VOL. 10, NO. 3, FEBRUARY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ARCHITECTURE FOR CLINICAL DECISION SUPPORT SYSTEM (CDSS) USING HIGH RISK PREGNANCY ONTOLOGY

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ABSTRACT

Shortage of medical professionals in the rural area has been one of the reasons why maternal mortality is still very high. Midwife family program had been introduced to overcome the shortage but the lack of skills in recognizing high risk pregnancy becomes another factor of high maternal mortality rate. A good prenatal care program will help to identify the danger in time and provide early management. Therefore, this paper provides solution by introducing a new architecture of clinical decision support system (CDSS) in the domain of high risk pregnancy. The proposed architecture is composed of seven main components. The ontological approach was used to develop the knowledge repository in the CDSS architecture. The need for CDSS was investigated through interview session, questionnaire distribution and observation. In addition, the comparison with other CDSSs approach is also highlighted in the paper.

Keywords: Ontology, decision support system, managing knowledge, high risk pregnancy, midwife.

INTRODUCTION

Midwives in Indonesia play an important role in improving maternal health and reducing maternal mortality rate. Although the introduction of safe motherhood programme has successfully increased the rate of safe birth handled by midwives, maternal mortality rate in Indonesia is still very high especially in the rural areas (Rita, 2010). Due to the large population of Indonesia, midwives is having large amount of work to do.

Besides that, the limitation of their job scopes has restricted their ability in identifying significant medical conditions. It was reported in Lancet maternal mortality rate that substandard diagnostic capability is part of the explanation to those unknown maternal death (Ronsmans, 2006). The large amount of work scopes and restriction on managing complication of a midwife triggers the need for the development of software exclusively in diagnosing.

Clinical diagnosis process is not a process where the decision can be made based on purely the medical knowledge itself. A combination of wide-ranging medical knowledge, observation of patient, laboratory investigations and advanced analytic skills is needed to confirm the medical condition. However, every clinician has different level of expertise and skills that even the most experienced clinicians might have the possibility to diagnose medical condition incorrectly (Reddy, n.d.). Therefore, researchers have been trying to develop clinical decision support system (CDSS) that assists healthcare provider in diagnosing clinical condition to minimize the human error and wrong diagnosis.

Clinical Decision Support System (CDSS) is "active knowledge systems which use two or more items of patient data to generate case-specific advice" (Wyatt & Spiegelhalter, 1991). Clinical decision support system (CDSS) has long existed in the medical field since 1950s to improve the health care quality. Generally, there are two types of CDSS which are knowledge based and non-knowledge based (Berner, 2007).

Non-knowledge based system like Bayesian networks and Artificial Neural Network is by far having less popularity when compared to knowledge based system. This is due to the limitation of the technique where the data are not well-structured enough to be learned from them and the reasoning behind the technique cannot be explained and understandable by the experts. The limitations have caused the biomedical community to barely acknowledge and evaluate the technique (Robert, 2007).

Knowledge based system using rules and logical conditions are preferable to the experts since these method matches with the human's natural reasoning process. The disadvantage of these methods is the challenge in programming the knowledge into rules when the data is large (Liljana, 2010).

Structural representation is the most resent knowledge representation methodology where this method is able to overcome both of the methods presented previously. The advantages of using structural representation are that the knowledge can be inserted and expanded easily and it is based on human's natural reasoning. If the system is constructed meticulously using this method, the knowledge can be well-expressed and easily understand.

There are three types of potential advantages using CDSS mentioned in Sintchenko et al. which are improved patient safety, improved quality care and improved efficiency in health care delivery (Coiera

VOL. 10, NO. 3, FEBRUARY 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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quoting Sintchenko et al., 2002). Several systematic reviews had been carried out to investigate the effectiveness of CDSS and the benefits on patients and health care providers (Hunt et al, 1998; Kawamoto et al., 2005; Garg et al., 2005). Rapidly growing CDSS had been proved to enhance clinical performances and its quality is improving as stated in Hunt D.L. et al. In Kawamoto K. et al., the review reported that decision support system has significantly shown improvement in clinical practice.

