New Concepts for Knowledge based Cataract Surgery Assistance
A First Clinical Approach

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Keywords: Knowledge Acquisition, Computer Aided Assistance, Semantic Network, Knowledge Representations, Knowledge Continuum, Expert System, Decision Support, Surgical Intervention.

Abstract: Concerning optimization of ophthalmosurgical interventions at human eyes, a knowledge based assistance system is developed to support the decision process of the surgeons before the real operation at the human eye. This is performed especially for cataract operations, when the real dark lens has to be removed and an artificial lens system must be implanted. Especially for complicated and complex interventions the computer-based system will be a helpful tool. The system has to guarantee a fast and efficient access to all operation relevant information. The result of such a concept should be an enhancement of operational quality and so an enhancement of the patient contentment. This means a very important factor for the human life quality.

1 INTRODUCTION

In the biomechanical system of the human eye, the intraocular lens is the most important component for the refraction process with about 30 dioptres to focus the rays, coming from outside to the retina. Parallel to the human aging process there is no possibility to prevent a fix dark cloudy lens and also there exist no medical treatments. Cataract surgical interventions at human eyes are the single method, to replace the old dark cloudy human lens by a new clear artificial lens (Augustin, 2001). This is performed about 600.000 per year only in Germany with increasing number. On the market, a lot of different lens systems with different haptics, optics, materials, and power refraction values complicate the selection of a best system.

A special configuration and selection of a patient related lens system can only guaranteed by a computer-aided decision support system, which considers the patient’s need regarding all his earlier diseases as well as the special clinical measurement equipment and the fabrication-related intraocular lens (IOL) features.

Based on computer logical reasoning, the human surgeon can plan and simulate his intervention by the software before the action takes place at the real patient. Figure 1 shows the way from planning the surgical intervention through regarding the wide spectrum of lens types to a simulated surgical process. Dependant on the simulation results, the operation plan can be changed and optimized.

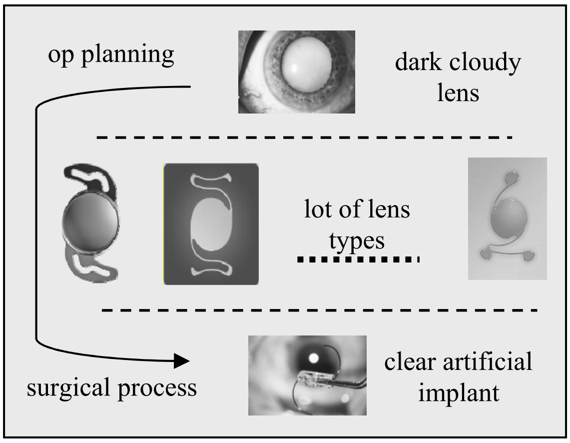

Figure 1: Planning the special implantation.

P. Scherer K., Rieder C., Henninger C., Baumeister J. and Reutelshöfer J..
New Concepts for Knowledge based Cataract Surgery Assistance - A First Clinical Approach.
DOI: 10.5220/0004516100640068
In *Proceedings of the 8th International Joint Conference on Software Technologies* (ICSOFT-EA-2013), pages 64-68
ISBN: 978-989-8565-68-6

2 KNOWLEDGE DOMAINS

The human expert knowledge is subdivided into four super classes of knowledge domains:

The *patient situation* includes all personal data including his history with all past diseases and his actual health state. In this situation the patient related best IOL-implant has to be found. But a lot of *intraocular lenses* are available, different in functionality, form, material, haptics, design, and refraction power values. To select the best option for the patient is not trivial.

Additionally, many clinical measurement and *diagnostic methods* are available and are applied in the preoperative situation of the human being. Some measured values can be wrong when for instance past diseases are not known.

An additional knowledge domain is the wide field of the different *surgical techniques*. The application of these methods depends also on the patient situation, the designed IOL, and the determined diagnostics. This complexity yields a computer-based structuring of the knowledge to support the surgeons by logical reasoning including the explanation of the reasoning process (Figure 2).

These four domains (patient’s situation, diagnostics, IOL types, and the surgical techniques) correlate among each other, so the dependencies are very complex and they are no longer linear. A formalized description of the different knowledge domains must be performed. They should be regarded before the final selection of the IOL and the implantation at the real patient is done. The elements of the knowledge domains and the correlations between them are represented as a semantic net with predicates, i.e., the ontology. This structure, especially in combination with an efficient visualisation is a very important help for the surgeons.

