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A WEB-BASED SEMANTIC INFORMATION RETRIEVAL SYSTEM TO SUPPORT DECISION-MAKING IN COLLABORATIVE DESIGN

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ABSTRACT

The quality of decision making in collaborative design is highly dependent upon the designer's ability to seek relevant information and interpret the available information within the appropriate domain to understand the design problem. It is unlikely that right decisions will be achieved based on inaccurate and incomplete information. This paper discusses a Web-based semantic information retrieval system to support decision making in collaborative design. The system has three features to facilitate designers to make better decisions: (1) the system can retrieve accurate information in the sense that it returns the right piece of information at fragment level rather than at whole document level; (2) the system returns information not only with the correct content but also an appropriate context, i.e. with rich semantics; (3) the system provides designers with a navigational graphical user interface which incorporates a concept hierarchy representing domain knowledge that allows inexperienced engineers learn from constant search feedback and to edge towards the final results. In this case, the whole information seeking process is always transparent to the users, who avoid going down blind alleys with zero returns. The system is developed using a J2EE architecture and Web services, and therefore can be hosted on any machine on a network and will allow engineers to access and retrieve information using Web browsers. Based on the experimental exploration of the system, it is concluded that the system offers to facilitate design engineers to reach better decisions in the collaborative environment through better information support.

Keywords: collaborative design, decision support, semantic information retrieval, Web service

1 INTRODUCTION

Engineering design is a highly dynamic, creative and information-intensive process. In recent years product development is experiencing a significant paradigm shift to collective and joint efforts of many designers [1]. In such a collaborative design environment, not only physical resources and equipment, but also knowledge and expertise can be geographically distributed. Stakeholders involved in collaborative engineering design, including customers, managers, designers and manufacturing engineers, all play varied roles in the design campaign. During this complicated and dynamic process, one of the major roles of the stakeholders is to make decisions with respect to the product, the design process and the design team, further to facilitate creativity and shared understanding of design goals, requirements and criteria. Making decisions involves asking a lot of questions and identifying where the information to support decision making resides [2]. Decision making in collaborative design distinguishes itself from conventional decision making in many features such as its complexity, multiple goals, dynamics and often opaqueness. Successful decision making in collaborative design teams requires better support to achieve an increase of knowledge to find better solutions and to ensure appropriate co-ordination of the team members in order to preserve the team's competence [3].

Badke-Schaub and Frankerberger [4] identified determining factors to the success of collaborative decisions related to "critical situations" from both individual preconditions (such as experience and motivation) and preconditions within a team including: the availability of information, the organisation of the groups and the quality of communication etc. Similarly, by addressing the importance of effective management and utilisation of information to design decision making, Zha and

Du further emphasise the importance of capturing the information generated in the design process to ensure traceability and establish design rationale [5]. Earlier, Dorner suggested that retrieval of more complete and conclusive information is the key to complex, team decisions [6]. The authors of this paper acknowledge the above views and believe that the inconsistency of stakeholders' perspectives and lack of uniform understanding of the information is a basic factor that reduces effectiveness of design decisions on a collaborative team.

Research work has been actively carried out in recent years aiming at improving information support for engineering design. Some of this research has addressed certain aspects of collaborative decision making and has proposed methods to handle some specific decision making problems. However, it is still a challenge to seek accurate, easy to access information with semantics that can provide effective decision support in collaborative design. This paper discusses a **web-based** system for **semantic information retrieval** (SIR) to enable designers to access networked computers and seek the provision of the required information **fragments** to facilitate shared understanding across team members, further to meet the product development demands for shorter time to market and right first time decisions to promote competitiveness in a global market.

The paper is organized as follows. Section 2 addresses information support in collaborative design decision making. Then Section 3 explores the key elements which are brought together through the SIR system in Section 4. The application of the SIR system to support design decisions is discussed in Section 5 followed by Section 6 drawing conclusions.

2 INFORMATION SUPPORT FOR DECISION MAKING IN COLLABORATIVE DESIGN

Traditionally, well-structured decision-making process, as illustrated in Figure 1, involves a series of activities including:

1. defining the problem;
2. gathering, interpreting and assessing information;
3. developing and weighing the alternatives;
4. selecting the best alternative and course of actions;
5. implement the solution;
6. monitor the process;
7. review;
8. learn from experience.