The systematic review by Garg A.X et al. said that many CDSSs improve practitioner performance. In Sintchenko et al, 2004, it is shown in the study that by using CDSS decision quality was significantly improved and the clinicians is more likely to choose CDSS over manual guidelines when CDSS is able to provide useful assistant to them. Although there have been evidences showing the advantages of CDSS, this technology is still facing great challenges especially in the recognition of the development and maintenance difficulty (Greenes, 2014).
The introductory of Integrated Prenatal Monitoring System (IPMS) and how CDSS is related to this system will be discussed in the next section. Then, the process of investigating necessity of integrating CDSS into IPMS and the results were presented. The structure of High Risk Pregnancy Ontology used in the CDSS was explained followed by a detail explanation about the newly proposed CDSS architecture.

INTEGRATED PRENATAL MONITORING SYSTEM

Introduction of IPMS

Integrated Prenatal Monitoring System (IPMS) is a research project currently proceeding in Universiti Teknologi Malaysia. The motivation of this research project is to reduce the maternal mortality rate and to improve health care services in Indonesia. This research project is intended to be developed for midwives in Indonesia. There are three main sub-projects under in the proposed IPMS which are Midwife Prenatal Kit, Clinical Decision Support System, and Teleprenatology. These three sub projects are interrelated with each other and will be integrated together as a whole when finished.

Midwife Prenatal Kit is a research project where a set of toolkits related to prenatal care are integrated as one package (Aditya & Pahl, 2014). The purpose of developing this kit is to provide optimum toolkit for midwives who have limited access to health care facilities. By utilizing this toolkit, the obstacle of access limitation can be greatly reduced.

The main feature in this toolkit is that it is equipped with a low cost B-scan ultrasound machine with integrated electronic medical record and clinical decision support system. This toolkit will also incorporate other essential equipments such as blood analyzer, stethoscope, fetal Doppler etc. This toolkit aims to provide a low cost and complete prenatal examination system consist of prenatal care development kit and respective software. Figure-1 shows the overall scheme of midwife prenatal kit.

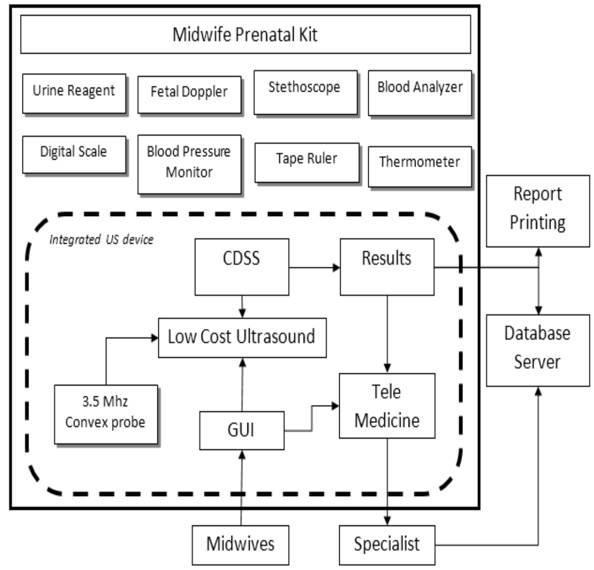

Figure-1. Overall scheme of midwife prenatal kit.

Teleprenatology is one of the imperative parts in IPMS. The web-based teleprenatology system consists of workstation for electronic medical record, prenatal data assistant and a server (Jalil & Pahl, 2014). In this research project, the highlight is the teleconference system integrated in the system. With the availability of teleconference, midwives are able to communicate with doctors in different places. This is believed able to help improving the communication quality between health care providers. The teleprenatology system also enables information to be shared among doctors and midwives. The overall scheme for web-based teleprenatology system is shown in Figure-2.

