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An Intelligent Tele-Healthcare Environment Offering Person-Centric and Wellness-Maintenance Services

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*Worldwide healthcare delivery trends are undergoing a subtle paradigm shift—patient centerd services as opposed to provider centerd services and wellness maintenance as opposed to illness management. In this paper we present a Tele-Healthcare project TIDE—*Tele−Healthcare Information and Diagnostic Environment. *TIDE manifests an 'intelligent' healthcare environment that aims to ensure lifelong coverage of person-specific health maintenance decision-support services—i.e., both wellness maintenance and illness management services—ubiquitously available via the Internet/WWW. Taking on an all-encompassing health maintenance role—spanning from wellness to illness issues—the functionality of TIDE involves the generation and delivery of (a)* Personalized, Pro−active, Persistent, Perpetual, and Present*wellness maintenance services, and (b) remote diagnostic services for managing noncritical illnesses. Technically, TIDE is an amalgamation of diverse computer technologies—Artificial Intelligence, Internet, Multimedia, Databases, and Medical Informatics—to implement a sophisticated healthcare delivery infostructure.*

KEY WORDS: Tele-Healthcare; wellness maintenance; intelligent systems; person-centric services; personalised lifetime health plan.

INTRODUCTION

The ever-increasing sophistication of computing and communications technologies coupled with equally broadened issues of healthcare are actuating a paradigm shift in traditional healthcare delivery trends. A case in point is the global shift in focus vis-à-vis (a) *Person-Centerd Services* as opposed to Provider-Centerd Services; and (b) pre-emptive emphasis on lifelong *Wellness Maintenance* as opposed to episodic Illness Management.[1,2] The underlying objective of person-centerd, wellness maintenance services is to promote the importance and maintainability of healthier lifestyles at the individual and community level. The modus operandi being the

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empowerment of individuals with "correct," "relevant," and "ubiquitous" healthcare services, so that they are able to make "intelligent" choices to minimise health risks by adjusting lifestyles, as opposed to taking measures to prevent illness and disease—i.e., enabling individuals to become active participants in decisions affecting their health.[3,4] For maximum utility, such "new" healthcare services need to be made available over the WWW, accessible from the home, or at least from the individual's immediate community. This is quite in keeping with the agenda of *Tele-Healthcare*—an integrated system to deliver pro-active, online, "person-specific" healthcare services inspired by WWW-based "intelligent" medical systems.[5]

The impact of intelligent medical systems, implemented using Artificial Intelligence (AI) technologies, in the healthcare arena is quite profound.[6–9] To date, there exists a number of provider-centric intelligent medical systems with functionalities ranging from clinical decision-support and critiquing[10,11] to acute patient monitoring[12,13] to image interpretation.[14] Albeit the successful "provider-centric" role of AI in healthcare, there is a case for re-aligning the role of AI based medical systems in line with the emerging "person-centric" healthcare delivery demands imposed by and on the healthcare industry. For instance, to ensure the delivery of Tele-Healthcare oriented services, there is an imminent need to broaden the role, and consequently the end-user functionality, of intelligent medical system vis-à-vis the promotion of the wellness maintenance paradigm.[15] For maximum impact, the new breed of intelligent medical systems need to shift emphasis from provider-centric decision-support during sporadic clinical episodes, towards "life-long" person-centric healthcare services that address the lifelong wellness as well as the illness-related needs of individuals. In a wellness maintenance role, intelligent medical systems can assist individuals to make intelligent and informed decisions to manage their own state of wellness.[16,17] Whereas in an illness management role, intelligent medical systems can have an advisory make-up, so as to assist individuals to triage the cases that can be self taken care of from the ones (through internet-based intelligent diagnostic systems) that may require a health professional's advice, and the ones that require instant attention of healthcare agencies. To maintain a continued presence and pro-active nature, the new breed of intelligent medical systems need to reach out to individuals, via the WWW, to provide remote and "virtual" monitoring and advisory services.

In line with the above assertions, in this paper we present a methodologically and functionally diverse perspective to intelligent medical systems. We present a Tele-Healthcare project TIDE—*Tele-Healthcare Information and Diagnostick Environment.*[15,18] TIDE manifests an "intelligent" healthcare environment that aims to ensure lifelong coverage of person-specific health maintenance decision-support services—i.e., both wellness maintenance and illness management services—ubiquitously available via the Internet/WWW. Taking on an all-encompassing health maintenance role—spanning from wellness to illness issues—the functionality of TIDE involves the generation and delivery of (a) *Personalized, Pro-active, Persistent, Perpetual, and Present* wellness maintenance services,[19] and (b) remote diagnostic services for managing noncritical illnesses. Technically, TIDE is an amalgamation of diverse computer technologies—Artificial Intelligence, Internet,[20] Multimedia,[21] Databases and Medical Informatics—to implement a sophisticated healthcare delivery info structure. The use of AI techniques realises "intelligent" wellness monitoring and illness management decision-support services. Internet technology allows for these services to be universally accessible via the WWW. Database technology is used to manage the centralized Electronic Medical Records (EMR) and Personalized Lifetime Healthcare Plans (PLHP). Finally, multimedia are used for "intuitive" and comprehensive healthcare information illustration and dissemination. This fusion of technology, role transformation, and behavioral change serves as the distinguishing facet of TIDE. In conclusion, we argue that the conception and implementation of TIDE, are both being pulled by and helping to draw a new agenda pertaining to how intelligent medical systems will fit into the modern and evolving healthcare environment.

