it Industrial Revolution.

KEY TERMS: SCIENTIFIC BREAKTHROUGH, INVENTION, RADICAL INNOVATION, INDUSTRIAL REVOLUTION, SECTORS OF BUSINESS ACTIVITY, PRODUCTION PROCESS, PARADIGM SHIFT

1. Introduction

1.1 Definitions of basic terms used in the paper: scientific breakthrough, invention, radical innovation, industrial revolution.

The aims of this research is to find out what leads to a new industrial revolution and the correspondent paradigm shift that happens in businesses. Such a change is of enormous importance since there should be preparation prior to the change. If the business is not prepared then this might have detrimental effect on it. The practical value of the research paper is to outline some of the characteristics of radical innovations in different stages of the production process. Recognizing these features will help managers to start management of change in the enterprise. The result would be that when a paradigm shift occurs the business will be prepared to carry on with its daily activities instead of trying to survive.

According to the Center for Science and Technology Studies1, “scientific breakthrough are those sudden discoveries that have a major impact on follow-up scientific research” (1). The Cambridge dictionary defines breakthrough as “an important discovery or event that helps to improve a situation or provide an answer to a problem”2. Merriam-Webster dictionary states it as “a sudden advance especially in knowledge or technique”3. We do make a difference though between a breakthrough and invention. The Cambridge dictionary defines invention as “Something that has never been made before, or the process of creating something that has never been made before”4. But as we can see from this definition it is not evident that this ‘something’ is breaking new grounds and/or is a cutting edge technology. Thus, we have to distinguish between a breakthrough and invention. The Cambridge dictionary defines invention as “something that has never been made before, or the process of creating something that has never been made before”4. But as we can see from this definition it is not evident that this ‘something’ is breaking new grounds and/or is a cutting edge technology. Thus, we have to distinguish between a breakthrough and invention. In accordance with a paper presented at the DRUID Celebration Conference in Barcelona, the large majority of all inventions are incremental, while only a small portion are breakthroughs (2).

From the interpretations of the term and with an aim for the objective of the research, the definition of breakthrough can be stated as: Sudden advances or events in science or technology made through consistent, focused and synergistic efforts that help to improve the situation or to respond to a problem.

Next we will define a very contradictory term, for which various definitions have been written. This is radical innovation. Some authors call it revolutionary innovation (Abernathy and Clark, 1985) “it is an innovation that has a destructive effect on a particular part of the production process or on the product itself because it renders the established technical and production competence obsolete” (3). In 1990 Kim Clark and Rebecca Henderson upgrade the definition, thus innovation becomes radical and “… introduces a new meaning, potentially accepted as a paradigm shift” (4). Jim Kalbach proposes a model of innovation types where he describes that a” breakthrough innovation refers to large technological advances that propel an existing product or service ahead of competitors” (5). He specifies that breakthroughs often result from R&D, “striving for the next patentable formula, device and technology” (5).

One of the latest interpretations for explaining both breakthrough and radical innovation was given by a McKinsey consultant, Emma Muckersie in 2016. Breakthrough innovation is “difficult as it requires the introduction of either a new technology or a new business model”. While radical innovations require both the introduction of new technology and the adoption of a new business model. Both processes are difficult, since “they need a different approach to research that involves significant business changes as well as huge investments” (6).

Radical innovations then can be defined as: revolutionary innovations that create new products. Through their widespread use, new industries are being created or existing ones are being destroyed. Radical innovations employ both the introduction of new technology and the establishment of a new business model, a paradigm shift can happen.

We can see that a breakthrough is distinguished from a breakthrough innovation and radical innovation. A breakthrough is when something has been invented. But unless it is implemented in practice only then it can become an innovation.

The last term that should be identified is industrial revolution. It is interesting to note that most definitions of Industrial Revolution actually include a definition of the First Industrial Revolution. Encyclopaedia Britannica defines “Industrial Revolution, in modern history, the process of change from an agrarian and handicraft economy to one dominated by industry and machine manufacturing”. There is no definition that clearly explains exactly what is meant by the general term industrial revolution. This is most likely due to the fact that the first revolution saw a dramatic change in production, creation of machines, materials, production methods and others that completely changed the way people live. Although statistically, the number of inventions and innovations put into

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1. https://www.cwts.nl/blog/article=r-2u2c4&title=is-it-a-scientific-breakthrough
practice, in the Second Industrial Revolution, is likely to top the rankings (7).

If the term is considered, according to the Cambridge dictionary industrial means “the companies and activities involved in the process of producing goods for sale, especially in a factory or special area”6. While revolution “is a very important change in the way that people do things”7.

2. Factors that bring about industrial revolutions.

Since the Industrialization Age, human kind develops more and more complex activities. During the last century, people talked about the First and the Second Industrial Revolutions. Then a Third was acknowledged. Today we discuss the Fourth and the Fifth Industrial Revolutions, known as Revolution 4.0 and 5IR. A new way to look at what are the important factors leading to different industrial revolutions is presented by Dr. David Brown8. In an interview for Forbes he stated that there are three characteristics that drove the first two revolutions. These factors are also present now in the Third Industrial Revolution. They are: a new energy source, a new communication system and a new financial system (8). In every industrial revolution these factors develop and become more complicated.

The research led to an interesting co-relation. The factors of production could be linked to a certain Industrial Revolution. In the past 100 years, developed economies have seen a transition from an agrarian economy (primary sectors of production), to manufacturing-based (secondary sector) economy, to an economy where the tertiary sector dominates. The use of better technology led to improved labour productivity, which enabled a higher output of manufactured goods and agriculture with less labour. The increased productivity helped in: increased income to spend on leisure activities and spare labour to work in a labour intensive tertiary sector (9). “Technological advances has enabled new service sector industries to develop. Tertiarisation started.” (9). Since this trend continued to develop, a quaternary sector has been established, somehow as a subdivision of the tertiary. It has been improved from the tertiary because it is focused on knowledge, intellectual activities, and is often associated with technological innovation. That is why sometimes it is called the “knowledge economy” (10). Various types of e-services, IT, the media, government, culture, education, scientific research, and web-based services become typical of the “post-industrial” economies (11). The workforce involved is typically well educated. Another subdivision of the tertiary sector is the quinary sector. It incorporates the “highest level of decision-making in a society” (10), who formulate policy guidelines in the different industries, the various government departments, in the sciences and technology, which have a far-reaching impact on the economy.

In the following table the sectors of business activity are linked to a corresponding industrial revolution and their features, according to Dr. Brown are outlined and further developed.

3. Identifying factors that can be used to evaluate innovation as radical.

From a managerial point of view, one of the most important processes is manufacturing, or in general terms – the production of the product/service. In the process, a product is produced that will be sold and will lead to a profit for the enterprise. With this profit, materials will be purchased again, other resources needed for production will be paid and the process will continue and become self-sustainable. Let’s look at figure 1.

![Figure 1: The production process](https://dictionary.cambridge.org/dictionary/english/industry)

Since the Industrialization Age, human kind develops more and more complex activities. During the last century, people talked about the First and the Second Industrial Revolutions. Then a Third was acknowledged. Today we discuss the Fourth and the Fifth Industrial Revolutions, known as Revolution 4.0 and 5IR. A new way to look at what are the important factors leading to different industrial revolutions is presented by Dr. David Brown. In an interview for Forbes he stated that there are three characteristics that drove the first two revolutions. These factors are also present now in the Third Industrial Revolution. They are: a new energy source, a new communication system and a new financial system.

Component 1: Input
This component takes into consideration the so-called input factors, which can be the following:

- Value of materials
- Materials
- Other resources needed

Value of materials - When choosing basic materials for the production process, materials that are with low value are always selected so that the cost of the finished product is not too high to sell at a certain price. What can affect the value is finding a supplier that offers material with the quality required by the manufacturer, but with a lower purchase price (part of a new business model). New material cheaper than the previous one can be discovered, too (scientific breakthrough).

Materials – some materials can be replaced by substitutes, in case they have the necessary physical and chemical qualities required for the properties of the material (scientific breakthrough or invention); a scientific discovery of a new chemical element, an alloy, a polymer, etc. (scientific breakthrough, invention).

Other resources - human resources, such as lower-paid workforce, skilled and trained personnel (new or improved business model).

Component 2: Process
The following factors are distinguished:

- Transformation
- Processes
- Machines, apparatus and equipment

Transformation is the alteration of raw material into a ready-to-use or semi-finished product. The methods of transformation may differ in whether the same physical and chemical processes are used. In the research and development process it is possible to discover changes that can be performed under better conditions, or without the use of expensive material. For example, the use of newly discovered materials, compounds, or alloys can make the process cheaper, faster or more profitable for the manufacturer (scientific discovery, invention, business model change possible).

Processes - The production of a particular product follows specific steps. Each phase of the production process is important for the quality of the product. When discovering new material, a new machine, or a new production method, there may be a reduction in the number of processes leading to the end product (breakthrough, invention). It can also lead to cost reductions of these processes. Some of them are more labor intensive, others are more expensive, so finding a cheaper alternative will be a good source of radical innovation.

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6 https://dictionary.cambridge.org/dictionary/english/industry

7 https://dictionary.cambridge.org/dictionary/english/revolution

8 https://www.researchgate.net/profile/David_Brown22
Machines, apparatus, equipment – During the development of technology, new, improved and sophisticated machines are produced (scientific breakthrough, invention). Usually, they are more expensive (but the payment is one-off if purchased). On the other hand, this implementation leads to a decrease in labor used, which reduces the cost of production (change of business model). The use of new technology can lead to the introduction of completely new processes.

Component 3: Output
The following factors influence the output needed to reach the end consumer.
• Distribution channels
• Time
• New use of the product
• New product

Each manufacturer has its own distribution channel which supplies the finished goods to consumers. The channel can be long, consisting of many stages, before reaching the end user. Or it can be really short, when the product is purchased directly from the manufacturer. In case there is a change in the way products reach the end user, this might be because of an introduction of a new business model e.g. radical innovation.

Time - The widely used proverb “Time is money” applies to businesses. Time is an important component of the whole production process. The significance to receive materials on time (JIT method), process them in a timely manner (use Kaizen), leads to the last phase – output. It might be of great importance for some products to reach the customer on time or as soon as possible (invention, change of business model).

A new type of product or new use can be achieved when at least one of the previous two components is changed. For example, if a product is made of new material and has new properties, it may possibly be used in a different, previously unknown way, which could lead to a change of the business model. This applies to products that have been modified. New products can be invented, so they can become part of a radical innovation.

4. Analysis of findings
The above information can be synthesized and some conclusions can be reached. The discovery of the steam engine, the use of coal and the creation of factories leads to a change not only in the inputs, but in the process component, too. That is why the outcome is different. Steam engine is considered a radical innovation, which led to mechanization of the production process. This on its own, caused a paradigm shift to happen. Not only cheaper and higher quality material started being produced, in large quantities for a very short amount of time (manufactured goods), but also the railroads and the steamships used to transport them (12). In the Second Industrial Revolution, the paradigm shift has happened when a new source of energy has been discovered – crude

<table>
<thead>
<tr>
<th>Sector of business activity</th>
<th>Industrial revolution</th>
<th>Features</th>
</tr>
</thead>
</table>
| Primary                    | First Industrial Revolution mid-18th to beginning of 19th century (12) | 1. Wood → Coal  
Use water and steam power to mechanize production (13)  
2. Steam-powered printing press, cheap paper & magazines, delivered rapidly (via trains)  
3. London Stock Exchange (8)  
A paradigm shift in production, transport |
| Secondary                  | Second Industrial Revolution – end of 19th to beginning of the 20th century (7) | 1. Coal → Crude oil  
Electric power to create mass production  
2. Telegraph, telephone, electrification, internal combustion engine  
3. Limited liability corporation, reduce risks for entrepreneurs  
A paradigm shift in the use of energy |
| Tertiary                   | Third industrial Revolution – 1969 (14) | 1. Crude Oil → Renewable resources  
2. The Internet, WWW  
3. The financial markets are less advanced, crowdfunding, peer-to-peer finance  
Truly global is the paradigm shift; Knowledge Economy; On-line education; Digitalization – use of Electronics; automated production |
| Quaternary                 | Fourth industrial revolution 1980s (15); (16) | 1. Tries to increase to the 50-100% range of using renewable resources, battery storage technology, biomass  
2. IoT, healthcare advances, needs more stable internet, better security, cheaper components, augmented and virtual reality, blockchain  
3. Google-wallet, Apple-pay, Africa-led mPesa. US Internet giants registering as banks – cheap infrastructure and billion-size customer base; cryptocurrencies  
The paradigm shift is unlimited access to knowledge through the use of technology; industries are disrupted; transformation of entire systems of production, management and governance; AI, Robotics, IoT, 3D printing |
| Quinary                    | Fifth industrial revolution, Davos, 2019 (17) | 1. Sustainable development goals (17)  
2. New, undeveloped methods of communication based on augmented and virtual reality  
3. To change from “for profit” to “for benefit” operating model Humanity, trust, culture, values, ethics (17) |
oil. Thus, electric power initiates the creation of mass production. Some examples of scientific breakthrougths and inventions are: the discovery of petroleum and its properties, the wide use of electricity, standardization of goods like soap, clothing etc., the internal combustion engine and many others. As a conclusion we state that the secondary sector of business activity can be directly related to the First and Second Industrial Revolutions, since it includes manufacturing, processing and changing raw material into finished goods. The first two revolutions had changed greatly the input and the process phases in the production process. The Third Industrial Revolution is driven by technologies of the digital engine of the Internet, renewable energy, AI and 3D printing. The transformations that had started already are changing everything we do, make, use and plan for the future (14).