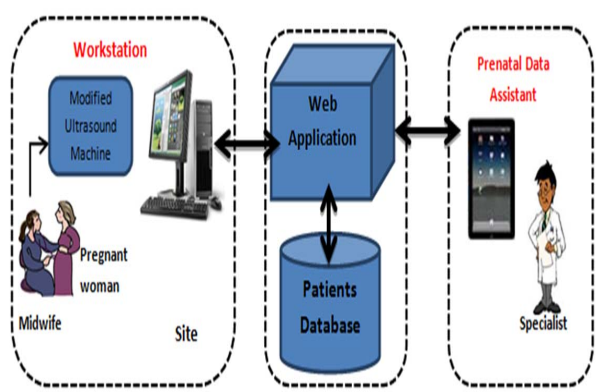

Figure-2. Overall scheme for web-based teleprenatology system.

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Clinical Decision Support System (CDSS) is the third component integrated in IPMS. This feature is an additional feature integrated in IPMS as it is designed to assist midwives in early detection of high risk pregnancy and provide crucial step in handling complications. The development of Midwife Prenatal Kit and Teleprenatology helps to improvise the architecture of CDSS. The structure of CDSS will be discussed in the next section.

The need of CDSS

The necessity of integrating CDSS into IPMS needs to be investigated before proceeds to the design and development phase. Interview study, experienced survey, and observation are the most common methods in collecting community view on specific subject (Caplinskas et al., 2004). In this research work, interview, distribution of questionnaires and observation had been carried out to gather the midwives opinion on the necessity of CDSS in IPMS.

Data collection had been carried out at Kampar, Riau, Indonesia for two weeks with the permission from Department of Health, Kampar. Questionnaire for this study was developed by analyzing existing questionnaires that have similar purpose. The questionnaire was divided into three parts: general, information management and other. General part contains questions for basic information of midwife. Second category asked about the management of basic information regarding antenatal care and high risk pregnancy. Then the last part consists of question on the topic of maternal diseases and their thought on CDSS.

The questionnaire was made of 30 questions. A total of 48 questionnaires had been distributed to midwives but only 32 came back. The researcher personally administered and guided midwives in answering the questionnaire. The questionnaires were given to midwives in Puskesmas Bangkinang Kota, Puskesmas Kampar Timur, Puskesmas Perhentian Raja and Rumah Sakit Norfa Husada. These were the only clinics that were able to reach due to distance and time limitation. Not every midwife were there when distributing the questionnaires, some of them are working in very rural area which is hard to reach. The idea of IPMS was presented to midwives before distribution of questionnaires.

In the questionnaire, midwives were asked to arrange the information they would like to have in preferences order if hospital computer system is available in the future at the place where they are working. The result was shown in Table-1. Based on Table-1, review patients' history of diseases becomes midwives first choice because their main job task is to judge the well-being and risk factors of a patient in basic antenatal care. This is extremely important to them as any high risk pregnancy case must be referred to the medical officer as soon as possible.

One of the reasons of choosing to review patient's history of diseases as first is because there is still no electronic medical record currently in the working places. Midwives have to go through a pile of file to search for patient's medical file and worse if the patient does not even have medical record. This problem is solved with the development of Teleprenatology in IPMS.

Table-1. Results of information preferences order.

Information options	Rank
Review patients' history of diseases	1
Diagnosis suggestion	2
Review patients' medicine records	3
Prescription network	4
Check drug interaction	5
Medical suggestions	6
Getting warning on potential misdiagnose	7

As we can see from the Table-1, diagnosis suggestion is the second highest of information preferences if hospital computer system is available for them in the future. Midwives explained that this is because they would like to compare their own diagnosis with the computer if possible. They believe if the computer is able to show diagnosis suggestion to them, their confidence level on the diagnosis is higher if it matches and the system can prevent any misdiagnosing being made. Their workload can also be shared if the computer system is able to show possible diagnosis to them. With this, the need to integrate CDSS into IPMS is proven.

