An Intelligent Decision Support System for the Prompt Diagnosis of Malaria and Typhoid Fever in the Malaria Belt of Africa

A. B. Adehor[1] and P. R. Burrell[2]

Abstract Malaria is endemic in Africa, though curable it is difficult to manage the prompt diagnosis of the disease because available diagnostic tools are affected by the harsh tropical weather. Also, the lack of electricity for the storage of current diagnostic tool in the rural areas as well as the fact that it has signs and symptoms that are similar to those of typhoid fever; a common disease in the region as well, is a major setback. This paper describes the research and development in implementing an Intelligent Decision Support System for the diagnosis of malaria and typhoid fever in the malaria subregions of Africa. The system will be mounted on a laptop, the one child per laptop, which will be powered by a wind-up crank or solar panel. The region chosen for our study was the Western Subregional network of malaria in Africa.

1. Introduction

Malaria is a climate sensitive disease and the parasites that transmit the disease strive very well in Africa's tropical region. Although the disease is curable, it is estimated that a child is killed every 30 seconds and there is an annual report of 500 million cases in Africa [1], [2]. In Africa, there are four Subregional networks (they are: Central Africa, East Africa, Southern Africa and West Africa) set up by the Roll Back Malaria Partnership to combat the disease from different fronts [3].

Although the disease can be managed at home by people with a minimum of 4-5 years education [4], [5]; its prompt diagnosis is hindered by the fact that current diagnostic tools are affected by the harsh tropical weather; the lack of qualified medical laboratory technicians to read test results; the lack of regular or no supply of electricity to preserve available diagnostic tools and the lack of adequate

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transport means to transport patients from the rural areas to the urban areas. These all contribute to the set back in the fight against malaria. Above all, the lack of basic social amenities in the rural areas prevents qualified medical personnel from taking up assignments in these areas of Africa. Thus, the treatment of the disease is left to resident healthcare personnel.

The fact that malaria can be managed at home by people with 4-5 years education does not make it a simple case. The complexity of the management of the disease is attributed to the fact that other fibrille illnesses have signs and symptoms that are very similar to those presented by malaria patients. One such disease is the water related disease Typhoid fever, which is also common in this region of Africa. Typhoid fever is caused and transmitted as a result of poor hygiene. It is known that a child dies every 15 seconds from water related disease [6], of which typhoid fever is one.

Thus, based on the fact that malaria has signs and symptoms that are similar to those of other fibrille diseases, makes home management, as well as management of the disease by healthcare personnel, difficult. This paper, describes the design and development of an Intelligent Decision Support System (IDSS) to aid in the management of the disease both at home and healthcare centres in rural areas. The system is intended to operate as a stand-alone system mounted on a desktop or laptop computer which will be powered by a solar panel or wind-up crank [7]. The system is also intended to be operated by people with little training.

2. Method

Our study was based on the Niger-delta region of Nigeria, in the West African Subregional networks [3], where malaria and typhoid fever are known to be prevalent [8].

The research was approached from two perspectives, which are: 1. whether the diseases could be diagnosed based on signs and symptoms in the region, 2. what people of the region do when they have fever.

The essence of the adopted method was to ascertain if both diseases could be diagnosed differentially based on signs and symptoms by following the principle that medicine is evidence-based and to provide possible applications in the wider sense (i.e. Africa and other malaria endemic region of the world).

3. Survey Findings

We carried out surveys in two regional states (i.e. Delta and Rivers States respectively) of the Niger-delta region of Nigeria in West Africa. In the first survey, 70 questionnaires returned by physicians were used to ascertain whether they could actually diagnose malaria and typhoid fever differentially based on signs and symptoms. This indicated that 60.4% of the physicians agreed to this fact. This finding was further substantiated by interviewing three consultants from the University of Portharcourt Teaching Hospital Portharcourt River state and the Federal Medical Centre Asaba Delta state Nigeria respectively.

A second survey targeted demography, in other to ascertain the demographic attitude when people have fever. In total, 330 questionnaires returned show that 41.4% actually go to a pharmacist to explain their condition; 36.2% will take medication based on previous prescription; 6.9% buy drugs without prescription from a chemist and 15.5% apply traditional African medicine.