A TELE-HEALTHCARE INFORMATION AND DIAGNOSTIC ENVIRONMENT: *TIDE*

We believe that in order to manage effectively the health status of each individual, healthcare systems must be centerd on the human life and be designed to enhance the quality and efficiency of care for individuals' health needs on a continuous basis. To meet this end, we need a comprehensive healthcare infostructure that can provide any relevant service and information for the person's healthcare regardless of geographical and time constraints. The above guiding principle lead us to offer the TIDE solution that is anticipated to deliver innovative healthcare related services to the general community.[5,15,18,22]

Objectives

The objectives of the TIDE project are to establish an "intelligent" healthcare system, leveraging advanced computer technologies so as to deliver hitherto unattainable wellness maintenance services to the individual, family and communitylevel (see Fig. 1 for a detailed healthcare system). TIDE aims to:

Act as an "intelligent," proactive and personalized agent, representing and guarding the person's long-term health-related interests and concerns. The innovative implementation of the *Personalized Lifetime Health Plan* (*PLHP*)[19] enables individuals to self-manage and interpret their health needs, for both wellness maintenance and noncritical illness, thereby providing a continuum of high-quality healthcare for the individual on a lifelong basis.

Empower individuals to take responsibility for and an active role in *monitoring* and *maintaining* their own (and their family's) health status on a day-to-day basis. This is to be achieved by providing a WWW-based, person-centric health monitoring and recording system.

Serve as an efficient healthcare information management infostructure to collect, organize, and distribute relevant (i.e., personalized) and up-to-date wellness maintenance knowledge, evidence, and service information to individuals.

Provide remote, WWW-based healthcare monitoring and illness-related diagnostic services, accessible from the home, or at least from within the individual's

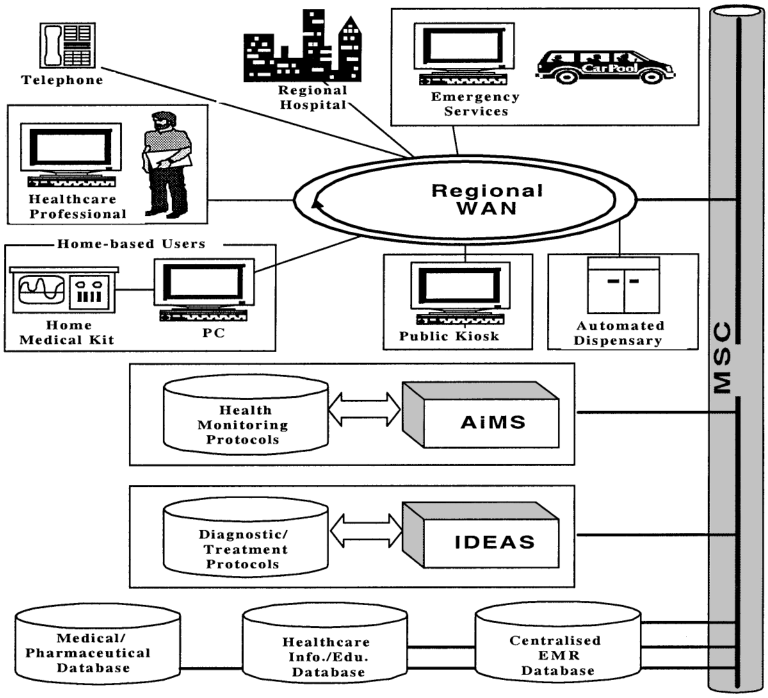

Fig. 1. The infostructure of TIDE. The Malaysian Multimedia Super Corridor (MSC) is shown as the healthcare delivery infrastructure.

immediate community; a feature made practical by the MSC's high-bandwidth multimedia environment.(5,22)

The Personalized Lifetime Health Plan

At the heart of TIDE is the PLHP(15,19) which serves as the decision-guide for the generation and coordination of both wellness- and illness-related services and information.

An individual will typically encounter many situational healthcare plans in his/her lifetime: these include immunizations, disease prevention plans, fitness and diet plans, health monitoring programs, treatment and rehabilitation programs, geriatric care packages and so on. Structurally, the PLHP (see Fig. 2) is a longitudinal health monitoring/maintenance chart, designed by healthcare providers, that manifests an "intelligent" amalgamation of existing medical records (the past), with healthcare provider recommended healthcare plans (the future). The PLHP comprises healthcare plans specifically tailored to the individual's current wellness- and illness-related requirements. The wellness-related plans are intended to educate individuals so that they understand the exact state of health, and are subsequently able to take preventive measures for health improvement. Whereas, the illness-related

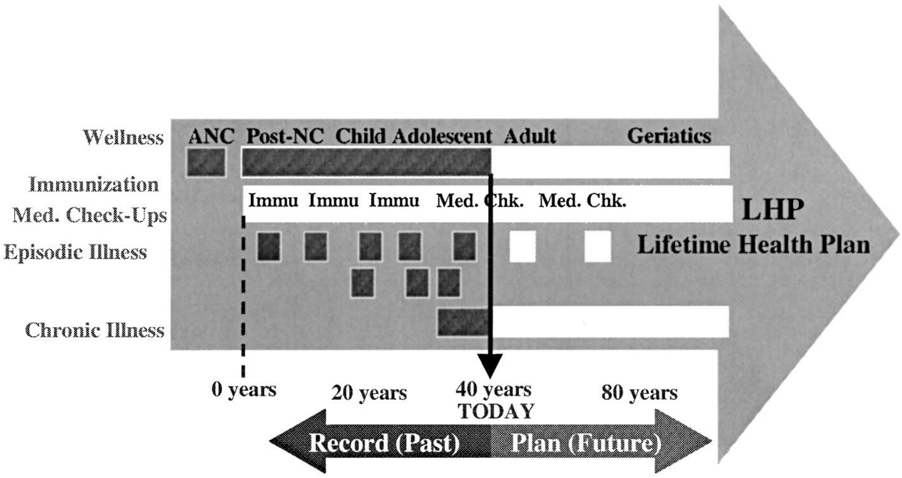

Fig. 2. An overview of a typical Personalized Lifetime Health Plan. The empty boxes are to be filled with prospective wellness and illness related information.

plans will enable individuals—or their families—to manage their weakened conditions so as to ensure a speedy recovery. This will also cover the required postillness actions, i.e., consultation appointments, rehabilitation programs (exercises, diet, drug use and interactions, complications and so on), personalized illness information and context-sensitive education material. In essence, the PLHP is intended to be easily understood by individuals, thereby placing them in a much better position to make well-informed health-related choices. Also, healthcare providers may refer to an individual's PLHP to ensure a continuum of care to the individual.