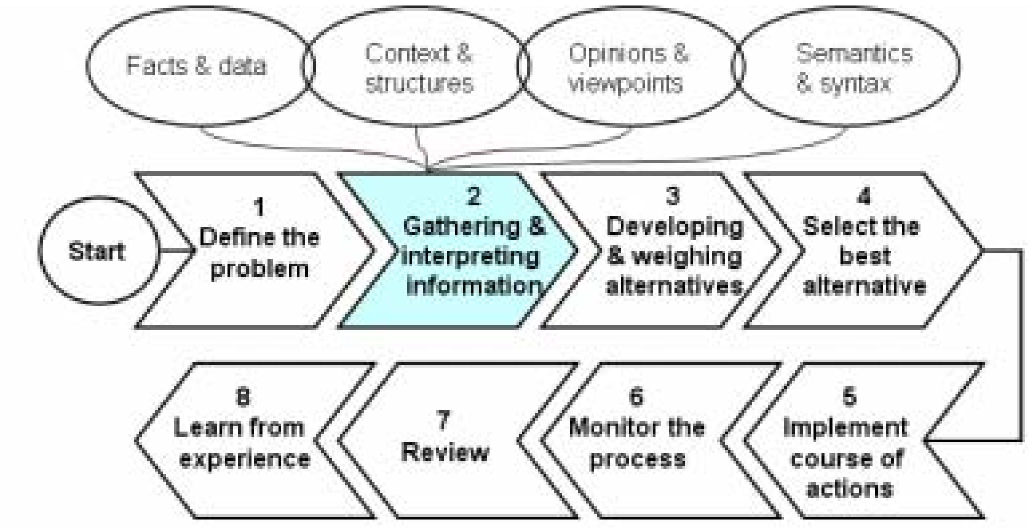

Figure 1 Overview of decision making process

It is believed that the quality of the information that has been gathered and how the information is interpreted are key factors to affect the decisions to be made. To support decision makers make the best possible decisions, information being gathered should not only include bare facts and data, but also is desired to have more comprehensive cues such as understanding from different viewpoints with context and structural information, and if possible with both syntax and semantics [7].

The above general decision making process may be refined to adapt to specific application domains. For example, decision making in collaborative design is not solely an individual activity, but also occurs at group level, i.e. about multiple parties working together as a team. Typically, Badke-Schaub and Frankerberger [4] proposed a novel model to clarify decisions in design. Their model distinguishes decisions related to “critical situations” and decisions related to “routine work”. The critical situations in design occur when engineers meet together to make decisions and discuss options etc. The remainder of the time engineers tend to work by themselves, preparing for the critical situations, which is suggested as “routine work”. In “critical situations”, engineers discuss options and plan work to be done (can be mapped onto activities 3 and 4 in the Figure 1), review the results of work and make decisions (activity 7 in Figure 1). On the other hand, the “routine work” aims at carrying out the necessary tasks (implementing and assessing the actions – activities 5 and 6 in Figure 1), learning and recording the results of this learning (“learn from experience”, activity 8 in the Figure 1).

The importance of information in decision making is under no doubt no matter which model we use to make decisions to solve real world problems. In the traditional model, as shown in the Figure 1, failure of the activity 2 – gathering information – can lead to failure of the whole process. With incomplete and inaccurate information, the decisions to be made are highly likely to be incorrect. In terms of Badke-Schaub and Frankerberger’s “critical situations” model, design decisions will depend on if the design information that has been recorded in a particular way can be retrieved by design teams and how it may be retrieved.

Recording of the outcomes of critical situations may be done in various ways, including the use of meeting minutes, IBIS-based rational capture tools such as the Design Rational Editor (DRed), or, increasingly, annotated video or audio meeting records. Modes of recording routine work include:

- recording outcomes of standard information processing activities, which we term “transaction activities” (for example using a design analysis tools to evaluate the performance of an artefact) in structured documents based on a transaction model such as an IDEF0 node [8], structured reports, design analysis models etc;
- recording outcomes of work carried out to gather assimilate and evaluate information (which we term “learning activities”) in report documents. Because of the importance of sharing and extending the results of such learning episodes, we suggest that extendible documents such as WiKi documents may be appropriate in this case.

