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Medical Diagnosis Expert System for Malaria and Related Diseases for Developing Countries

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Abstract

There is a strong need for cost-effective technologies to manage disease processes and thus reduce morbidity and mortality in the developing countries. Yet bringing intelligent healthcare informatics to bear on the dual problems of reducing healthcare costs and improving quality and outcomes is a challenge even in countries with a reasonably developed technology infrastructure. This paper focused at how appropriate an application of Medical Diagnosis Expert System (MDES) is to manage diseases in developing countries. MDES is usually designed to enable clinicians to identify diseases and describe methods of treatment to be carried out taking into account the user capability. The MDES described here is implemented using the *C Language Integrated Production System* (CLIPS). The CLIPS is an expert system, which has a shell composed of four modules: the user interface, the explanation system, the inference engine and the knowledge base editor. In the system, a number of patient cases will be selected as prototypes and stored in a separate database. The knowledge is acquired from literature review, human experts and the internet of the specific domain and is used as a base for analysis, diagnosis and recommendations.

Keywords

Developing, Affordability, Appropriateness, Expert System, Medical Diagnosis, Developing Countries, Artificial Intelligence

1. Introduction

An *expert system* is a computer system that emulates the decision making ability of a human expert [1]. By so doing, it acts in all respects like a human expert, using human knowledge to solve problems that would require human intelligence. When patients seek the help of medical experts, they do so for diagnosis and treatment of their various health problems. This can also be to confirm a clinically suspected diagnosis or to obtain more accurate information. For example, in the developing countries where malaria is endemic and commonly associated with the "factor of developing" called poverty, the malaria disease may be suspected by the presence of fever. However, because of the presence of many other diseases causing fever, confirming the diagnosis of malaria may be difficult, unless by the exclusion of other causes of fever on history, physical examination and on microscopic examination of a blood slide [2].

In the developing countries, malaria is known to have a major negative effect on economic development [3]. This socioeconomic implication of malaria makes it an important issue in its diagnosis. The *Plasmodium falciparum* protozoa causing malaria caries a poor prognosis with high mortality if untreated, but it has an excellent prognosis if diagnosed early and treated appropriately [4]. This is made worse if the right diagnosis is not made in the presence of some other diseases with symptoms almost non-distinguishably in common with malaria and is said to constitute the differential diagnoses of malaria (malaria-related diseases). These include but not restricted to: dengue fever, enteric fever (typhoid infection), African trypanosomiasis (sleeping sickness) and pulmonary tuberculosis.

In situations such as above, confirming the diagnosis of malaria [5] becomes a difficult task for the physician. This is because the diagnostic procedures of gathering the requisite data, as in signs, symptoms and investigations to narrow the differential diagnosis and arrive for instance at the correct diagnosis of malaria rather than of typhoid fever, which is a complex process. However, employing intelligent health informatics into the process drastically simplifies it and ensures that misdiagnosis or missing data is eliminated from the medical care system.

This work specifically deals with the use of an affordable and available expert system (CLIPS) to exactly diagnose malaria and delineate its related diseases in the developing countries using Nigeria as a case study. This is important because previous medical diagnosis expert systems had been costly and focused on diseases peculiar to the developed world. Secondly, the present work is in a developing country, for a developing country and by a developing country.

The finished work will enable the clinicians to identify malaria or its related diseases and describe methods of treatment to be carried out taking into account the user capability. The CLIPS expert system uses inference rules and plays an important role that will provide certain methods of diagnosis for treatment. In the system, a number of patient cases are selected as prototypes and stored in a separate database, known as the knowledge base. The knowledge is acquired from literature review and human experts of the specific domain (in this case malaria experts) and is used as a base for analysis, diagnosis and recommendations. Therefore, the clinical diagnosis is performed via the expert system, based on patient data. The work is experimented on various scenarios in order to evaluate its performance.

2. Literature Review

Expert System is itself a major aspect of *artificial intelligence*, which is the branch of computer science concerned with making computers behave like humans [6] [7] [8] [9]. Expert system as a computer system usually consists of two core parts in its kernel: a knowledge base and an inference engine [10]. A knowledge base represents knowledge in certain domain and stores all the facts and rules about a particular problem in that domain. An inference engine is a set of algorithms, which perform reasoning, judgment and decision making. However, for a user to interact with the expert system, there has to be an additional part: the user interface. Therefore, the entire expert system architecture in the most simplified version consists of three parts: a knowledge base, an inference engine and a user interface (**Figure 1**).

