GENERATING EXPERT SYSTEMS TO DETECT SPECIFIC BACTERIA TYPES AND EXTRACT HANDWRITING FROM BANCK CHECKS

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ABSTRACT

Detecting specific types of bacteria in a microscopic Bacteria Colony Image (BCI) is a tedious and time-consuming task. Based on the previous experience in the field of computerized signature and handwriting analysis, we generated two expert systems to detect specific types of bacteria in BCI and to extract handwriting from binary bank checks images using the same software platform developed for this purpose. Using the Domain Expert Guided Heuristic Search (DEGHS) and the platform, we generated an expert system that succeeded in cases where no algorithmic approach can be applied. We exploited the fact that the function of an expert system is determined mainly by its knowledge base to generate different expert systems by modifying the content of the knowledge base. The mechanism used expedite very much the development of the expert system to reach its best performance.

KEYWORDS

bacteria type detection, bacteria colony image, generating expert systems, guided heuristic search, hybrid intelligence.

1. INTRODUCTION

We introduced last year (2021) an algorithmic approach to detect cancer in lungs CT images [1,2]. In this research work, we present a Software Machine (SM) developed for generating expert systems in different application fields using the heuristic search we developed. The Domain Expert (DE) plays a central role in the generation process via what we called Domain Expert Guided Heuristic Search (DEGHS). We generated two different expert systems in completely different fields using this machine and the DEGHS search technique we developed. The first ES is used to extract unconstrained handwriting from unconstrained form bank checks, and the second one is used to automatically detect specific types of bacteria in microscopic BCI. Since the *DE plays the central role in the ES generation process*, the professionality of this DE will appear in the design of the SM, and in the generated expert systems using this machine because the ES is *the executable version of the DE knowledge and experience*. Therefore, we will define the DE concept, and explain briefly how the DE who designed the SM and proposed the DEGHS developed his experience, knowledge and professionality.

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The domain expert is in the general sense a person who has a deep knowledge and high professionality in a specific subject like the medicine doctor, the documents analyst, and so on. In fact, the DE who designed the SM is two domain experts in one person: A Domain Expert in Electronic Circuits Design and Implementation (DEECDI) and a DE in Signature Verification and Analysis (DESVA). The final achievement reported in this paper came a result of the interaction between these two DEs.

In 1981, the first author of this paper was a DEECDI where he completed a training course in electronic techniques at Dresden University, Germany in 1976 [3], and worked on developing voice ciphering/deciphering systems using pulse techniques in 1977 in the graduation project for the bachelor degree in Electronic Engineering [4]. Then in November, 1977 he was dispatched by the Scientific Studies and Research Center (SSRC) of Damascus, Syria to attended a very high level training course at Barry Research Corporation in the silicon valley of USA (California) on the design, operation and maintenance of a computerized sounder station for High frequency Communications covering all the spectrum of analogue and digital circuits and their using with microprocessors and minicomputers and transmitting and receiving equipment [5] after completion of a total immersion English language course at Berlitz school of languages, Palo Alto Office [6]. The sounder station was installed in Damascus and put in real operation in 1978. During his work at the SSRC he worked also with the design and implementation of professional Metal detectors [7] and Modems [8].

With the above qualifications, and during his work at the Faculty of Mechanical and Electrical Engineering at Damascus University as a lecturer assistant, he obtained a scholarship from the Japanese Government as a research student. Soon he was dispatched by Damascus University in 1983 to prepare for Doctor Degree in Information Engineering at Nagoya University, Nagoya, Japan (7 researchers of this university received Nobel Prize recently).This was the first case of its kind in Syria (he was the first Syrian Ph. D. student in Japan). After finishing the Japanese language course, in a few days of work at Nagoya University Computation Center (a giant Computer Center) with the signature data prepared by Fujitsu Company, and the programs he received from his advisor, and with his professionality and explorative mind in dealing with research problems as a DEECDI, he discovered the *High Pressure Regions in off-line signatures* by applying the half-power points of the curve of the resonant circuit from electrical circuit theory to the histogram of the signature and considered pixels with gray levels higher than this level as high pressure pixels and the others as low pressure ones. This principle gave amazing results in distinguishing between genuine signatures and skillfully forged ones, and the findings and their developments appeared in local (Japanese) and international publications [9-11]. Within two years, he became known worldwide in this field. During his work on computerized solutions of signature verification and analysis, M. Ammar studied famous references on suspect documents and their scientific examination [12] and linked between theory and application so that he became a domain expert in signature verification and analysis and in handwriting analysis. Later he was certified by the American Board of Forensic Examiners (ABFE) as a *handwriting analyst* and a *forensic document examiner* [13, 14], so that M. Ammar became formally a domain expert in signature verification and analysis (DESVA). With the previous brief explanation, we can consider M. Ammar as a DEECDI, and a DESVA. We notice that the first DE provided the second one with a *golden chance* to start his higher education in Japan quickly with a big momentum.

2. RELATED WOKS

Ammar M., et al, announced in 1985 reaching an automatic method to extract signature image from non-homogeneous noisy background as a part of a general approach to detect skilled off-line forgery signatures, which was unsolved problem [10]. Several months later they announced in TOKYO the complete method of automatic signature verification using pressure features in the monthly convention of the professionals in image processing and pattern recognition (Kenkyukai, held in Tokyo university in Feb. 1986) [9]. Later in October 1986, the topic was published in the 8th international conference on pattern recognition held in Paris [11], which means that the best specialists in the world have approved Ammar's method in High Pressure Regions extraction and using it for skilled forgery detection in off-line signatures, and M. Ammar became famous worldwide in this field. Due to the impressive content, another paper appeared on the same subject in a the (IEEE, Trans SMC journal) [15]. In Marse 1987, Ammar and his group presented the algorithm he developed to select the most effective features in a feature set of n features in (n x n) evaluations instead of n! and used the results to divide the features into groups according to their type and effectivity [16]. In July of the same year in Montreal-Canada, another paper on the same topic appeared in a professional international symposium on handwriting and computer applications [17], followed by a detailed paper on the same topic in the book "computer recognition and human production of handwriting", world scientific [18].