In principle, each individual is assigned a single PLHP; ideally, generated at birth this dynamic PLHP will maintain currency by being periodically updated, by healthcare providers, to meet the ever-changing healthcare needs of an individual, for instance, tuning the PLHP to account for temporary disablement or occurrence of a chronic illness. Currently, the medical and health-related knowledge incorporated in a PLHP is pertinent toward Malaysian lifestyles.

Functionally, the PLHP forms the basis for the TIDE applications to chart and monitor an individual's state of wellness and illness in relation to his/her present health profile and future health needs (see Fig. 2). For instance, in a wellness maintenance context TIDE will monitor the progress of an individual based on the healthcare plans—for instance, immunizations plans, treatment and rehabilitation programs, fitness plans and so on—prescribed within the PLHP. Similarly, in an illness management mode, the PLHP will provide the basis to operationalize the illness plans and record the health profile of an individual for future use by a healthcare practitioner.

It may be noted that TIDE maintains comprehensive, cumulative, correct, coherent and changing PLHPs for each of its users. For maximum healthcare coverage, TIDE incorporates various triggering mechanisms to prompt and even induce individuals to refer to their PLHPs via TIDE.(Fig. 3).

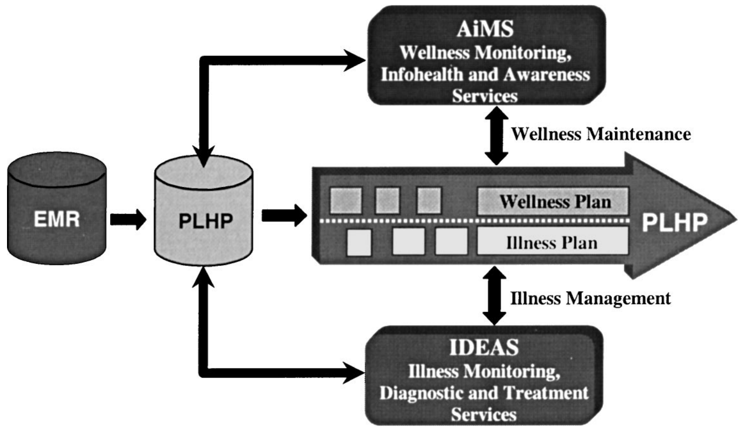

Fig. 3. A Personalized Lifetime Health Plan for an individual and the role of AiMS and IDEAS.

The Intelligent Components of TIDE

At the heart of TIDE are two AI-based healthcare systems:

1. *Automated Health Monitoring System(AiMS):* Designed to deliver wellness maintenance services and information to ensure individuals remain healthy for prolonged periods of time. AiMS provides WWW-access to the wellness plans prescribed in the PLHP, together with intelligent support to assist individuals to monitor, manage, and interpret their healthcare needs on a day-to-day basis.
2. *Illness Diagnostic and Advisory System(IDEAS):* Designed to cater for the illness management needs of individuals vis-à-vis the illness plans in the PLHP. Furthermore, IDEAS provides the functionality to provide timely medical advice whenever an individual encounters a noncritical illness episode. In a person-specific decision-support mode, IDEAS can make a diagnosis for a noncritical illness, prescribe a treatment plan and direct the patient to a pharmacy. If IDEAS is unable to attend to a problem a referral is to be made to a health-care professional.

The Functionality of TIDE

Functionally, TIDE is responsible for the maintenance and delivery of each individual's PLHP, comprising both wellness and illness plans. The wellness plans will include personalized health information, education, therapeutic care, and monitoring advice and information to keep the individual healthy. The illness plans, on the other hand, will contain rehabilitation and treatment plans for episodic illnesses. During the lifetime of an individual, he/she is likely to remain in the wellness cycle for most of the time yet there would be instances when the individual will fall in the illness cycle. Figure 3 shows how both AiMS and IDEAS interact with an individual throughout his/her lifetime with regards to the PLHP. To cater for the above two eventualities, TIDE provides healthcare coverage in the following manner:

1. The healthcare requirements of an individual are chartered in the PLHP, remotely stored in the PLHP repository at a server. On the client side, users need to log in (based on pre-determined user-id and passwords) to the TIDE infostructure to activate and make available the existing PLHP for subsequent operations.
2. Interaction with the user and TIDE is via a dynamic HTML interface accessible through a web browser. The expert systems within TIDE, i.e., AiMS and IDEAS, will conduct a "virtual consultation session" with the user to determine his/her current health profile. The virtual consultation session is a WWW-based dialog between the user and the TIDE applications, during which TIDE forwards a number of dynamically generated (HTML-based) questionnaires to the user, either to collect information or to verify available information and/or derived conclusions. The user is expected to provide valid responses to the questions presented by TIDE. Based on the user's responses the next questionnaire is generated and passed back to the user. Note that each consultation session spans across multiple transactions between the user and TIDE. The attractive feature of TIDE is that it dynamically generates the questions (seamlessly compiled as a WWW-based questionnaire) to be asked from the user, based on the users current health profile and his/her earlier submitted responses. This is a step forward from the "static" questionnaires presented by most WWW-based applications, which at times may contain irrelevant and inconclusive questions.
3. The wellness monitoring aspects of the PLHP will be handled by AiMS. Here the user can not only report on the plans in the PLHP but also comment on new physical and behavioral changes/developments. This information will prompt the concerned healthcare provider to review the PLHP, and tune it if needed.
4. The illness management aspect is covered by IDEAS. Furthermore, if the individual is suffering from any noncritical illness, then TIDE can suggest a diagnosis based on the individual's current symptoms/signs and finally prescribe a treatment plan. Again, users can report on health issues not addressed in the current PLHP for the perusal of the healthcare provider.
5. TIDE determines whether there is a need to pro-actively disseminate healthcare information as packaged HTML documents. In case, TIDE concludes, during the inferencing process that there is a need for the delivery of certain information then it will be "pushed" to the user. Nevertheless, the user is always free to access the Healthcare Support Contents within TIDE.
6. To conclude interaction with TIDE the user needs to log out of TIDE. The built-in data maintenance operations ensure that the PLHP is correctly updated and stored back into the PLHP repository.
7. Finally, if during the virtual consultation session, TIDE believes that there is an urgent need for an intervention/consultation by a healthcare provider, then an alert signal (an email) is sent to the concerned healthcare provider(s) to follow-up the case.