After the questionnaires were collected, interview session was conducted with 8 midwives, 4 midwife supervisors and Head Section of Family Health. Midwives who involved in the interview process are divided into three categories: those whose working experience is less than 3 years, 3 to 10 years and more than 10 years. Midwives supervisors are those who in charge of managing a group of midwives working in one clinic. Head Section of Family Health is responsible to the affair of health promotion and family health. The interview session were recorded and conducted face to face individually. The interview sessions were time challenging since they have a very tight schedule.

In the interview process, all the interviewees unanimously agreed that implementing CDSS in health care systems will definitely improve the current health care services. The midwives said that by implementing IPMS especially CDSS in the health care service; their daily burden will be reduced and their work will be more organized. With the possible diagnostic and recommendations displayed in the antenatal care report, they believed fewer mistakes will be made and prompt actions can be taken before it is late.

The Head Section also expressed that if developed properly CDSS will absolutely improve the quality of midwifery care. He also mentioned that currently there is no computerized hospital system in the health care system including CDSS. He said that although the system may be costly and may take some time to develop, it will be worthy and promising to health care services.

Observation was executed when visiting all the clinics. The infrastructures and facilities of the clinics were also carefully examined. The observations revealed that there is no hospital computer system available in the place. All the information is still documented in paper. Each of the patient bring along their paper-based medical record for each antenatal care. If the medical book record is missing at the hand of the patient, there is no second copy of the record and midwives have to provide a new one to the patient. So, if the old medical record is missing and it is difficult for midwives to check patient’s medical history. Since diagnosis is made based on many factors for example obstetrics history, family history and so on, midwives may have chances in misdiagnosing the patient without that important information.

ONTOLOGY

Introduction of Ontology

Ontology is a formal structural representation describes the concepts and relationships in a specific domain interest (Horridge, 2011). Ontology is increasingly popular in health informatics. There are some reasons why ontology is developed and integrated in a system. The main reason is for its powerful features: *vocabulary* and *taxonomy* (Gasevic, 2009). These two features have enabled the knowledge to be machine accessible. Vocabulary is used to describe the definition of terms and relationships between terms while taxonomy helps in organizing the hierarchy of the concepts (Fernandes, 2010).

Knowledge sharing and knowledge reusing are another motivation of using ontology. Since the ontology provides common understanding of information structure, each party is able to share and discuss information from the domain with each other. Reusing the knowledge has become a convenient to software developer because they can either further extend the ontology or integrating several ontologies into one for applications development (Noy and McGuinness, 2001).

Other driving forces in using ontology are the convenient in changing the knowledge base and the benefits of dividing the domain knowledge and operational knowledge. If our knowledge towards real world has change, the ontology can easily be change without interrupting the operational knowledge (Noy and McGuinness, 2001).

Ontology data collection

Knowledge in high risk pregnancy ontology was collected through interview, clinical observations, and literature review. Interview sessions were conducted with five clinicians (1 O&G specialist, 2 doctors and 2midwives). During the interview, clinicians were mainly asked for the concept of antenatal care, information about high risk pregnancy, their job scopes and limitation as well as the interaction between each clinician. The interviewees also contributed their ideas into the considerations of the system design and the knowledge to be included in ontology file.

Clinical observation (Becerra-Fernandez, Gonzalez, A., & Sabherwal, R., 2004) is vital for the development of ontology and CDSS because what is observed from the real world can be very different from the descriptions in the documents. Thus, clinical observation helps us to have a better understanding of clinical diagnosis process. During this process, all the medical information such as obstetric history, pregnancy status, personal status, laboratory tests were collected. This information is crucial to the collection of ontology vocabulary.