3.1 Syndromic Diagnosis of Malaria

Our initial survey findings from physicians and the interview sessions with the medical consultants confirm that malaria can be diagnosed based on signs and symptoms, which is in accordance with the research work carried out by Bojang et al [9] on the syndromic diagnosis of malaria table 1.

Table 1. "Sensitivity and specificity of different methods of diagnosing malaria in Gambian children during high malaria transmission season"[3]

Method of diagnosing malaria	Malaria diagnosed if score >=	Sen.(%)	Spec.(%)	PPV
Field worker using algorithm.	7 8	88% 70%	62% 77%	55% 62%
Computer calculated score using algorithm.	7 8	89% 70%	63% 78%	56% 63%
Computer calculated score using a simple count of signs and symptoms.	4 5 6	90% 73% 46%	38% 59% 81%	43% 48% 56%
Physician's diagnosis without laboratory results.		82%	61%	53%
Physician's diagnosis after seeing laboratory results.		100%	71%	65%

The results from the work of Bojang et al [9] show that a count of 7 to 8 signs or symptoms, by field workers using algorithms and computer generated algorithms, gave a high positive predictive value (PPV), while the PPV of diagnosis by physicians showed these results increased. The only problem that affected the results of these findings is that field workers often enter wrong signs or symptom, thus affecting the PPV of the disease.

However, such problems associated with entering wrong signs or symptoms are not eminent in the IDSS; as this system applies the traditional method of evidence-based medicine. The system asks questions in two formats: 1. Questions that are directed at users, requires the user to critically observe the patient for specific signs or symptoms depending on the question generated from previous answer to a

[3] Keys on the table: Sen. = sensitivity, spec. = specificity and PPV= positive predictive value"

question, 2. The second question is directed at the patient. This prevents users of this system from entering wrong signs or symptoms. The system also does not require users to observe patient for signs of splenomegaly or hepatomegaly based on Bojang et al [9] findings.

3.2 Differential diagnosis of Malaria, Typhoid fever and other Fibrille Illnesses

The syndronmic diagnosis of malaria, based on the aforementioned survey findings would suggest that the disease can be diagnosed differentially from other fibrille diseases based solely on signs and symptoms. We used a simple model to capture signs and symptoms that are similar to known fabrille diseases in the region from the consultants interviewed.

The model is a simplistic differential diagnostic model for the diagnosis of malaria, typhoid fever and unknown-fever, in which individual modules with signs and symptoms can be encapsulated [10], and methods are used to access each module (figure 1). Questions are generated as the user interacts with the system. At this stage, unknown-fever could be meningitis, pneumonia or pyrexia.

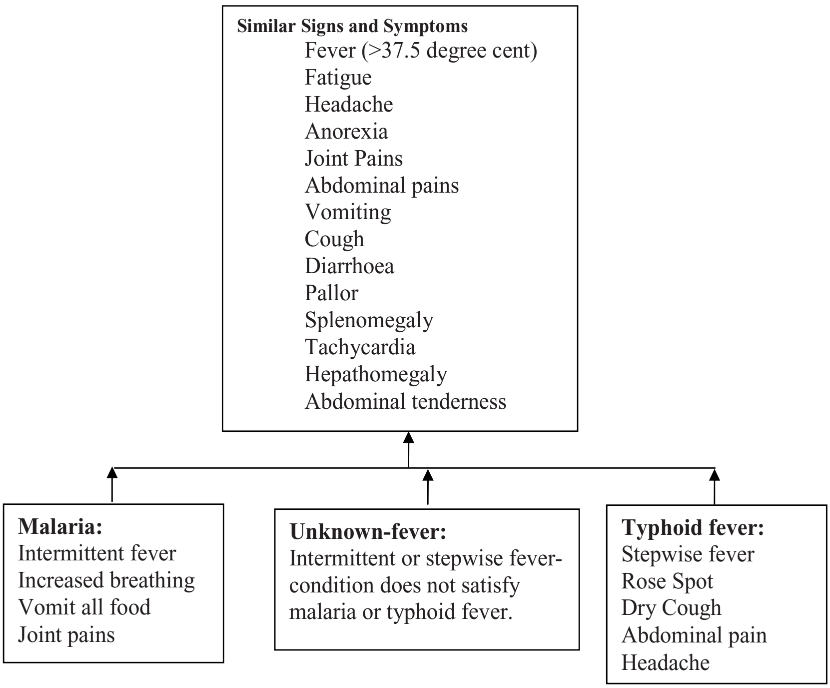

Figure 1 Simple Differential Diagnostic Model for Diagnosing malaria, typhoid and unknown-fever