There have been many successful and economically valuable applications of expert systems. Expert systems provide benefits such as reducing skill level needed to operate complex devices, diagnostic advice for device repair, interpretation of complex data, "cloning" of scarce expertise, capturing knowledge of expert who is about to retire, combining knowledge of multiple experts and intelligent training [11]. A typical conceptual architecture of an expert system is shown in **Figure 2**.

2.1. General Applications of Expert Systems

The spectrum of applications of expert systems technology to solve problems in industrial, commercial and other areas is so wide as to defy easy categorization. About seven categories of applications have been delineated for expert systems technologies [12]. These include: Diagnosis and Troubleshooting of Devices and Systems of All Kinds; Planning and Scheduling; Configuration of Manufactured Objects from Subassemblies; Financial Decision Making; Knowledge Publishing; Process Monitoring and Control; and Design and Manufacturing.

As a category of expert system, *Diagnosis and Troubleshooting of Devices and*

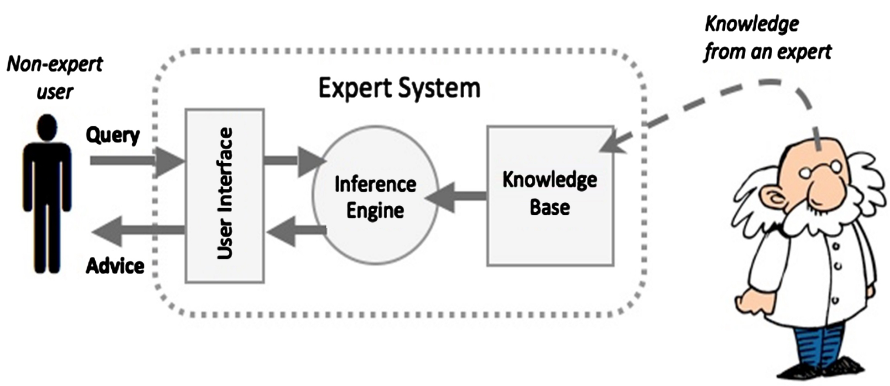

Figure 1. The concept of expert system. (Retrieved from http://www.Bandicam.com)

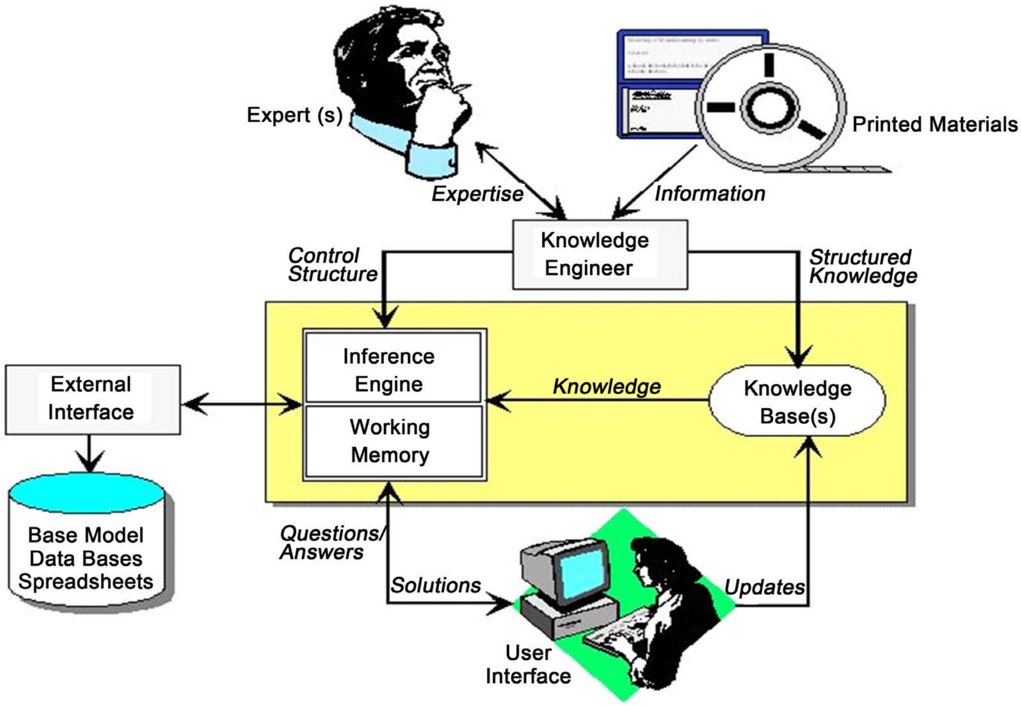

Figure 2. A typical architecture of an expert system. (Retrieved from http://slideplayer.com/slide/6911313/23/images/25/Conceptual+Architrecture+of+a+Typical+Expert+System.jpg)

Systems of All Kinds is said be the most popular spectrum of application of expert systems. It comprises systems that deduce faults and suggest corrective actions for a malfunctioning device or process [13].