The failures of economic systems that we are observing now: insufficient use of renewable resources, expensive materials for 3D printing and building AI, breach of security in some countries and many other factors, lead to the Fourth Industrial Revolution, which is knowledge based. Scientists, businesses, start-ups and other organizations are trying to educate people, to find solutions to the recurrent problems. That is why the Founder and the Executive Chairman of the World Economic Forum (WEF), Klaus Schwab in 2016 calls this period a Fourth Industrial Revolution, or 4.0 and states that “…. it is evolving at an exponential rather than a linear pace…. it is disrupting almost every industry in every country. And the breadth and depth of these changes herald the transformation of entire systems of production, management, and governance” (13).

Some of the discussions in the WEF in Davos 2019, were focused on the global climate crisis becoming a catastrophic problem. But there is still something larger, leaders have said; “the march of successive industrial revolutions intensifies the risks of dehumanizing economic progress, to the point that we face now an existential threat in both environmental and humanitarian terms” (17). That is why the Fifth Industrial Revolution will be dedicated to humanity. Another goal would be to try to prepare human kind for the challenges ahead. A big obstacle, though is presented by the fact that “65% of children entering education today will end up in careers that don’t yet exist” (17).

5. Conclusion

The research has outlined some fundamental points. Radical innovations are changing the paradigm of industries and this is being described as an industrial revolution. In relation to this, a distinction is made between the Third, Fourth and Fifth Industrial Revolutions.

Society undergoes different stages of development. Each stage marks a significant change in the way of human existence caused by a corresponding change in the way of thinking. This has been stimulated by a change in the tools of labor. Inventions and innovations are an integral part of this evolutionary process. Changing the tools of labor is drastic, that is why it leads to striking transformations in people’s lives. If radical innovations are recognized and acknowledged, then successfully implemented by managers into the business, they may alter a business entirely by changing existing market, eliminating competition, or completely creating a new market.

Bibliography


Address sequence generator for memory BIST investigation

Mikalai Shauchenka
Lichtenbergschule Darmstadt
nik.sh.de@gmail.com

Abstract: In this paper a method of construction of a generator for address sequences with given values of switching activity, based on the idea of Antonov and Saleev and with use of Toeplitz and Hankel matrices, was proposed. The broad possibilities of this approach and the limitations associated with conflicting requirements for the values of the rows of the matrix and their linear independence are shown. Examples of the formation of standard address sequences used for self-testing of storage devices are described.

Keywords: ADDRESS SEQUENCES, MBIST, SWITCHING ACTIVITY, QUASI-RANDOM SEQUENCES

1. Introduction

The memory devices of modern System-on-a-Chip take up the biggest portion of the area overhead occupied by modern systems [1, 2]. As a result, memory Built-In-Self-Tests (MBIST) have become a common practice in research and application [2, 3]. Modern memory BIST play a crucial role in providing embedded memory of high quality, regardless of the size and level of its architecture. Traditionally, a memory BIST based on march algorithms for testing consists of a number of march elements with a given memory cell address sequence [3, 4]. To achieve high fault coverage, a memory cell address generator types various sequences [5, 6], and can take between 26% and 33% of the whole MBIST [3].

In this paper an address sequence generator for the implementation of MBIST, based on an application of the Antonov and Saleev method [7, 8] is considered. As shown in [6], the occupied area overhead and performance are key properties of such a generator. To significantly reduce the area overhead that is required to store the generating matrix from $m^2$ binary memory cells down to $2m-1$ binary cells, the use of special forms of generating matrices like the Toeplitz matrix and Hankel matrix [6] is justified.

The most common property of an address sequence that is used to test memory devices is the switching activity [1, 2, 3, 4]. Based on the specific of the generating matrices the properties of the address sequences generated according to them are investigated

2. Mathematical model

Let’s consider the address sequence $A(n) = a_0(n) \ldots a_{m-1}(n)$, where $a_i(n), \ i \in \{0, 1, 2, \ldots, m\}$ and $n \in \{0, 1, 2, \ldots, 2^m - 1\}$ as a m-dimensional vector that consists from $2^m$ m-dimensional binary vectors in binary space. Now the problem of generating the necessary address sequence can be regarded as the generation of m-dimensional binary vectors $A(n)$ according to the procedure of generating elements of the binary space [6]. The foundation of the m-dimensional binary space is the set of linearly independent vectors $\{V_1, V_2, \ldots, V_m\}$, $V_i = v_{i1} v_{i2} \ldots v_{im}, v_{ij} \in \{0, 1\}$ that allows to generate the whole binary vector space (all of the $2^m$ binary vectors) through their linear combinations:

$$A(n) = V_1 b_1(n) \oplus V_2 b_2(n) \oplus \ldots \oplus V_m b_m(n).$$

The binary coefficients $B(n) = b_0(n) b_{m-1}(n) b_{m-2}(n) \ldots b_2(n) b_1(n); b_i(n) \in \{0, 1\}, i \in \{1, 2, \ldots, m\}$ form (1) represent the whole set of $2^m$ binary vectors. Then the vector space $A(n)$ generated according to (1) is of dimension $m$ and consists of $2^m$ vectors. So, the vectors $A(n)$ can be used as an address sequence [6]. An effective modification of the classic model (1) for the generation of address sequences was proposed by Antonov and Saleev in [7] and was applied in practice for the generation of address sequences [5, 6, 7]. The essence is the use of the Gray Code sequence to transform the classic relation (1) into a recursive relation with two operands. The main element of such an approach is the basis $\{V_1, V_2, \ldots, V_m\}$ that is represented by a generating square matrix $W$ of size $m \times m$. The matrix can have any entries. The only restricting factor is the linear independence of the set of vectors $V_i$ [6]. To reduce the area overhead required for storing the matrix $W$ and to assure their maximum rank, an original method for generating matrices of special types like the Hankel matrix and the Toeplitz matrix was proposed [6].

3. Switching activity

To judge the properties of the address sequences $A(n) = a_0 a_{m-1} a_{m-2} \ldots a_1 a_0$, generated with Antonov’s and Saleev’s method, the new metric $P(a_j), j \in \{0, 1, 2, \ldots, m-1\}$ was introduced. It defines the number of switches (changes) of the $j$-th bit of $a_j$ in such a sequence. The deciding factor for the judgement of the switching activity is the type of the generating matrix $W$, as shown in [5]. In the case of the Toeplitz matrix, the basis $v_i$ of the matrix $W$ is presented by a Set of linearly dependent binary vectors constructed from $2^m-1$ binary values $v_1, v_2, \ldots v_{2^m-1}$ (2).

$$W = \begin{bmatrix} v_{m+1} & \cdots & v_3 & v_2 & v_1 \\ v_{m+2} & \cdots & v_4 & v_3 & v_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{2m-1} & \cdots & v_{m+3} & v_{m+2} & v_{m+1} \\ v_{2m} & \cdots & v_{m+4} & v_{m+3} & v_{m+2} \end{bmatrix}.$$ (2)

For a generating matrix $W$ and an arbitrary value $j$ the value of the metric will be calculated by the expression (3).

$$F(a_j) = \sum_{i=1}^{m} v_{i-1+j} 2^{m-i}.$$ (3)

The maximum value $maxF(a_0)$ and minimum value $minF(a_0)$ of this property, taking the values of $2^m - 1$ and 1 respectively, are equal to the corresponding values for a generating matrix with linear independent vectors $V_i$ [5]. However, in this case an even greater correlation between the switching activities of the digits of the address sequence can be observed. So, all the entries of the m-th column of the matrix $W$ being equal to 1, namely $v_1 = v_2 = \ldots = v_m = 1$, ensure the maximum switching activity of $2^{m-1}$ of the digit $a_1$ of the address sequence $A(n)$. Respectively, the switching activity of the m-th digit of an cannot be less than $2^{m-1}$, since for the first column of the matrix $v_1 = 1$ and the switching activity of the $m-1$-th bit is equal to $2^{m-2} (v_{m+1} = 0)$.

Based on the specific of the generating matrix $W$ (2), namely the structure of its rows, the integral measure of the switching activity for the number sequence can be calculated by this expression:

$$F(A) = \sum_{i=1}^{m} 2^{m-i} \sum_{j=1}^{m} v_{j-1+i}.$$ (4)
The second sum in relation (4) represents the number of ones in the i-th row of the matrix (2). For the general case considered in (5), the switching activity \( F(A) \) of the address sequence \( A(n) \) takes the minimum value for the Gray Code sequence [6] that is determined by the matrix type (2). Then, for a matrix that consists out of \( m \) different rows, each containing one entry 1, we have \( \min F(A) = 2^m - 1 \) according to (4). The highest estimate of \( F(A) \) is also uniquely defined by the type of the generating matrix [6] that in this case has only entries 1 in the first row and one zero in all the other rows. Then

\[
\max F(A) = 2^{m-1}m + \left( \sum_{i=2}^{m} 2^{m-i} \right)(m-1) = 2^m m - 2^{m-1}m + 1
\]  
(5)

The given estimates of the switching activity of \( F(A) \) are fair for the Toeplitz matrix (2) as well as for the Hankel matrix. The range of possible values of the specified characteristics is defined by the maximum and the minimum values and shows the possibility of generating address sequences with given values for these characteristics.

4. Standard address sequences

The main generalized mathematical model (1) and its modifications considered in the previous sections is the generating matrix \( W \) on which the main properties of the address sequences and their subsets depend. For the implementation of a memory BIST the generator should generate at least a subset of these sequences, since their combinations have characteristic properties that are closely related to the possibility of memory fault discovery [1, 3, 4]. The considered method for generating address sequences allows to generate a huge number of address sequences, having an estimated maximum of \( 2^{2m} \), out of which the standard sequences take up an important portion [3]. The set of such sequences includes: linear sequences; Gray Code sequences; sequences of the Complement type; sequences of the Limited type; sequences with hamming distance equal to 1 for all pairs of addresses; and a number of other sequences.

Let’s consider the generation with the proposed method of the most important and widely used address sequences listed in [3] and shown in table 1 in the form of their generating matrix \( W \).

Linear address sequences \( A(n) \), also called counting sequences, are the main sequences in the sequence family for memory BIST. An example of such a sequence is shown in table 1, for the case of \( m = 4 \), in form of a generating matrix \( W \), that is a Hankel matrix. For minimal load during the test, sequences with minimum switching activity are used. Out of these sequences, the Gray Code sequences stand out.