THE WELLNESS PERSPECTIVE: AUTOMATED HEALTH MONITORING SERVICES

Wellness maintenance and illness prevention, needless to emphasize, plays a crucial role not only to an individual's quality of life but also to a societal well-being.[23,24] The objectives of AiMS—an WWW-based intelligent and automated wellness monitoring and advisory system—is to provide (a) customized guidelines for home-based wellness monitoring and (b) close to human-specialist quality counselling. The proposed humanistic interface of the AiMS is expected to promote a high feel-good factor among the public with regard to the health status.

Functionally, AiMS is a health monitoring system that helps to keep track, manage, interpret an individual's health history, and offer health maintenance advice and information. Each session with AiMS entails several important functions: (a) it collects an individual's current health data—a dynamic and pro-active web-based questionnaire is generated to acquire specialized information; (b) it interprets the acquired information and explains to the individual medically relevant facts; (c) it monitors the individual's health status based on his/her PLHP and it subsequently renders medically relevant advice to maintain a healthy lifestyle; (d) it provides reminders for scheduled therapy and appointments and can electronically schedule medical appointments; (e) it also alerts healthcare agencies whenever an emergency situation is detected. Being in an early stage of implementation and utilization, AiMS currently provides monitoring services for depression, hypertension, diabetes, and cardiovascular- related diseases.[25] Functionally, AiMS comprises two main modules.

Personalized Health Monitoring

From a wellness maintenance perspective, wellness monitoring involves a daily check of the PLHP in order to look for any health-related abnormalities and inconsistencies with respect to the health status reported in the PLHP.

The *Personalized Health Monitoring* (*PHM*), as the name suggests, incorporates "intelligent" programs to monitor an individual's health based on his/her current health profile as noted in the PLHP. PHM supports an WWW-based, "virtual" consultation session, whereby based on the individual's health needs as noted in the PLHP, PHM will "intelligently" ask pertinent questions to determine (a) the user's current health profile (as shown in Fig. 4) and (b) whether the user is conforming to any prescribed wellness maintenance/treatment/therapeutic/rehabilitation plan(s). Combining both the past health profile (and suggested wellness maintenance plans) with the present health status, PHM output comprises a merged set of *Health Expectations, Health Tips, and Health Advice.*

Health Expectations are evidence based health events that require planning. They include such items as the routine immunization schedule, mammograms for females over 45, a new Health Risk Appraisal to be performed, etc. All of these health expectations have the following characteristics: (a) Once activated (see below) they are for a uniquely identified person; (b) time by which the expectation needs to be satisfied; (c) the event that is expected; and (4) the action(s)—such as notification of

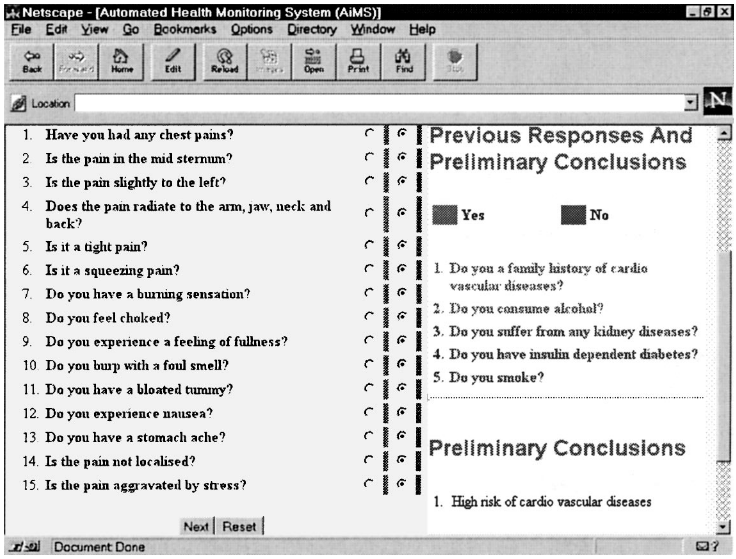

Fig. 4. A typical screen for a consultation session with AiMS.

Primary Care Provider, rescheduling *n* times, etc.—to be performed on the "success" or "failure" of event satisfaction.

- *Health Tips* are lifestyle recommendations that do not occur at a particular time but suggest (or even exhort) on-going behavioral changes. Compared to a health expectation, an individual can revert to old habits and "undo" the benefits of the health tip. By contrast, once a health expectation is satisfied, it cannot be undone and the benefits remain. For example, a tetanus booster will reduce or eliminate the risk of tetanus for 5–10 years, but stopping smoking only reduces the risk until the individual starts smoking again.
- *Health Advice* are actions recommended to ensure a state of wellbeing (shown in Fig. 5). Typical advice are: (a) a list of do and don't activities; (b) to monitor certain health indicators such as cholesterol and glucose levels and perhaps suggest procedures to monitor these indicators; (c) to undergo a detailed medical examination or to see a healthcare professional; (d) to undertake a particular therapy or treatment programme.