Examples of this include Medical diagnosis and diagnosis of engineered systems. Aside from this categorization of applications of expert systems, it can be viewed along several major application areas of expert system such as agriculture, education, environment, law manufacturing, medicine, power systems etc [14].

Expert systems currently play important roles in medicine, medical practice or medical care. About nine areas of the medical practice have been identified to employ the use of computer expert systems. These are [15]: Prediction of Disease, Prevention of Disease, Diagnosis of Disease, Staging of Disease, Therapy of Patient, Rehabilitation of Patient, Health Status of the Patient, Counselling of the Patient, Advocacy for the Patient.

Categorically, expert systems can be applied in the following tasks in the medical practice [16]: Generating alerts and reminders, Diagnostic assistance, Therapy critiquing and planning, Agents for information retrieval. In the task of *diagnostic assistance*, an expert system can help suggest likely diagnoses based on patient data, when a patient's case is complex, rare or the clinician making the diagnosis is quite inexperienced in the given specialty.

2.2. Applications of Expert Systems in Medical Diagnoses

The most prolific application of expert systems to date has been in the area of medical diagnosis. This is probably because of the expert systems have been very effective in this area. The expert system can be used to assist a physician in diagnosing medical problems of a patient or else be used in the interpretation of medical test results.

A classical medical diagnosis expert system is the *MYCIN*. It was developed to capture the knowledge of medical experts in infectious blood diseases [17]. MYCIN captured the expertise of clinicians on blood diseases to provide accurate and quick diagnosis of the present disease and the proper therapeutic recommendation. Another feature that made MYCIN valuable apart from its ability to diagnose infectious blood diseases, is its contributions to the understanding of introducing an expert system into the workplace.

Aside from MYCIN, another expert system, *Diagnosis Pro* provides differential diagnosis in the field of general internal medicine, family practice, paediatrics, geriatrics and gynecology. After the physician has entered the most important attributes (signs, symptoms lab result, X-ray results) the system generates a list of possible diseases arranged in a hierarchical format. By highlighting any disease in the list, the physician gets an instant review, including clinical presentation and characteristics, recommended lab tests, pathophysiology, rule outs, complications and more. The physician can also rule out or confirm a disease by entering the name of the disease and receiving all the information associated with it.

Another expert system used in medical diagnosis is the Global Infectious Diseases & Epidemiology Network, GIDEON. In addition to diagnosis, GIDEON is used for simulation and informatics in the fields of geographic medicine and infectious diseases, and Clinical Microbiology. The expert system was designed to diagnose all the world's infectious disease, based on symptoms, signs, laboratory testing and dermatological profile. Though, GIDEON is country specific. The database incorporates 327 diseases, 205 countries, 806 bacterial data and 185 antibacterial agents. Gideon's diagnostic module enables the user to access all epidemiological parameters, clinical hints, diagnostic tests, and optimal therapy. After specifying the suspected country of disease, acquisition and entering the sign and symptoms of the patient, GIDEON provides a ranked list of differential diagnosis.

Then, Post-Operative Expert Medical System, POEMS provides decision support system for post-operative care. POEMS was developed to give advisory and decision support to less experienced staff. It interactively receives data obtained from the patients based on the standard strategy used by the medical staff, viz., past medical history, operative history, examinations and investigative tests. From these data, POEMS presents an ordered list of likely, possible and not-likely candidate diagnosis and can answer questions on how the diagnosis was reached, and what further investigative action could be taken to focus on a particular diagnostic candidate.

2.3. Malaria and Related Diseases

Malaria is a potentially life-threatening disease caused by infection with *Plasmo-*

dium protozoa transmitted by an infective female *Anopheles* mosquito. Infection caused by a particular specie of the protozoa called *Plasmodium falciparum* caries a poor prognosis with high mortality if untreated, but it has an excellent prognosis if diagnosed early and treated appropriately [18].