In the general case, the generation of address sequences with minimum switching activity is performed with a matrix \( W \) with minimum amount of zero values. Both the Hankel matrix with a diagonal of ones or the Toeplitz matrix with the main diagonal consisting of ones (see table 2) can be used for this purpose. At the same time, the maximum load during testing requires the maximum switching activity of the address sequences. For this purpose, the Complement sequences and the Limited sequences often find use. As can be seen from table 1, the maximum value of the switching activity is achieved by the maximum number of nonzero values in the generating matrix \( W \). Indeed, for sequences of the Limited type, the number of nonzero values in the matrix \( W \) reaches the maximum possible value for matrices of maximum rank of \( m^2 - m + 1 \), which provides the ultimate switching activity. For both cases the Toeplitz and the Hankel matrices can be used. Address sequences with a hamming distance of one for all pairs of addresses [3] can be only generated for the case of \( i = m - 1 \) with the Toeplitz matrix (see table 1 for an example where \( m = 4 \)) and for \( i = 0 \) with the Hankel matrix. The proposed method allows to generate a large set of quasi-random sequences [8] with the use of different Toeplitz matrices. An example of such a matrix is shown in table 1. It should be noted that the maximum rank of the matrix \( W \) is a necessary condition for all of the reviewed cases.

<table>
<thead>
<tr>
<th>Linear</th>
<th>Gray Code</th>
<th>Complement</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Table 1. Generating matrices for standard address sequences" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusion

In this paper a method of construction of a generator for address sequences with given values of switching activity, based on the Idea of Antonov and Salev and with use of Toeplitz and Hankel matrices, was proposed. The broad possibilities of this approach and the limitations associated with conflicting requirements for the values of the rows of the matrix and their linear independence are shown. Examples of the formation of standard address sequences used for self-testing of storage devices are described.

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Thermodynamic analysis of three-cylinder steam turbine from combined cycle power plant

Vedran Mrzljak, Jasna Prpić-Orsić, Ivan Lorenčin, Nikola Andelić
Faculty of Engineering, University of Rijeka, Rijeka, Croatia
E-mail: vedran.mrzljak@riteh.hr, jasna.prpic-orsic@riteh.hr, lorenecin@riteh.hr, nandelic@riteh.hr

Abstract: The paper present thermodynamic analysis of three-cylinder steam turbine, which operates in a combined cycle power plant. It is performed analysis of each turbine cylinder and of entire steam turbine. Comparison of steam turbine cylinders shows that intermediate pressure cylinder develops the highest real power and has the highest efficiencies while low pressure cylinder has the highest ideal (isentropic) power, the highest losses and the lowest efficiencies – therefore, improvement potential of the low pressure cylinder is the highest. Entire observed steam turbine has an energy efficiency equal to 86.58 % and exergy efficiency equal to 89.26 %, what is lower in comparison to high power steam turbines from some conventional land-based steam power plants but also higher in comparison to low power marine steam turbines.

KEYWORDS: STEAM TURBINE, COMBINED CYCLE POWER PLANT, THERMODYNAMIC ANALYSIS

1. Introduction

Combined cycle power plants are complex systems which consist of at least one gas turbine (Brayton process) and of at least one steam turbine (Rankine process) [1]. A connection between those two processes is heat recovery steam generator (HRSG) which uses exhaust heat from gas turbine(s) to produce steam for steam turbine [2]. HRSG must be carefully designed with an aim to utilize entire possible heat from exhaust gases and simultaneously to always provide steam of required operating parameters [3].


In this paper is presented a thermodynamic analysis of three-cylinder steam turbine, which operates in a combined cycle power plant. It is performed calculation of efficiencies and losses for each cylinder and for the entire steam turbine. Obtained results show that by taking into account all the cylinders, low pressure cylinder has the lowest efficiencies (and the highest losses), therefore possible improvements should be based firstly on this cylinder.

2. Analyzed steam turbine description, characteristics and operating parameters

General scheme of the analyzed steam turbine (along with operating points required for thermodynamic analysis) is presented in Fig. 1. Each cylinder is of single flow without steam extractions. All the cylinders are connected to the same shaft which drives an electric generator. It should be noted that in Fig. 1 are not presented all the components inside HRSG, presented are only elements through which passes main steam flow streams required for steam cylinders operation.

Steam operating parameters in each analyzed turbine cylinder and for the entire steam turbine is the baseline for energy efficiency and exergy efficiency of combined cycle power plant electrical power output estimation. Comparison of ideal and real expansion processes inside each cylinder and for a whole steam turbine is the baseline for energy (isentropic) analysis, therefore in Table 2 are presented steam specific enthalpies for ideal (isentropic) expansion in each turbine cylinder. Operating points in Table 2 are marked in accordance with expansion processes presented in Fig. 2.

Fig. 1. Scheme of the analyzed steam turbine and operating points

Fig. 2. h-s diagram of real (polytropic) and ideal (isentropic) expansion process in each turbine cylinder

Table 1. Steam operating parameters in each operating point of the analyzed turbine

<table>
<thead>
<tr>
<th>O.P.*</th>
<th>Pressure (bar)</th>
<th>Temperature (°C)</th>
<th>Mass flow rate (kg/s)</th>
<th>Specific enthalpy (kJ/kg)</th>
<th>Specific entropy (kJ/kg K)</th>
<th>Specific exergy (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>103.27</td>
<td>537.78</td>
<td>39.11</td>
<td>3467.90</td>
<td>6.7028</td>
<td>1474.00</td>
</tr>
<tr>
<td>2</td>
<td>17.58</td>
<td>300.25</td>
<td>39.11</td>
<td>3031.60</td>
<td>6.8380</td>
<td>997.40</td>
</tr>
<tr>
<td>3</td>
<td>16.87</td>
<td>518.51</td>
<td>54.78</td>
<td>3512.30</td>
<td>7.5676</td>
<td>1260.60</td>
</tr>
<tr>
<td>4</td>
<td>1.76</td>
<td>228.03</td>
<td>54.78</td>
<td>2928.00</td>
<td>7.6841</td>
<td>641.53</td>
</tr>
<tr>
<td>5</td>
<td>1.69</td>
<td>220.12</td>
<td>62.52</td>
<td>2912.40</td>
<td>7.6715</td>
<td>629.76</td>
</tr>
<tr>
<td>6</td>
<td>0.051</td>
<td>33.23</td>
<td>62.52</td>
<td>2440.30</td>
<td>7.9915</td>
<td>62.16</td>
</tr>
</tbody>
</table>

* Operating points refer to Fig. 1.
### 3. Equations for the energy and exergy analyses

#### 3.1. Energy and exergy analyses of any control volume

Energy analysis of any control volume is defined by the first law of thermodynamics \([10, 11]\). Mass and energy balance equations for a control volume in steady state, while neglecting potential and kinetic energy, can be expressed according to \([12, 13]\) by using equations:

\[
\sum m_{in} = \sum m_{out} , \tag{1}
\]

\[
Q_{in} + W_{in} + P\delta_{in} = Q_{out} + W_{out} + P\delta_{out} , \tag{2}
\]

where the energy flow of any fluid stream can be calculated according to \([14]\) as:

\[
E_{en} = \dot{m}\cdot h . \tag{3}
\]

Exergy analysis of any control volume is defined by a second law of thermodynamics \([15]\). The exergy balance equation is defined, according to \([16]\), as:

\[
\sum (\dot{m}\cdot e)_{in} + X_{heat} = \sum (\dot{m}\cdot e)_{out} + P + E_{ex,D} , \tag{4}
\]

where the exergy transfer by heat ( \(X_{heat}\) ) at the temperature \(T\) can be defined according to \([17]\) as:

\[
X_{heat} = \sum (1-T_0/T)\cdot Q . \tag{5}
\]

Specific exergy of fluid stream is defined as \([18]\):

\[
e = (h-h_0) - T_0 \cdot (s-s_0) . \tag{6}
\]

Similar to energy flow, the exergy flow of any fluid stream can be expressed as \([19]\):

\[
E_{ex} = \dot{m}\cdot e = \dot{m}\cdot [h(h-h_0)-T_0\cdot(s-s_0)] . \tag{7}
\]

Energy and exergy efficiencies in general form can be defined as:

\[
\eta_{en(ex)} = \frac{\text{energy (exergy) output}}{\text{energy (exergy) input}} . \tag{8}
\]

These governing equations are used in observed steam turbine (and all of its cylinders) energy and exergy analysis.

#### 3.2. Energy and exergy analyses of steam turbine from combined cycle power plant

Energy (isentropic) analysis of observed steam turbine and all of its cylinders is based on comparison of real (polytropic) and ideal (isentropic) expansion processes \([20, 21]\) according to operating points presented in Fig. 1 and Fig. 2 as well as according to steam operating parameters presented in Table 1 and Table 2. Exergy analysis of the observed steam turbine and its cylinders is based on real steam expansion processes only \([22]\).

In Table 3 are summarized and presented equations for the energy analysis of each steam turbine cylinder, while in Table 4 are summarized and presented equations for the exergy analysis of each steam turbine cylinder. Equations for the energy and exergy analyses of the whole steam turbine are summarized and presented in Table 5.

<table>
<thead>
<tr>
<th>Point*</th>
<th>(bar)</th>
<th>enthalpy (kJ/kg)</th>
<th>entropy (kJ/kg·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>103.27</td>
<td>3467.90</td>
<td>6.7028</td>
</tr>
<tr>
<td>2</td>
<td>17.58</td>
<td>2956.30</td>
<td>6.7028</td>
</tr>
<tr>
<td>3</td>
<td>16.87</td>
<td>3512.30</td>
<td>7.5676</td>
</tr>
<tr>
<td>4</td>
<td>1.76</td>
<td>2871.30</td>
<td>7.5676</td>
</tr>
<tr>
<td>5</td>
<td>1.69</td>
<td>2912.40</td>
<td>7.6715</td>
</tr>
<tr>
<td>6</td>
<td>0.051</td>
<td>2342.20</td>
<td>7.6715</td>
</tr>
</tbody>
</table>

* Operating points refer to Fig. 2.

### 4. Results and discussion

Real (polytropic) developed power of each cylinder and whole steam turbine, calculated according to data from Table 1, is presented in Fig. 3. In real exploitation, HPC develops the lowest real power equal to 17065.75 kW (when compared to other turbine cylinders). LPC develops real power of 29513.99 kW, while the highest real power is developed in IPC (32007.14 kW).

According to ideal (isentropic) steam expansion, Fig. 2, LPC will develop slightly higher power in comparison to IPC (35646.84 kW in comparison to 35113.09 kW), while the ideal power developed by HPC will remain the lowest (as real power) in comparison to the other cylinders.

Real (polytropic) developed power of the whole turbine is equal to 78586.88 kW, while in an ideal situation, when all steam expansion losses are neglected, analyzed turbine will develop ideal (isentropic) power equal to 90771.03 kW.
Steam exergy flows at the input and output of each cylinder and the whole turbine are essential elements in the calculation of exergy destruction and efficiency. Steam exergy flows at the input and output of each turbine cylinder and the whole turbine are presented in Fig. 4.

From Fig. 4 can be seen that when comparing turbine cylinders, the highest steam exergy flow input (69053.92 kW) has IPC, while the highest steam exergy flow output (39013.02 kW) has HPC, what can be explained by a fact that steam after HPC will be used in two other cylinders, therefore high value of steam exergy flow at HPC output can be expected. The lowest steam exergy flow output, equal to 3886.08 kW has LPC, what is also expected because after LPC steam will be delivered to the condenser and will not be used anywhere in the steam turbine process. The high value of steam exergy flow at the LPC output (if occurs) will be indicator of increased losses (unused steam exergy) in the steam turbine process.

The whole observed turbine has a steam exergy flow at the input equal to 166079.34 kW, while steam exergy flow at the output of the whole turbine is 78041.23 kW.

The whole observed steam turbine has steam exergy flow at the input equal to 166079.34 kW, while steam exergy flow at the output of the whole turbine is 78041.23 kW.

The whole observed steam turbine has exergy efficiency equal to 89.26 %, while its energy efficiency is equal to 86.58 %. Calculated energy and exergy efficiencies of the whole turbine lead to conclusion that observed steam turbine has lower efficiencies in comparison to high power steam turbines from some conventional land-based steam power plants [23], but simultaneously higher in comparison to low power marine steam turbines [24, 25].

5. Conclusions

This paper presents a thermodynamic analysis of three-cylinder steam turbine, which operates in a combined cycle power plant. It is obtained developed power, energy and exergy efficiencies and loses for each steam turbine cylinder and for the entire steam turbine. The most important conclusions derived from this analysis are:
- When observing steam turbine cylinders, IPC develops the highest real power (32007.14 kW), while LPC has the highest ideal (isentropic) power of 35646.84 kW.
- For each cylinder and entire steam turbine it is observed that energy loses are higher and energy efficiencies are lower in comparison to exergy loses and exergy efficiencies.
- The highest loses and the lowest efficiencies (both energy and exergy) are observed in LPC what along with the highest ideal (isentropic) power show the highest improvement potential for this turbine cylinder (if compared to other cylinders).