In collaborative design, even though there is a lot of interaction and communication within the project groups, individual designer – if not an executive or group leader – to a larger extent they are working on their own (“routine work”) but have to co-ordinate the ideas and the subsequent strategies with the other team members, in which case search and retrieval of information is of great importance for a successful decision making. Therefore it is essential that team members can record their design ideas and solutions in appropriate document format for other team members to use, and seek information from others as inputs of their design tasks. This is not trivial because information retrieval and access is a tightrope walk between information overload and missing information availability. To address the information support issue in the collaborative decision making, a real collaborative design episode is to be described in the following.

Figure 2 shows a DRed diagram to illustrate a collaborative design event leading to a decision. For example, a design team is dealing with lubrication system issues in an engine design. Two design options can be identified, option 1 is to “separate LP/IP and HP oil chambers and scavenge”, option 2 is to “remove floor of IGB sump to allow SABG to be new IGB sump”. Following each option, advantages, disadvantages, more choice of solutions have been identified and explained accordingly by the design team. For example, following option 1 to separate oil chambers, there are three more issues to be considered:

- Extra scavenge route required (negative issue);
- Partial separation of chambers already achieved via a HP/IP baffle previously designed/ manufactured for development test (positive issue);
- May be difficult to create reliable seal between the two chambers (later identified not to be an issue), and so on.

Figure 2 illustrates how a DRed diagram supports the documentation of a collaborative design activity, and how the "ideas" that have been identified on the diagram lead to questions posed by the design team. These questions can be supported by information systems:

- The design episode would be preceded by the collection of drawings, reports and CAD models for the part of the product in question. Ideally this would be done at the time of the meeting, and the collection updated as discussion develops.
- The example design proposal "separate HP/IP oil chambers and scavenge" is used as a search term in an information retrieval system which could lead to identification of a report indicating that the "partial separation had already been achieved via HP/IP baffle previously designed/ manufactured"
- The question "may be difficult to achieve a reliable seal between the two chambers" should lead to an routine design episode in which a designer examines the feasibility of incorporating a seal in the design – the designer would need to retrieve the engineering CAD models of the chambers, and CAD models of the seals, together with design guidelines for their use.
- The comment "Previous piped scavenge arrangement may be useful staring point for designing new scavenge route" would be based on study of reports and CAD models/drawings of the piped scavenge arrangement.

