**ISSN:1306-3111**
e-Journal of New World Sciences Academy
2010, Volume: 5, Number: 3, Article Number: 1A0097

**ENGINEERING SCIENCES**
Received: March 2009
Accepted: July 2010
Series : 1A
ISSN : 1308-7231


**Fatih Başçiftçi**
**Harun Sümbül**
Selcuk University
basciftci@selcuk.edu.tr
habu_58@hotmail.com
Konya-Turkey

# DESIGNING AN EXPERT SYSTEM FOR DETECTION OF TUBERCULOSIS DISEASE WITH LOGIC SIMPLIFICATION METHOD

**ABSTRACT**

In this study; a controlled Expert System (ES) have designed to diagnosis of Tuberculosis (TB) disease and truth table have created by considering the probabilities of TB (12 symptom, $2^{12}$=4096 different cases). According to the probabilities of TB disease, 6 different cases have accepted as output values and reduced rule bases have obtained. These output values have been processed by an ES and have tried to diagnosis of the TB disease with help to ES. As a result; in this study, we have obtained very good results in diagnosis of the TB with ES. The results of analyses have indicated that the controls performed with ES have provided both less time, less probability and reliable, consistent diagnosis and that are feasible to in real life.

**Keywords:** Logic Simplification, Reduced Rule Bases, Expert System, Minimization Method, Diagnosis of TB.

# TUBERKULOZ HASTALIĞININ TEŞHİŞİ İÇİN LOJİK SADELEŞTİRME METODU İLE BİR UZMAN SİSTEM TASARIMI

**ÖZET**

Bu çalışmada; TB hastalığının teşhisi için kontrollü bir uzman sistem (US) tasarlanmış ve TB hastalığının belirtileri (12 belirti, $2^{12}$=4096 değişik durum) dikkate alınarak doğruluk tablosu oluşturulmuştur. TB hastalığının belirtilerine göre 6 farklı durum çıkış değeri olarak alınmıştır ve indirgenmiş kural tabanları elde edilmiştir. Elde edilen bu değerler bir uzman sistemde kullanılmış ve uzman sistemler yardımıyla TB hastalığı teşhis edilmeye çalışılmıştır. Sonuç olarak bu çalışmada, US ile yapılan TB teşhisinde iyi sonuçların alındığı gözlemlenmiştir. Yapılan analizler sonucunda US ile yapılan kontrolün hem daha az zaman, daha az ihtimal, hem de gerçek ve güvenilir teşhisler sağladığı ve bunun gerçek hayatta kullanılabilirliği görülmüştür.

**Anahtar Kelimeler:** Lojik Sadeleştirme, İndirgenmiş Kural Tabanları, Uzman Sistem, Minimumlaştırma Metodu, TB Teşhisi

## 1. INTRODUCTION (GİRİŞ)

With two million deaths and twelve million new active cases per year and two billion people (one third of the world's population) harboring latent infection, Tuberculosis (TB) is a global threat. Worldwide there are roughly 12 million new active cases annually, and of those about 2 million will die every year [1]. TB, caused by the bacterium My co-bacterium tuberculosis (Mtb), is a growing international health crisis [2].

TB is currently the main cause of adult death from a single infectious disease in developing countries [3]. According to the World Health Organization worldwide, disease mortality was approximately 1.5 million people, with 5 million new and relapse cases in 2005 [4]. Figure 1 shows the percentages distribution of new and relapse cases in the six continents. Most TB cases occur in low and middle – income countries, where the identification of tubercle bacilli in sputum microscopy with conventional light microscope is the primary method for diagnosing pulmonary tuberculosis. The non-invasive characteristic of the sputum procedure is important because repeated examinations are needed for early detection of the disease [5]. These techniques lack sensitivity and consequently clinicians must as 2 month because these bacilli take 5-20h to duplicate. Manual screening for the bacillus is a labor intensive task with a height false – negative rate [6]. Automatic screening entails several advantages, such as a substantial reduction in the labor workload of clinicians.