4. Knowledge Analysis and Representation

The knowledge analysis of the system was carried out using the Mockler Situation Analysis methodology [11]. The result of our situation analysis indicated that there were 8 building blocks (figure 2) upon which the foundation of the differential diagnosis of malaria, typhoid fever and other fibrille diseases could be based. This was aided by interviewing five physicians in our selected region in the West African Subregional network.

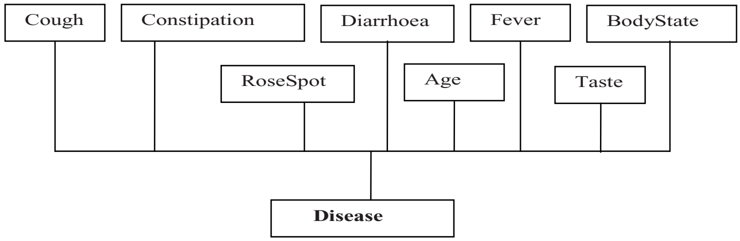

Figure 2 Building Blocks for the Differential Diagnosis of fibrille Diseases.

Thus, in order to effectively represent our findings; we represented each building block (i.e. cough, constipation, rosespot, diarrhoea, fever, bodystate, taste and age) in a decision table as rules. The disease block has rules of its own which are encapsulated [10] and each of the 8 blocks can only gain access to the various signs or symptoms through questions directed at the user or the patient. The decision tables were passed on to the consultants at the University Teaching Hospital Portharcourt to incorporate uncertainty in the line of reasoning. In order to have a reference standard for the signs and symptoms on each table, as compared to the system generated certainty factor (CNF), the experience of both consultants was incorporated into the system (CNF in a scale of 0-100). The system will diagnose the illness based on the answers provided by the user, as depicted in figure 3.

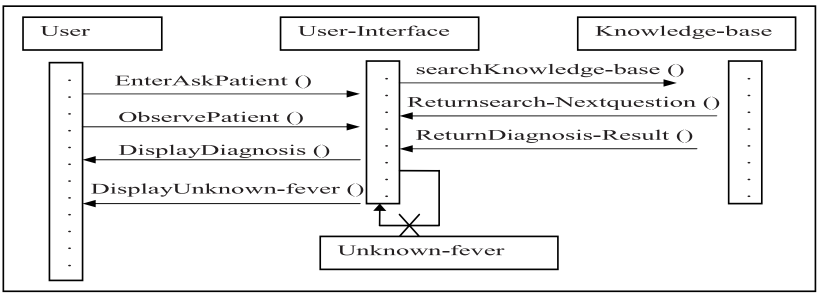

Figure 3 Simple component Interaction of the system with User

4.1 System Design and Implementation

The system was designed and developed using rapid prototyping with a simple expert system shell because of its simplicity and fast learning curve. The knowledge-base of the shell holds details of the heuristics as shown in the general architecture of the system (figure 4).