"Personalized" Healthcare Information and Services

Relevant primary healthcare information, with an educational and informing context, has been shown to improve patient satisfaction without taxing consultation time of physicians.[26] *The Personalized Healthcare Information and Services* (*PHIS*) module provides (a) WWW-delivered up-to-date wellness-oriented information—such as drug-diseases interactions, allergies, anatomical facts, etc.—customized to suit an individual's current health requirements;[27] and (b) a WWW-accessible suite of support services such as: an *immunization planner*—an intelligent program that

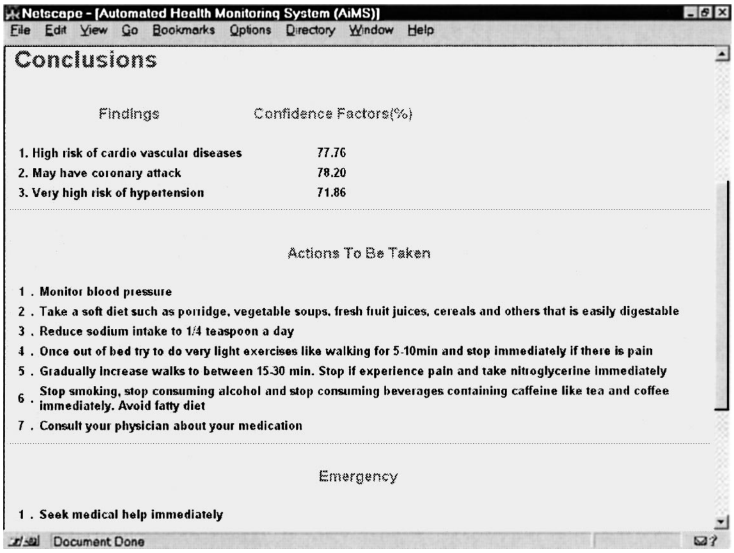

Fig. 5. Health Advice rendered by AiMS at the conclusion of the consultation.

keeps track of personal (and family) immunization and rehabilitation programs; a *dietary guide* that can calculate the daily/weekly calorie intake of an individual and consequently propose dietary plans that satisfy constraints imposed by the individual's health status; an *exercise/fitness monitor* that charts exercise plans, ranging from rudimentary to strenuous exercises, again based on the individual's health needs; a *stress level indicator* that can identify the stress level of each individual based on his/her lifestyle, *body mass index* (*BMI*) *guides.*

THE ILLNESS PERSPECTIVE: "INTELLIGENT" DIAGNOSTIC AND TREATMENT ADVISORY SERVICES

IDEAS is an intelligent person-centric diagnostic system that aims to provide "virtual" medical consultation for noncritical illnesses over the WWW. IDEAS encapsulates medical practice rules and treatment protocols as practised by Malaysian doctors.

The need for IDEAS derives from the observation that there is a growing trend (especially in urban populations) to self-prescribe over-the-counter medication for minor ailments for instance cough, cold, sore throat, fever, etc. Equipped with specialized medical knowledge, IDEAS can regulate the practice of self-diagnosis by providing individuals a facility (over the WWW) to readily consult an "intelligent medical system" to obtain a medically validated diagnosis and prescription. Functionally, IDEAS conducts an WWW-based "virtual consultation session" comprising *dynamically* generated questionnaires for the collection of an individual's illness history (see Fig. 6). Next, based on the collected information and the individuals

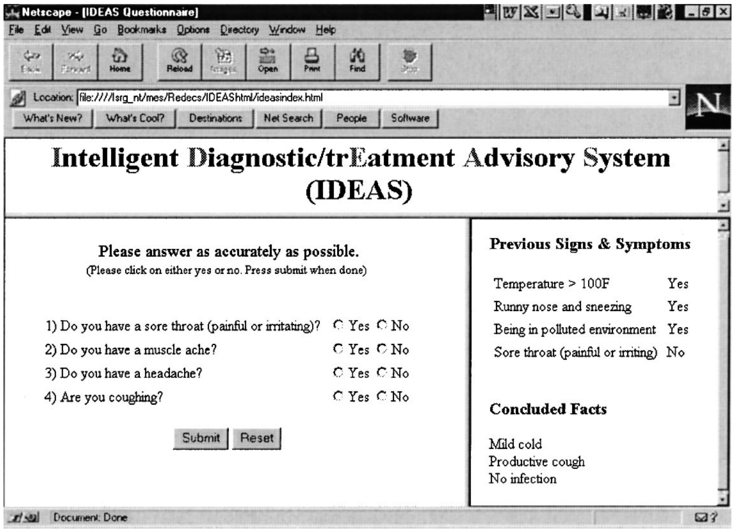

Fig. 6. Snapshot of an IDEAS for the collection of signs and symptoms from patients.

PLHP, IDEAS will come up with a diagnosis and treatment plan (see Fig. 7). For medical completeness, IDEAS makes a diagnosis by not just considering the current signs and symptoms of an individual, rather it also takes into account factors such as the individual's medical history, present medications and treatment plans if any,

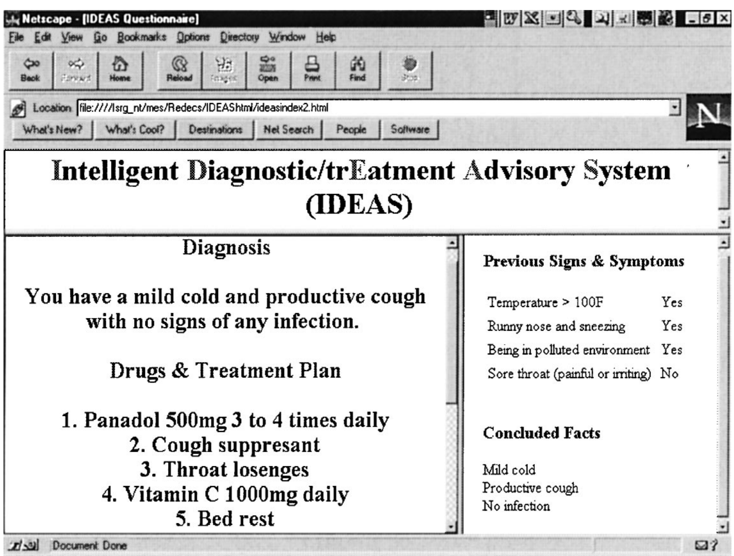

Fig. 7. Snapshot of the IDEAS screen, depicting both the diagnosis and the treatment plan.

as recorded in the individual's PLHP. IDEAS, at present, minimally covers a small set of conditions: cough, cold, sore throat, diarrhoea, abdominal pain, chest pain, dizziness, and earache.