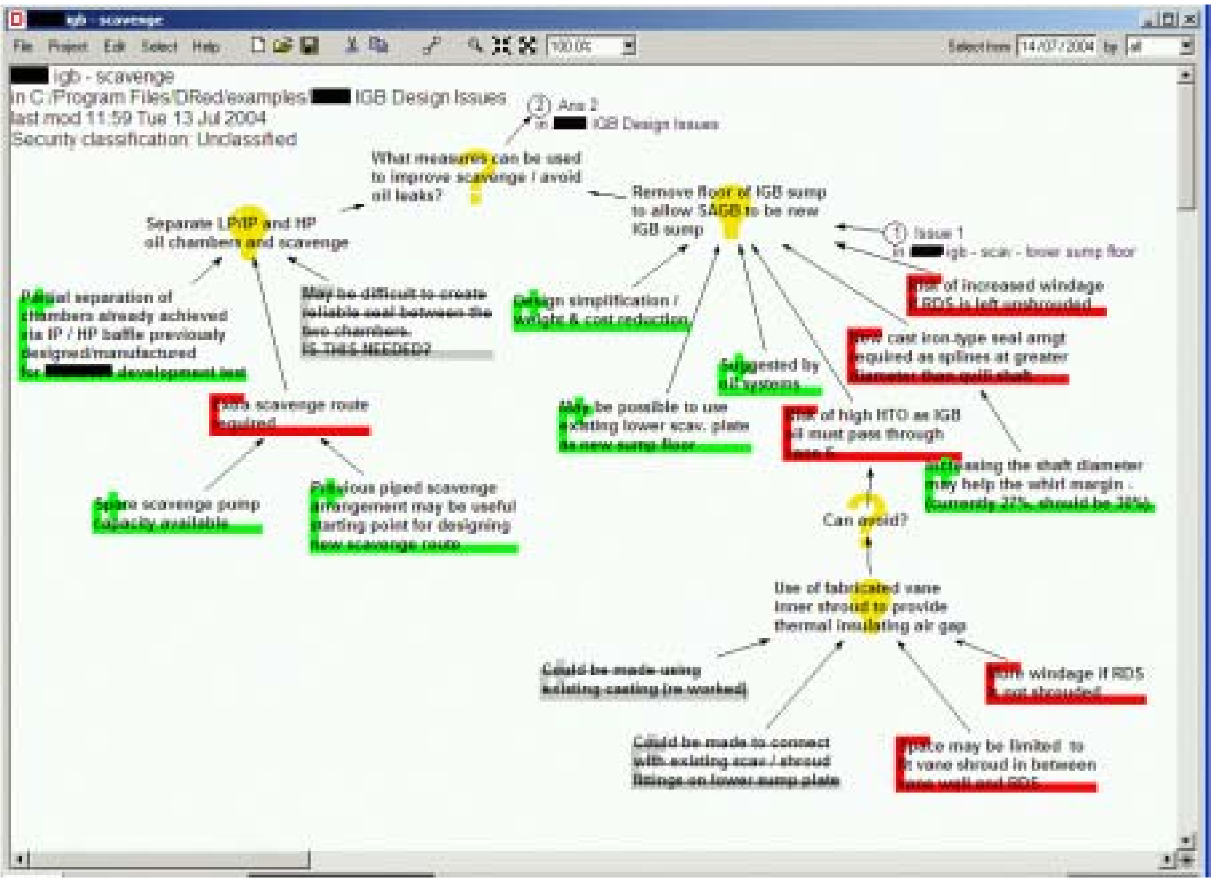

Figure 2 DRed diagram to capture design solutions [9]

The following sections will discuss a web-based semantic information retrieval system that is dedicated to within document search for fragments to support team designers in the above design environment.

3 THE KEY ELEMENTS

The three important elements in the SIR system which distinguishes itself from other IR systems are: retrieval of document **fragments** for accuracy of the retrieved information, context-centred semantics to ensure information relevancy and use of a navigation hierarchy.

3.1 Fragments as accurate information

Most IR systems retrieve whole documents to the information users. In collaborative design, it is often the case that designers are not intending to seek whole documents but rather specific fragments in long documents, for example a description of a method or a process from a 500 page report. To enable this, this paper proposes decomposition of documents into fragments with engineering significance based on a study of document structure and context information. The authors have developed eleven decomposition schemes to allow document contents to be organised and accessed from different viewpoints. For information about the document decomposition schemes, please refer to authors' earlier publication [10].

Document mark-up technology has been identified as a mechanism to explicitly 'tag' the document fragments defined in the decomposition schemes. XML (eXtensible Mark-up Language) has been employed in this research because XML allows us to specify specific DTDs (Document Type Definition) and Schemas that support specific domain areas, in this case using a vocabulary or lexicon of engineering design based on our study of engineering design documents and our empirical study of engineer's behaviours of using documents [11]. Document mark-up can be done either manually or automatically. In engineering design, manual mark-up is often not efficient when there are many documents to be handled. Therefore, the authors have investigated an automatic mark-up approach based on knowledge engineering [12].

Fragment extraction from the documents is done through a Java programming. The advantage of using programming for extraction is that extraction rules can be flexibly defined and implemented when a variety of engineering documents are to be dealt with. Details about the extraction rule definition and implementation strategy has been discussed elsewhere [13].

The process of obtaining fragments from documents is shown in Figure 3, represented using an IDEF0 notation. The three activities (decompose documents, mark-up documents and extract fragments), and information flows between the activities (inputs, outputs, mechanisms and controls of the activities) are clearly illustrated in the figure.

