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Clinical decision support system (DSS) in the diagnosis of malaria: A case comparison of two soft computing methodologies

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ABSTRACT

The purpose of this study is to make the case for the utility of decision support systems (DSS) in the diagnosis of malaria and to conduct a case comparison of the effectiveness of the fuzzy and the AHP methodologies in the medical diagnosis of malaria, in order to provide a framework for determining the appropriate kernel in a fuzzy–AHP hybrid system. The combination of inadequate expertise and sometimes the vague symptomatology that characterizes malaria, exponentially increase the morbidity and mortality rates of malaria. The task of arriving at an accurate medical diagnosis may sometimes become very complex and unwieldy. The challenge therefore for physicians who have limited experience investigating, diagnosing, and managing such conditions is how to make sense of these confusing symptoms in order to facilitate accurate diagnosis in a timely manner.

The study was designed on a working hypothesis that assumed a significant difference between these two systems in terms of effectiveness and accuracy in diagnosing malaria. Diagnostic data from 30 patients with confirmed diagnosis of malaria were evaluated independently using the AHP and the fuzzy methodologies. Results were later compared with the diagnostic conclusions of medical experts. The results of the study show that the fuzzy logic and the AHP system can successfully be employed in designing expert computer based diagnostic system to be used to assist non-expert physicians in the diagnosis of malaria. However, fuzzy logic proved to be slightly better than the AHP, but with non-significant statistical difference in performance.

1. Introduction

The task of making an effective and efficient differential medical diagnosis is pivotal in medical practice. This is because of the impact of this singular decision making process in the eventual illness trajectory and disease prognosis. Medical diagnostic process involves a complex mental exercise and a state space search of medical knowledge, which could become unwieldy and complicated especially when the variables involved are numerous and the patients presenting symptoms non-specific (Akinyokun & Adeniji, 1991). Podgorelec and Kokol (2001) recognized that a very important task in achieving hospital efficiency is to optimize the diagnostic process in terms of the number and duration of patient examinations, with corresponding accuracy, sensitivity, and specificity, as this is known to reduce morbidity and mortality rates, control costs and improve both doctor–patient and community–facility relationships. The task of medical diagnosis, like other diagnostic processes, is made more complex because a lot of imprecision is involved. Patients may not be able to describe exactly what has happened to them or how they feel; doctors and other health care practitioners may not understand or interpret exactly what they hear or observe; laboratory reports are not instantaneous and may come with some degree of error; and medical researchers cannot precisely characterize how diseases alter the normal functioning of the body (Szolovits, Patil, & Schwartz, 1988). This conundrum is compounded when a particular pathological process presents with ambiguous symptoms that are similar to those of other conditions, as in the case of malaria (Birnbaumer & Rutkowski, 2003; Driver, 2009), or in situations when expert medical practitioners are in short supply and pressured.

The need to arrive at the most accurate medical diagnosis in a very timely manner is heightened in the case of malaria and other tropical conditions, as it is understood that quick and accurate diagnosis and timely initiation of treatment is a sine-qua-non to the reduction of complications (Thierfelder, Schill, Hatz, & Nuesch, 2008), will cut costs and reduce human suffering. Early diagnosis and prompt treatment of malaria is a major strategy for malaria

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control (Praveen et al., 2008). In order to improve the possibility of early and accurate diagnosis of malaria, there is the need for the application of artificial intelligence or other decision support systems in the diagnostic process, because these are known to improve practitioner performance, reduce costs and improve patient outcomes (Seising, 2006). A number of expert technology oriented systems have attempted to mitigate these challenges, and have attempted to address the subjects of knowledge acquisition, representation, and utilization in medical diagnosis. However, the problem of managing imprecise knowledge still exists. Clinical decision support systems utilize patient's data and some inference procedures to generate case specific advice and suggestions to the practitioner (Wyatt & Spiegelhalter, 1991). Four major areas these support systems have found applicability in medical practice include; administrative procedures and referrals, managing clinical complexity and details, cost control and supporting clinical diagnosis, promoting best practices and improving the efficiency of medical practice (Perreault & Metzger, 1999).

2. Context

The first attempts at creating decision support tools for medical diagnosis began with the application of statistical methods for medical diagnosis, initiated by the pioneering efforts of Lipkin, Hardy, and Engle in the 1950s at the Cornell Medical School (Kulikowski, 1987). Logical and probabilistic approaches were applied to the diagnosis of hematological disorders. This era saw the applicability of Bayesian inference, utility theory, Boolean logic and discriminant analysis to medical diagnostic problems (Ledley & Lusted, 1959). Bayesian inference is a popular statistical decision making process, which provides a paradigm for updating information by using Bayes theorem, a statement of conditional probabilities relating causes (states of nature) to outcomes. Utility theory allows decision makers to give formalized preference to a space defined by the alternatives and criteria. The scores for each alternative are combined with measures of each criterion's importance (i.e. weight) to give a total utility for the alternative. Boolean logic is a form of algebra in which all values are reduced to either true or false, while discriminant analysis is a mathematical approach which tries to differentiate between classes, categories or clusters or groups. This form of logic was unable to address the complexities involved in the diagnosis of complex medical conditions because of its dependence on partitioning samples into 'yes or no' or 'positive and negative' values only.