Commonly presenting clinical symptoms for malaria include: paroxysmal fever, shaking chills and sweats (every 48 or 72 hours, depending on the species), headache, cough, fatigue, malaise, arthralgia and myalgia. Many other diseases have some of these symptoms in common with malaria. As a result these other diseases are said to constitute the differential diagnosis of malaria and referred here as malaria-related diseases. The most important malaria-related diseases include: dengue fever, zika virus infection, chikungunya virus, pneumonia, influenza, enteric fever (typhoid infection), pyogenic infection, leptospirosis, infectious mononucleosis, HIV seroconversion, ameoebic liver abscess, African trypanosomiasis (sleeping sickness), rickettsial infection, legionnaires' disease and pulmonary tuberculosis.

In situations such as above, confirming the diagnosis of malaria becomes a difficult task for the clinician. Best clinical practices require that this be done by placing the differentiating signs/symptoms side by side with the differentiating investigations. This will rule out the least likely diagnosis leaving only a most likely one. This elimination methodology is applied serially until the specific diagnosis of malaria or otherwise is made. It is true that in some cases a patient may be affected by more than one disease sharing similar signs and symptoms. In such cases the patient can be diagnosed with more than one disease.

But then, providing reliable data gathering as in signs, symptoms and investigations as well as diagnostic decision support is a complex and herculean process. Yet this is the goal of public health efforts. To improve on healthcare delivery, the tools to accomplish these are continuously being rendered digital in form of intelligent healthcare informatics. Though, these tools have been expensive, unsupportable, and inaccessible, especially for developing countries.

2.4. The Designed Medical Diagnoses Expert System (MDES) for Malaria and Related Diseases

The MDES is designed using the C Language Integrated Production System (CLIPS). CLIPS is rule-based expert system tool originally developed by the Software Technology Branch (STB), NASA/Lyndon B. Johnson Space Center. It is rule-based because knowledge here is represented in rules, based on experience. **Figure 3** shows the architecture of the MDES for Malaria and Related Diseases. It consists of the MDES Shell modules and the non-shell modules of the MDES. The MDES shell is made up of four modules: the user interface, the explanation system, the inference engine and the knowledge base editor. The non-shell modules of the MDES are the user, the Case specific data (working storage), the Knowledge base, the malaria-specific data from patients, the knowledge from medical experts, and the knowledge from literature, web etc. (**Figure**

3).

1) *The MDES Shell Modules:*

User interface is the code that controls the dialog between the user and the system. MDES makes the system to ask the user directly for clinical features (signs and symptoms) and investigation questions to first make diagnosis and then propose treatment.

The *Explanations System* gives the system the ability to explain the reasoning process that it used to reach a recommendation. This is useful because it allows the user to see unknown diagnostic criteria of some diseases or syndromes. *Inference engine* is the module that chooses domain inference or logical rules to the knowledge base to be executed depending on the malaria-specific case. *Knowledge base editor* is a module of the MDES that allows creating and updating the knowledge base, supports the operations on database systems—insert, delete, modify, display.

2) *The Non-Shell MDES Modules:*

The *user* is the clinician who is going to employ the expert system as a decision support system to aid him in making his diagnosis of malaria and its related diseases. *Knowledge base* is a collection of rules or other information structures derived from the *medical expert*, *literature*, *web etc*. Rules are typically structured. *Case specific data* constitutes the working storage of the data specific to the diagnosis of malaria and related diseases, entered into the MDES from patients during a particular session with the MDES.

3. Using the Template

In the Expert System, MDES shell designed using CLIPS, the knowledge base was built by accumulating factual knowledge from medical experts of the specific medical domain of malaria. In this case the consultants (medical experts) in internal medicine, community medicine, general medical practice and paediatrics in Abia State University Teaching Hospital, Aba, Abia State, Nigeria were used. This was done by the use of a specialized questionnaire given to the medical experts to gather the experts' knowledge on malaria and its related diseases'