In 1988, Ammar proposed the principle of signature description by computer which gives a symbolic description of the signature in a sophisticated manner and used it for the classification of a signature database into specific types and studying their nature. This work appeared in the 9th Int. Conference of Pattern Recognition in Rome, Italy [19], and used this description even for verification [20]. The application of signature description to signature analysis, announced by the same group, appeared in the 4th Int. conference of the Graphonomics society in Norway [21]. In 1989, M. Ammar, and as **a new trend in signature analysis by computer and its applications**, he developed an Interactive System with graphical and image display abilities, with the system ability to explain its response in natural language, for signature verification and analysis. He wrote a paper about the possible applications of this system with practical examples. One of the applications was to study the *stability of one's signature*(a common problem), and training those who complain the instability in the form of their signature to stabilize it, with some more applications, but warned that the same training application may be misused to produce undetectable forgery even by the best computerized systems. This paper appeared in the 5th International Conference of Image Processing and Analysis 5ICIAP in 1989 in Italy [22]. This interactive system received a great attention in Japan where it was written about and posted in a full page of the 17 million reader Japanese newspaper "Chunichi", and appeared in a televised report in the 6:00 PMprime time news of the TOKA television for 5 minutes. Later, I (Maan) recognized why the Japanese paid such attention to this system. The reason was because it appeared within the period of the National Project (the 5th Generation Computer) issued by Japan, which concentrates on developing the "intelligent computer". In fact, the interactive system, M. Ammar made, is really "**the truly intelligent system"** as described by Luger [23], and the computer running it is an intelligent computer in this field. In 1990 the detailed research about structural description and classification of signatures, appeared in a high rank and famous (PR Journal) in this field [24]. In 1989 with the distinguished reputation Ammar realized, he was asked to analyze the documents of several actual cases of suspect Japanese documents. One among these cases involves 13 documents claiming over quarter million dollars. All these documents were judged by Ammar system to be forgeries. These findings appeared in a paper in an international workshop in Bonace, France, 1991 [25]. In 1992 M. Ammar, realized extraordinary results using a new technique he called "**Ammar matching technique**", and according to the results obtained using his data (prepared by Fujitsu company) he considered the performance a **"breakthrough in this field"**. The new technique appeared in a paper in the proceedings of the 11th In. Conf. on pattern recognition, held in the Netherlands [26]. Commenting on this copious production of signature related researches, R. Plamondon (*a prominent researcher in signature related field*) described Ammar M. and his group in his review paper [27] as **"the most active group in this field,** in the world, of course**"**.

On a rather different track in the same field, in 1989, Ammar received an invitation letter from the International Academic Services (IAS) in the USA, congratulating him on his achievements and inviting him to work in the USA in research and teaching [28]. In 1990, and in connection with this letter, he travelled to the USA to communicate with those people, and to present his paper in the 10^{th} Int. conference on pattern recognition 10thICPR held in Atlantic City, USA. The paper was about a comparison between parametric and reference-pattern-based features in signature verification [29], which led to a well-known paper describing new advances in signature verification, by the same author [30]. After completing his mission in the USA, he decided to go back to his country and start ***a new trip*** *in the field of signature verification and analysis concentrates on building* ***a PC-based signature verification and analysis software system on his cost.***

In 1990 he established a new research group in his country. They could build Personal Computer (PC)-based signature verification and analysis system (SIGVA 1.0), and established a company to market this product (SigSoft company, Damascus, Syria, 1995). This achievement was reported in an international conference paper in Canada in 1995 [31]. In 1995 also, M. Ammar received the certification of the *American Board of Forensic Examiners* in forensic document examination [13], and in forensic handwriting analysis [14]. In 1997 he received the certification of the justice ministry in Syria as the first examiner (highly qualified) of forensic documents [32].

Sigva-1.0 attracted investors from Germany and USA to Syria. The negotiations led to cofounding with Sam Koo ASV Technologies Inc. in 1998 in New York, USA. The work continued in developing the ASV system for USA banks by ASV Technologies Inc. via three groups: the first and essential one in Damascus, the second one in Stuttgart in Germany and the third one in New York in the USA with the supervision and coordination between the three groups by M. Ammar until the first ASV (Automatic Signature Verification) server was set up in NY in 2000, and the US patent of that system was received in 2002 [33].

In 2001, M. Ammar joined Applied Sciences University in Amman, Jordan as full professor specialized in Image processing and Intelligent Systems. While teaching Image processing, Artificial Intelligence, Decision support Systems, and several other subjects, he published several papers in the fields of AI, Computer Vision, and Image processing, *with some relation to the content of this paper* [34-37].

In 2010, he received an invitation from Lambert Academic Publishing (a German International Publisher) to write his experience and works in a book. In 2011, the book "Intelligent Signature Verification and analysis" was published by the LAP [38]. With the progress of the work of ASV Technologies, serving hundreds of banks in the USA, more and more requirements appeared. Among them increasing further the correct verification rate of the system. As a response to that need, Ammar proposed and implemented the "multi-feature set " verification decision which gave important improvement in correct verification rate [39-40]. By that time, 2011, the system had verified over one billion bank check without wrong decisions, with moving a handful of signatures at the end of each batch of tens of thousands of signatures as suspects for visual verification [39].

At this point in the trip of developing signature verification and analysis software, the company (ASV Technologies Inc.) asked M. Ammar to work on handwriting extraction from bank checks. This request led to the achievements reported in this paper.

3. THE COMPLEXITY OF THE REQUIRED WORK AND THE PROPOSED SOLUTION

After discussion with the company about what is really wanted, the result came as follows: The wanted work is extracting “unconstrained handwriting on a bank check image” (may take any form), and the check design is also “unconstrained”, (the check may come from different banks, and consequently, the design of the check is ***unpredictable***). Moreover, all check images are binary, and some are with bad quality.

Taking in consideration that the bank check is a complicated design in nature (contains different fields for writing and signing, symbols, decorations, logos, etc.), everything could be variable, and the objects we should extract “handwriting” are variables and unconstrained. for the first moment, the task seemed to be extremely difficult (if it were possible at all), but finally, M. *Ammar accepted the challenge*. The research achievements are presented in this paper with some further developments that led to the ES generating machine, reported in this paper. The four bank checks shown below in Fig. 1 are examples of the check images to extract handwriting from. With this kind of problems, Expert systems could be the suitable approach because they work with incomplete data, therefore, we will explain in brief about an expert system and how to build it, then apply that to our problem.