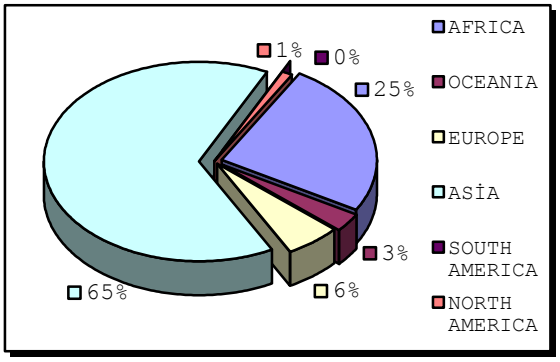


Figure 1. Distribution of new and relapse tuberculosis cases in 2005
(Şekil 1. 2005'deki eski ve yeni TB durumlarının dağılımları [4])

There are a lot of method relevant to TB disease, for instance a circuit-based simulation, using an antibody-based piezoelectric biosensor, fuzzy logic, image processing and neural computing, lazer therapy and so forth.. However, our used method that Logic Simplification Method is considerably a new method to diagnosis of Tuberculosis (TB) disease, including truth table, input and output values, reduced rule bases. We used these input values (12 symptom, $2^{12}$=4096 different cases) and simplified output values (6 different cases) to diagnosis of Tuberculosis (TB). Thus, we can decide about TB and similar diseases of TB with lesss symptom, instead of a lot input values. Whereby our method, we can obtain not only less time and probability, but also reliable, practice and consistent diagnosis.

- **Expert System (Uzman Sistem)**

Expert Systems, or knowledge-based systems, are a branch of artificial intelligence [7]. An ES is a computer program that attempts to replicate the reasoning processes of expert and can make decisions and recommendations, or perform tasks, based on user input. Knowledge

engineers construct ES in cooperation with problem domain experts so that the expert's knowledge is available when the expert might not be, and so that the knowledge can be available at all times and in many places, as necessary. ES derives their input for decision making from prompts at the user interface, or from data files stored on the computer. The knowledge base upon which the input is matched is generally represented by a series of IF/THEN statements, called production rules, which are written with the domain expert to approximate the expert's reasoning. The degree of belief the expert has in her conclusion is represented as a confidence factor (CF) in the ES. For instance, the expert may feel that conclusion based upon the input has a 95% probability of being correct, so the CF would equal 95 [8].

The inner structure of an ES is made up with three parts: the knowledge base; the database; the rule interpreter. This is analogous to the production system where we have the set of productions; the set of facts held as working memory and a rule interpreter. You can see this structure at Figure 2.

The knowledge base holds the set of rules of inference that are used in reasoning. Most of these systems use IF-THEN rules to represent knowledge. Typically systems can have from a few hundred to a few thousand rules. The database gives the context of the problem domain and is generally considered to be a set of useful facts. These are the facts that satisfy the condition part of the condition action rules as the IF THEN rules can be thought of. The rule interpreter is often known as an inference engine and controls the knowledge base using the set of facts to produce even more facts. Communication with the system is ideally provided by a natural language interface. This enables a user to interact independently of the expert with the intelligent system [14].

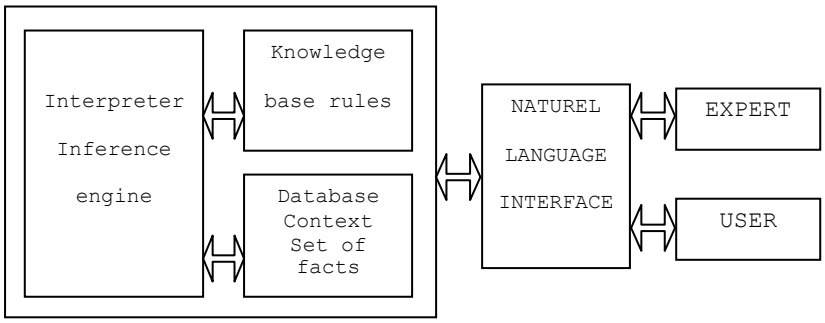


Figure 2. An expert system's structure
(Şekil 2. Bir uzman sistemin yapısı)