Further research about this steam turbine will be based on its optimization and on finding possibilities for improving each cylinder operation, starting with a low pressure cylinder.

6. Acknowledgments

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7. References


Determination of empirical coefficients of heat dissipation characteristics by optimization methods for a spark-ignited car engine

Pavel Bolotov, Lloyd Rexford Neuburg

MGTU N.E. Bauman, Moscow, Russia

bolotovpo@student.bmstu.ru

lloyd.neuburg@gmail.com

Abstract: For the development of new engines, as well as to obtain the correct results from mathematical modeling, numerical methods should be used, with the help of which verification of mathematical models takes place. This approach can significantly reduce the material and time costs at the development stage. The influence of the optimization method used in processing the experimental data of engine indexing to obtain semi-empirical coefficients of the form Wiebe is explored. A comparison is made of the rate of calculation of the coefficients of the Wiebe formula using brute force and gradient methods. In both methods, the integral using the modulus of the difference between squares of the experimental and calculated dependences is chosen as the target function. Analysis of the rate of calculation of the coefficients of the Wiebe formula showed the need to use the combined use of both methods: the global minimum of the objective function by the method of brute force with a large step and near the optimal point - the gradient method.

Keywords: PISTON ENGINE, HEAT DISSIPATION, INDICATOR DIAGRAM, OPTIMIZATION, OBJECTIVE FUNCTION, BRUTE FORCE METHOD, GRADIENT DESCENT METHOD

1. Formulation of the problem

When designing new engines, numerical methods are used, by which it is possible to significantly reduce the time and costs of developing new and improving existing piston engines [1]. Traditionally, the improvement of the engine is associated with the design and with the improvement of working processes. At present, special attention is paid to the improvement of the working process in the combustion chamber of a piston engine, since many toxic components are released into the environment with the exhaust gases [2,3,4]. Simulation of the combustion process in a piston engine is a difficult task, since it involves the calculation of a large number of physicochemical processes. In order to obtain a detailed account of all these processes, the use of computational fluid dynamic methods is required [5,6], which leads to the need to use large computational resources and long simulation times. In addition, at this stage of development of computer technology and calculation algorithms, this method does not allow for numerical optimization of a large number of parameters of the cylinder processes, especially for engines.

To calculate the cylinder processes in the early stages of design, semi-empirical formulas are needed, allowing for rapid optimization based on the laws of physics and chemistry. These models are successfully used in the study of the combustion process, but first they require verification, coupled with the processing of experimental data, and the refinement of a number of empirical coefficients of the mathematical model.

Experimental data can be obtained by means of indicator diagrams, such as the one shown in Figure 1. Indicator diagrams measure the change in pressure in the cylinder over the course of a cycle. A pressure sensor is placed in a cylinder and measurements are taken at a set frequency. In addition, parameters such as atmospheric temperature and fuel consumption are measured, which are necessary for determining the heat release rate and total amount.

In this experiment, pressure readings were measured on a VAZ 2101 engine with an AVL pressure sensor GH12D at 20kHz, see Figure 2. By using a well-known engine with a large amount of supporting literature, it was possible to verify the legitimacy of the methodology used in this experiment. The empirical coefficients of heat dissipation characteristics obtained during the experiment could be compared to the results of previous studies, and if the results were sufficiently comparable, such methodology could then be implemented in the design of new engines or those which lacked a significant amount of research literature.

Fig. 1 Example of an indicator diagram.

Fig. 2 Pressure Sensor AVL GH12D

Before the process of determining the empirical coefficients of heat dissipation could continue, a method for selecting the most appropriate indicator diagrams to analyze had to be developed. Pressure readings such as those shown in Figure 3 highlight the significant variability in cylinder pressure readings over the course of just a few cycles for a given engine mode.
For this experiment, indicator diagrams taken from the same engine modes were compared with one another and an average pressure reading was determined. The measured cycle which was closest to this average was then chosen as the indicator diagram to be used to represent that specific mode. The average indicator diagram was determined two ways. First, it was decided to select the recording which was closest to the average indicator diagram, based on integrating the pressure readings over a set of crank angles from -100 to 100 degrees see Table 1. These specific values were chosen to ensure the intake and exhaust strokes were excluded from the combustion analysis. Next, the pressure readings were integrated at cylinder volumes which corresponded to the set of crank angles chosen in the first approach, which resulted in finding engine work output, see Table 2.

Based on the results, it was decided to select the most suitable indicator diagram based on integration of pressure over degrees, instead of pressure over volume, mainly due to the fact that this process is far simpler to integrate.

### Table 1: Minimum, Average and Maximum Pressure Readings integrated over degrees from indicator diagrams (2000rpm with 80% open throttle)

<table>
<thead>
<tr>
<th>RPM</th>
<th>Min Pressure (bar)</th>
<th>Avg Pressure (bar)</th>
<th>Max Pressure (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1739</td>
<td>2660</td>
<td>4470</td>
</tr>
<tr>
<td>2500</td>
<td>5266</td>
<td>5936</td>
<td>6387</td>
</tr>
<tr>
<td>3000</td>
<td>5907</td>
<td>6375</td>
<td>6881</td>
</tr>
</tbody>
</table>

### Table 2: Minimum, Average and Maximum Pressure Readings integrated over cylinder volume from indicator diagrams (2000rpm with 80% open throttle)

<table>
<thead>
<tr>
<th>RPM</th>
<th>Min Work (J)</th>
<th>Avg Work (J)</th>
<th>Max Work (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>87</td>
<td>130</td>
<td>219</td>
</tr>
<tr>
<td>2500</td>
<td>337</td>
<td>380</td>
<td>409</td>
</tr>
<tr>
<td>3000</td>
<td>362</td>
<td>390</td>
<td>422</td>
</tr>
</tbody>
</table>

Once all necessary measurements had been recorded and a method for choosing the correct indicator diagram had been determined, it was possible to continue with the task of refining the empirical coefficients for the combustion model.

Currently, combustion models can be divided into two large classes. The first class is combustion models, in which the kinetics of the process, the propagation of the flame front, etc. are calculated. The second model can be attributed to the calculation of heat generation or the rate of heat generation. With the help of such models the proportion of heat at a specified point in time can be calculated. These models allow for the calculation of the cylinder processes at high speed, but they require setting the "right" empirical coefficients to ensure the required calculations are accurate, while the models for calculating the heat release rate factor can be quite complex [7,8] and difficult when solving complex modern cylinder process optimization tasks [9,10].

There is a large number of semi-empirical dependencies for calculating the rate of heat release, but the formula of the Soviet scientist Wiebe has been most widely used [11,12,13]. In the derivation of this formula (1), the assumption of the chain mechanism of combustion of Semenov is used [11]. The formula for calculating heat dissipation is:

\[
x = 1 - \exp\left[-6,908 \left(\frac{\tau}{\tau_z}\right)^{(m+1)}\right],
\]

where \(m\) is the rate of combustion; \(\tau\) - the current time from the start of the combustion process, \(\tau = 0 \ldots \tau_z\); \(\tau_z\) - the duration of the combustion process.

### 2. Object of study

In this work, an approximation of the experimental heat dissipation curve in various modes was performed by numerical methods for an automotive engine with spark ignition with a piston stroke of 66 mm and a cylinder diameter of 76 mm.

### 3. Mathematical Model

For the selection of parameters in the formula Wiebe, it is necessary to process the experimental data (indicator diagrams) and obtain the experimental heat release rate. To do this, we write the system of equations [14]:

\[
dp/p + dV/V = dT/T,
\]

\[
dQ/dt = p \cdot dV/dt + m \cdot Cv \cdot dT/dt,
\]

where \(p\) - pressure, Pa; \(V\) - volume, m3; \(T\) - temperature, K; \(R\) is the specific gas constant, \(m\) is the mass of the mixture, kg; \(Cv\) is the specific heat at constant volume, J/kg/K.

Solving the system of equations (2,3) we obtain the ordinary differential equation

\[
dQ/dt = k/(k-1) \cdot p \cdot dV/dt + 1/(k-1) \cdot V \cdot dp/dt,
\]

where \(k = Cp/Cv\), for spark ignited gasoline engines, depending on the temperature, \(k = 1.280 \ldots 1.315\) [15].

On the other hand, the derivative of heat supplied to the combustion chamber can be expressed as follows:

\[
dQ/dt = dQw/dt + dQx/dt,
\]

where \(Qw\) - the amount of heat absorbed from the combustion chamber into the wall, J; \(Qx\) - the amount of heat supplied during combustion, J.

Traditionally [11], at the end of the combustion, the amount of heat released as a result of chemical transformation from the fuel is calculated by the formula:

\[
Qx = Hu \cdot qc,
\]

where \(qc\) - cyclic fuel supply; \(Hu\) is the lowest calorific value of the fuel.

To simplify [14], one can make the following simplification:

\[
dQw/dt = -\chi \cdot dQx/dt,
\]
As the objective function, we take the sum of the modulus of the squares of the difference between the calculated curve and the experimental one. In this task, one should look for the minimum of the objective function:

\[ f(a) \rightarrow \min, \]

where \( a = \Sigma [ (\Delta X / \Delta \phi) - (\Delta X_{\text{exp}} / \Delta \phi)]^2 \); \( \Delta X_{\text{exp}} / \Delta \phi \) — burning time; \( \Delta X / \Delta \phi \) — rate of fuel burned by the diffusion mechanism; \( C = \log (1 - 0.999) \).

For a spark motor, the varying variable is the burn rate \( m_v \), which ranges from 0 to 7.

This task can be solved in two ways:

1) brute force method. To do this, we divide the range of varying variables with a constant step and calculate the value of the heat release rate using the Wiebe formula at every point. After that, we find a series of values of the objective function and determine the minimum among them. This method allows one to determine the global extremum, but requires a large amount of computation;

2) gradient method of multidimensional optimization (method of steepest descent). This is an iterative numerical method for solving optimization problems, which makes it possible to determine the extremum (minimum or maximum) of the objective function much faster than the brute force method. However, during the solution, the local minimum of the objective function is determined, which does not always coincide with the global extremum.

Comparison of two numerical methods for different engine operating modes is given in Table 4.

<table>
<thead>
<tr>
<th>Engine operating modes</th>
<th>Brute Force</th>
<th>Gradient Descent Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crankshaft speed, min⁻¹</td>
<td>( m_v )</td>
<td>( t_{\text{calc}} )</td>
</tr>
<tr>
<td>2000</td>
<td>0.84</td>
<td>14.3</td>
</tr>
<tr>
<td>2500</td>
<td>0.67</td>
<td>12.1</td>
</tr>
<tr>
<td>3000</td>
<td>1.01</td>
<td>10.0</td>
</tr>
</tbody>
</table>

From the data of Table 4, the counting time using brute force is about 10 times lower than the counting rate using the gradient method. The use of the combined method: a full exhaustive method to determine the global extremum and the gradient method to refine the found solution, will reduce the computation time with a high accuracy of determining the empirical coefficients of the formula Wiebe.

Figure 5 shows the processing result of the experiment and the calculation results by two methods using the example of a spark-ignited engine (at a crankshaft rotation speed of 2000 min⁻¹).

The brute force method [16,17] allows the coefficients to be determined with sufficient accuracy, but its implementation requires a large amount of calculations, which leads to an increase in the simulation time. It follows that with an increase in the number of variables, the simulation time increases significantly.

The gradient descent method [18, 19, 20] makes it possible to find the minimum of the objective function in 10 ... 30 iterations, which leads to a reduction in the calculation time. However, the gradient descent method allows us to find the local minimum of the objective function, in contrast to the sequential search method.

As a result of the application of numerical methods, sets of coefficients (see Table 3) were obtained for the Wiebe formula for several modes that can be used for further calculations of the cylinder processes. Combining optimization methods makes it
possible to find the global minimum of the objective function using the brute-force method with a large step, and in the vicinity of this point, to use the gradient method.