Literature search was on high risk pregnancy domain was also carried out to extract information. Huge amount of information related to high risk pregnancy has been available in the form of published paper, guidelines, and books. Main keywords that had been used to search are “high risk pregnancy”, “pregnancy complication”, and “maternal diseases”. Guidelines from WHO entitled Managing Complications in Pregnancy and Childbirth: A guide for midwives and doctors” was a large source of data for information extraction. A book by John T. Queenan with title “Protocols for High-Risk Pregnancies” was another valuable source in constructing the ontology concept.

Based on the data obtained from these three methods, the basic concepts of high risk pregnancy was able to be established. After the data collection, the information gathered was coded into formal language: Web Ontology Language (OWL) using the Protégé open source ontology editor.

Structure of high risk pregnancy ontology

The ontology was designed based on the step by step approach from “Ontology Development 101: A Guide to Creating Your First Ontology”. This guide was developed in Stanford University. Protégé, an open access and free editor ontology editor that has been widely used in medical informatics is also developed by Stanford Medical Informatics group. This group has been very active in bioinformatics and medical research.

The ontology consists of four main classes which are ClinicalFinding, RiskFactor, Testing and Treatment. Under the concept of ClinicalFinding, there are sub-classes: Effect, MaternalDisease, PregnancyStatus,and Sign&Symptoms. This class mainly covers the clinical finding of patient. A snapshot of High Risk Pregnancy Ontology was shown in Figure-3.

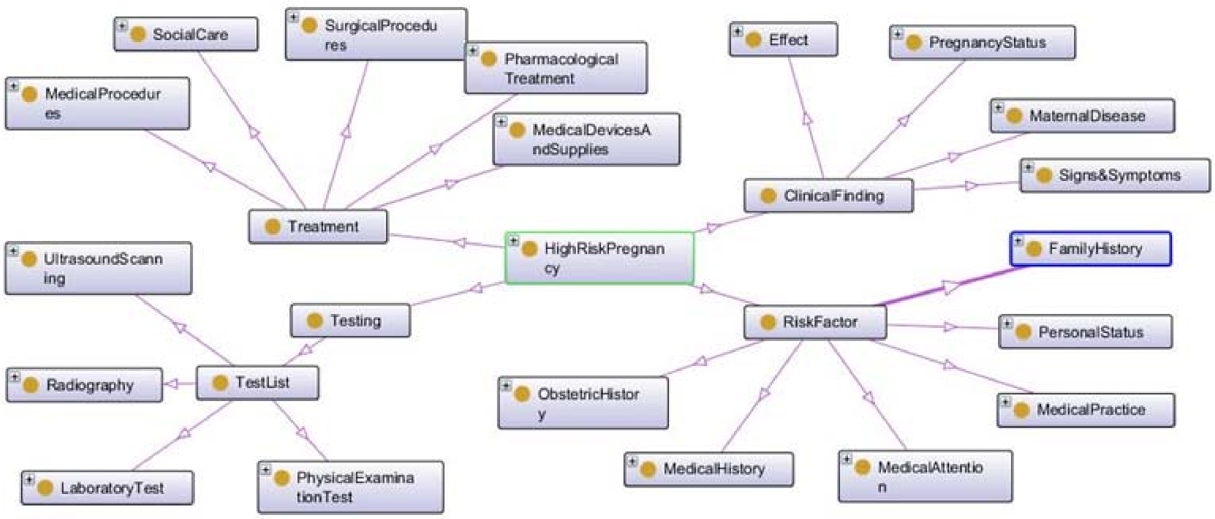

Figure-3. Snapshot of high risk pregnancy ontology.

Then the class Risk Factor has six sub-classes which are FamilyHistory, MedicalAttention, MedicalHistory, MedicalPractice, ObstetricHistory, and PersonalStatus. This class is for describing any criteria of patient that might endanger the well-being of patient. As for Treating class, it contains information for further diagnosis needed to be done in establishing the decision. It has three sub-classes called Radiography, LaboratoryTest and PhysicalExamination.