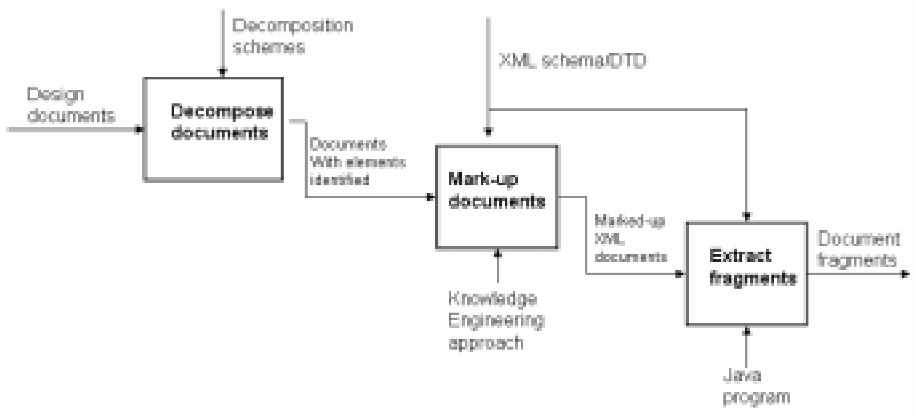

Figure 3. Process to obtain fragments from design documents

3.2 Context centred semantics to ensure relevant information

It is not surprising that so far there is no consensus definition for semantic information. Generally, it is interpreted as meaningful information, defined as data with truth. Recently, Floridi proposed semantic information as appropriateness within a certain well-defined context [14]. The authors of this paper consider semantic information as the combination of above views. To achieve this, the authors define information meaning by giving a piece of information content in a document with context, to enable a designer to judge the information's appropriateness.

The context meaning of a piece of information (i.e. document fragments in this research) has been studied from different viewpoints including its metadata aspect, technical aspect, physical structure aspect, logical aspect, media type aspect etc. The following figure illustrates how context meaning can add extra value to the information content within a document for a user to perceive and interpret the information.

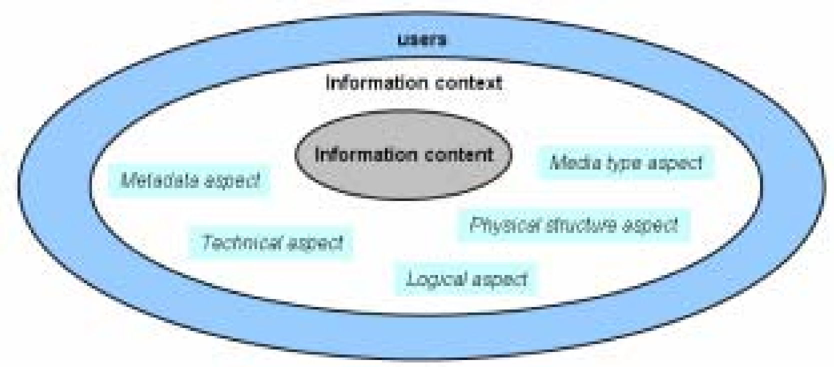

Figure 4. Information context adds value to information content

Metadata is defined as data about data [15]. This definition is easy to understand but is too simple and doesn't take into account the notions of abstraction and reflexivity. In this paper, metadata refers to information about a document such as publication date, author, editor, keywords and topic area. Therefore, metadata of a document provides a means for users to search for information according to multiple characteristics of the documents to answer questions concerning who (author), what (topic) and when (date) etc.

Table 1. Summarisation of added values and user benefits of using context information

Document context	**Added value**	**User benefits**
metadata	Author, create date, topic, keywords, version etc.	-Find the information from the newest version of a document. -Only retrieve the information authored by Prof. X and published by a journal Y
Technical aspect	Instruction, procedure, function, schedule, process etc.	-Find the fragments to describe the function of the LP/IP and HP oil chambers. -Find the instructions for installing oil seals.
Physical structure aspect	Paragraph, title, heading 1, section, chapter, sentence, note, list etc.	-Find the paragraphs describing sealing between oil chambers. -Find section titles including the term oil chambers
Logical aspect	Introduction, conclusion, discussion, aim, method, outcome	-Find the discussion paragraph on LP/IP and HP oil chambers. -Find the sections describing the aims of design studies involving oil chambers.
Media type aspect	Text, graph, diagram, drawing, image, audio, animation etc.	-Find a drawing of an oil chamber. -Find an animation to show the lubrication flows in an engine.

The technical aspect of context defines information characteristics in terms of process, products, customers or problems. Design engineers also have great interests in information elements such as function, instruction, schedule and procedure etc.