![Graph](image_url)

**Fig. 5** The dependence of the heat release rate (a) and heat release (b), obtained experimentally and by calculation, on the angle of rotation of the crankshaft (φ); 1 – experimental curve, 2 – brute force method, 3 – method of steepest descent

### 4. Summary

1. Using two optimization methods, the mv coefficient for the semi-empirical heat release Wiebe formula is obtained, in several modes with partial engine load; the difference between the results obtained by different methods ranged from 4.6 to 8.2% - such a result can be considered satisfactory.

2. The application of each optimization method: brute force and gradient, has its own advantages and disadvantages. The combination of these methods can significantly increase the speed of calculations and the accuracy of determining the empirical coefficients of the b formula.

### 5. References


Abstract: Over the last few years, Deep learning has begun to play an important role in analytics solutions of big data. Deep learning is one of the most active research fields in machine learning community. It has gained unprecedented achievements in fields such as computer vision, natural language processing and speech recognition. The ability of deep learning to extract high-level complex abstractions and data examples, especially unsupervised data from large volume data, makes it attractive a valuable tool for big data analytics. In this paper, we review the deep learning architectures which can be used for big data processing. Next, we focus on the analysis and discussions about the challenges and possible solutions of deep learning for big data analytics. Finally, have been outlined several open issues and research trends.

Keywords: BIG DATA, BIG DATA ANALYTICS, DEEP LEARNING, AUTO-ENCODERS, DEEP BELIEF NETWORKS, CONVOLUTIONAL NEURAL NETWORKS, RECURRENT NEURAL NETWORKS, RESTRICTED BOLTZMANN MACHINES

1. Introduction

Recently, Deep learning and Big data analytics are the very active fields of research in the science and engineering domains. Big data is defined as digital data, which is difficult or impossible to manage and analyze with traditional software tools and technologies [1]. Analyzing of data and obtaining knowledge and useful information from them is very important for making motivated decisions in organizations, new scientific revelations, national security and healthcare fields. The demand for data analysis in real-time has led to the creation of Big data analytics. Big data analytics is a process of extracting useful information from large volumes of data to make optimal (best) decisions. The size of data has considerably grown in the last decade, with the emergence of social networks, Internet of Things, cloud computing and other technologies. The rapid increasing of data volume, along with the promises potential opportunities for all sectors of society, creates problems for data mining and information processing [2]. Dealing with these data can be supported by Deep learning capabilities, especially its ability to deal with both the labeled and unlabeled data which are often collected abundantly in Big data. Deep learning is an attractive research topics that belong in Artificial Intelligence (AI). DL refers to machine learning techniques that based on supervised and unsupervised methods to automatically learn hierarchical representations in deep architectures. It has achieved unprecedented success in applications of essential fields such as computer vision, speech and audio processing, and natural language processing [3-7].

The ability of Deep learning to extract high-level, complex abstractions and data representations from large volumes of data, especially unsupervised data, makes it attractive as a valuable tool for Big data analytics [4-6]. More specifically, Big data analytics problems such as semantic indexing, data tagging, fast information retrieval, and discriminative modeling can be better addressed with the aid of Deep Learning. In addition, there are need to use of Deep learning methods in solving of different problems that faced Big data analytics such as fast moving streaming data, highly distributed input sources, noisy and poor quality data, high dimensionality, scalability of algorithms, unsupervised and un-categorized data, limited supervised / labeled data and format variations of raw data.

The structure of the paper is organized as follows: Section 2 presents a brief review of typical deep learning models which are the most widely used for big data analysis and feature learning. Section 3 introduces possible solutions of deep learning for big data analytics challenges. Section 3 gives some open issues and research trends; and the final section is conclusions.

2. Brief review of deep learning architectures

Deep learning refers to a set of machine learning techniques that learn multiple levels of representations in deep architectures. In the last few years, various deep learning architectures have been developed. A brief overview of the deep learning architectures has been looked throw that are commonly used in Big Data analytics below.

2.1. Autoencoder and Stacked Autoencoders (SAEs)

As one of the most widely used deep learning techniques, Stacked autoencoders (SAEs) are constructed by stacking several autoencoders that are the most typical feed-forward neural networks [7]. Autoencoder is a kind of unsupervised learning structure that owns three layers: input layer, hidden layer, and output layer (Fig 1.). The process of an autoencoder training consists of two stages, i.e., encoding stage and decoding stage. Encoder is used for mapping the input data into hidden representation, and decoder is referred to reconstructing input data from the hidden representation. SAE is typically trained by two stages, i.e., pre-training and fine-tuning. In the pre-training stage, each auto-encoder model is trained in a unsupervised layer-wise manner from bottom to top. This operation is repeated until the parameters of all the hidden layers are trained. After all the hidden layers are trained, backpropagation algorithm is used to minimize the cost function and update the weights with labeled training set to achieve fine-tuning [7, 8].

Fig. 1 Architecture of autoencoders.

2.2. Restricted Boltzmann Machines (RBMs) and Deep Belief Network (DBN)

Deep belief network is the commonly used, and successfully trained architectures in deep learning [9]. DBN is stacked by several restricted Boltzmann machines, as presented in Figure 3. RBMs are the most popular version of Boltzmann machine [5,7]. The Restricted Boltzmann Machine (RBM) is a probabilistic graphical model or a type of stochastic neural network. The network consists of two layers, i.e., visible layer and hidden layer (Fig. 2). The restriction is that there is no interaction between the units of the same layer and the connections are solely between units from different layers.

Deep belief networks have the potential to learn the representation of features using structured and unstructured data. It consists of input, hidden, and output layer. RBM uses DBN to construct a model that consists of two layers that are fully connected to each other. DBN combined strategies of unsupervised pre-training and supervised fine-tuning. The unsupervised stages intend to learn data distributions without using label information and supervised stages perform local search for fine tuning[7]. In the literature, DBN model is used by many researchers to efficiently and accurately process big data.
In particular, a graphical processing unit (GPU)-based model using stacked RBM in parallel to handle large volume of data with minimized process. The power of deep learning is that it can train and handle millions of parameters at a time. Several restricted Boltzmann machines can be stacked into a deep belief network.

2.3. Convolutional Neural Networks (CNNs)

The convolutional neural network (CNN) is a multilayer, feed-forward neural network that uses perceptrons for supervised learning and to analyze data. It is used mainly with visual data, such as image classification. CNN architecture is different from other neural networks. The hidden layers in CNN contain convolutional layer, subsampling layer (pooling layer) and a fully connected layer (Fig. 3). Characteristically, CNN start with convolutional layer that accepts data from input layer. The convolutional layer is responsible for convolution operations having few filter maps of same size. The convolutional layer uses the convolution operation to achieve the weight sharing while the subsampling is used to reduce the dimension [6, 7].

Following the convolutional layer, a subsampling (or pooling) layer is usually used to reduce the dimension of the feature map. It can typically be realized by an average pooling operation or a max pooling operation. After the second stage, CNN uses a fully connected layer and then a softmax layer with output classes for classification and recognition.

During recent years, CNN has achieved great success in many applications such as image analysis, speech recognition, text understanding and so on [7].

2.4. Recurrent Neural Networks (RNNs)

Recurrent neural network considered as another class of deep networks for unsupervised / supervised learning that is very powerful for modeling sequence data (e.g., speech or text). RNN learns features for the series data by a memory of previous inputs that are stored in the internal state of the neural network. The connections between neurons is constructed with a directed cycle (Fig. 4). Unlike traditional networks, where inputs and outputs are independent of each other, the recurrent neural network captures the dependency between the current sample with the previous one by integrating the previous hidden representation into the forward pass. From a theoretical point of view, the recurrent neural network can capture arbitrary-length dependencies. However, it is difficult for the recurrent neural network to capture a long-term dependency because of the gradient vanishing with the back-propagation strategy for training the parameters. To tackle this problem, some models, such as Long Short-Term Memory, have been presented by preventing the gradient vanishing or gradient exploding [7]. The recurrent neural network and its variants have achieved super performance in many applications such as natural language processing, speech recognition and machine translation.

3. Deep learning in Big Data analytics

The big data application process generally includes stages such as data generation, data management, data analytics, and data application. Big data analytics, which is considered the most important phase in the whole chain, refers to the process of discovering patterns from data. In this stage, there are several challenges (such as high dimensionality, scalability of algorithms, fast moving streaming data, noisy and poor quality data and so on), which is made big data analytics much more difficult and complicated than normal-sized data analytics [10].

In this section have been provided the analysis and discussions about the challenges and possible solutions of deep learning for big data analytics.

3.1. Complex data representation

Big Data is usually collected from different domains which consists of multiple modalities. Each modality has a different representation, distribution, scale, and density. For example, text is usually represented as discrete word-count vectors, but an image is represented by real values of pixel intensities [11]. The using of existing methodologies for the processing of such data is almost impossible. The solution of this problem is possible owing to the integration of heterogeneous data.

Deep Learning is more fitting for heterogeneous data integration due to its potentiality of learning variation factors of data and providing abstract representations for it. Deep learning has been demonstrated to be very effective in integrating data from different sources [3]. Some multi-model deep learning models have been proposed for heterogeneous data integration.

For example, Ngiam et al. [12] developed a multi-modal deep learning model to learn representations by integrating audio and video data. Srivastava and Salakhutdinov [13] developed a multimodal Deep Boltzmann Machine (DBM), for text data and image objects feature learning.

Ouyang et al. [14] presented multi-modal deep learning model, called multi-source deep learning model aims to learn non-linear representation from different information sources. In this model each source of information is used as input data for the two hidden layers deep learning model. Extracting features separately are then combined for joint representation.

Generally, though the architecture of the proposed multi-modal deep learning models is different, their ideas are similar. In particular, multi-modal deep learning models firstly learn features for single modality. Then learned features are combined as the joint representation for each multi-modal object. These models have been achieved more superior productivity than traditional deep neural networks for heterogeneous data feature learning. However, these models combine the learned features of each modality in a linear way. So they are far away effective to capture the complex correlations over different modalities for heterogeneous data. In order to eliminate this problem, Zhang et al. [15] presented a tensor deep learning model, called deep computation model, for heterogeneous data.

3.2. Super-high dimensionality

Big data in specific domains is often super-high dimensional. Generally, with the increase of the data dimension, the required amounts of time or memory go up exponentially. The problem is that existing machine learning and data mining algorithms are not well scalable to high-dimensional data (such as, images), or are not computationally efficient.
Chen at al. [16] developed marginalized stacked denoising autoencoders (or mSDAs) which scale effectively for high-dimensional data and is computationally faster than regular stacked denoising autoencoders (SDAs). This approach marginalizes noise in SDA training and therefore does not require other optimization algorithms to learn parameters.

Zhang et al. [17] proposed a new tensor-based representation algorithm for image classification. The algorithm is realized by learning the parameter tensor for image tensors which the algorithm preserved the spatial information of image.

Convolutional neural networks also can scale up effectively to high-dimensional data. On ImageNet dataset with 256×256 RGB images, CNNs produced state-of-the-art results [4]. For instance, Krizhevsky et al. [18] trained one of the largest Deep Convolutional Neural Networks (DCNN) to classify ImageNet LSVR-C 2010 contest which comprises 1.2 million high-resolution images belonging to 1000 different image classes. It is one of the most well-known CNN architectures for classification. This large DCNN consists of 650,000 neurons with 60 million parameters and eight layers.

Maggiori et al. [19], proposed an end-to-end framework for the dense, pixel-wise classification of satellite imagery with convolutional neural networks.

The above Deep Learning algorithms for Big Data Analytics involving high dimensional data are not sufficient, and requires new methods for better performance of DL techniques to handle high-dimensional data.

3.3. Unscalable computation ability

A big dataset often includes a large number of attributes and many class types of samples, so some frequently used data mining and machine learning algorithms, is not work well. In order to learn features and representations for large amounts of data, some large-scale deep learning models have been developed. They can nealy grouped into three categories, such as parallel deep learning models, GPU-based implementation, and optimized deep learning models [7].

Existing deep learning systems commonly use data or model parallelism, but unfortunately, these strategies often result in suboptimal parallelization performance. Z. Jia et al. [20] proposed FlexFlow, a deep learning system that automatically finds efficient parallelization strategies for DNN applications. Authors evaluate FlexFlow with six real-world DNN benchmarks on two GPU clusters and show FlexFlow significantly outperforms state-of-the-art parallelization approaches.