In an additional role, IDEAS monitors the illness plans prescribed in the PLHP: IDEAS records the necessary signs, symptoms, and vital statistics for future use by a healthcare practitioner during clinical examinations.

TIDE IMPLEMENTATION DETAILS

TIDE manifests an infostructure that provides a seamless synergy of AI-based healthcare decision-support systems (i.e., AiMS and IDEAS), databases storing the EMRs and PLHPs and WWW-based programs and protocols. The TIDE infostructure is developed along the lines of an "open architecture," enabling not only a synthesis of diverge technologies but also the means to integrate it with other healthcare resources/systems. For instance, our use of Java and XML facilitate the WWW-wide distribution and collection of PLHPs and EMRs.[28,29] Here we will focus on the intelligent components of TIDE, i.e., the expert systems—AiMS and IDEAS (Fig. 8).

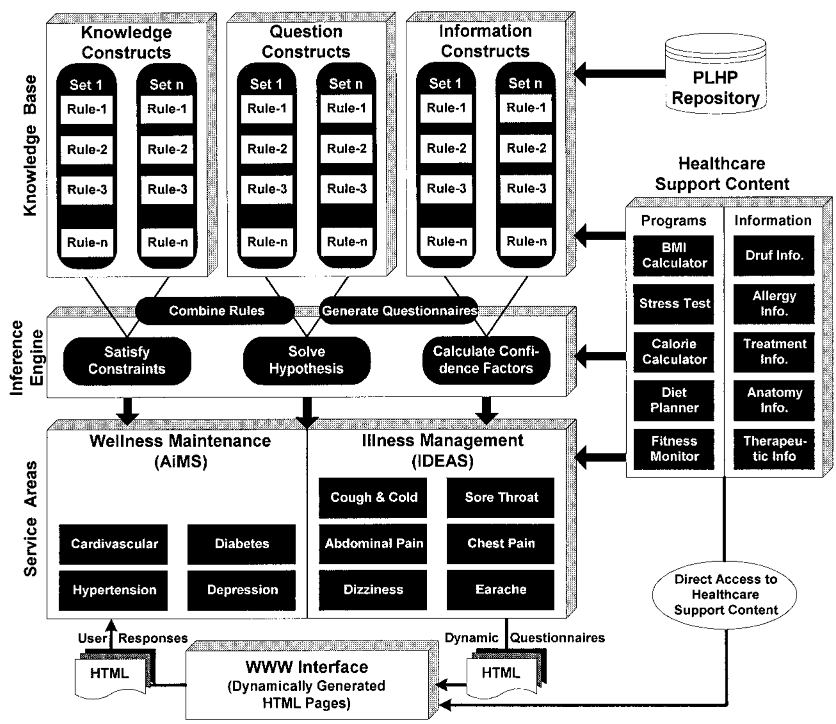

Fig. 8. The functional architecture for TIDE.

Hybrid Inference Strategy

For both AiMS and IDEAS, we have implemented a hybrid inferencing strategy, whereby both forward and backward chaining mechanisms are simultaneously used in tandem to infer conclusions from the given facts (by the user). Typically, forward chaining is used to derive a conclusion based on the inputs provided by the user, whereas for consistency-checking of the dynamically selected rules and input validation the backward chaining strategy is applied in concert with the staple forward chaining strategy.

Dynamic Questionnaires

For all activities TIDE presents an electronic questionnaire (a HTML page) to the user to acquire certain facts and values. Typically, WWW-based systems present pre-designed, generic questions to users, whereby usually some of the questions are deemed as highly irrelevant in the present context. An intelligent feature of TIDE is that it dynamically generates contextually relevant questionnaires (HTML pages) based on the status and nature of the problem at hand. When a user *submits* a HTML-based questionnaire with problem-specific answers, TIDE's inference engines operate on the answers provided by the user vis-à-vis the manipulation of the knowledge and question rule constructs to satisfy the multiple hypothesises active at that stage of the consultation. Depending on the outcome of the inferencing exercise, the next set of questions are dynamically generated to pursue further the multiple hypothesises in order to arrive at a conclusion. This strategy realises a highly personalized and more realistic "consultation session," whereby each time the user interacts with TIDE, the user-interface adapts to follow the present health profile of the user, as opposed to a standard routine user-interface. This approach is highly appropriate as in the context of personalized healthcare services, the health needs and conditions of individuals may vary, hence it is unrealistic to pre-determine a standard set of questions for all users. Note that, this strategy imposes the extra responsibility on the inference engines within TIDE to "intelligently" generate subsequent questionnaires (as HTML pages) that may contain the next set of pertinent questions. Note that, the questions asked by TIDE follow the inferencing or search path taken by the inference engine.

Multiple Rule Constructs

Expert medical knowledge, in particular the Malaysian medical procedures, is represented using typical *if ...then ... else* statements. Conceptually, the rule structure is divided into three functionally distinct constructs:

Knowledge Constructs represent pure medical knowledge that can be inferred over during the reasoning cycle.

Question Constructs detail the question(s) to ask during the reasoning cycle to acquire values for various premises. Note that the questions to be posed to the user are dynamically determined based on the state of active hypothesis(es).