Treatment class is responsible for the medical care and treatment related concept. Under the hierarchy of Treatment class, there are five subclasses: MedicalDevicesAndSupplies, MedicalProcedures, PharmacologicalTreatment, SocialCare and SurgicalProcedures. The ontology was constructed within the job scope and capability of a midwife.

PROPOSED NEW CDSS ARCHITECTURE

The proposed new CDSS architecture consists of seven main components: knowledge authoring environment, electronic medical database, case database, machine learning, inference engine, query engine and user interface. Each of the components has its own function in the system. The first step in building CDSS is the construction of knowledge base. The success of CDSS is influenced heavily by the construction of the knowledge base (Liljana, 2010).. Hence, knowledge authoring environment requires special attention throughout the development process.

In the knowledge acquisition environment, we need to design the workflow carefully so that the knowledge acquisition and translation process are able to be performed in a systematic way. On completion of the knowledge acquisition and translation, knowledge editor and verification tool are necessity. There are many knowledge editors available in the field now; one of the common use software is Protégé which is software to develop the ontology in semantic web. Protégé also provides an automatic reasoner to verify the knowledge base build in owl file. Query engine is an engine helps to retrieve the data from the owl file. It does not involve in any inference process.

Having medical knowledge base alone is not enough to decide the result of a decision making process. The knowledge base together with machine learning system will complete the whole decision making process. There has been much successful research in machine learning for medical diagnosis (Magoulas, 2001; Wasan, 2006). The proposed decision algorithm in this system is based on hybrid approach of Bayesian Network and Case Based Reasoning. The component of decision algorithm in this CDSS architecture was named machine learning. The function of machine learning system is to find long term observation whether the rule in semantic is true or false and update the rules relationship to the highest probability

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of true/false when new data is added into the system. The new data is illustrated as case database in the CDSS architecture.

Another important element in the CDSS architecture is electronic medical record (EMR). EMR in this system acts as the input of the inference engine and smooths the process of entering patient information. EMR has been widely implemented in most of the hospitals information system nowadays for its benefits in health care (Menachemi, 2006). Study had also shown that EMR is able to improve the quality of care when integrated with CDSS (Agrawal, 2002). Therefore electronic medical record is selected to be included in the CDSS architecture. The main function of this component is to facilitate the process of retrieving the patient data.

The last component in CDSS architecture is user interface. User interface is where the interaction of the user and the system occurs. Users enter the data through the interface and the interface will display the result on the interface after the inference process is complete. The architecture of proposed CDSS is shown in Figure-4.

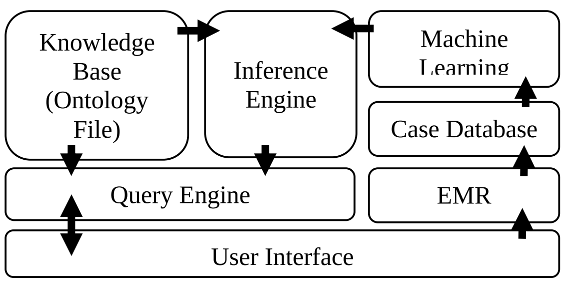

Figure-4. CDSS architecture.

Reasoning mechanism

One of the most vital parts in CDSS is the reasoning mechanism. Researchers have been working very hard to try mimic human reasoning in making decision as close as possible. The reasoning mechanism used in the proposed system would be a hybrid of case–based reasoning and Bayesian Network.

Bayesian Network method works in calculating the occurrence probability of the medical conditions to decide the outcome. The limitation of using this method is the probability of data is fixed and difficult to change. Case-based reasoning approach is similar to the human reasoning where it is based on experience. This approach collects old information and updates the information when new information is inserted into system. The information becomes dynamic in this approach.