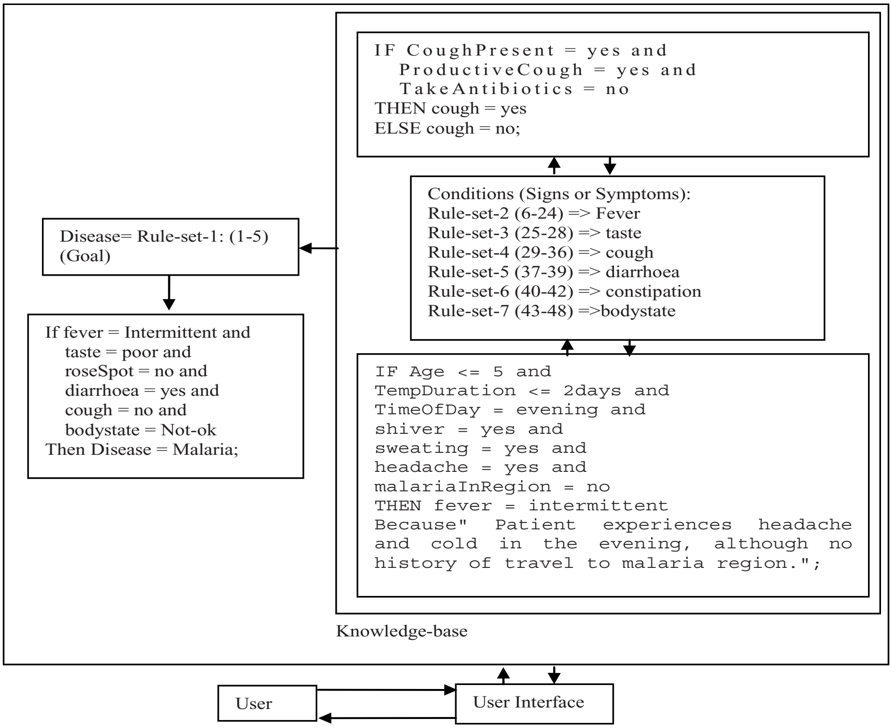

Figure 4 General System Architecture

The decision table for each building block has a group of questions that are asked in such a way that a set of three questions or more need to be answered in order to prove that a patient, suspected of having cough, actually had cough and that the cough is not as a result of any medication. The knowledge-base responds to each question by searching and generating the next question in accordance to the user and patient answers. This same principle is applied in all the other building blocks. For example, to prove that a patient has fever, a total of 18 questions will be asked in different combination and the question combination depends on answers provided by the user.

Thus, the system works in such a way that questions asked are relevant to a particular hypothesis [12].

The system has a total of 53 rules in its knowledge-base; of which 5 depicts the disease-state (i.e. 2 malaria, 2 typhoid fever and unknown-fever) and the remaining 48 rules represent the building blocks (fig. 2). Thus, for a particular sign or symptom to be confirmed as being present in the patient; each set of questions relating to a hypothesis is proved to be true and all sets, that have been proved to be true, then combine with other confirmed signs or symptoms to give the final disease diagnosis.

The system can also give explanations as to why a particular question was asked as well as to how it arrived at the diagnosis of the disease and how certain it is regarding the diagnosis. Figure 5 shows how the system prevents users from entering incorrect signs or symptoms.

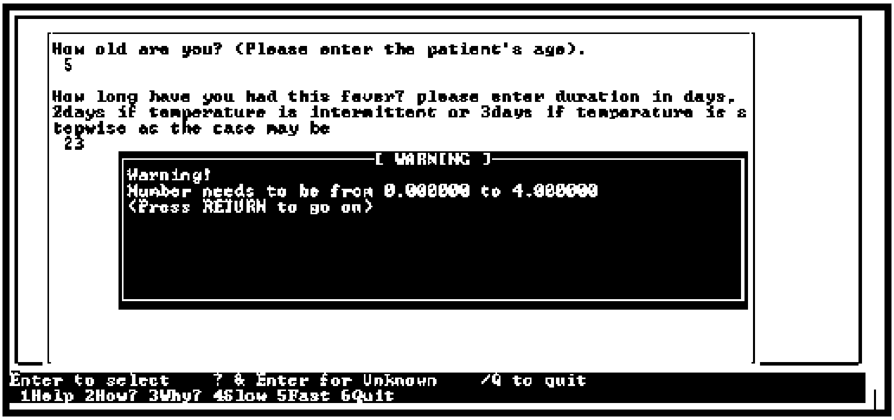

Figure 5 User prevented from entering incorrect data or signs and symptoms.

5. System Evaluation

So many diagnostic tools have been developed over the years for the prompt diagnosis of malaria and typhoid fever and many more are still being sort after. The problem is not that these tools lack the efficacy of diagnosing these diseases, but the lack of qualified medical personnel to actually interpret the test results. Also, some test like the extraction of bone-marrow for detection of typhoid fever bacteria, with an accuracy of 90%, is very painful and there is no less painful or simpler way of extracting the typhoid bacteria. However, of the known tests for the early detection of typhoid fever; the Polymerase Chain Reaction test proved to be very effective but it is affected by the harsh tropical climate as well as its high implementation cost [13].

The sure test for the diagnosis of malaria is the thin and thick blood smear. This test, though effective, lacks qualified people in rural areas to read smear results. The lack of a constant electricity supply in the rural areas is another big hindrance as microbiological chemicals require cold storage medium.