Dean et al. [21] determined the possibility of training a deep network with billions of parameters using tens of thousands of CPU cores. Authors have developed a software framework called DistBelief that can utilize computing clusters with thousands of machines to train large models. DistBelief needs 16 thousand CPU cores to train a large deep learning model with 10 million images and billion parameters.

Sun et al. [22] presented techniques to accelerate distributed training of DNN on GPU clusters. They used two clusters: a cluster with 16 machines, each having 8 Pascal GPUs and a cluster with 64 machines, each having 8 Volta GPUs.

Coates et al. [23] deployed a less expensive cluster of (GPU) servers and also Commodity Off-The-Shelf (COTS) HPC technology with a high-speed communication network to coordinate distributed computations. This system is capable to training for 1 billion parameters networks on just 3 machines in a few days and is capable scaling up to 11 billion parameters with 16 machines. Therefore, this system is affordable for everyone who wishes to explore large scale systems.

Novikov et al. [24] proposed a tensorizing learning model based on the tensor-train network. Authors converted the neural network to the tensor format to use the tensor-train network to compress the parameters. This method could reduce the computational complexity and improve the training efficiency in the back-propagation procedure.

There is a need to develop new algorithms for scalable deep learning which make it suitable for high dimensional data processing and analysis.

3.4. Fast moving streaming data

One of the challenging aspects in Big Data Analytics is dealing with streaming and fast-moving input data. The data stream is generated at an extremely fast speed, and its distribution characteristics are in high-speed dynamic changes, which must be processed in real time.

Deep learning to handle streaming data, as there is a need for algorithms that can deal with large amounts of continuous input data. In recent years, a lot of incremental learning methods have been presented for high-velocity data feature learning.

Zhou et al. [25] proposed an incremental feature learning algorithm to determine the optimal model complexity for large-scale datasets based on the denoising autoencoder. The model quickly converges to the optimal number of features in a large-scale online setting. In addition, the algorithm is effective in recognizing new patterns when the data distribution changes over time in the massive online data stream. Calandra et al. [26] demonstrated Adaptive Deep Belief Network to learn from online, nonstationary stream data.

Y. Li and et al. [27] proposed an incremental high-order deep learning model based on parameter updating and structure updating to meet the requirements of dynamic big data online analysis and real-time processing. The model has the ability to incrementally learn the characteristics of new data online, also retains the ability to learn the original data features, and real-time processing of dynamic data streams.

3.5. Noisy and poor-quality data

There are a huge number of noisy objects, incomplete objects, inaccurate objects and imprecise objects in Big data. This low-quality data is widespread in Big data. For example, there are over 90% missing attribute values for a doctor diagnosis in clinic and health fields. Some traditional learning algorithms have obviously not been valid for processing the data with 90% missing values.

In the past few years, some methods have been proposed to learn features for poor-quality data.

Wang and Tao presented a non-local auto-encoder model to learn reliable features for corrupted data [280]. The model achieved high performance in image denoising and restoration. Mao et al. [29] proposed a very deep fully convolutional auto-encoder network for image restoration. Since this method is based on convolutional operations, its main limitation is the local nature of the extracted features.

In [30], a deep convolutional neural network has been proposed for image denoising, where residual learning is adopted to separating noise from noisy observation.

Recent methods based on CNNs can only operate local similarities and they are incapable to capture non-local similar to itself patterns, which have been highly successful in model-based methods. In order to exploit both local and non-local similarities, in [31], has been proposed a graph-convolutional neural network, to perform image denoising. This method provides the best visual quality, recovering finer details and producing fewer artifacts.

4. Results and discussion

Researches show that significant progress has been obtained in the application field of deep learning algorithms in Big data analytics. DL sufficiently simplifies solution of Big data analytics problems as analysis of large data volumes, semantic indexing, data tagging, information retrieval, classification and prediction. At the same time, deep learning has achieved limited progress in the field of stream data and low-quality data processing, model scaling, distributed computing, and high-scale data processing. Below have been outline several open issues and research trends.

1) Continuous increasing of volume of big data makes it necessary to create more large-scale deep learning models. Such large-scale deep learning models that can be trained for Big Data
may no longer be effectively trained, depending on the available techniques and computing power. It is important to create new learning structures and computing infrastructures in the future to solve this problem.

2) Modern multi-modal deep learning models simply combine in a linear form the learned features of each modality. This often does not lead to the necessary results. There is a need to investigate the effective fusion ways of learned features to improve the productivity of multi-modal deep learning models. At the same time, deep computational models have a large number of parameters that caused their high computational complexity. There is a need to research in the field of reducing the computational complexity of deep computational models.

3) Most of the integrated learning algorithms that based on updating one or more parameters or structures are effective only for a hidden layer, traditional learning models. There is a need to research of the application possibilities of integrated learning algorithms to deep learning models and deep architectures.

4) It is important to investigate reliable deep learning models for low-quality data in the near future, due to the rapid growth of low-quality data.

5) There is a need to develop new parallel and distributed algorithms/frameworks for scalable deep learning models.

5. Conclusion

In this paper has been investigated how deep learning algorithms and architectures are used to solve Big Data analytics problems. An overview of significant literature according to the application of Deep Learning in different domains showed that Deep Learning has the potential opportunities to the solving of many analytics and learning challenges faced by Big Data analytics unlike traditional machine learning methods. But while Big Data offers enough training objects for deep learning, it creates problems for large scale, heterogeneity, noisy labels, and non-stationary distribution, among many others. In order to realize the full potential of Big Data, we need to address these technical challenges with new ways of thinking and transformative solutions. For this reason, there is need for extensive investigations in the field of deep learning the future.

References


Nagata patch interpolation for finite volume mechanical contact simulations

Ivan Batistić1, Željko Tuković2, Philip Cardiff1, Peter De Jaeger3
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia1
University College Dublin, School of Mechanical and Materials Engineering, Belfield, Ireland2
NV Bekaecr SA, Belgium1
ivan.batistic@fsb.hr

Abstract: This paper describes a finite volume contact algorithm with surface smoothing using the Nagata patch interpolation. Nagata interpolation is derived from existing discretisation, using the mesh points positions and their calculated normal vectors. The contact between a deformable and a rigid body is analysed, whereas the rigid body is described with Nagata patch interpolation. Such approach allows a more accurate evaluation of the resulting contact stresses and forces.

Keywords: MECHANICAL CONTACT SIMULATION, SURFACE SMOOTHING METHOD, NAGATA PATCH INTERPOLATION, FINITE VOLUME METHOD, FOAM-EXTEND

1. Introduction

As the finite element method is a common approach in the numerical stress analysis, it is also the most developed and advanced numerical method for calculating mechanical contact problems [1]. Recently, the finite volume method has established itself as a noteworthy alternative to the widely used finite element method in the simulation of stress analysis problems. Since the finite volume method proved to be capable of resolving strongly non-linear fluid flow problems, it is successfully applied to non-linear solid mechanics problems [2, 3].

Although the development and application of the finite volume method for stress analysis problems began more than two decades ago, the mechanical contact applications are still limited. The first finite volume mechanical contact calculation algorithm is proposed in [4] for linear elastic solids, where the contact constraint is enforced using the Dirichlet-Neumann partitioned procedure. The proposed Dirichlet-Neumann partitioned procedure was appropriate for two-dimensional cases, but it showed substantial limitations in three-dimensional applications, where it was difficult to prevent unphysical stresses at the edge of the contact surface. Because of the mentioned limitations, a contact algorithm based on the penalty method is developed in [5]. The proposed algorithm is based on the explicit update of contact force calculated at mesh points using penalty method. The calculated contact force is imposed on boundary via Neumann boundary condition. The algorithm was originally developed for three-dimensional frictionless problems. The extension on problems with friction and large elastoplastic deformation is done in [2]. The proposed contact calculation algorithm showed good stability and accuracy for complex contact problems. In order to better describe the friction in metal forming processes, the algorithm is extended to consider the lubrication in [6]. The lubrication is modelled by the Reynolds lubrication equations and solved numerically using the finite area method.

Algorithms for calculating contact problems with the finite element method cannot be directly applied to the finite volume method. In the finite element method, the weak form of the equation is solved. The contact effects are introduced via additional contact constraints. The main advantage of the chosen surface smoothing method is that it can be carried out efficiently and locally. The proposed procedure is implemented and tested in the foam-extend open source library.

2. Mathematical model

For each bodie in contact the conservation of linear momentum is considered:

\[ \frac{\partial}{\partial t} \int_\Omega \rho \frac{\partial u}{\partial t} \, d\Omega = \oint_\Gamma \rho \mathbf{b} \, d\Omega, \]  

(1)

where \( \rho \) is the density, \( u \) is the displacement vector, \( \sigma \) is the Cauchy stress tensor, and \( b \) is a body force per mass unit. With appropriate constitutive equation for each bodie, the eq. (1) is reformulated into total Lagrangian form. After the finite volume discretisation, a system of algebraic equations is obtained and solved in a segregated manner using iterative solvers. Contact is introduced via Neumann boundary condition, where the contact constraints are enforced using penalty method. More details about finite volume discretisation and solution procedure can be found in [2, 3].

2.1 Contact constraints

The mathematical background of the contact problem is defined by the contact constraints. The contact constraints can be divided into normal and tangential constraints. Accordingly, the normal contact constraints describe the normal component of the contact force, whereas the tangential constraints describe the tangential component of the contact force. The normal contact constraints are formulated using the Karush-Kuhn-Tucker conditions, being stated as:

\[ g_\sigma \geq 0, \quad p_\sigma \leq 0, \quad p_\sigma g_\sigma = 0, \]  

(2)

which must hold for all points on contact surface. The first term in the eq. (2) represents the geometric impenetrability condition. The second term allows only compressive contact pressure \( p_\sigma \), whereas the third term is the complementarity condition. Tangential contact constraints are described by a friction law. Most famous and simplest friction law is Coulomb law, which is described by the following three conditions:

\[ \| \mathbf{t} \| - \mu | p_\sigma | \leq 0, \quad t \mathbf{r} + p_\sigma \mathbf{g}_\sigma \mathbf{r} + \frac{\partial p_\sigma}{\partial \mathbf{g}_\sigma} = 0, \]  

(3)

where \( \mu \) is the constant friction coefficient, \( \mathbf{g} \) tangential relative sliding velocity and \( t \) the frictional force vector. The first term in eq. (3) limits the frictional contact force, the second term defines its direction, whereas the third term is the complementarity condition. To conclude, the contact conditions, i.e. components of contact force, are described by nonlinear functions. Hence, they are the main source of the nonlinearity of contact problems.
3. Surface smoothing method

From the numerical point of view, the finite volume analysis of contact problems can be divided into two categories. First, the general category represents contact between deformable discretized bodies whereas the second category is the simplification in which one body is rigid. For contact problems with large difference between stiffness of the contact bodies, the stiffer body can be represented as a rigid. Such approach leads to less computational effort and can be used in the simulations of complex engineering problems like: metal forming processes, rubber seals, tyre on road, indentation tests [7, 8, 9]. The representation of rigid body surface can be done using analytical surfaces, piecewise linear discretisation or with parametric patches obtained with surface smoothing. The analytical approach is limited on simpler geometry, whereas piecewise discretisation poses some drawbacks when point projection is calculated. Using surface smoothing methods, rigid contact surface is accurately and continuously described using higher order interpolations. Although, various surface smoothing methods have been developed in the finite element method, the recently applied Nagata patch interpolation can be easily generalized and efficiently applied on arbitrary piecewise linear finite volume mesh topology.

3.1 Nagata patch interpolation

The Nagata patch interpolation was originally proposed by Nagata [10]. The interpolation is based on a quadratic polynomial, requiring only position and normal vectors at the nodes of the surface mesh. The features of the proposed interpolation algorithm allows its efficient and robust application on arbitrary mesh topology. It is important to note that the proposed formulation can handle discontinuity of normals, sharp edges and singular points. In the presented study the interpolation method is used on smooth rigid surfaces, discretized with triangular facets.