It became evident in the early 1970s that statistical tools were unable to deal with very complex clinical problems (Gorry, 1973), paving the way for the exploration of the utility or the application of artificial intelligence (AI) principles in medical diagnosis. This era started with the efforts made by Kulikowski in 1970, aimed at moving away from purely engineering approaches toward a deeper consideration of the 'cognitive model' that explains the physicians thinking processes and reasoning in medical diagnosis (Kulikowski, 1987). Pattern recognition methods were the focus of AI applications in medical diagnosis until 1974 when Shortliffe published the first rule based approach for therapy advice in infectious diseases (Shortleaf, 1974). Rule based programs used the "if-then-rules" in chains of deductions to reach a conclusion, but it was later observed that rule based systems were only good for narrow domains of medicine, because most serious diagnostic problems were so broad and complex that straightforward attempts to chain together larger sets of rules encountered major difficulties, hence such systems lacked the model of the disease or clinical reasoning (Szolovits et al., 1988). The addition of new rules with the expectation of overcoming such difficulties led to unanticipated interactions between rules, with the resultant serious degradation of program performance (Davis, 1982). Furthermore, rule based systems attempted to represent different kinds of information (defining terms, expressing domain facts, supporting inference, and problem solving) in the same formalism. This compounding of different kinds of knowledge resulted in poorly structured systems that were difficult to understand and/or maintain (Swartout, 1996).

As research in the application of DSS in medical diagnosis deepened, emphasis shifted to the representation and utilization of unstructured, imprecise, and dynamic knowledge. Szolovits (1995) argued that uncertainty was the central and critical fact about medical reasoning. Uncertainty and imprecision therefore should characterize the sources of information available to medical expert systems or DSS. Such sources include the patient, physician, laboratory and other technical methods of evaluation, and mathematical models that simulate the diagnostic process (Kaeding & Flor, 1995). Soft computing techniques in the form of DSS have since then been used by researchers in this field to manage the issues of uncertainty and imprecision in medical diagnosis (Song & Kasyanov, 2003; Szolovits, 1995). One of the earliest efforts in this direction attempted to develop heuristic methods for imposing structure on ill-structured components of medical diagnosis, resulting in the INTERNIST-1 diagnostic program (Miller, Pople, & Myers, 1982; Pople, 1982, Chap. 5), the evolutionary algorithms (Podgorelec & Kokol, 2001), case-based reasoning (Ochi-Okorie, 1998), hypertext-based systems (Timpka, Padgham, Hedblom, Wallin, & Tibblin, 1989), and knowledge base technology (Uzoka & Famuyiwa, 2004). This culminated in the utilization of fuzzy logic (FL) and analytic hierarchy process (AHP) systems in attempting to resolve the problems of imprecision and uncertainty in medical diagnosis. This is because of the ability of fuzzy logic to handle vague information (Bonissone and Goebel, 2001) and the ability of AHP to mathematically model unstructured information (Saaty, 1977).

The AHP has been proposed for the building of the kernel of medical decision support system in Rabelo et al. (1996) and Hummel et al. (1999), while a framework for utilizing AHP in the diagnosis of fever has been reported as well (Saaty & Vargas, 1998). The AHP is a multi-criteria decision analysis (MCDA) method that uses mathematical algorithms to transform qualitative subjective judgments into quantitative data, which produces a computational model that serves as input into the evaluation of decision alternatives. It uses judgments from a group of decision makers along with hierarchical decomposition of a problem to derive a set of ratio-scaled measures for decision alternatives. With the AHP the analyst structures a problem hierarchically and then, through an associated measurement-and-decomposition process, determines the relative priorities consistent with overall objectives (Hartwich & Janssen, 2000).

Fuzzy models are discussed elsewhere (Dubois & Prade, 1995; Sattar & Goebel, 1990; Wainer & Sandri, 1999). Zadeh (1965) described fuzzy logic as a generalization of the conventional set theory and a mathematical way to represent the vagueness of parameters. The basic idea in fuzzy logic is that statements are not just 'true' or 'false', but sometimes "partial truths" or "partial falses". Fuzzy logic exhibits complementary characteristics by offering a very powerful framework for approximate reasoning. Fuzzy systems are capable of acquiring knowledge from domain experts, and attempt to model the human reasoning process at a cognitive level (Abraham and Nath, 2000).

These two systems have found utility in the field of medical diagnosis over the years. Wang and Sullivan (2000) proposed guidelines for the use of fuzzy modeling and a decision support expert system in medical diagnosis and treatment. Zahan (2001) introduced and implemented a fuzzy based expert system in the non-invasive diagnosis of myocardial ischemia. Karlik, Kocyigil,