## 2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

TB is one of the most common infectious diseases worldwide. In developing countries, TB is associated with high morbidity and mortality rates. The disease is increasing in Western countries especially among immune compromised individuals such as patients who are HIV (Human Immunodeficiency Virus) infected [9].

### 2.1. Symptoms of Tuberculosis Disease (Tuberküloz Hastalığının Belirtileri)

Symptoms of TB have been given;

- A cough that lasts (for more than 3 weeks)
- High fever (systematic symptom)
- Sweat (specially during night)
- Come out sputum and blood as coughing
- Loss of appetite

- Weight loss
- Weakness
- Weariness
- Hemoptysis
- Thorax, back and flank aches
- Shortness of breath (respiratory symptom)
- Hoarseness (in the future)

### 2.2. Special Symptoms for Tuberculosis (Tuberküloz Hastalığının Özel Belirtileri)

Cough, Sputum, hemoptysis: We have to doubt for every cough that continue more 3 week. Cough can also sometimes occur with bloody sputum.

Thorax, back and flank aches: When Plevra attitude exists, we can see ache changing with breathe.

Heartbeat: The rhythmic contraction and relaxation of the heart as it pumps blood. The beat creates a characteristic sound.

### 2.3. Similar Diseases of TB (Tuberkuloz Hastaliğina Benzer Hastaliklar)

There are some diseases similar to TB because of symptoms and specialties. These diseases are; Primer TB, Post Primer TB, Sarkidoz, Plörezi and Mumps.

SARKIDOZ: Some laboratory tests or radiological imaging alone are not enough to differ sarcoidosis and tuberculosis (TB). As sarcoidosis and TB have similar histological characteristics and both of diseases may occur concurrently or following the other, mycobacteria was thought to have a role in etiology of sarcoidosis. This review provides the similarities and the differences of TB and sarcoidosis, also the current literature information on the role of mycobacteria in etiology of sarcoidosis [10].

PRIMARY TUBERCULOSIS: Primary gastric tuberculosis is rarely seen. It usually produces a diagnostic challenge and may mimic peptic ulcer disease and even a neoplasia. We present a case of primary gastric tuberculosis initially thought to be a neoplasia [11].

PLOREZI: Plörezi, covered to lungs' outside plevre, which a thin membrane, infection or inflammation. Like this, another plevre's membrane, covered to all of the chest blank. When healtly and lungs are inflatig, at plevre's two leavies are sliding from each order. At Plörezi is not a Pneumnia or Tuberculosis, but it can be complicated one of them on an order lungs' infection. However, these diseases had been explained detailed in resources [12, 13].

## 3. LOGIC SYNTHESIS (LOJİK SENTEZ)

Two-level logic minimization is a basic problem in logic synthesis [19, 20]. The minimization of Boolean Functions (BFs) can lead to more effective computer programs and circuits. Minimizing functions can be important because, electrical circuits consist of individual components that are implemented for each term or literal for a given function. This allows designers to make use of fewer components, thus reducing the cost of a particular system [21, 22].

A wide variety of Boolean minimization techniques have been explained in [19-22], most of which work on two-step principles: first, identifying the prime implicants (PIs) of chosen On-minterm and second, determining a set of the essential prime implicants (EPIs). Since the size of the PIs can be as large as $3^n/n$ for a function of $n$ variables The PIs identification step can become computationally impractical as $n$ increases [15, 20].