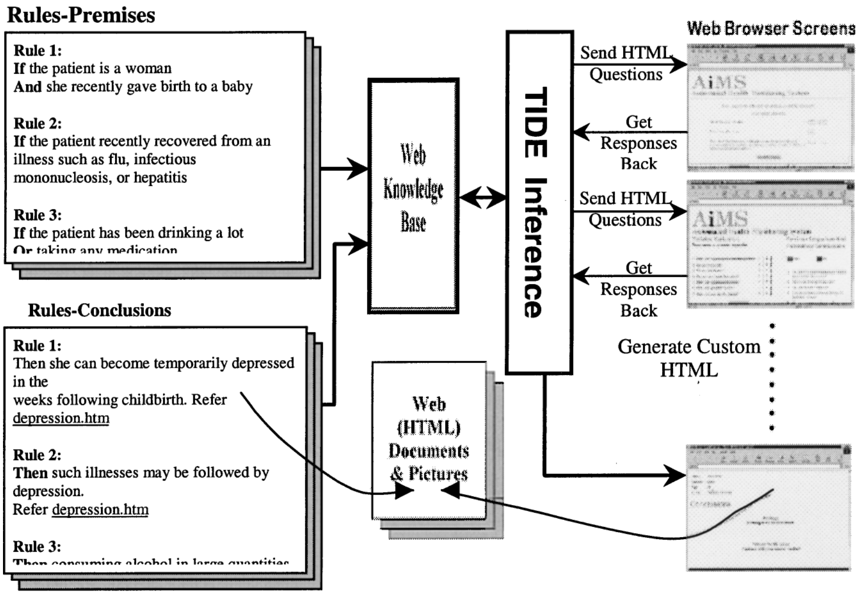

Fig. 9. Illustrating the rule constructs-the top box shown the question construct and the bottom one the rule-answer construct. Also, the right hand-side shows the transactions involved in the generation of the dynamic *healthcare support documents* during the consultation session.

Information Constructs represent HTML-based healthcare-support information that is presented to the user (as part of the output) when the rule is satisfied (shown in Fig. 9).

Operationally, the rules combine in a dynamic manner, during inferencing, to address the reasoning needs and diagnostic scope.

Healthcare-Support Content (Documents and Programs)

A feature of TIDE's rule structure is that it incorporates links to *healthcare-support documents*, containing information such as (a) explanations regarding the question asked and the conclusions drawn, (b) recommendations based on the conclusion of the rule, (c) related healthcare information to assist wellness maintenance, (d) community-based general facts and statistics related to the users problems and so on. During the inferencing process, whenever a rule "fires," the *healthcare-support documents* (implemented as HTML pages) associated with the rule are automatically "pushed" to the user. This improves the efficacy of the delivery of healthcare information as (a) the information is pro-actively directed to the individual, and (b) it is personalized, i.e. problem-specific, information is directed to the user, this avoiding a possible overload of information and also an *ad hoc* search for information by the individual. The *healthcare-support documents* are routinely updated by healthcare professionals which ensures the currency and accuracy of the information. Together with the information packages, we have implemented a number of healthcare support programs that cater for varying wellness maintenance needs.

Knowledge Representation

In Prolog notation each rule (more specifically the knowledge construct) is represented as the predicate—*rule/6*—which has the following form:

rule(Rule No, Disease Type, Premise-List, Conclusion-List, Conclusion Level, Confidence Factor).

The following are examples of a few rules from the knowledge base:

rule(1, hypertension, ['may have very severe hypertension':0.3, 'complying with treatment plan':0.3], ['may have hypertensive crises'], action, 0.88).
rule(2, diabetes, ['blood sugar>140mg/dL':0.6,'random':0.6, 'disease history of non-insulin dependent diabetes':0.6], ['blood sugar high'], diagnosis, 1.0).

Confidence Factor Manipulation

Rules in TIDE have a *confidence factor* (CF) that is instrumental in the firing of the rule. We have implemented two levels of CFs: (1) every premise has its own CF, known as the *premise confidence factor* (*PCF*), that is reflective of its significance within the rule, (2) the entire rule has another CF, known as the *rule confidence factor* (*RCF*), which is used when the rule fires. Note that a rule may have multiple premises, and the firing of the rule depends on the satisfaction of "some or all" of its premises. Rule firing is based on the following scheme:

Case 1: If all the premises of a rule are satisfied then the rule fires with its own RCF.
Case 2: If some of the premises of a rule are satisfied, (1) we take a cumulative product of the PCF of the satisfied premises to obtain the *cumulative confidence value* (CCF) of all "true" premises; (2) CCF is then subtracted from the rule's own RCF to obtain the *premise strength* (PS); (3) if the PS is greater than a pre-specified threshold the rule is deemed to have fired with a CF equivalent to the difference between the RCF and the CCF. The threshold value is user

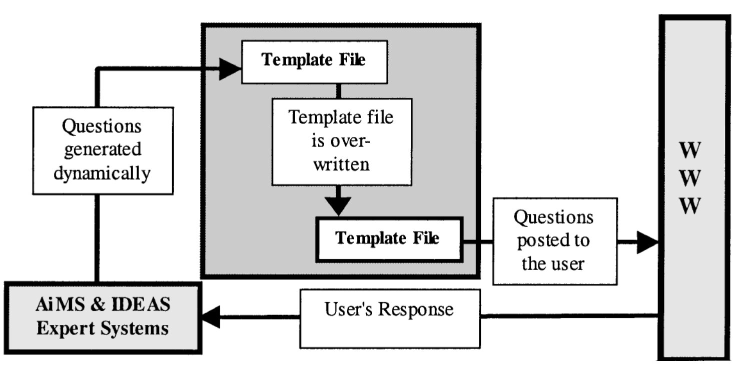

Fig. 10. Functional diagram depicting the process of dynamically generating web pages.

scaleable—the higher the threshold more premises need to be satisfied, whereas a lower threshold implies that a few "true" premises can fire the rule. This scheme is implemented to introduce some flexibility in the rule satisfaction criteria, whereby a rule can "fire" even if some of its "more significant" premises are satisfied, as opposed to the satisfaction of all premises within a rule. Below we give two examples of the manipulation of confidence factors for the same rule with different responses.

rule(10, depression, ["feels like fainting":0.4, "dizziness":0.5, "palpitation":0.3, "shortness of breath":0.6, "fatigue":0.5, "heart rate slow":0.5], ["may have bradycardia"], action, 0.9).