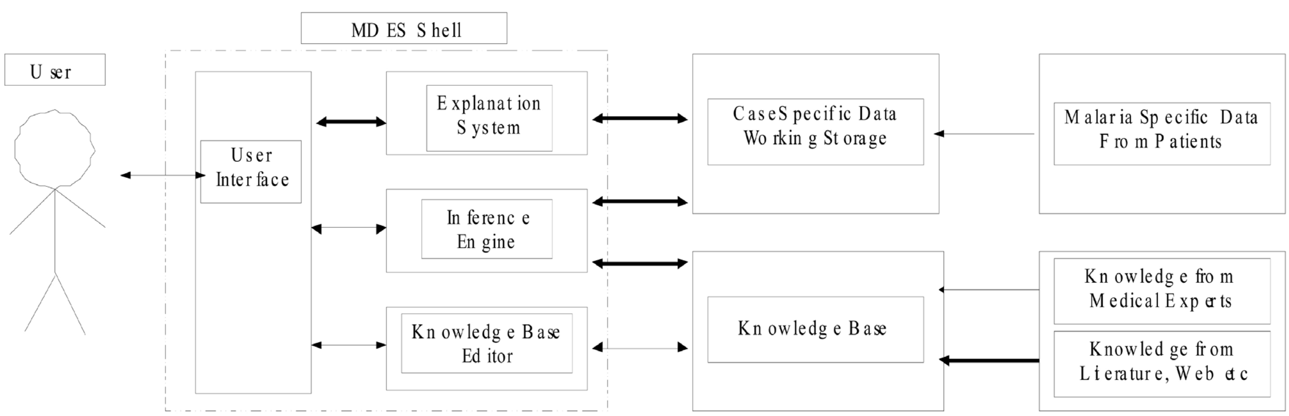

Figure 3. Architecture of the medical diagnosis expert system (MDES) for malaria and related diseases.

conditions, namely their symptoms, signs, possible clinical investigations and treatment options.

The questionnaire was divided into five sections: Preamble/Consent Request; Professional/Demographic Data; Clinical Signs and Symptoms; Clinical Investigations; and Therapy. The Preamble/Consent Request section briefly introduced the project and provided for the respondents consent. The Professional/Demographic Data section was used to retrieve vital demographic and professional information from the respondents.

The Clinical Signs and Symptoms section was used to gather the possible clinical presenting signs and symptoms of malaria and its related diseases. The Clinical Investigations section contains questions used to retrieve possible clinical investigations like laboratory tests or radiological investigations that can be done to elicit malaria or its related diseases. Finally the Therapy section was used to gather possible treatment for each of the differential diagnoses of malaria.

The data accumulated from the specialized questionnaire above were analyzed by establishing possible associations between the signs and symptoms of patients with given clinical investigations. Further knowledge was acquired from literature review of books and journals in the domain of malaria and its related diseases and then from the internet. These were used as a base for analysis, diagnosis and recommendations. Knowledge in the design was represented via a production rule.

The signs, symptoms and investigation results were the determining factors for diagnosis of malaria or any of its related diseases. Five diseases were provided for diagnosis in the designed system: malaria, dengue fever, enteric fever (typhoid infection), African trypanosomiasis (sleeping sickness) and pulmonary tuberculosis. The possible signs, symptoms and investigation reports of these diseases were organized in groups, which helps in diagnosis. Each disease entity or unit is provided with three groups of signs/symptoms/investigation results used as determining factors in the diagnosis as follows:

1) *Sr* = *Sign*/*Symptom*/*Investigating report is Strongly Required for Diagnosis*;

2) *Rn* = *Sign*/*Symptom*/*Investigating report is Relevant but Not necessary for diagnosis*;

3) *Nr* = *Sign*/*Symptom*/*Investigating report is Not Related/Relevant for diagnosis.*

Table 1 displays the signs and symptoms, while **Table 2** displays the possible clinical investigations for malaria and related diseases as accumulated in the knowledge base. Different rules exist for diagnosis based on the three groups of determining factors of Sr, Rn and Nr for signs/symptoms/investigation results of malaria and related diseases diagnoses. The system provides a simple, interactive, text oriented, command prompt and menu based interface. It stores all the rules as a batch file. So the series of rules can automatically read or run directly from a batch file as a result of a batch command. That is whenever the user clicks the batch file icon, the CLIPS file with rules will start automatically.

Then, **Table 3** shows an example of a Production Rule for malaria, using the signs/symptoms/clinical investigation results of malaria and related diseases in Table 1 and Table 2. In the production rule, the If, then condition is applied.