Document fragments can also have a logical aspect of context. For example, does a part of a document represent an introduction, a discussion or a conclusion? Is it an aim or objective? Comparatively, the physical structure aspect of context information defines the nature of fragments in terms of their actual appearance such as title, first level heading, paragraph, list or note etc. However, from an information user's viewpoint, these aspects of contextual information may indicate or imply the weight or importance of the information content.

Media type has been used as an important aspect of contextual information by engineers in practice. For example, a designer may wish to find a diagram/graph/drawing etc. of an oil chamber rather than a purely text description of it. Nowadays much design information can also be recorded in and retrieved from audio and video, or maybe with animation as well.

The potential of having contextual information can be further elaborated with the examples as described in Table 1. Consider the case that a designer is seeking information elements (i.e. fragments) concerning “oil chambers”. By identifying contextual information, information users can benefit from its added value (with the expressions underlined) as summarised in the Table.

3.3 A navigation scheme with constant feedback

It is often experienced by many information users when using free text search engines that they get lost in the middle of searching process, especially when a huge number of results are returned for a single search. For example, in the case of “Results 1 - 10 of about 2,360,000 for oil chamber, page 1 of 236,000 pages”, it can be frustrating for the users to sift through the information and lose the context of “where they are”. To remedy this, a navigation mechanism has been explored in this research to provide users with the context information that has been identified in previous sections. To do this, three important steps need to be undertaken:

- define a faceted concept hierarchy representing context information for a subject in which a design team may be interested;
- identify and define relationships across the concepts and facets;
- associate document fragments with pre-identified concept hierarchy.

Figure 5 shows part of the concept hierarchy that represents document context information (not a complete list) discussed in Section 3.2 together with an information content hierarchy. Information content hierarchy has been discussed in authors’ earlier publication [16]. This section will focus on the part of the context hierarchy and the navigation scheme implemented in authors’ recent research. For example, in a certain case of search, four fragments a1, a2, a3 and a4 within document **a** are returned as the initial result. On the left side it shows that fragments a1 and a4 are classified into a concept in the content hierarchy through a faceted classification scheme [16], in the meantime a1 is associated with three facets in the context hierarchy: author, process and diagram. And a3 is associated with facets of paragraph, conclusion and text. Therefore, by referring to the context hierarchy, information users always know where they are and can assess how useful the fragments would be to their design work. From the example, information users clearly notice that fragment a1 is a diagram of process, and a4 is a paragraph of conclusion.

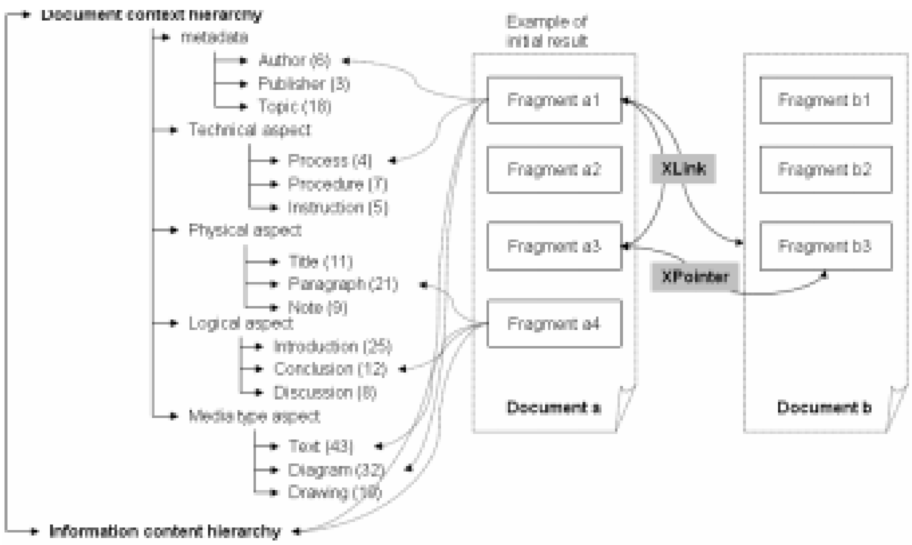

Figure 5. A navigation scheme built upon the context hierarchy

Very often, after they have retrieved a process diagram (fragment a1), design engineers may wish to view a text explanation of the diagram, which is in fragment a3. After reading fragment a3, the designer further wishes to know the method that the process diagram is created with (for example, is it an IDEF0 or a UML diagram?), and the method is documented in another document – fragment b3 in document **b**, as seen from the right hand side of the Figure 5. To enable information users to do this, XLink and XPointer technologies [17] have been identified and employed in the research. XLink is