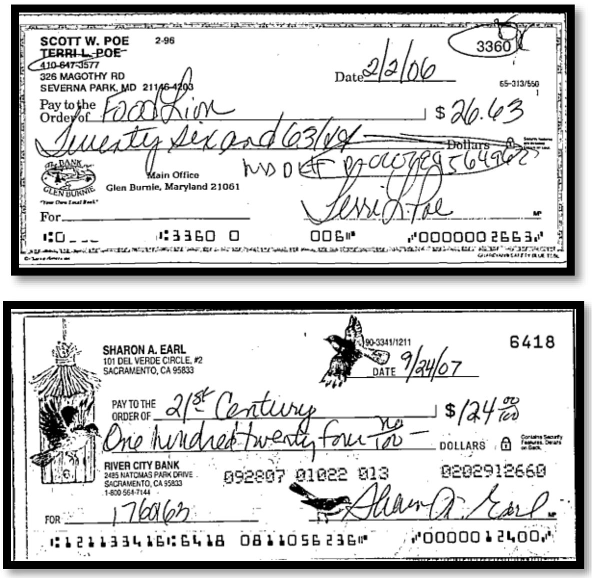


Fig. 1 (a, b, c, d, raster) Four examples of the bank checks to extract handwriting from.

4. Minimum Requirements of an Expert System and Building Team

Any expert system must contain at least: (1) a knowledge base, (2) an inference engine and (3) a user interface. An explanatory component and conflict resolution mechanism can be added [41]. The heart of the expert system is the knowledge base (facts, rules and heuristics) and the inference engine that applies rules to the facts to infer new facts. Rules that represent the knowledge of the *domain expert* are collected and formulated by the *knowledge engineer* and programmed and stored in the KB by the specialized *programmer*. The **domain expert**, the **knowledge engineer** and the **programmer** are the necessary team to build the ES.

4.1. Considerations in forming the ES building team

The team of building an ES must be formed taking in consideration the following points:

1- The Domain Expert (DE) is a person with a professional experience and knowledge in the specific domain.
2- The Knowledge Engineer (KE) is a person who is familiar with the specific domain and with programming. He must understand the key concepts from the DE and formulate them in a form the programmer can understand and program in executable form.
3- The programmer (P) is a person who masters programming in the desired language.

4.2. Characterization of the problem and specifying the contents of the KB

As we mentioned above, the check form is unconstrained so that logos, decorations, symbols, and other objects may differ from one bank to another as we have shown in Fig. 1. All what we know is that the objects we must extract are **"handwriting"** which may contain names, numbers, symbols and words. We must keep in mind also that the handwriting style may differ substantially for one person to another. We will try now to characterize the wanted objects in general:

1 – It is a pen line produced by freehand movement controlled by the brain.
2 – It almost may never contain completely straight lines or 90-degree angles.
3 – It is Smooth and should not contain broken strokes, unless it is a forgery.
4- Signature which must be on the check is a *special type of handwriting* may contain decorations and special long curved strokes.

We will build a Rule – based ES *to extract handwriting from bank checks*. The contents of the KB are facts, rules, and heuristics, summarized as follows:

Facts:

Facts related to this problem domain are features of the signature in special and the handwriting in general. Those features are studied, extracted and used extensively [11,16-22,24-26, 29-31].

Rules:

The rules will depend essentially on the ranges the values of those features may vary inside and still differ from printed objects. Unlike signature verification cases in which those ranges can be learned from the training data, here, those ranges will be found heuristically with the help of the DE and the software machine designed for this purpose. In our problem, there is no training data, but there is only test data.

Heuristics

Instead of "state evaluation function" used in heuristic search in the search process to reach the goal state in a problem like chess game [23], we will use here what we called *Domain Expert Guided Heuristic Search* (DEGHS) because the evaluation of the distance to the goal (best result here) can't be estimated by a number, but it is a visual judgment of a general view of the handwriting on a check. The DE evaluates the improvement obtained and then select the new movement (changing range values, introducing new features, etc.).

5. HANDWRITING EXTRACTION APPROACH

This approach consists of 2 main stages: (1) preprocessing, and (2) handwriting extraction.

5.1. Preprocessing

Before starting the actual handwriting extraction process, we segment the check image into components in order to extract features from these components (Facts), and then apply DEGHS using the rules suggested by the DE. Preprocessing is done in three steps:

1. Applying a Connected Component Labeling (CCL) process to the check image.
2. Closing using a square structuring element with 3 side value.
3. Dilation using a square structuring element with 4 side value.

This preprocessing fattens the printed characters giving them higher density to be removed later by rules.

5.2. Handwriting Extraction

As we mentioned in section 3, we *do not know anything about handwriting on the binary check image* ***except that it is handwriting*** *(no information about spatial positions, form or density). We also don't know anything about the design or content of the bank check* therefore we will detect the handwriting by applying this global rule: delete any object on the check image if it has any one of the non-handwriting characteristics. The remaining will be the handwriting, *if available*. This solution is very general. We have to go inside its specifics according to the DE recommendations.

5.2.1. Approaching the solution

We started from this fact: a human can recognize handwriting from printed text and other shapes in a document easily. According to DE explanation, that is *because the printed text features like the compactness of the characters and sharp change in stroke direction, and so on., are clearly different from those of handwriting already explained in section 3.* Our DE suggested the following ***requirements of the solution.***

5.2.2. Requirements of the solution

1- We need some features to be used for distinguishing between handwriting objects and other objects might find in the check. Essentially, those features should be available in the following references [11, 16-22,24-26, 29-31], as mentioned before.
2- The performance of these features must be evaluated with some data to choose the suitable ones.
3- Since there is no training data for the contents of the design of the checks or for the handwriting, we have to proceed as follows: (1) select some features recommended by the DE based on his knowledge and experience, (2) start testing with some heuristics suggested also by the DE about the ranges of the values of the features that can be used to distinguish between handwriting and other objects, (3) update the ranges of values and/or used features according to the results obtained so that better result is hoped, (4) retest and *evaluate the results*. (5) repeating steps 2-4 until we get the best result.
4- How can we evaluate the result? When using heuristic search in AI problems like chess playing, there is a state evaluation function that returns a value telling us how far from the goal, and based on that value the next move is estimated. Here, we can't design such cost function because the distance to the goal can't not be measured by numbers because evaluation is visual. Now we must define the goal state and in between states.
5- Our goal state is the maximum amount of handwriting extracted with other objects removed. This state can't be measured by numbers but by **visual estimation** given by the DE, therefore we call this kind of heuristic search "Domain Expert Guided Heuristic Search" (DEGHS).
6- The first step we must go is segmenting the check image into its objects. this can be done by Connected Components Labeling (CCL).
7- In order that the DE can give his response flexibly and in reasonable time, we have to provide him with these abilities:

Displaying the input image, (2) displaying the processed image at any stage, (3) displaying any component selected with its image, some other helpful images, and values of all features used, as well as any preprocessing done with parameter values used. The DE must also be provided with the ability of easy selection of any segmented object (CC) using its label, for convenience. We must also provide the ability to select the features the DE wish to use with their value ranges and any conditions desired (AND, XOR, etc.).