For instance, to diagnose malaria, if sign/symptom of paroxysmal fever is present and Strongly Required (Sr) for diagnosis, and if shaking chills is also Strongly Required (Sr) for diagnosis, both will be connected by AND. So also will fatigue and positive rapid diagnostics test (and all Strongly Required (Sr) signs/symptoms) for diagnosis will be connected by AND. On the other hand, signs/symptoms like myalgia, arthralgia and headache, which are all Relevant but Not necessary (Rn) for diagnosis will be connected by OR. Finally, signs/symptoms

Table 1. Table of signs and symptoms of malaria and related diseases.

Signs/Symptoms	Malaria	Dengue fever	Enteric (Typhoid) fever	African Trypanosomiasis (Sleeping Sickness)	Pulmonary Tuberculosis
*fever, paroxysmal	(Sr)	(Sr)	(Sr)	Intermetent (Sr)	Chronic (Kg)
*headache	(Sg)	(Sg)	dull frontal (Kg)	(Sg)	(Sg)
*malaise	(Sr)	(Sr)	(stupurous) (Sr)	general (Sr)	(Sg)
*retro-orbital pain	(Ux)	(Kg)	(Ux)	(Ux)	(Ux)
*cough	(Sg)	(Ux)	(Sg)	(Ux)	(Sg)
*painless skin chancre	(Ux)	(Ux)	(Ux)	(Kg)	(Ux)
*anorexia	(Ux)	(Sr)	(Ux)	(Ux)	(Kg)
*fatigue	(Sr)	(Ux)	(Ux)	(Ux)	(Kg)
*arthralgia	(Sg)	(Sg)	(Ux)	(Sr)	TB arthritis (Sg)
*constipation	(Ux)	(Ux)	(Sg)	(Ux)	(Ux)
*abdominal pain	(Ux)	(Ux)	(Sr)	(Ux)	(Ux)
*weakness	(Sg)	(Sg)	(Ux)	(Ux)	(Ux)
*erythematous skin lesions	(Ux)	(Ux)	(Ux)	(Sr)	(Ux)
*myalgia	(Sg)	(Sg)	(Ux)	(Sr)	(Ux)
*weight loss	(Ux)	(Ux)	(Ux)	(Ux)	(Kg)
*shaking chills	(Sr)	(Ux)	(Ux)	(Ux)	(Ux)
*nausea and vomiting	(Ux)	(Sg)	(Ux)	(Ux)	(Ux)
*haemoptysis	(Ux)	(Ux)	(Ux)	(Ux)	(Kg)
*facial oedema	(Ux)	(Ux)	(Ux)	(Sr)	(Ux)
*sweating	(Sg)	(Ux)	(Ux)	(Ux)	Night sweats (Kg)
*rash	(Ux)	(Sr)	(Ux)	Irregular (Sg)	(Ux)
*sore throat	(Ux)	(Sg)	(Ux)	(Ux)	(Sg)
*transient urticarial	(Ux)	(Ux)	(Ux)	(Sg)	(Ux)
*lymphadeno pathy	(Ux)	(Sr)	(Ux)	(Sr)	(Ux)
*chest pain	(Ux)	(Ux)	(Ux)	(Ux)	(Kg)
*back pain	(Ux)	(Ux)	(Ux)	(Ux)	(Sg)

Table 2. Table of investigations for malaria and related diseases.