used to support navigation from one fragment to another within the same document, or to another document (pointing at the start of the document). XPointer is to support navigation from one fragment to another fragment residing inside a different document.
The above navigation scheme has been implemented together with a No Zero Match mechanism [18] to realise a user navigation interface which can provide constant feedback to users in a way that they will be guided to the results step by step after every query is conducted and search results are refined.

4 ARCHITECTURE OF SIR SYSTEM

The three elements discussed in Section 3 are designed as application components. Each of the components is code that implements a set of well-defined interfaces. They are manageable, discrete elements. All three components are not entire applications – they cannot run alone. Rather they can be used as pieces to solve the larger problem of information retrieval. The three components and other essential components to develop the SIR system have been brought together through a Web based, server-side development platform, i.e. Java 2 Platform Enterprise Edition (J2EE). J2EE is a conglomeration of concepts, programming standards, and developments, all written in the Java programming language. J2EE allows us rapidly to construct distributed, scalable, reliable and portable secure server-side deployments. Figure 6 shows the architecture for the SIR system. Three tiers are designed for the system: a client tier, a J2EE server tier and a back-end system tier. In the client tier, information users access the system through internet protocols HTTP (Hypertext Transfer Protocol), and are provided with the navigation GUI (Graphical User Interface) to browse through the concept hierarchy for the information. A keyword search engine is also incorporated in the GUI, which provides users the option of using combined search strategies to speed up the information seeking process.

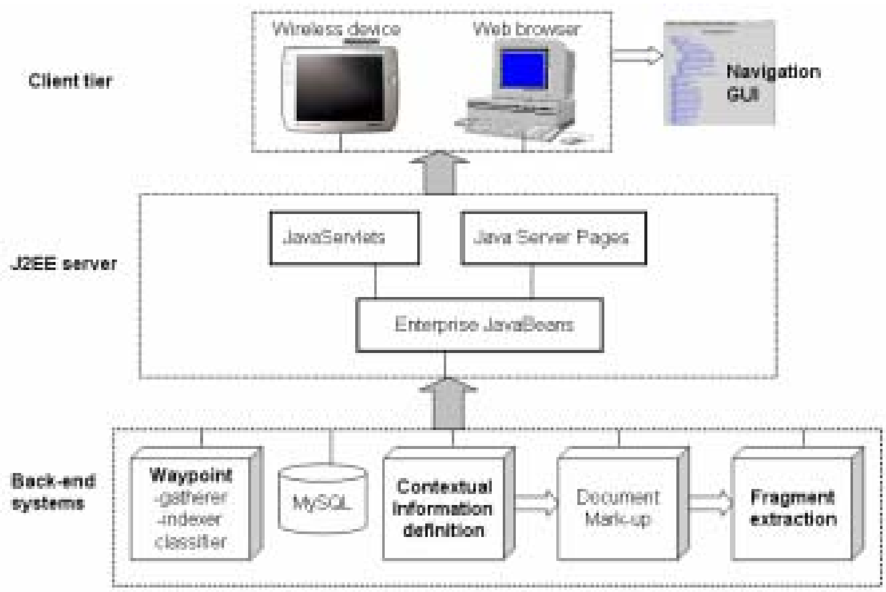

Figure 6. Architecture of the SIR system

Most of the preparation work is done at the back-end. Contextual information definition and identification has been undertaken through document decomposition. Fragment extraction is supported by the preceding work of document mark-up, in this case text information is marked-up with XML, graphics are marked-up with SVG [19] and bitmap images are processed with HTML (Hypertext Mark-up Language). Waypoint [16] has been integrated as a legacy platform to perform the function of information gathering, index building and faceted classification. All the information (documents and fragments) processed through Waypoint system are stored in a MySQL relational database.
Lying between the client tier and the back-end systems is a J2EE server, which comprises JavaServlets, JSP (Java Server Pages) and EJB (Enterprise JavaBeans) to assemble the system components and enable the functionality to external users. This structure demonstrates the advantages of resource pooling, networking and integration with legacy systems. It has great potential when we