8- When we started to work with this subject, we designed and implemented a platform that enables the DE to interact easily with all what we mentioned above (with the help of the KE and the P, if needed) to give him high flexibility in suggesting heuristics, testing them, evaluating the result, making changes and retest again and again until the best result is reached. Fig. 2 shows this platform during one of the DE tests. This platform with the software tied to it is called SM.

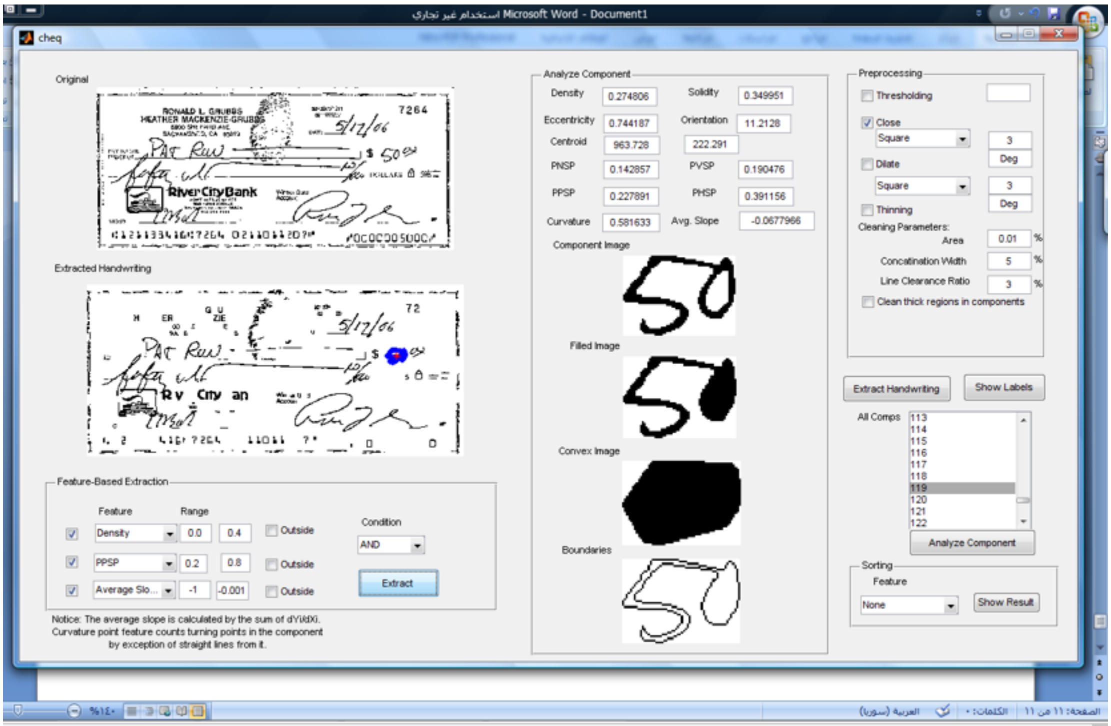


Fig. 2 a screen shot of the platform (SM) during a specific stage of the DE tests.

5.2.3. Description of the screenshot

The image in the top left corner is the original image; the image below it directly is the result of an intermediate stage in which the component No. 119 which is actually the handwritten number "50", and appears in the right side of the check image colored blue for easy location by eye. In the vertical field in the middle in which the image of the No. 50 appears, three more images helpful in evaluation: filled image, convex image, and boundary image. Above the component image, the values of 12 candidate features of the component appears (density, eccentricity, centroid, PNSP, PPSP, curvature, solidity, orientation, PVSP, and PHSP). In the rightmost field on top, the possible preprocessing operations, some special cleaning operations, below that in the same field the number of the CCs appear with the ability to select any component and see all relating results like those appear in this screenshot. The ability of sorting the CCs is also provided. Going back to the left vertical field and below images, we find adjustable feature value ranges with some logical conditions to apply.

5.2.4. Obtained results using the SM for ES development

Fig. 3 shows the handwriting extracted from two different binary check images. The ES was tested with tens of checks (83 check images) and gave very good results.

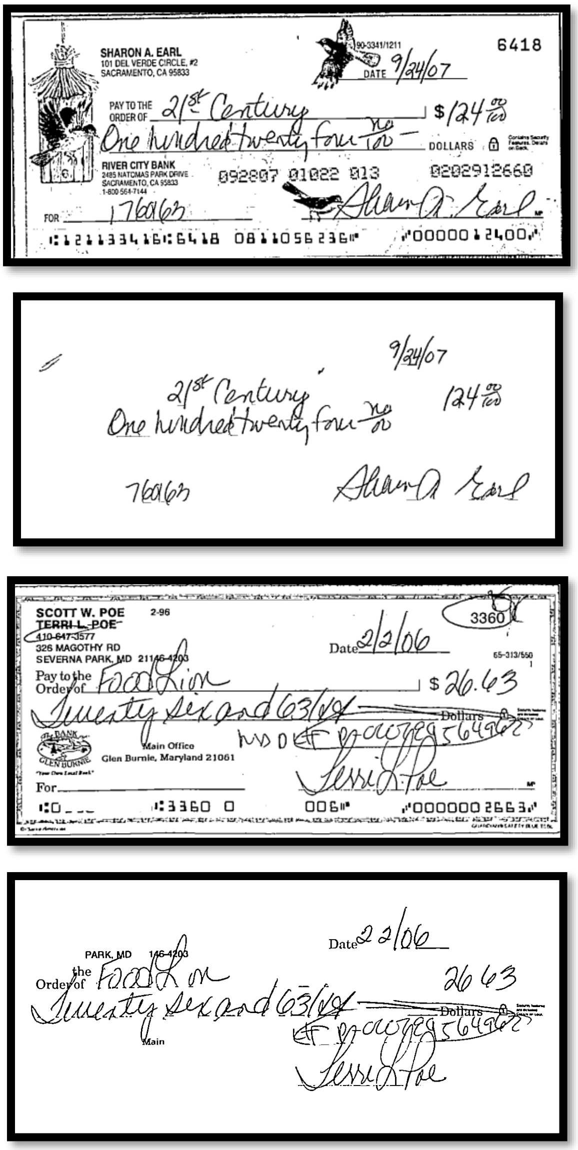


Fig. 3 original binary image (left), and extracted handwriting (right).