Clinical Investigations	Malaria	Dengue fever	Enteric (Typhoid) fever	African Trypanosomiasis (Sleeping sickness)	Pulmonary Tuberculosis
*PCV/Hg conc	(Sg)	(Sg)	(Sg)	(Sg)	(Ux)
*wbc count	(Ux)	(UX)	(Sg)	(Ux)	(Sg)
*Sputum culture	(Ux)	(UX)	(Ux)	(UX)	(Kg)
*Fluorescnt dyes/uv indictor tests	(Sg)	(Ux)	(UX)	(Ux)	(UX)
*PCR may detect dengue virus	(Ux)	(Kg)	(UX)	(Ux)	(UX)
*Bld Culture	(Sg)	(UX)	(Kg)	(Kg)	(UX)
*Stool Culture	(Ux)	(UX)	(Kg)	(Ux)	(UX)
*Urine Cultur	(Ux)	(UX)	(Kg)	(Ux)	(UX)
*Tissue Cultur	(Ux)	(Kg)	(Ux)	(Ux)	(UX)
*Blood/Serum Assay	(Ux)	(Sg)	(Ux)	(Ux)	(UX)
*ESR	(Ux)	(UX)	(Ux)	(Kg)	(Ux)
*AFB staining	(Ux)	(UX)	(Ux)	(Ux)	(Kg)
*Bloodsmears (thin/thick or unstained/ Giemsa-stained)	(Kg) (plasmodium)	(Ux)	(Ux)	(Kg) (trypanosomes)	(Ux)
*Chest X-ray	(Ux)	(Ux)	(Ux)	(Ux)	(Kg)
*Widal test	(Ux)	(Ux)	(Kg)	(Ux)	(Ux)
*Rapid diagnostic tests	(Kg)	(Ux)	(Ux)	(Ux)	(Ux)
*Platelet cnt	(Sg)	(Sg)	(Ux)	(Kg)	(Ux)
*Aspiration (chancre, lymph node or bone marrow)	(Ux)	(Ux)	(Ux)	(Kg) (trypanosomes)	(Ux)
*Lumbar puncture	(Ux)	(Ux)	(Ux)	(Kg) (trypanosomes)	(Ux)
*CSF assay	(Ux)	(Ux)	(Ux)	(Kg) (trypanosomes	(Ux)
*Liver functn	(Sg)	(Ux)	(Ux)	(Ux)	(Ux)
*Renal fnctn	(Sg)	(Ux)	(Ux)	(Ux)	(Ux)
*Electrolyte conc (esp Na)	(Sg)	(Ux)	(Ux)	(Ux)	(Ux)

Table 3. Production rule for malaria.

If there is fever, paroxysmal (Sr)
AND shaking chills (Sr)
AND fatigue (Sr)
AND positive rapid diagnostic test (Sr)
OR myalgia (Rn)
OR arthralgia (Rn)
OR headache (Rn)
NOT positive stool culture (Nr)
Then the Disease is Malaria

like positive stool culture, which is Not Related/Relevant (Nr) for diagnosis is connected by NOT. Then the diagnosis is confirmed to be malaria. Therefore, diagnosis is performed via the designed expert system, based on patient data put into the system.

4. Results and Discussion

The user interface of the MDES is represented by the CLIPs dialog window. The system has a file saved as CLIPS file (example, malaria.clp). The file contains the knowledge base, which is a combination of questions a physician is expected to ask a patient who is suspected of having malaria or its related diseases. This is compiled as a program in CLIPS and when executed, produces a diagnosis as an end result, *viz.*, malaria or any of its related diseases (*i.e.* malaria, dengue fever, enteric fever, African trypanosomiasis or pulmonary tuberculosis), depending on user's response to the combination of questions. The system takes for granted that a clinical assessment has been done by the physician on the patient. So it's the results of the clinical assessments (clinical signs, symptoms and investigation results) that make up the knowledge base.

The system follows a diagnostic pattern following user's responses to the combination of questions asked by the system. Each time the user runs the system, he clicks the CLIPS icon and the CLIPS dialog window opens. He then loads the file containing the combination of questions on malaria and related diseases by typing (load "filename.clp"). The next command typed is (run). This executes the program "filename.clp" loaded into the CLIPS interpreter. The responses of the user with Y (Yes) or N (No) will determine what the final diagnosis from the system will be.

Figures 4-6 show the results produced by the system for the diagnosis of malaria, typhoid fever and dengue fever respectively.

The MDES system presents both diagnostic and treatment recommendations for malaria and related diseases. A major bottleneck of this research is seen when there are a lot of symptoms and signs requiring diverse and non-correlated diagnosis of malaria related diseases other than those in the knowledgebase, *vis.* malaria, dengue fever, enteric fever African trypanosomiasis and pulmonary tuberculosis.

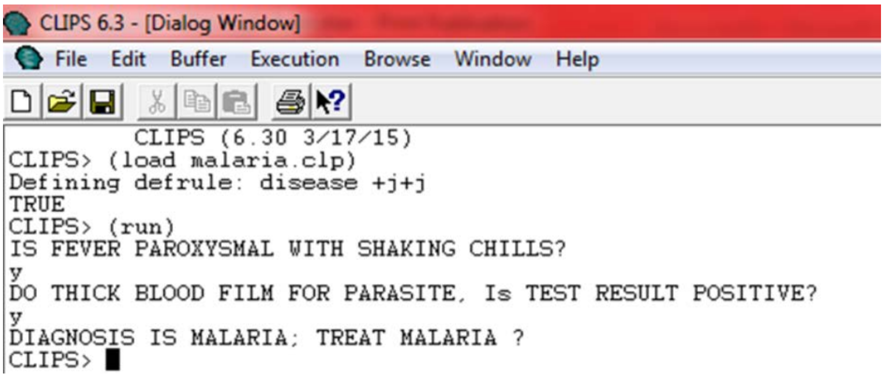

Figure 4. Screen shot of MDES for diagnosis of Malaria.