First, the probability of each relationship between terms in ontology is saved in percentage contributing to the occurrence of disease. When new patient data presents, the data is added to the percentage of occurrence in the ontology and thus update the changes to the probability of each possible term like sign symptom, complications and testing methods. The inference engine then matches the patient data from EMR with the updated probabilistic ontology to give suggestions on diagnostic and recommendations. The proposed CDSS model is shown in Figure-5. The proposed CDSS model was modified from the work of Liljana A. and Loskovska. S.

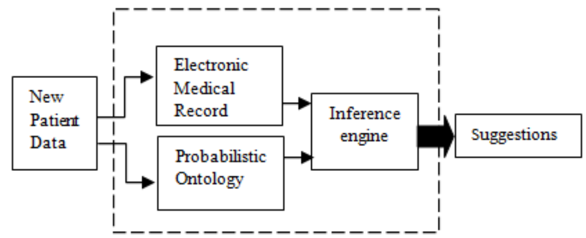

Figure-5. Proposed CDSS model.

Besides, this hybrid approach is able to provide long term observations in clinical finding. The observations can help to verify the rule of semantics. Mistakes of semantics rule can be identified if the percentage of occurrence does not match with the semantic rule. Furthermore, any new clinical finding from the observations can also contribute to medical knowledge discovery.

CDSS workflow in IPMS

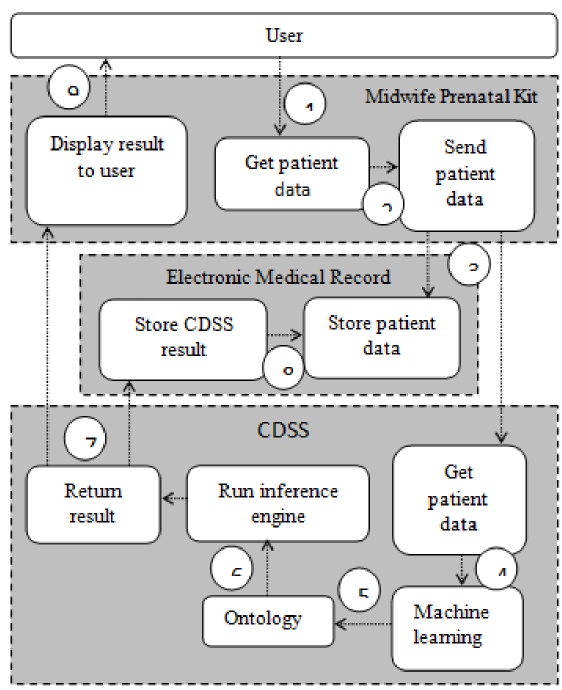

Figure-6. CDSS workflow in IPMS.

Figure-6 shows the general workflow of CDSS in IPMS. First, the user keys in the patient information into the Midwife Prenatal Kit. All information like signs and symptoms, pregnancy status, medical history, laboratory testing and so on is obtained from the antenatal care. All the information is saved in the system and sends the data to the database server.

The patient data is then stored in EMR and sent to CDSS environment. In the CDSS environment, the patient data serves as new data to the machine learning and update the information in ontology. The inference engine run the reasoning based on the patient data and ontology file to produce result.

The result from CDSS is returned to both Midwife Prenatal Kit and EMR. Then, the result in Midwife Prenatal Kit is shown to the user in a report for antenatal care. The CDSS result is also stored in the EMR as patient data.

From the workflow, it can be noticed that the patient data does not need to be inserted twice for the activation of CDSS. When the data is first entered on the system, the patient data will be sent to the CDSS automatically and present CDSS result to the user automatically in the final antenatal report. The user will prone to use CDSS when it is automatic since the system is more time efficient in this way.

Another unique feature in this system is that the ability of its decision algorithm to self updating. Very often when the decision algorithm is out of date, the system will no longer be used anymore. The decision algorithm's self updating ability is shown when the new patient data is fed to the machine learning component and update the probabilistic ontology.