5.2.5. The extreme cases

We may consider the checks shown already in Figs. 3 ordinary cases of bank cheks written with full spontaneity, as ordinary cases. Now what happen if the check image can be considered to have uexpected content (no handwriting or full of noise, as the cases c and d in Fig. 1.). The result of these two checks is shown below in Fig. 4. As can be seen, we got almost complete perfomance where in the no handwriting check we detected no handwriting, and the heavy noie in the noisy check was removed without effect on the handwriting detected completely, with only on prined letter (can be removed by post processing).

At this point of development, the company asked whether the system can extract Chinese handwriting, and sent us a test check shown in Fig. 5(left). We started to work with this check using our SM, We could in a few hours modify the content of the KB of the ES to get the result shown in Fig. 5 (right) where we got excellent result.

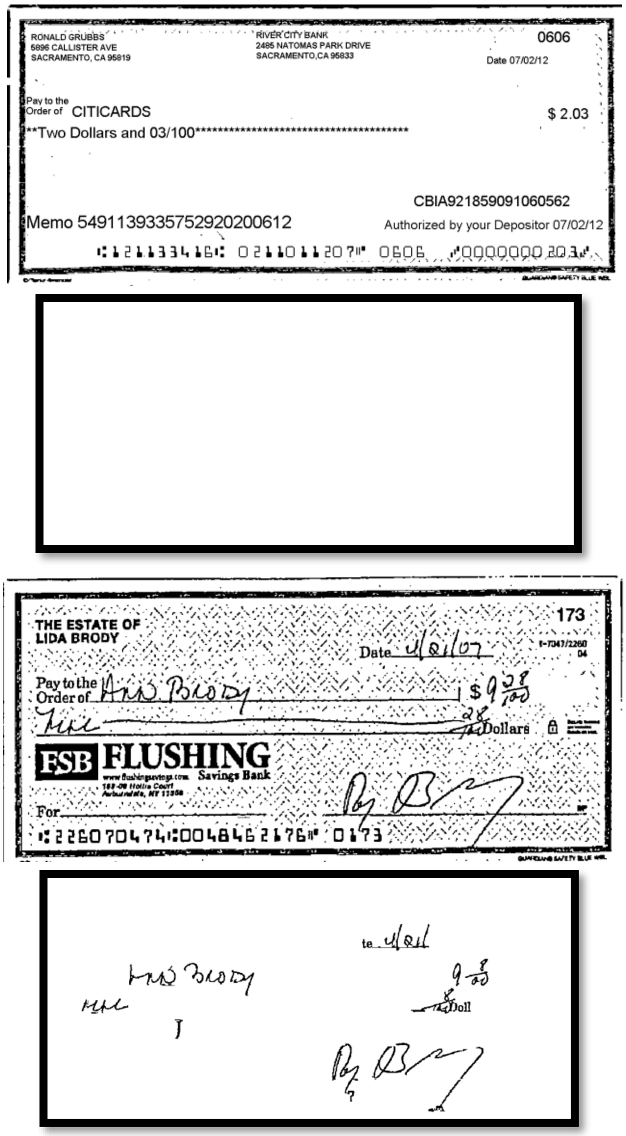


Fig. 4 “no handwriting” check image and “noisy image”, respectively. No handwriting detected in the first and the handwriting detected excellently in the second (excellent result).

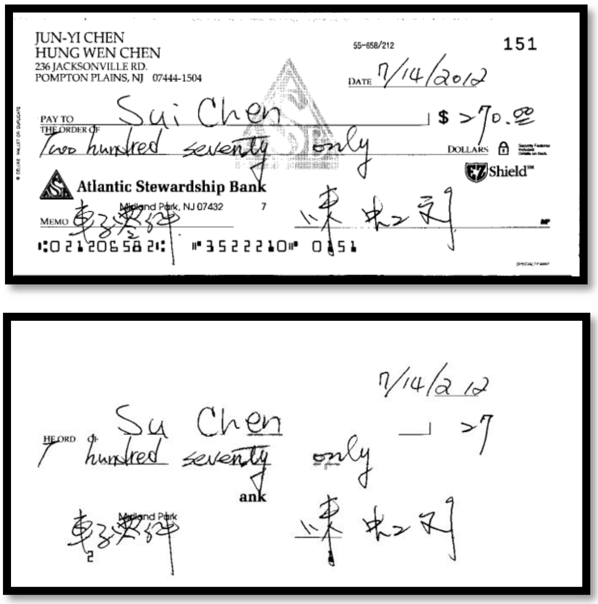


Fig. 5 A check image with Chinese handwriting (left), and extracted handwriting (right). AS can be seen, the result is excellent.

6. GENERATING AN EXPERT SYSTEM IN A COMPLETELY DIFFERENT FIELD

In fact, the principle of “expert system generating machine” was proposed by the first author (M. Ammar) in a local publication at Damascus University 9 years ago [42]. In this section, and to *reinforce this principle,* we introduce using our SM to generate another ES to detect specific types of bacteria in a BCI.

6.1. An ES for detection of specific bacteria types in a BCI

In fact, M. Ammar with 32 years of teaching in the BE department at the FMEE, Damascus university, and 8 years as Head of Department, can be considered as a DE in Biomedical Engineering (BE) field. During his work at the BE department, he translated and wrote several books for the department [42-45], and was active in interaction with Damascus hospitals and the department, especially with Damascus University educational hospital. In that hospital one of the coauthors (K. Ammar) is working as supervisor of the *Bacteria Laboratory*. During discussion with her, she expressed great interest in automatically detecting specific types of bacteria by computer from a microscopic BCI containing very big number of objects like that shown below in Fig. 6. Therefore, we found it a good chance to test the ability of our SM to generate expert systems in a field completely different from checks and handwriting.

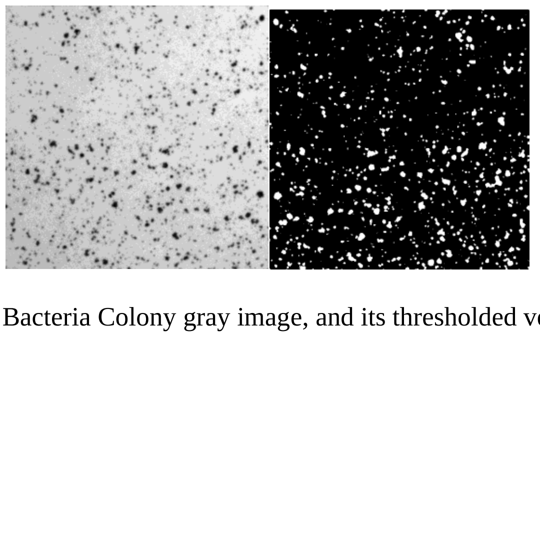


Fig. 6. Bacteria Colony gray image, and its thresholded version.