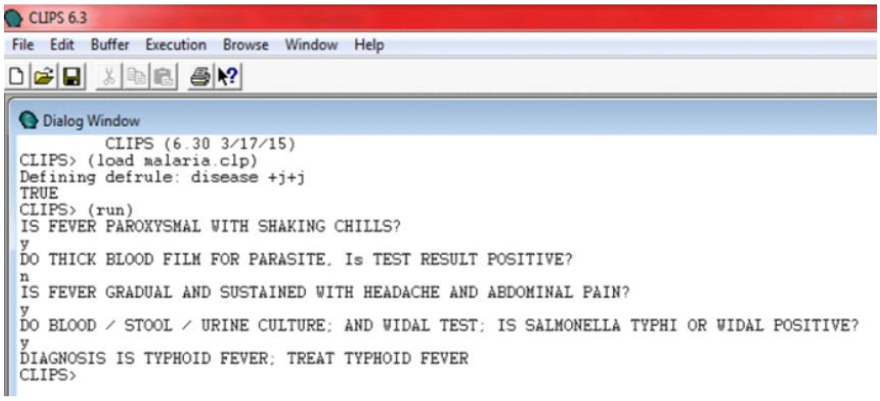

Figure 5. Screen shot of MDES for diagnosis of Typhoid fever.

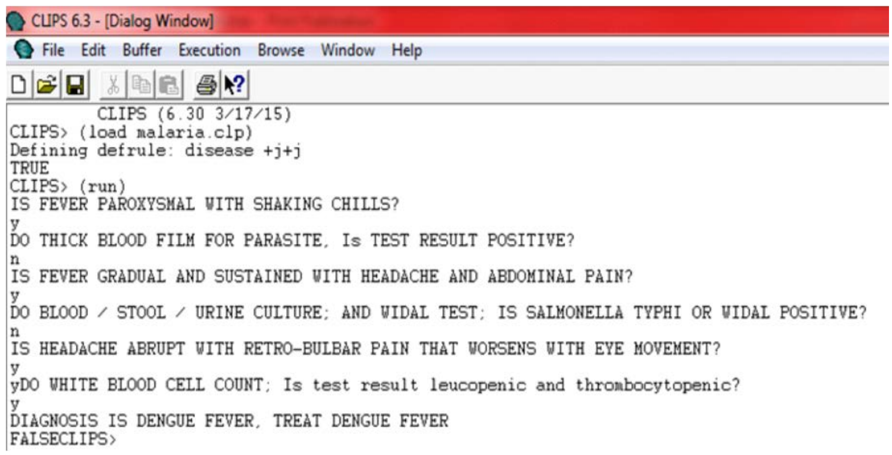

Figure 6. Screen shot of MDES for diagnosis of Dengue fever.

MDES used declarative statements to represent knowledge and the method of grouping signs, symptoms and clinical investigation results associated to therapy brought facility to user on building the knowledge base. In contrast, the use of traditional relational databases is not suitable for determining alternative options in decision making.

5. Conclusions

It is important to note that the MDES system designed here, like other expert systems, is not intended to replace clinician-experts activities but only to be a complementary tool. The humans can elaborate decisions using their knowledge and intuition. The intuition allows the elaboration of the decisions without the use of all the necessary knowledge, this way sometimes problems, for which does not exist elaborated solving methods, can be solved. The artificial thinking prompted by expert systems allows the problems solving based on existent problem solving methods sometimes verifying many conditions. This way, the artificial agents can solve many times the problems precisely, verifying conditions that can be ignored by the humans.

The developed MDES helps doctors and patients in providing decision support system, interactive training tool and expert advice. The system constitutes part of intelligent system of diagnosis for malaria and related diseases. The system was evaluated by doctors and patients. A number of doctors and patients tested the system and gave a feedback of possible relevant additions to the system applications. This includes the expansion of the system to include other endemic and infectious diseases of the developing countries. Therefore, we are prepared to expand the capabilities of the MDES in future works.

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