Table-2. Comparison with other CDSSs approaches.

Research	Research question	Reasoning algorithm	Domain
Xiao et al (2012)	How to create ruled-based knowledge repository in CDSS?	Rule based	Urinary Tract Infection
Cho & Kim (2008)	How to centralize knowledge repository in specific application?	Not discussed	Hypertension
Abas et al (2011)	How to computerize the clinical paths and guidelines into machine-understandable format?	SWRL rule based	Acute postoperative pain
Chen & Bau (2013)	How to computerize and execute guidelines with ontological approach?	Fuzzy logic	Diabetes mellitus
Our approach	How to provide a computerized system in formal structural representation for decision making?	Hybrid approach : Bayesian Network & Case based Reasoning	High risk pregnancy

DISCUSSION

Clinical diagnosis process is a very sophisticated process where it requires extensive medical knowledge and years of experience to be excellent in it. Each medical practitioner has different level of expertise depending on the situation to evaluate the medical condition of patient. Osheroff, Forsythe et al had categorized three comprehensive information needs which are currently satisfied information, consciously recognized information needs and unrecognized information needs. Misdiagnosing was categorized in the third category where the information that is important in evaluating the patient is deemed unimportant by the medical practitioner. Diagnostic mistake happens due to the expertise difference among medical practitioners. If CDSS is to be constructed with the right architecture, CDSS could be used worldwide without varying in expertise.

Another reason is that human have limited memory to remember all the medical knowledge he has once learnt. One of the questions in the questionnaire distributed to midwives was to ask them listing out all the sign and symptoms, risk factor and management of eclampsia. There had been a pattern when the experienced midwives were able to answer that question very fast. Whereas for those who have little experienced midwives, they took some time to answer. Even though the experienced midwives are able to list out the answer very quickly, the answers are still not as complete the guideline. This has shown that human is not able to memorize all the things at one time. Unlike human, CDSS has no problem in remembering all medical facts that have been stored in it.

Table-2 shows comparison with other CDSSs approaches. In the research by Xiao et al, rule driven knowledge base had been used in the CDSS architecture. The disadvantage of using rule driven knowledge base is that it is difficult to change and update the knowledge in the future. As for the architecture of this study, ontological

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approach was used to develop the knowledge base. Ontology has the advantage where the knowledge can be changed easily if knowledge of the domain has been outdated. By using ontological approach, the knowledge repository becomes more flexible to changes.

In the previous architectures (Chen & Bau, 2013; Xiao et al., 2012; Abas et al, 2011; Cho & Kim, 2008), they have not put self updating reasoning algorithm into one of the architecture considerations. All decision algorithms in the studies are not designed to have the ability of updating the decision algorithm automatically. In our approach, we suggested hybrid approach using Bayesian
Network and Case based Reasoning with probabilistic ontology. The advantages of having self updating decision algorithm is that it can be used for a long time and it can even provide long term observations assisting in clinical new findings.

CONCLUSIONS

In this study, architecture for CDSS using high risk pregnancy ontology had been developed. The CDSS architecture was categorized into 7 main components which are knowledge base, inference engine, machine learning, case database, EMR, query engine, and user interface. The need of CDSS was investigated before designing the architecture. The results from data collection proved the need of CDSS for midwives. This paper also described the importance of ontology-based CDSS in assisting midwives in their daily job scope and improving the quality of health care service. Ontological approach had been used as a foundation in the development of CDSS. For the future works, CDSS will be developed based on the proposed architecture and the new architecture will be evaluated for its capability and usability.

ACKNOWLEDGEMENT

The authors would like to thank Ministry of Education Malaysia for the providing financial support of this project. The authors would also like to express gratitude to Universiti Teknologi Malaysia for the supporting during the conduction of this study. This research was supported by Tier 1 Research University Grant, Universiti Teknologi Malaysia under the vote 04H93.

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