- **Minimization Method (Minimumlaştırma Metodu)**

In order to simplify the formed function, Exact Direct Cover Minimization Algorithm has been developed. This algorithm is explained in [22]. Exact Direct Cover Minimization Method algorithm is given in below.

1. Put $I=0$, $C=0$, $SW=\varnothing$
2. Take out the first minterm from $S_{ON}$ set, mark it by $\lambda$,
3. Transform one by one all of elements of $S_{OFF}$. Mark it by $Q0$,
4. Apply the absorption operation to $Q0$. Mark the result by $Q1$,
5. Coordinate Subtract the set $Q1$ from the $n$ dimensional full cube $xx...xx$. Where $n$ the number of variables of Boolean Function. Mark the result by $S_{PI}$,
6. Apply the Great or Less operation to $S_{PI}$ set. Note that element $\alpha$ is greater than element $\beta$ if the set of $S_{ON}$ # $\alpha$ is powerless than the set of $S_{ON}$ # $\beta$,
7. Save only the most greatness *Prime Implicant (PI)*,
8. If the result is not single element then $SW=SW \cup \lambda$ and go to 2
9. If the result is single element then mark it by *Essential Prime Implicant (EPI)*, $I=I+1$, $C=C+1$,
10. Put $S_{ON}=S_{ON}$ # $EPI$, $SW=SW$ # $EPI$, $S_{EPI} = S_{EPI} \cup EPI$
11. If $S_{ON} \neq \varnothing$ then go to 3
12. If $SW = \varnothing$ then END else $S_{ON} = SW$
13. If $S_{ON}=\varnothing$ and $SW \neq \varnothing$ then go to 40
14. go to 1
40. CALL BS (Branching Subroutine)
41. go to 3

BS

1. Take out the first minterm from $S_{ON}$ set, mark it by $\lambda$ and $I=I+1$,
2. Transform one by one all of elements of $S_{OFF}$ set. Mark it by $Q0$,
3. Apply the absorption operation to $Q0$. Mark the result by $Q1$,
4. Coordinate Subtract the set $Q1$ from the $n$ dimensional full cube $xx...xx$.
5. Apply the Great or Less operation to the elements of $S_{PI}$ set.
6. If the result is single element then mark it by $EPI$, Otherwise select one of them and mark it by $EPI$, $C=C+1$,
7. Put $S_{ON}=S_{ON}$ # $EPI$, $S_{EPI} = S_{EPI} \cup EPI$,
8. RETURN

$S_{ON}$: The set of ON minterms any of that make the function equal to 1
$S_{OFF}$: The set of OFF minterms any of that make the function equal to 0
#: Coordinate Subtraction (Sharp Product) Operation

## 4. EXPERIMENTAL RESULTS (DENEYSEL SONUÇLAR)

In this study, we used the Logic Simplification Method. Symptoms of disease are the input values of function. Also, similar diseases and possibilities of TB can be thought as output values of function. According to this information formed a logic function that has 12 input variables ($2^{12}$=4096 different case) and 6 outputs. In this function, 4096 different cases evaluated for each one output function. In the early stages of TB disease there may be no symptoms. Later, the most common symptoms include A long lasting cough, High fever (systematic symptom), Sweat (specially during night), Come out sputum and blood as coughing, Loss of appetite, Weight loss, Weakness, Weariness, Hemoptysis, Thorax, back and flank aches, Shortness of breath

(respiratory symptom), Hoarseness (in the future). Table 1 show below input and output values for function.

In order to simplify the formed function, Exact Direct Cover Minimization Algorithm has been developed. This algorithm has explained in [15, 16, and 17].