![Fig. 1 Nagata patch interpolation.](image)

For triangular Nagata patch (see Fig.1), the interpolated surface is given by the quadratic polynomial:

\[ x(\eta, \zeta) = c_0 + c_1 \eta + c_2 \zeta + c_3 \eta^2 + c_4 \zeta^2, \quad (4) \]

where \( \eta \) and \( \zeta \) are the local coordinates defined on the patch region, and satisfy the next condition:

\[ 0 \leq \zeta \leq \eta \leq 1. \quad (5) \]

The coefficients in equation (4) are:

\[ c_0 = x_{00}, \quad c_1 = x_{10} - x_{00}, \quad c_2 = x_{11} - x_{10}, \]
\[ c_3 = c_1 - c_2, \quad c_4 = c_2, \quad c_5 = c_3, \quad c_6 = c_3, \quad c_7 = c_2, \quad c_8 = c_1, \quad c_9 = c_0, \quad c_{10} = c_0, \quad c_{11} = c_0, \]

where \( c_1, c_2 \) and \( c_3 \) are the vectors obtained with the edge interpolation. For each edge \((x_{00}, x_{10}), (x_{10}, x_{11})\) and \((x_{00}, x_{11})\), quadratic Nagata curve can be defined (see Fig. 2):

\[ x(\zeta) = x_1 + x_2 - x_1 - c_1 \zeta + c_2 \zeta^2 \quad \text{where} \quad 0 \leq \zeta \leq 1. \quad (7) \]

![Fig. 2 Nagata edge curve](image)

Vectors \( x_1 \) and \( x_2 \) are the position vectors of the edge end points, and \( c \) is the unknown coefficient vector. Coefficient vector \( c \) is calculated as:

\[ c = \begin{bmatrix} n_1 & n_2 \end{bmatrix} \begin{bmatrix} 1 & -a \\ 1 & 1 \end{bmatrix} \begin{bmatrix} n_1(x_2 - x_1) \\ n_2(x_2 - x_1) \end{bmatrix} \quad (a \neq \pm 1), \]

\[ \begin{bmatrix} 0 \\ (a = \pm 1) \end{bmatrix}, \quad (8) \]

where \( a = n_1, n_2 \) and \([\cdot, \cdot]\) represent a matrix composed by two vectors. Equation (8) is derived from the assumption that the Nagata curve is orthogonal to the unit normal vectors \( n_1 \) and \( n_2 \) at points \( x_1 \) and \( x_2 \) respectively. For the parallel normal vectors \((a=\pm 1)\), the Nagata curve describes the linear segment, because of the zero coefficient vector \( c \). More details about the Nagata patch interpolation on triangular and quadrilateral patch can be found in the literature [11, 12].

3.2 Point normal calculation

In order to construct the Nagata patch, the calculation of normals at mesh vertices is conducted. The normal vectors at mesh points are estimated with normals from the point neighbouring faces. The calculation is done using the weighted average of the unit normal vectors of all neighbouring faces:

\[ n_p = \frac{\sum_{i=1}^{6} \omega_i n_{p,i}}{\left| \sum_{i=1}^{6} \omega_i n_{p,i} \right|}, \quad (9) \]

In the presented study each neighbouring face contributes equally to the normal vector calculation (mean weighted equally). In the literature more advanced approach can be found, such as mean weighted by angle or mean weighted by areas of adjacent triangles [12].

4. Contact algorithm

The first part of the contact algorithm is the contact search. For each mesh point \( P \) of the deformable body potential Nagata contact candidates are identified. The potential contact candidates are calculated using the Axis Aligned Bounding Box quick rejection test. Such approach generates false candidates which are detected and eliminated using the Separation Axis Theorem algorithm. Using potential candidate list, for each contact point, the closest point projection is calculated for all candidates in order to find the minimal normal gap value. The relationship between the coordinates of contact point and closest point on Nagata patch is described with the following equation:

\[ P_{proj}(\eta, \zeta, g) = x(\eta, \zeta) + g_n n(\eta, \zeta) - P = 0, \quad (10) \]

where \( P \) denotes the contact point on the deformable contact surface, \( x \) closest point on the Nagata patch and \( n \) unit normal vector of the Nagata patch (see Fig 2). The patch normal vector is calculated as follows:

\[ n = \frac{t_1 \times t_2}{|t_1 \times t_2|}, \quad (11) \]
where \( t_1 \) and \( t_2 \) are surface tangents at point \( x(\eta, \zeta) \), defined as:

\[
\begin{align*}
  t_1 &= \frac{\partial x}{\partial \eta} = x_{10} - x_{30} + c_1(1-\eta)(\eta-\zeta) + (e \cdot c_2), \\
  t_2 &= \frac{\partial x}{\partial \zeta} = x_{1i} - x_{3i} + c_2(1-\eta)(\eta-\zeta) + (e \cdot c_1). 
\end{align*}
\]

(12)

The solution of \( P^{proj} = 0 \) provides the local coordinate of the closest point \( \bar{x} \) on the Nagata patch. In order to solve the eq. (10) the Newton-Raphson method is used:

\[
s_i = s_i - [\nabla P^{proj}(s_i)]^{-1}[\nabla P^{proj}(s_i)],
\]

(13)

where \( s_i = [\eta, \zeta, g_n]^T \) represents the solution vector at iteration \( i \). The Jacobian matrix \( \nabla P^{proj} \) of the system of equations in the eq. (13) is defined as follows:

\[
\nabla P^{proj}(\eta, \zeta, g_n) = \left[ \frac{\partial}{\partial \eta}, \frac{\partial}{\partial \zeta}, \frac{\partial}{\partial g_n} \right] P^{proj}(\eta, \zeta, g_n).
\]

(14)

In order to calculate the eq. (14) the gradient of the normal vector with respect to the local coordinates is evaluated using the Weingarten formula.

![Fig. 3 Closest point projection.](image)

For most cases solution of the eq. (13) is obtained with less than four iterations. With the obtained normal gap at mesh points, normal contact pressure is calculated using the penalty method, whereas the value at face center is obtained using the inverse distance interpolation.

2. Numerical examples

The proposed contact algorithm is implemented in the open-source foam-extend library as the extension to the work previously done by [2, 5]. The accuracy and efficiency of the proposed contact algorithm are tested via two numerical examples. The first example is a simple two-dimensional example of compressed cylinder tube with an exterior rigid tube. The second case is the finite element benchmark case initially proposed by Krstulović-Opara [13]. The examined numerical examples comprise frictional and frictionless contact between rigid and deformable body, whereas the deformable body includes large deformation and large sliding. In both numerical examples, the Neo-Hookean material model is chosen for the deformable body. The results are compared with the current finite volume contact algorithm [2, 5], where the piecewise linear surface description is used.

5.1 Compressing cylindrical tube

Elastic cylindrical tube (Young’s modulus \( E = 200 \) MPa, Poisson’s ratio \( \nu = 0.3 \)) with inner radius \( r_i = 50 \) mm and thickness 15 mm, is initially overlapped \( \delta = 1 \) mm with exterior rigid cylindrical tube. Due to the symmetry of the problem, only 1/4 of the model is considered, which is discretized with 10 cells in radial and 40 cells in a circular direction. Rigid cylinder tube is discretised with two meshes (see Fig. 4), whereas mesh A consists of the same number of faces in the circular direction, resulting in accurate calculation of the normal gap at mesh points. At the contact interface, frictionless contact is assumed. From the Fig. 5 it can be seen that non-conformal discretisation on the contact interface produces stress oscillations, whereas application of surface smoothing produces results with a smooth distribution of radial stress.

![Fig. 4 Cylindrical tube mesh: a) conformal, b) non-conformal discretisation at the contact interface.](image)

![Fig. 5 Radial stress distribution on the contact surface.](image)

![Fig. 6 Unstructured mesh of a half-tube, 580 triangles (mesh A).](image)
with coefficient of friction $\mu=0.1$. The cylindrical contractor is respectively. The friction is described with Coulomb friction law modulus and the Poisson’s ratio are defined as $E=100$ and $\nu=0.3$, half-tube has a radius of $r=3$ and 15 units of length. The Young’s where the finite element method is used. 

smoothing is used. Obtained results are in good agreement with [11] iterations per timestep is decreased for both meshes when mesh on both meshes studied. In this example, the average number of surface smoothing leads to approximately the same force evolution finitely discretisation produces results closer to ones obtained using poor approximation of the cylinder surface geometry. Furthermore, coarse discretisation leads to bad force evolution because of the

100 equal increments. From Fig. 8 it is possible to conclude that coarse discretisation leads to bad force evolution because of the poor approximation of the cylinder surface geometry. Furthermore, finer discretisation produces results closer to ones obtained using surface smoothing. It is important to notice that the application of surface smoothing leads to approximately the same force evolution on both meshes studied. In this example, the average number of iterations per timestep is decreased for both meshes when mesh smoothing is used. Obtained results are in good agreement with [11] where the finite element method is used.

5.2 Cylindrical contactor sliding in a half-tube

This case represents the sliding of an elastic cylindrical contactor in a rigid tube. The cylindrical contactor dimensions are $2\times2\times2$ with the curvature radius $r=3$ in the contact surface. The half-tube has a radius of $r=3$ and 15 units of length. The Young’s modulus and the Poisson’s ratio are defined as $E=100$ and $\nu=0.3$, respectively. The friction is described with Coulomb friction law with coefficient of friction $\mu=0.1$. The cylindrical contactor is uniformly discretized with 100 control volumes, whereas the rigid half-tube is discretized with unstructured mesh composed by 580 and 2442 triangles (see Fig. 6 and Fig. 7). At initial configuration the cylinder contactor overlaps rigid tube by $\delta=0.01$ units. The axial displacement of 10 units in $z$ direction is prescribed and solved via the cylinder

Fig. 7 Unstructured mesh of a half-tube, 2442 triangles (mesh B).

6. Conclusion

A patch smoothing procedure for the finite volume mechanical contact simulations is presented in this work. The implementation is done in the foam-extend framework, as an extension of the existing code developed for large deformation contact problems [2, 5]. The results are compared with the existing finite volume contact algorithm via two numerical examples. The results show that the Nagata patch interpolation allows more accurate evaluation of contact stresses. Furthermore, because of the continuous description of boundary, the force oscillations are reduced. For the future work, the efficiency and robustness of the current implementation will be tested and presented. Moreover, the implementation will be extended to handle the contact between deformable bodies.

7. Acknowledgements

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8. References


Fig. 8 Comparison of the contact force as a function of displacement for piecewise linear and the smooth surface description of the half-tube.

![Fig. 7 Unstructured mesh of a half-tube, 2442 triangles (mesh B).](image-url)
Диагностика DOS атак на киберфизические системы на основе иерархических скрытых Марковских моделей

Diagnostics of DOS attacks on cyber-physical systems based on hierarchical hidden Markov models

Prof. Dr. Alguliyev R., Assoc. Prof. Imamverdiyev Y., PhD. Sukhostat L.
Institute of Information Technology, Azerbaijan National Academy of Sciences – Baku, Azerbaijan
rasim@science.az; yadigar@itt.science.az; lsh practest@gmail.com

Abstract: Cyber-physical systems are widely used in many fields, and the need to ensure their information security has increased dramatically after a series of cyberattacks in recent years. Cyberattacks on cyber-physical systems pose a significant risk to the health and safety of human lives and threaten serious damage to the environment. The paper proposes an approach based on hierarchical hidden Markov models to detect attacks on denial-of-service of cyber-physical systems.

KEYWORDS: CYBER-PHYSICAL SYSTEM, CYBER-ATTACK, DENIAL-OF-SERVICE ATTACK, HIERARCHICAL HIDDEN MARKOV MODELS

1. Введение

В последние годы значительные достижения в области приложений, мониторинг и автоматизация потребили внимание к обеспечению безопасности, эффективности и отказоустойчивости киберфизических систем (КФС). Они интегрируют данные, связи и вычислительные компоненты с физическими системами и требуют детальных исследований в области анализа и синтеза таких систем [1]. Получение нежелательного доступа к этим физическим системам стало возможным благодаря киберкомпонентам. Доступные технологии связи, инициирующие переход от защищенных, закрытых сетей к открытым и беспроводным сетям (wireless sensor network, WSN), являются более уязвимыми к внешним помехам. Обмен данными в WSN происходит многоканальным образом, когда узлы не обмениваются данными напрямую с центральным управлением.

Непрерывный мониторинг по всей КФС обеспечит защиту целостности системы и обнаружение кибератак на ранней стадии, что позволит избежать потерь.