The DE and the KE made a discussion to characterize the problem before asking the programmer to program a system for that purpose, of course using the SM.

6.2. Steps used in developing the bacteria ES

1 -Specifying the general knowledge in hand

1. The image to work with is a gray level one, shown in Fig. 6.
2. The image contains objects darker than the background (lower gray levels).
3. The image contains very big number of objects (hundreds) vary in shape and size.

2 – Getting more specific knowledge from the DE

1. The objects (bacteria) to be detected are among the larger objects in the image, and they are approximately bigger that 2% of the area of the total image.
2. Objects to be detected are two types:
3. The first type has relatively low density measured by the area of the object divided by the area of the rectangle confining it.
4. The second type has a higher density compared with the first one.
5. The circumference of the objects of the second type is smoother than the first one and more homogenous.

As we can see, this knowledge is general and relative. The exact knowledge of aimed objects is known only by the DE, therefore we *must follow the heuristic methodology in cooperation between the DE, the KE, and the programmer, using our SM.*

3 – The heuristic methodology (HM) to be used

1 – Design and/or select suitable features to detect approximate shapes of the objects according to approximate knowledge described in the above 5 points.
2 **-** Using this approximate knowledge to retrieve objects satisfying its content, (candidates), and show them to the DE.
3 – Modify the features and/or their values according to the comments of the DE to become closer to detect the wanted objects.
4 – Repeating 2 and 3 until reaching the goal which is (detecting the desired bacteria objects as accurate as possible, if exist).
5 – The final finding of the features, their values and ranges, rules and conditions become the content of the KB.

4 - Applying the actions needed to implement the HM

1 – Segmenting the binary BCI into its components in which we must search for the bacteria objects to be detected.
2 – Deleting the objects with area less than 2% of the total image area.
3 – Designing or selecting a function to compute the density and another one to compute the smoothness and then fine tune their parameters to reach the goal with the supervision of the DE
4 – Determining the logical functions necessary to combine the effects of the functional functions to reach the goal.
5 – Using DEGHS to reach the minimum and maximum limits of the features values and the necessary logical operations to give the final form of the Rules to be used by the ES to efficiently detect the wanted objects (bacteria).

Fig. 7 shows the BCI in an intermediate stage during the process of generating the bacteria types ES.

We will show below the results of some key actions implemented to reach the goal:

- Thresholding the BC image. The result is shown in Fig. 6.
- Deleting objects less than 2% of the total area of the BC image. A part of a table of 9 features of the 118 components remained is shown in Fig. 8. The features are: Curvature, average slope, orientation, eccentricity, density, percentage of positively, negatively vertically and horizontally slanted pixels in the boundaries of the object (CC). Features in the table are sorted according to the values of "density" feature.
- Fig. 9 shows the result of deleting components with area less than 5% of the BCI area. Remaining components are 24 and the values of the 9 features of all the 24 components (objects) sorted by the curvature (the right most column in the table) are shown in the table in Fig. 9.
- Fig. 10 (left): shows the 12 objects remaining from those in Fig. 9, (middle): the Table of the nine features sorted by values of curvature in the rightmost column, (right): remaining 5 objects belonging to the values (0.56-0.67) in the right most column. These 5 objects were accepted by the DE as type I bacteria objects are shown enlarged in fig. 11.

5 - Bacteria type II final result

Fig 12 shows the two objects of type II bacteria reached at the end of the DEGHS (bacteria objects with higher density, higher smoothness, and more homogeneity) with their geometrical measures. The enlarged objects appear in 4 types: original, filled, convex hull and boarders represented by 8-directionals. These figures with the tables are used in evaluating the results during DEGHS.

We show in Fig. 13 a pictorial summarization of the work of the bacteria ES generated by the DE, SM and the DEGHS.

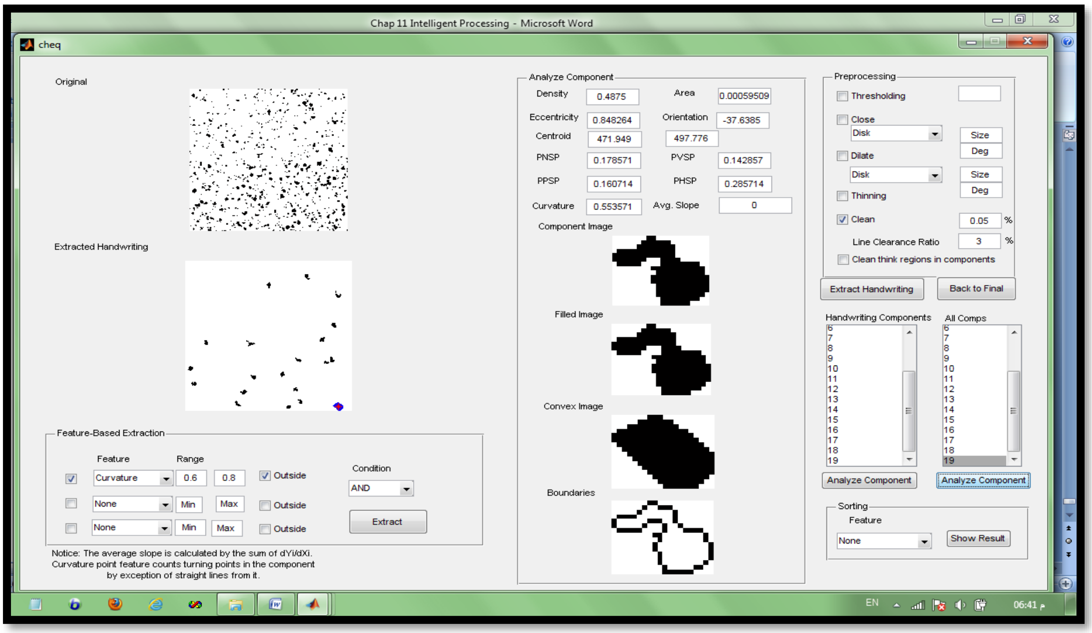
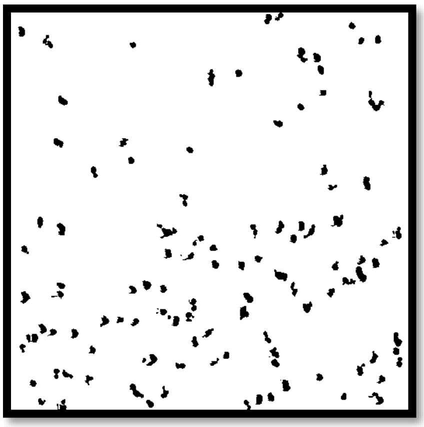
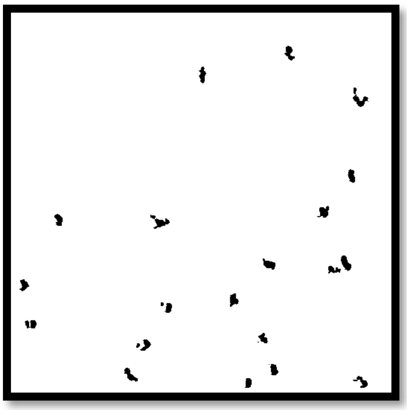