Example 1		**Example 2**	
Premises	**User Response**	**Premises**	**User Response**
'feels like fainting':0.4	Yes	'feels like fainting':0.4	Yes
'dizziness':0.5	No	'dizziness':0.5	Yes
'palpitation':0.3	No	'palpitation':0.3	No
'shortness of breath':0.6	Yes	'shortness of breath':0.6	Yes
'fatigue':0.5	No	'fatigue':0.5	Yes
heart rate slow':0.5	No	Heart rate slow':0.5	No
CF Calculation		**CF Calculation**	
CCF = 0.4 ∗ 0.6 = 0.24		CCF = 0.4 ∗ 0.5 ∗ 0.6 ∗ 0.5 = 0.06	
PS = RCF − CCF = 0.9 − 0.24 = 0.66		PS = RCF − CCF = 0.9 − 0.06 = 0.84	
Conclusion		**Conclusion**	
PS < threshold (0.7)		PS > threshold (0.7)	
"may have bradycardia" (Rule Does Not Fire)		***"may have bradycardia"* (Rule Fires)**	

Dynamic Web-Based User-Interface

Dynamic generation of web-based user-interfaces, i.e., electronic questionnaires, though is an "intelligent" feature but is quite tedious to implement, especially when we consider that TIDE is a Prolog based system. This functionality is achieved by first designing a generic layout of the questionnaire and storing it in a template file. Simply put, the inference engine collects the relevant questions, based on the user's responses and the reasoning outcome, and writes the questions (as per the specified format) in the template file. The updated template file is posted to the user by the *ProWeb* toolkit. When the user responds, their answers are then mapped back, via the web-based questionnaire, to the contents (i.e., rule premises) of the template file, to initiate the reasoning exercise. Figure 10 shows a simple functional diagram to elucidate process of dynamically generating web pages.

Technical Implementation

TIDE is largely implemented using *Prolog,* more specifically *LPA Prolog 3.5.* The TIDE infostructure resides on a server: interactions between the client (the users) and TIDE is conducted over the WWW using the toolkit *ProWeb*, which allows clients to effectively "talk" with the server side TIDE applications. User's interaction with the TIDE applications is via a dynamically generated HTML user interface. The inference engines, in concert with ProWeb, dynamically generates HTML pages which are passed back and forth to realize the many interactions during a consultation session. The web-based user-interface is developed using HTML and Java Script and the graphical charts are derived from Java applets. The functionality of TIDE demands frequent access to patient's EMR/PLHP that may be stored in a centralised server-based database. Database connectivity is implemented using the toolkit *ProData*, that provides a tight coupling between LPA Prolog and all DBMS which support ODBC. The database connection is established such that we are able to use Prolog rules over the entire contents of the database, with no need to download any part of the database, i.e. all database operations are done "on the fly." The PLHP and EMR is implemented using XML and their transfer over the WWW is conducted by Java Applets on the client side and Java Servlets at the server hosting the PLHP repository. Finally, we will like to point out that TIDE is one of the few successful Prolog based AI applications that extend their functionality over the WWW.

CONCLUDING REMARKS—LOOKING AHEAD

In conclusion, we emphasise that the conception of TIDE has added an extra dimension to the efficacy of intelligent medical systems, by addressing wellness-oriented services. In the realm of Tele-Healthcare, TIDE serves as personal health maintenance systems that will help track, manage, and interpret an individual's health history, and in return offer advice to individuals and patient health updates to health-care providers. Each interaction with TIDE is an active process, with an intelligence bias, that performs several important functions: it collects patient data; it checks, interprets, and explains to the subject medically relevant facts and plans; it adapts its advice based on the subject's prior experiences and stated preferences; it performs "sanity checks" on both medical efficacy and cost-effectiveness of diagnostic conclusions and therapeutic plans; it monitors wellness progress and it helps educate, encourage, and inform the individuals. Finally, this role transformation for intelligent medical systems is instigating the erosion of the long-standing distinction between treatment of disease and preservation of health, with the emergence of new healthcare delivery patterns that are reliant on a systematic amalgamation of diverse technologies, i.e., networked computers, Internet/WWW and AI.

Malaysia has proposed an enterprising and challenging "Tele-Healthcare" vision for national healthcare.[22] The vision is in line with international trends in healthcare vis-à-vis a paradigm shift towards a preventative, self-care, client-focused approach to the delivery of healthcare services. For our case, the systematic amalgamation of an innovative healthcare philosophy with leading edge IT support have realised an all-encompassing, holistic healthcare model for Malaysia.[5] In keeping with this vision, the TIDE project can be envisaged as a novel initiative that aims to promote a paradigm shift towards a ‘person-centred system of healthcare’. We argue that, in line with global Tele-Healthcare trends, the conception of TIDE provides a suite of services that (a) pro-actively reach out to individuals, (b) are seamless in implementation and delivery, (c) are continuous in presence, and (d) are tailored to the individual’s and community’s requirements. Indeed, a corollary of this wellness maintenance approach is that the cost of healthcare is anticipated to reduce substantially as healthcare will be more home-based with the patient/person more involved in making health-related decisions and choices. Looking ahead, the above specifications have instigated a new starting point for the next generation of AI based intelligent medical systems.

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