Основными компонентами КФС являются сенсоры, которые измеряют ключевые переменные, представляющие интерес, аккумуляторы, которые помогают системе выполнять определенные задачи, а также другим важным компонентом системы является коммуникационная сеть. Поэтому безопасность КФС должна быть обеспечена для всех трех компонентов. В случае подтверждения вероятной киберугрозы для КФС должны быть предприняты корректирующие действия. Это характеризует непрерывный мониторинг КФС.

Так кибератаки можно сгруппировать следующим образом: атаки раскрытия (disclosure attacks), атаки обмана (deception attacks) и атаки срыва (disruption attacks) [2, 3].

Действие атаки отличается от случайного вбрасывания. Кибератаки могут получить доступ к КФС и соответствующим образом воздействовать на нее.


С ростом сложности всей КФС гарантия защиты может быть обеспечена для ее отдельных компонентов. В связи с этим необходима системная перспектива, которая сфокусирована на предотвращении атак на КФС, и если атаки все же происходят, убедиться, что система устойчива, выявляя воздействие этих угроз.

Скрытые Марковские модели (hidden Markov model, HMM) применялись для обнаружения кибератак [6, 7], но сталкивались с определенными трудностями, а именно, рассматривались небольшие наборы данных и наблюдалась чувствительность к ошибкам. Но, предложенные в 1998 году иерархические скрытые Марковские модели (Hierarchical hidden Markov model, HHMM) способны преодолеть указанные ограничения, сочетая в себе отдельные вероятностные модели [8].

В данной статье предлагается HHMM, которая может быть применена для обнаружения и ранней диагностики кибератак на КФС на основе полученных данных.

2. Иерархические скрытые Марковские модели

HHMM можно описать следующим образом.

Пусть имеется последовательность наблюдений \( O = (o_1, o_2, ..., o_T) \) размерности \( T \). \( o_i \) представляет собой \( i \)-й показатель, который был получен блоком КФС.

Пусть \( s^r_i \) - состояние HHMM на шаге \( i \), а \( r \in \{1, ..., R\} \) - индекс иерархии, принимающий значение \( r = 1 \) для корневого состояния, \( r = \{2, ..., R - 1\} \) - для оставшихся внутренних состояний и \( r = R \) - для производственных состояний (production states).

Модель характеризуется вероятностью перехода между внутренними состояниями и выходным распределением производственных состояний. Для каждого внутреннего состояния \( s^r_i \) при \( r \in \{1, ..., R - 1\} \) существует матрица вероятностей переходов между состояниями \( A^r \), где \( A^r_{ij} = p(s^r_{i+1} | s^r_j) \) - вероятность горизонтального перехода из состояния \( j \) в состоянии \( i \) на уровне \( r \). Вектор начальных распределений по подсостояниям \( \pi^r \) включает элементы \( \pi^r_{ij} = p(s^r_{i} | s^r_j) \) для \( r \in \{1, ..., R - 1\} \) и \( \pi^r_j \) является вероятностью вертикального перехода. Каждое производственное состояние \( s^r_i \) параметризуется вектором выходного параметра \( s^r_e \), форма которого зависит от особенностей модели наблюдения \( p(x_j | s^r_{i-1}, s^r_{i}) \) соответствующей \( j \)-му производственному состоянию.

Параметрами модели является \( \lambda = \{ \{ A^r \}_{r \in \{1, ..., R-1\}}, \{ \pi^r \}_{r \in \{1, ..., R-1\}}, \{ s^r_e \}_{r \in \{1, ..., R-1\}} \} \).
Генерация стохастического процесса начинается с корневого узла $s^1$. Наблюдение для первого шага в последовательности $i$ генерируется произвольно для одного подсостояния в соответствии с начальным распределением $\pi^1$. Для каждого внутреннего состояния $s^j_i$ одно из подсостояний выбирается случайно в соответствии с вектором начальных вероятностей $\pi^j$. Единичное наблюдение генерируется по вектору состояния выходных параметров $s^j_i$, когда внутреннее состояние переходит в производственное состояние $s^R_i$. Управление возвращает внутреннее состояние, приводящее к текущему производственному состоянию $s^{R-1}_i$, которое выбирает в соответствии с матрицей переходов $A^{R-1}$ следующее состояние на том же уровне.

Все уровни, начиная со второго, имеют конечное состояние, которое является окончанием процесса активации стохастического состояния. Происходит передача управления родительскому состоянию всей иерархии. Переход управления от всех рекурсивных активаций к корневому состоянию $s^1$ завершает процесс.

Модель является сильно связанной, т.к. все состояния могут быть достигнуты за конечное число шагов, начиная с корневого состояния [8].

### 3. Предлагаемый подход

В данной работе предлагается подход на основе ННММ, который используется для проверки наличия «необычного» поведения в компонентах КФС, вызванного DoS атаками, приводящее к сбоям.

![Рис. 1. Предлагаемая модель на основе ННММ для обнаружения DoS атак на КФС](image1.png)

Предлагаемая модель способна коррелировать события, происходящие относительно далеко друг от друга в последовательностях наблюдений, сохраняя при этом вычислительную управляемость марковских процессов. Каждое из скрытых состояний представляет собой самостоятельную вероятностную модель, то есть каждое состояние также является НММ. В результате ННММ генерирует последовательность событий путем рекурсивной активации одного из подсостояний, когда достигается производственное состояние. Затем управление возвращается в состояние, в котором возникает цепочка рекурсивной активации. Множество состояний и вертикальных переходов индуцирует древовидную структуру, где корневое состояние является узлом в верхней части иерархии, а листья - производственными состояниями.

Предлагаемая модель позволит нам обнаруживать и прогнозировать события DoS атаки на КФС. Каждое состояние связано с распределением вероятностей по возможным выходным символам. В этом контексте событие может быть событием ввода в заблуждение сенсора (ЗС), компрометации киберузла (ККУ) или событием изменения де йствия/сбой актуатора (ИД/СА). Если такое событие не обнаружено, то модель переходит на следующий иерархический уровень и производит проверку на попытку кибератаки на систему.

![Рис. 2. Пример входных данных для предлагаемой ННММ модели с целью обнаружения DoS](image2.png)

Предлагаемая модель ННММ для диагностики DoS атаки на КФС показана на рис. 1.

### 4. Результаты экспериментов

В нашем исследовании с целью обнаружения DoS атаки на КФС на вход модели ННММ подаются сигналы, поступающие от компонентов системы. На рис. 2 показаны примерные входные данные для предлагаемой модели (данные сенсора, число пакетов полученных по сети, уровень наполнения бака водой для системы водоочистки сырой воды). На рис. 3 приводится результат обнаружения атаки на сеть КФС (зеленым цветом обозначена DoS атака).

![Рис. 3. Результат обнаружения DoS атаки на основе ННММ модели](image3.png)

### 5. Заключение

Взаимодействие беспроводных технологий помогает обнаруживать такие события, как неправильное поведение актуаторов или их отказ вызванные кибератаками на КФС, и помогает автоматически регулировать свойства приборов в соответствии с решениями, принятыми кибер-системой.
Применение диагностики на основе ННММ для обнаружения скоординированных кибератак типа DoS, показало высокую производительность. Это исследование было оценено на небольшом наборе данных. В настоящее время такие кибератаки могут длиться и дольше, поэтому в дальнейшем планируется провести оценку предлагаемого подхода на больших наборах данных. Чтобы уменьшить чувствительность данных к шумам, в данном исследовании проводится диагностика для нескольких компонентов КФС поэтапно, извлекая соответствующие события атаки. Таким образом, предложенная модель на основе ННММ может быть применена для выявления таких атак на основе состояния.

6. Литература


Automatic generating linear programming problems based on the interface data to determine the optimal number of techniques

Laman Mammadova
Azerbaijan National Academy of Sciences
Institute of Control Systems

Summary: This article considers the generation of the canonical form of linear programming to determine the optimal number of techniques. The linear programming problem was solved using the created software interface as a result of solving the problem during the generation process.

KEYWORDS: DECISION-MAKING, CANONICAL, GENERATION, LINEAR PROGRAMMING

1. Introduction

The use of mathematical methods in the development of modern economics, including the solution of many economic issues, and the adoption of correct and effective decisions as a result are of great importance. The famous management researcher, Chuster Bernard, considered management as a form of management decision making [1]. Decision making is an integral part of any management function, such as information sharing. The need for management decisions occurs at all stages of the management process and relates to any aspect of management activities. The decision-making process clearly confirms the continuity of management activities, reflecting the real problems, relationships and interrelations within the organization. In addition, learning about the process of making and implementing decisions allows us to learn the content of governance. The following models are used in making management decisions:

1) Games theory model.
2) Model of the theory of sequences
3) Resource management model
4) Linear programming model.
5) Economic analysis model.
6) Physical model.
7) Anological model.
8) Mathematical model.

The linear programming model is used to design optimal production programs. In this case, the main goal is to determine how many products are manufactured to generate the maximum profit mass with a certain amount of raw materials, details, equipment working hours and profitability of product types. Most of the optimization models used in the management system are usually combined with the requirements of the linear programming model. Since the optimization process is expensive, it is used to develop the strategic and tactical tasks of any subsystem of the management system. Operative tasks, however, usually need to be addressed using simple, heuristic methods. These methods are mainly: a) analysis; b) forecasting; c) modeling.

In the economic application of linear programming theory, most of the issues are considered where finding of the maximum or minimum value for any linear function is required [2].

2. Problem statement

It is worth noting that you can come up with web software designed to solve the linear programming problem by simplex, which is software for mathematical data entry. As an example, the website "Simplex Method Tool" by Stefan Waner in 2016, however, has not created a friendly interface for user. On such web pages, user input data directly solves the problem using the simplex method [3]. The issue is dedicated to the elimination of this deficiency. Thus, software had been created to determine the optimal number of techniques. It has built enough comfortable interface for user. After entering user input in the created software, the problem comes to linear programming and generates the canonical form for solving simplex [4].

The problem is the generation of the canonical form of linear programming on the basis of interface data to determine the optimal number of techniques. The number of weapons and technical potential [5]. One of the most important tasks is to divide technology into specified categories and know the number of different types of techniques. With the developed software interface, the information needed to automatically generate the canonical form can be stored in a file with a specific structure. It should be noted that generally reading data from a file and writing data to a file are of particular importance in this software. Interface data should be read only from certain files and transmitted to the user. The user should be able to save the data in a specific file to use the data he or she chooses for the next period of time, even if it does not fully resolve the issue for any reason or excuse after launching the software. The file structure needed to read the interface data and the file structure needed for writing are different. The process of reading and writing files should be set up that for any time it will enter to the base of its side so that it is possible to notice new weapons and used these weapons in the software. With this information, the canonical formulation of the necessary data for the complete solution of the problem and based on this data the linear programming problem are solved.

3. Problem Solution

The establishment of an algorithm for determining the number of different techniques based on the interface data is a prerequisite for solving this problem. Thanks to the interface of written software during the solution, the user can choose different category techniques, weapons, and include the coefficients needed to solve the problem [2].

The user can save the available forces and their number for the battle from his own, the weapons that can be dispatched and their maximum number, in which types of operation (attack or defense) of battle from his own and the enemy in the file which has predefined structure after selecting from software interface (to use the file as a base). The enemy's choice of attack or defensive action during the war (as well as his own) ensures the changing of coefficients used in the generator.

Based on the entered interface data, the number of confused is found with the numbering of different weapons. Based on this number, the basic coefficients for the canonical
form of linear programming problem are defined and base variables are generated. The input data for the number of selected available forces and the number of weapons that can be ordered creates a called right side vector in the canonical writing form. The simplex method of linear programming problem was chosen as the solution. Generation of the canonical form allows a complete solution of this problem with the simplex method.

4. Conclusion

As a result, knowing the enemy forces and operating conditions, it was possible in the case of solution of this problem to determine the optimal number of techniques for defeat. The software created as a result of the solution of problem not only determines the optimal number of each technique during the battle, but also finds the estimated number of personal staff losses.

In the software files with a certain structure had been used as the base. The data displayed on the interface is read from the files defined at the start of the program, and the selected data can be stored in the newly created files using the interface.

When software is created, generation process is completely done correctly and the optimum result is achieved.

References