Table 1. Input and output values for function
(Tablo 1. Fonksiyonun giriş ve çıkış değerleri)

| Input Symbols | Input Cases | Output Symbols | Output Cases |
|---|---|---|---|
| x1 | A long lasting cough | y1 | TB |
| x2 | High fever | y2 | Primer TB |
| x3 | Sweat (specially during night) | y3 | Post Primer TB |
| x4 | Come out sputum and blood as coughing | y4 | Sarcoidosis |
| x5 | Loss of appetite | y5 | Plörezi |
| x6 | Weight loss | y6 | Mumps |
| x7 | Weakness | | |
| x8 | Weariness | | |
| x9 | Hemoptysis | | |
| x10 | Thorax, back and flank aches | | |
| x11 | Shortness of breath | | |
| x12 | Hoarseness (in the future) | | |

Table 2. Simplification output values for function
(Tablo 2. Fonksiyonun sadeleştirme çıkış değerleri)

| Output Symbols | Output Cases | Simplification function | | |
|---|---|---|---|---|
| y1 | TB disease | 010100000010<br>1111xxxxx00x<br>1111x0xxxxxx<br>1111xxxx1xxx | 111x11011010<br>1111xxxxx1x0<br>1111xx1xxx1x | 1111xx0xxxx1<br>1111xxx0xxxx<br>11111xxxxxxx |
| y2 | Primer TB | 1010x1101000<br>xx1x111xxxx1<br>xx1x11xxxx0x<br>xx1x11xx1xxx | 10101x101101<br>xx1x1101xxxx<br>xx1011xxxxxx<br>1x1x11xxxx1x | xx1x11xxx0x0<br>xx1x11x0x1xx<br>x11x11xxxxxx |
| y3 | Post Primer TB | 101010101100 | 111xx11x1111 | |
| y4 | Sarkidoz | 1011101001x1<br>1x101x10001x<br>1111xx1xxx1x<br>1x1xx00xxx1x<br>1x1x11xxxx1x<br>110xxxxxxx1x | 1011x01x0010<br>101x011x011x<br>1x1xxxx1xx11<br>1x1xxxx0x11x<br>1x11xxxx1x1x<br>11x0xxxxxx1x | 101000110x1x<br>101xxxx1x01x<br>1x1x0xx0xx1x<br>1x11xxxxx11x<br>1x1xxxxx111x |
| y5 | Plörezi | xxxxxxx111xx | | |
| y6 | Mumps | 101010101010<br>xxx0xx1x11x1<br>xxxxx11111xx<br>xxxxx01x11xx | 111110111x11<br>0xx1xx1x11xx<br>11xxxx1x11xx<br>xxxxxx1x111x | xxxx1x1x11xx<br>x0xxxx1x11x0<br>xx0xxx1x11xx |

Table 3. Disease probabilities for y3 output and results
(Tablo 3. Y3 çıkışı için hastalık olasılıkları ve sonuçları)

| Output Symbols | Cases | Symptom and Output Cases | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | x 1 | x 2 | x 3 | x 4 | x 5 | x 6 | x 7 | x 8 | x 9 | x 10 | x 11 | X 12 |
| y3 | Post Primer TB 101010101100 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| y3 | Post Primer TB 111xx11x1111 | 1 | 1 | 1 | x | x | 1 | 1 | x | 1 | 1 | 1 | 1 |

Table 4. Rule table for y3 output
(Tablo 4. Y3 çıkışı için kural tabanı)

| IF | input | | | | | | | | | | | | THEN | output |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | x 1 | x 2 | x 3 | x 4 | x 5 | x 6 | x 7 | x 8 | x 9 | x 10 | x 11 | x 12 | | Y3 |
| | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | | Primer TB |

## 5. FINDINGS AND DISCUSSIONS (BULGULAR VE TARTIŞMALAR)

TB will continue to be one number the public health problem of our country with more than one crore of patients at one time. The main hurdle in the control of tuberculosis is poor cure rate (35%) due to high drop out because of long duration of treatment. With present strategy of treatment, the control of TB is a far cry for several decades. In near future the situation will further deteriorate due to AIDS and during resistance, unless and until some new methods of treatment are not used [9].

When we simplified the disease truth table (table1) which has 12 input variability and 6 output functions with the developed method, the values in Table 2 have been obtained.