build large business systems for complex application scenarios such as big collaborative design applications.
The SIR system was developed with Web services in mind to promote Web communication among design teams. This has been realised with the combination use of the advanced Web technologies SOAP (Simple Object Access Protocol), WSDL (Web Service Description Language) and UDDI (Universal Description, Discovery and Integration). This also gives the system potential to extend with the perception that SIR system is able to talk to other disparate systems on the network of the design team.

5 APPLICATION OF THE SIR SYSTEM TO SUPPORT DECISIONS

When using the SIR system to support decision making in collaborative design, it is expected that the SIR should provide efficient and effective information support with regard to design tasks provided that the information has been documented in the right format such as text, images and graphics etc. Experimental exploration has been undertaken with three types of documents in engineering design: company technical reports, student project posters and a CADCAM textbook. The following table presents some examples from a student design exercise of how the SIR responds to decision requirements, and the user interactions with the system by simply selecting the facets from the document context and content hierarchy combing with keyword search engine if necessary.
The above examples show that the information returned by the SIR is small fragments such as a paragraph, a table, a graph or a process diagram, which answers specific questions related to specific design decisions that design engineers need when solve a design issue. This is facilitated by the implementation of the context information to narrow down and focus on the pertinent information elements. Information users (even inexperienced design engineers who have only limited knowledge of the formula student cars) who can't easily formulate a precise query for free text search engine can still use the navigation scheme presented with the context hierarchy and facets in the GUI to guide themselves to reach a search result. In this case, the provision of context information with explicit terms (facets) is of benefit since it is not necessary to "guess" the correct search terms for information seeking to be successful. This idea has been backed up by colleagues' previous research, for example it has been found that it is an important issue for inexperienced engineers to know what to ask (a dedicated information system) [20].

6 DISCUSSION AND CONCLUSIONS

This paper has addressed the issue of information support for decision making in collaborative design. A novel SIR system has been discussed to provide pertinent document fragments with both correct content and appropriate context information. The system is developed on the J2EE platform, JavaServlets and JSP together with Web technologies such as SOAP, WSDL and UDDI, which makes the SIR a truly Web-based system that design engineers connected through Internet can access and retrieve accurate information at ease. The GUI empowered with the navigation scheme (benefited from the context information hierarchy) provides information users (whether experienced or not) with extra help to reduce cognitive effort but achieving uniform interpretation of the returned information, further facilitating design engineers to make better decisions.
This paper reported the research on limited types of design documents such as reports, meeting minutes, product manuals and drawings. The document mark-up process to obtain fragments has been done within the master copy of the documents. The authors have realised that further work on this issue should investigate multi-dimensional mark-up. Part of authors' ongoing effort is exploring the stand-off mark-up within CAD models, for example using stand-off mark-up with XPointer references to the annotated regions in the source documents (CAD models).

Table 2 Examples to show how SIR supports design issues

Design issue	Decisions for the design	Information needs for decisions	Users interactions with the SIR (by selection of contextual facets)	SIR system response
Formula student car	Should a supercharger be used?	Find the reasons for using a supercharger	Facet: metadata/subject/ formula student car; Facet: physical aspect/body/ paragraph; Facet: logical aspect/ rationale; Keyword: supercharger	Returns: One text paragraph explaining the advantages of supercharging; One graph comparing power curves of standard and supercharged engines
	How to measure performance of chassis?	Show a summary of the key performance indicators for the classis analysis	Facet: metadata/subject/ formula student car/chassis; Facet: physical aspect/ heading/ Facet: media type aspect/ table; Facet: logical aspect/ summary; Keyword: key performance indicators	Returns: A table which summarises the key performance indicators
	How to carry out FE modelling?	Find the process model associated with the formula student car about FE modelling?	Facet: metadata/subject/ student formula car; Facet: media type aspect/ diagram/process diagram; Keyword: FE model	Returns: One process diagram of FE modelling

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