Fig. 7. The BCI in an intermediate stage during the process of generating the bacteria types ES.



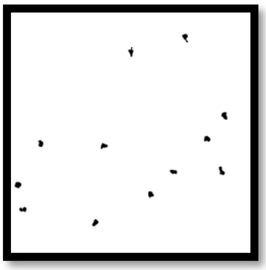
PNSP	PVSP	PPSP	PHSP	Density	Eccentricity	Orientation	Average Slope	
0.21	0.38	0.19	0.18	0.35	0.80	-51.54	0.06	0.65
0.25	0.17	0.21	0.36	0.38	0.80	-15.86	0.06	0.65
0.26	0.24	0.22	0.33	0.39	0.85	-41.46	0.03	0.67
0.02	0.30	0.30	0.15	0.39	0.94	52.66	-0.30	0.54
0.13	0.26	0.32	0.32	0.42	0.93	36.12	-0.16	0.55
0.09	0.24	0.30	0.30	0.42	0.90	35.59	-0.25	0.55
0.37	0.18	0.06	0.20	0.44	0.93	-49.18	0.25	0.57
0.08	0.14	0.46	0.27	0.44	0.91	42.55	-0.29	0.70
0.25	0.25	0.17	0.17	0.46	0.84	-59.39	0.04	0.56
0.33	0.12	0.09	0.24	0.47	0.90	-29.30	0.26	0.64
0.23	0.33	0.15	0.07	0.47	0.93	-74.19	0.05	0.53
0.23	0.29	0.20	0.29	0.48	0.65	63.59	0.08	0.57
0.32	0.26	0.06	0.06	0.49	0.94	-65.00	0.23	0.53
0.20	0.32	0.20	0.12	0.50	0.93	-78.07	-0.02	0.61
0.17	0.15	0.30	0.05	0.50	0.80	64.62	-0.10	0.63
0.24	0.28	0.18	0.20	0.51	0.87	-74.88	0.08	0.64
0.17	0.31	0.28	0.08	0.51	0.86	73.49	-0.11	0.61
0.10	0.17	0.27	0.17	0.51	0.89	45.25	-0.09	0.53
0.13	0.32	0.26	0.05	0.51	0.89	68.96	-0.10	0.55
0.15	0.15	0.26	0.37	0.52	0.66	36.30	-0.17	0.63

Fig. 8. Objects with area larger than 2% of the total BCI area (118 objects) and the values of 9 features computed for them shown in the partial table.



Index	PNSP	PVSP	PPSP	PHSP	Density	Eccentricity	Orientation	Average Slope	
8.00	0.00	0.00	0.00	0.00	0.90	0.60	90.00	0.00	0.00
13.00	0.00	0.00	0.00	0.00	1.00	0.87	0.00	0.00	0.00
16.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
5.00	0.00	0.14	0.14	0.00	0.77	0.74	64.10	-0.13	0.21
12.00	0.06	0.29	0.12	0.03	0.80	0.80	82.80	-0.06	0.24
9.00	0.09	0.24	0.18	0.00	0.71	0.81	77.89	-0.06	0.36
15.00	0.21	0.17	0.04	0.34	0.59	0.84	-25.71	0.19	0.38
17.00	0.16	0.34	0.11	0.05	0.72	0.81	-77.13	0.05	0.42
2.00	0.15	0.38	0.11	0.08	0.70	0.73	-2.61	0.05	0.43
11.00	0.13	0.22	0.20	0.13	0.64	0.72	86.51	-0.09	0.46
19.00	0.12	0.31	0.19	0.23	0.60	0.57	58.99	-0.07	0.48
3.00	0.23	0.17	0.13	0.10	0.69	0.83	-75.35	0.15	0.50
20.00	0.20	0.18	0.12	0.27	0.62	0.88	-8.19	0.02	0.53
22.00	0.19	0.33	0.10	0.12	0.71	0.89	-79.55	0.09	0.55
4.00	0.37	0.18	0.06	0.20	0.44	0.93	-49.18	0.25	0.57
21.00	0.32	0.23	0.09	0.09	0.58	0.90	-63.41	0.19	0.57
14.00	0.22	0.22	0.17	0.14	0.54	0.78	-56.00	0.11	0.58
10.00	0.23	0.40	0.21	0.02	0.60	0.93	89.74	0.00	0.60
6.00	0.17	0.15	0.30	0.05	0.50	0.80	64.62	-0.10	0.63
18.00	0.24	0.28	0.18	0.20	0.51	0.87	-74.88	0.08	0.64
7.00	0.25	0.17	0.21	0.36	0.38	0.80	-15.86	0.06	0.65
23.00	0.21	0.38	0.19	0.18	0.35	0.80	-51.54	0.06	0.65
24.00	0.26	0.24	0.22	0.33	0.39	0.85	-41.46	0.03	0.67
1.00	0.23	0.25	0.28	0.15	0.57	0.72	89.50	0.00	0.75

Fig. 9. The remaining 24 objects and the values of the 9 features.