However, research work by Bojang et al [9], shows that malaria could be diagnosed based on signs and symptoms and that one does not have to detect splenomegaly or hepatomegaly in a patient in order to diagnose malaria (table 1).

Other authors like Chandramohan et al [14], have written algorithm for diagnosing malaria. Research studies [15], show that clinical diagnosis based on signs and symptoms is also justifiable.

Other work carried out in the area of malaria diagnosis, utilising different forms of information systems, can differentiate malarial specie from blood smear [16], use signs and symptoms [17] and use ontology driven multi-agents [18]. These systems have demonstrated the effectiveness of such methods, but they rely heavily upon an established clinical and IT infrastructure to perform their diagnosis, something which is lacking in the rural areas of Africa.

Based on these findings and the survey finding in the region of focus, we concluded that an IDSS that can diagnose malaria and typhoid fever can be based on the practical fact that medicine is evidence based.

The system is able to differentiate different strains of the diseases (i.e. 2 malaria and 2 typhoid strains) in a region, based on its prevalence considering the patient age and travel history. For the prototype, only one strain for each disease was used, as the same treatment applies to both. It was suggested by the physicians who tested the system that it should also incorporate other fibrille diseases like pneumonia and meningitis, so that the application could be used in Wider-African context (i.e. the four Subregional networks). There is an intention to include this in the next incarnation.

The reliability of the system, as compared to both physicians' reference standard, was measured and it was demonstrated that the system could diagnose a disease with a reasonable level of accuracy. The results of the analysis, as shown in figure 6, indicates that typhoid fever bears a closer CNF to the physicians CNF in the majority of cases, and to a lesser degree with cases of malaria. This is as expected because during consultation the certainty of the diagnosis increases as the search criteria is narrowed to signs or symptoms that are very specific to the disease. Typhoid fever has far more discernable signs and symptoms than that of malaria (e.g. diarrhoea is more specific to typhoid fever). Further work is being undertaken to refine the knowledge base for malaria which will overcome these deficiencies.

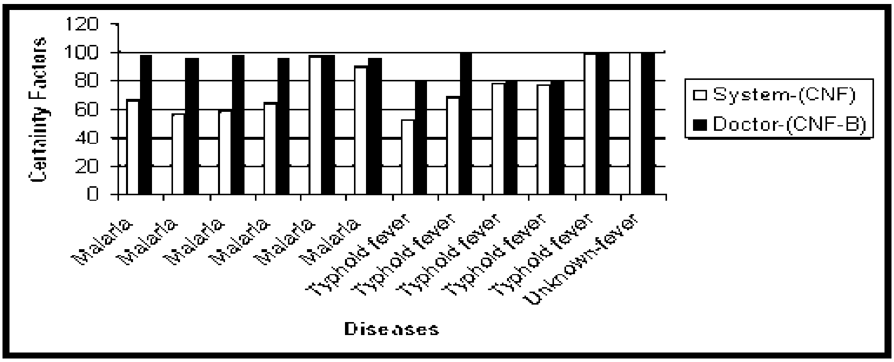

Figure 6 System diagnosis as compared to physicians' reference standard

The present system is a stand-alone application using human judgement and intelligent decision support techniques which provide efficient search strategies to interrogate the knowledge base [19]. It will therefore be suitable, in the future, to mount this on the One Laptop Per Child (OLPC) computer, powered by a wind-up crank or solar panel, making it suitable for the home and healthcare management of malaria and typhoid in rural areas. Thus it overcomes the problems associated withthe lack of basic amenities for the management and storage of available diagnostic tools.

6. Conclusion

Although the system is a relatively straightforward application of medical diagnostics, its method of reasoning provides a more sophisticated data entry approach by eliminating the possibility of entering wrong or conflicting information. This increases its effectiveness when used by novice users, as would be the case in rural areas of the African malaria belt.

The system is simple to learn with little training and this, together with its portability, would make it ideal for people in these rural areas where rural healthcare centres lack the necessary diagnostic tools and medical personnel. Other applications, based upon our demographic findings, would be that the system may be useful for home management of malaria and typhoid fever or for those in a Pharmacy practice where the management of anti-malaria and antibiotic drugs could be based upon the system's diagnosis in cases where a prescription from a physician is not available.