The mean of 0, 1 and x which shows like simplification function at Table 2, is: For 0; there is not symptom. For 1; there is symptom. For x; it is not importing for symptom of represent disease who is ill person. For example; Disease probabilities for y3 and results have been given in table 3.

According to Table 3, the mean of 101010101100 output values; we can say Post Primer TB diseased a person who has x1, x3, x5, x7, x9, x10 probabilities and has not x2, x4, x6, x8, x11, x12 probabilities. Furthermore, if we want to see the result (for 101010101100) in an expert system:

**Rule:** IF x1 is 1 and x3 is 1 and x5 is 1 and x7 is 1 and x9 is 1and x10 is 1 and x2 is 0 and x4 is 0 and x6 is 0 and x8 is 0 and x11 is 0 and x12 is 0 THEN patient is Post Primer TB.

## 6. CONCLISION AND RECOMMENDATIONS (SONUÇ VE ÖNERİLER)

The clinical, laboratory and radiological findings of our patients with tuberculosis who have been followed for the last seven years in our clinic are evaluated retrospectively. According to an investigation's results, of the all patients 30 (76%) were diagnosed as Pulmonary tuberculosis, and 9 (24%) as Post Primer tuberculosis. The highest rate of complaints were primarily high fever (32; 82%), secondary coughing (29; 74%). However, other spectrums are High fever 32 (82%), a long lasting cough 29 (74%), Sweat (48%), Come out sputum and blood as coughing (41%), Shortness of breath (23%), Loss of appetite (2%0), Weight loss (%17), Vomit (15%), Head ache (%12),

Hemoptysis (12%), Thorax, back and flank aches (10%), Weakness (10%), Weakness (5%) and Diarrhea (2%) [18].

In this study; all the probabilities of the 12 symptoms which are the general symptoms of TB disease, have been evaluated and whether there are TB or similar diseases or not are researched as output. In the reduction of symptoms, Logic Simplification Method has been used. By this method, reduced functions for each output have been obtained.

In conclusion, we thing that use logic simplify method might be used as a reliable in ascertain to TB to treatment.

**REFERENCES (KAYNAKLAR)**

1. Chakrabarti, P., (2007). "Early, Easy, Inexpensive Diagnosis An Urgent Need for Global TB Control." Frontiers in the Convergence of Bioscience and Information Technologies, FBIT 2007, pp:241-244.
2. May, E., Leitao, A., Faulon, J.L., Joo, J., Misra, M., and Oprea, T.I., (2008). "Understanding virulence mechanisms in M. tuberculosis infection via A circuit-based simulation framework." Engineering in Medicine and Biology Society, 30th Annual International Conference of the IEEE, pp:4953 – 4955.
3. Marly, G.F., Filho, Cicero F.F., Sena, Juliana F., Salem, J., and de Lima, Mari O., (2008). "Automatic identification of mycobacterium tuberculosis with conventional light microscopy." Engineering in Medicine and Biology Society. 30th Annual International Conference of the IEEE, pp:382 – 385.
4. World Health Organization, Global Health Atlas. Available:http://www.who.int/globalatlas/
5. Crncevik-Urek, M., Stipic-Markovic, A., Kardum-Skelin, I., Stipic, J., Crnek, V., and Urek, R., (2002). "Induced sputum. A method for cytologic analysis of bronchial specimens. "Acta Clinica Croata, volume:41, no:2, pp.89-93.
6. Veropoulos, K., Learmonth, G., Campbell, C., Knight, B., and Simpson, J., (1999). "Automatic identification of tubercle bacilli in sputum. A preliminary investigation." Analytical and Quantitative Cytology and Histology; volume:21, no:4, pp:277-281.
7. Mockler, R.J. and Dologite, D.G., (1992). "Knowledge-Based Systems. An Introduction to Expert Systems." Macmillan Publishing. Newyork.
8. Hendee, J.C., (1998)., "An expert system for marina environmental monitoring in the Florida Keys National Marine Sanctuary and Florida Bay." Proceedings of the Second International Conference on Environmental Coastal Regions, editor: C.A. Brebbia, Computational Mechanics Publicationas/WIT Press, Southampton, pp.57-66.
9. Tabarra, K.F., (2007 November). "Ocular manifestations of systemic disease." Edited by Russell W. Read. Riyadh, Saudi Arabia. Volume:18(6), pp:493-501.
10. Erbaycu, A.E. and Güçlü, S.Z., (2005). "Sarkoidoz ve Tüberküloz: Benzerlikler Farklılıklar, Sarkoidoz Etyolojisinde Mikobakterilerin Rolü." İzmir Göğüs Hastalıkları ve Cerrahisi Eğitim ve Araştırma Hastanesi, Göğüs Hastalıkları ve Tüberküloz Kliniği, İZMİR Solunum Hastalıkları, Cilt:16, ss:95-101.
11. Zengin, K., Taskin, M., Cicek, Y., Unal, E., Ferahman, M., and Dogusoy, G., (2003). "Primary Gastric Tuberculosis Mimicking Gastric Tumor that Results in Pyloric Stenosis Eur. Surg." Cilt:35, ss:220-221.