Index	PNSP	PVSP	PPSP	PHSP	Density	Eccentricity	Orientation	Average Slope	
8.00	0.14	0.03	0.00	0.28	0.79	0.85	-11.58	0.11	0.22
7.00	0.19	0.11	0.11	0.17	0.68	0.50	-65.61	0.00	0.36
3.00	0.17	0.26	0.11	0.03	0.73	0.74	-81.18	0.08	0.43
1.00	0.14	0.11	0.17	0.11	0.75	0.43	24.44	-0.05	0.44
10.00	0.16	0.16	0.14	0.14	0.73	0.57	-16.37	0.03	0.46
11.00	0.24	0.30	0.09	0.15	0.56	0.90	-65.69	0.13	0.50
6.00	0.21	0.43	0.15	0.17	0.51	0.87	-87.49	0.04	0.51
2.00	0.21	0.08	0.18	0.23	0.67	0.81	2.72	0.07	0.56
12.00	0.22	0.27	0.12	0.15	0.65	0.77	-67.15	0.12	0.59
5.00	0.16	0.21	0.21	0.29	0.54	0.75	12.29	-0.05	0.63
4.00	0.15	0.18	0.32	0.06	0.58	0.79	54.52	-0.17	0.65
9.00	0.27	0.36	0.18	0.18	0.51	0.83	-69.98	0.20	0.67

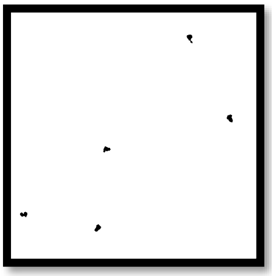


Fig. 10 (left) remaining 12 objects remaining from those in Fig. 10, (middle) Table of the nine features sorted by values of curvature in the rightmost column, (right) remaining 5 objects belonging to the values (0.56-0.67) in the right most column. These 5 objects are shown enlarged in fig. 11.

Fig. 11. The five objects of type I bacteria reached at the end of the DEGHS (type I final result).

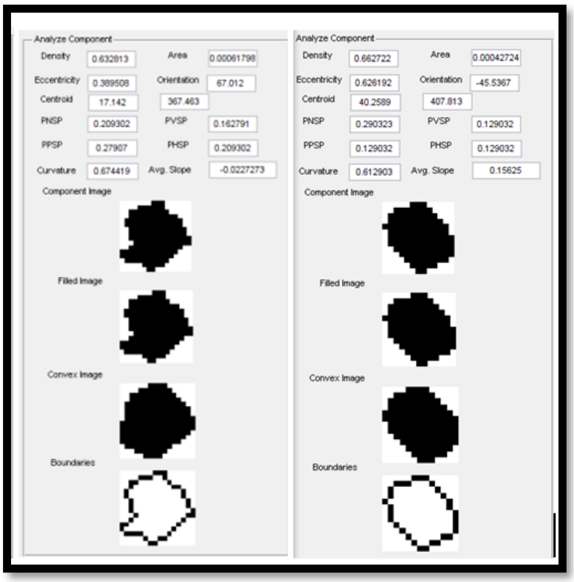


Fig. 12. The two objects of type II bacteria reached at the end of the DEGHS with their 4 shapes and values of candidate features.

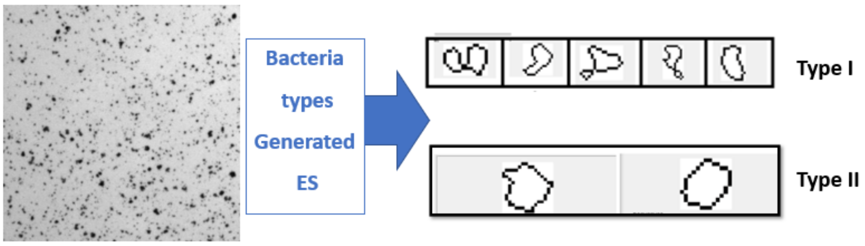


Fig. 13. Pictorial summarization of the work of the generated bacteria types ES

Any more development needed?

When introducing a method or approach, this question appears: is there any limitation in performance? our answer: as far as realizing the principle of generating expert systems in the sense we proposed is concerned, we see no limitations, however, if the volume of data used in testing is concerned, we believe that we have to test our machine with more samples for English language checks. In this regard, we may say, when the volume of checks is very big, we may use "grouping" principle to expand the ability of the system. In fact, "grouping" is one of the secrets of success of ASV Technologies over 20 years of work without problems with millions of checks investigated every day. Concerning the Chinese language, we tested only one sample with excellent result, but it must be tested with much more samples. Concerning the bacteria ES, we are very optimistic.

7. Hybrid Intelligence and our SM

In a previous publication [46], we called our SM when used by the DE with the DEGHS, to generate expert systems "an expert system generating machine". Now, if we look at the essence of the generation process which was developed in 2013 [42], we find that it mixes the Artificial intelligence (represented by the heuristic search) with the human intelligence represented by the knowledge and judgment of the DE who evaluates the state and guides this heuristic search until the goal is reached. Therefore, the result of mixing human intelligence and artificial intelligence can be called Hybrid Intelligence which enabled us to reach solutions that can't be reached neither by algorithmic approaches nor by known AI techniques.

8. Conclusion

We have introduced in this paper a software platform called it Software Machine (SM). This machine is designed to give the Domain Expert who will guide what we called "Domain Expert Guided Heuristic Search" with the widest choices of processing the image, computing the values of its features, displaying some useful types of its images, enabling him to apply some logical conditions (AND, XOR, ..) to the features when applying the rules of the ES to be generated, to solve the problem in hand, using some possible preprocessing techniques, and showing all these choices and their results in one screen giving him the ability to evaluate the situation at a glance, and giving his judgement to proceed to a next move or stop and accept the final result. Besides reaching a solution to some problems where no algorithmic approach can be applied, We found by practical applications that this machine speeds up very much reaching the desired solution for this class of problems. As a real applicartion, we applied the machine to generatng an expert system to extract unconstrained English handwriting from unconstrained form (design) binary bank check with high effectivity, even if the check is noisy sometimes. We also could modify the KB of the first ES quickly to do the same thing when the used language is a mixture of Chinese and English. As reinforcing of the principle of ES Generating Machine, we could easily generate an ES that detects the objects of two types of bactiria in a bactiria colony microscopic image containg very large number of microscopic bacteria objects, efficiently. We showed also that interaction between different DEs may be very useful in research. Finally, we reached the conclusion that the process of ES generation we developed is in essence a Hybrid Intelligence process.

FUTURE WORK

We plan to generate a practical expert system to detect automatically specific types of bacteria in a microscopic Bacteria Colony Images to be used in Damascus University Educational Hospital.

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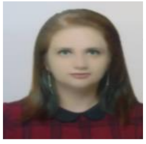

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