One other important use would also be as a training tool in providing semi-skilled medical assistants with the necessary knowledge and practice to confidently diagnose malaria and typhoid in the early stages.

The benefits of this system can not be overemphasised as the model applied in the Niger-delta region can be applied to the wider Africa malaria subregions as well as other malaria infested regions of the world.

References

1. Webster. D, "Malaria Kills One Child Every 30 Seconds", Journal of Public Health Policy, Vol. 22, No. 1 (2001), pp. 23-33.
2. Unicef, "World Malaria Report 2005- Fact Sheet". Source: http://www.unicef.org/media/files/MalariaFactSheet.pdf [online] [Accessed November 02, 2007].
3. ROLLBACKMALARIA.ORG, Source: http://www.rollbackmalaria.org [online] [Accessed January 09, 2008]
4. Dike et al, "Influence of education and knowledge on perceptions and practices to control malaria in Southeast Nigeria", Social science and medicine 63, July 2006, pp. 103-106.
5. Simoes et al, "Performance of health workers after training in integrated management of childhood illness in Gondar, Ethiopia: Bulletin of the World Health Organization", 1997, 75, (Supp l.1), pp. 43-53.

6. Adam Hart-Davies, "What Wateraid Does For Us", Oasis-the Wateraid journal, Spring/Summer 2006, pp. 6-8. Source: http://www.wateraid.org [Accessed October 15, 2006].
7. Walter, B., In: "$100 Laptop News for the Community ", OLPC News 2007, One Laptop per Child. Source: http://laptop.org, [online] [Accessed November 02, 2007].
8. Tanyigna et al, "Comparison of blood, bone marrow aspirate, stool and urine cultures in the diagnosis of enteric fever", Niger J Med. 2001 Jan-Mar; 10(1):21-4.
9. Bojang et al, "A prospective evaluation of a clinical algorithm for diagnosis of malaria in Gambian Children", Tropical medicine and International health, vol. 5 No. 4 April 2000, pp. 231-236.
10. Shiffman, R. N. and Greenes, R. A., "Improving Clinical Guidelines with Logic and Decision-table techniques: Application to Hepatitis immunization Recommendation", Medical Decision Making 1994 Vol. 14(3), pp. 245-254.
11. Darlington, K., In: "The Essence of Expert Systems", 2005, pp. 110-133, Pearson Education Ltd.
12. Winston. P. H., Artificial Intelligence 3rd ed. 1992, pp. 129-132, Addison Wesley.
13. Haque et al, "Early Detection of Typhoid by Polymerase Chain Reaction", Ann Saudi Med 1999; 19(4): 337-340.
14. Chandramohan, D., et al, "A clinical algorithm for the diagnosis of malaria: results of an evaluation in an area of low endemicity", Tropical Medicine and International Health, Vol. 6, No. 7, July 2001. pp. 505-510.
15. WHO/USAID, "New perspectives: Malaria Diagnosis", Report of a joint WHO/USAID informal consultation 25-27, 1999. Source: http://www.who.int/tdr/cd_publications/pdf/malaria_diagnosis.pdf [online] [Accessed December 01, 2007]
16. Shankar, P., et al, "Decision support systems to identify different species of malarial parasites", AMIA Annu Symp Proc > v.2003; 2003: 1006. Source: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1480132 [online] [Accessed March 08, 2008].
17. Anigbogu, S., et al, "Artificial Intelligence-Based Medical Diagnostic Expert System For Malaria And The Related Ailments", Journal of Computer Science & Its Applications, June 2006, Vol. 12 No. 1, Source: http://www.ncs.org.ng/pdf/Malaria%201.pdf [online] [Accessed March 08, 2008].
18. Koum, G., et al, "Design of a Two-level Adaptive Multi-Agent System for Malaria Vector driven by an ontology", BMC Med Inform Decis Mark. 2007, 7:19, Source: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1925067 [online] [Accessed March 08, 2008].
19. Frawley W., et al, "Knowledge Discovery in Databases: An Overview", Source: http://www.egeen.ee/u/vilo/edu/200304/DM_seminar_2003_II/Applications/frawley92 knowledge.pdf [online] [Accessed March 08, 2008].