12. FitzGerald, J.M., Mayo, J.R., Miller, R.R., Jamieson, W.R., and Baumgartner, F., (1992). "Tuberculosis of the thymus: Chest." Volume: 102, pp:1604-5.
13. Demircan, S., Uzar, A. ve Topçu, S., (1997). "Tüberkülozda cerrahi endikasyonlar." Solunum Hastalıkları Dergisi. Cilt:8, ss:643-50.
14. http://www.cs.cf.ac.uk/Dave/AI1/mycin.html
15. Kahramanlı, Ş., Güneş, S., Şahan, S., and Baştçiftçi, F., (2007). "A New Method Based on Cube Algebra for The Simplification of Logic Functions." The Arabian Journal For Science and Engineering. ISSN: 1319-8025, Volume:32, Number:1B, pp:101-114.
16. Baştçiftçi, F., (2007). "Simplification of Single Output Boolean Functions by Exact Direct Cover Algorithm Based on Cube Algebra." Warsaw-Poland, ISBN:1-4244-0813-X, pp:427-431.
17. Baştçiftçi, F. ve Kahramanlı, Ş., (2007). "An Off-Cubes Expanding Approach to the Problem of Separate Determination of the Essential Prime Implicants of the Single-Output Boolean Functions." Warsaw-Poland, ISBN:1-4244-0813-X, pp:432-438.
18. Kurt, A., Poyrazoğlu, G., Turgut, M., Akarsu, S., Çıtak, A.N., Aydın, M., Kabakuş, N., Yılmaz, E., ve Aygün, A.D., (2006). "Tüberküloz Tanısı ile İzlenen Hastaların Klinik ve Laboratuar Özellikleri." Fırat Tıp Dergisi: Cilt: 11, Sayı:(1), ss:55-58.
19. Sasao T., (2001). "Worst and Best Irredundant Sum-of-Product Expressions." IEEE Transactions on Computers, Vol. 50(9), pp. 935-947.
20. Mishchenco, A. and Sasao, T., (2003). "Large-Scale SOP Minimization Using Decomposition and Functional Properties." IEEE CNF, Design Automation Conference, Proceedings, pp:149-154.
21. Kahramanli, S. and Başçiftçi, F., (2002). "Boolean Functions Simplification Algorithm of O(N) Complexity." Journal of Mathematical And Computational Applications, Vol. 8, No 4, pp:271-278.
22. Başçiftçi, F., (2006). "Local Simplification Algorithms for Switching Functions." PhD Thesis, Graduate School of Natural and Applied Sciences, Selcuk University.