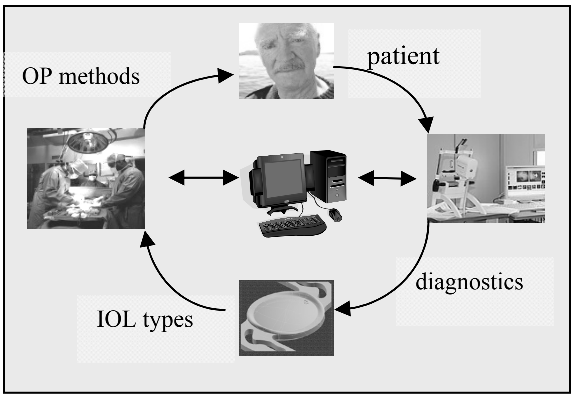

Figure 2: The different knowledge domains.

3 SYSTEM ARCHITECTURE

A knowledge-based approach is well suited to make available as well the human expertise as the background deep knowledge to map the logical reasoning process to computer software (Studer et al., 1988). So, the need is to find out formal structures to manage the different knowledge domains. The knowledge-based support system is conceptualized and realized in different semantic layers:

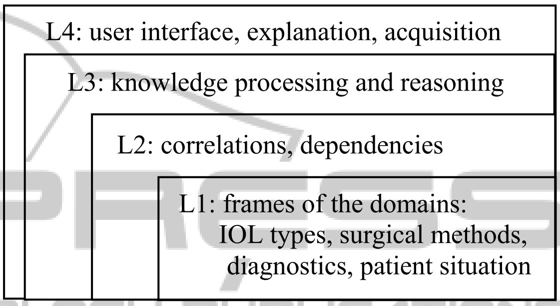

Figure 3: Layer based architecture of the system.

On the basic layer L1, a frame-based information system is performed with all features of the different ontologies. The descriptive layer for the interested information categories is a hierarchical class – subclass system with a refinement process and special specification from class to subclass. An ontology concept consists of the declarative part of the semantics, the meaning in this knowledge-based approach, the sources (publications, authors and so on), and multimedia representations (pictures, tables, movies) (Benjamin et al., 1998).

On the layer L2, the concept of the semantic dependencies is subdivided into different types of relations (predicates), based on natural language. The knowledge elements of layer L1 can be correlated by so called weak links, that means semantic associations between the different items. They are used to generate a suggestion for the surgeon, also to consider the semantic neighboured knowledge domain when regarding a first one. The surgeon can be guided from one interest of point to the next in an intelligent manner. An additional type of relation is performed by a stronger relation like a rule in a rule-based expert system. If the premises of the first domain are given, then the second knowledge items result as conclusion from the preconditions.

Based on the static description of the concepts in L1 including their correlations in L2 the reasoning process in layer L3 depends on the different correlation types. Weak links can be regarded as a helpful navigation to neighboured interested knowledge items in the knowledge base. Strong links can be used under consistent inference rules in the predicate calculus 1st order to generate necessary conclusions in a logical way.

In layer L4 the formulized knowledge is correlated with the surgeon's natural language by the man machine interface. As well the acquisition of new cataract specific knowledge must be generated in a user specific efficient manner. Also the explanation of the performed reasoning process is a very important tool for controlling the human decision process.

4 SURGEONS INTELLIGENT SUPPORT

Concerning an enhancement and optimization of the decision making process of the ophthalmic surgeons, there is a need to correlate all information getting from the patient situation, the latest lens characteristics, and the instantaneous powerful methods of the diagnostic equipment.

The assistance system allows for an intelligent user machine communication (surgeon - assistance system). The information part of the knowledge system is combined by an intelligent navigation through the available knowledge domains of the cataract surgery net. The semantics is represented by weak and strong links to associated knowledge domains.

So the intelligent assistance tool for the cataract surgery has the following advantages when compared classical software information systems:

- The knowledge base can be extended using a comfortable graphical knowledge acquisition component in an easy and consistent manner.
- Furthermore the assistance system supports the reasoning process of the surgeon and it can identify the patient-related optimized implantation. In this sense, a very expensive surgical intervention can be reduced and the contentment of the patient will be improved.
- A further available feature is the possibility to use logical forward and backward chaining mechanisms in the associated knowledge network to explain the logical dependencies.

Regarding the above mentioned features, the system is predestined as a tutorial system for inexperienced doctors and also a decision support system for experienced surgeons. In comparison to literature and books the knowledge-based assistance is a dynamical system, which can be updated and extended by the latest cognitions from the experts.

The knowledge base of the applied support system is considered under two points of view:

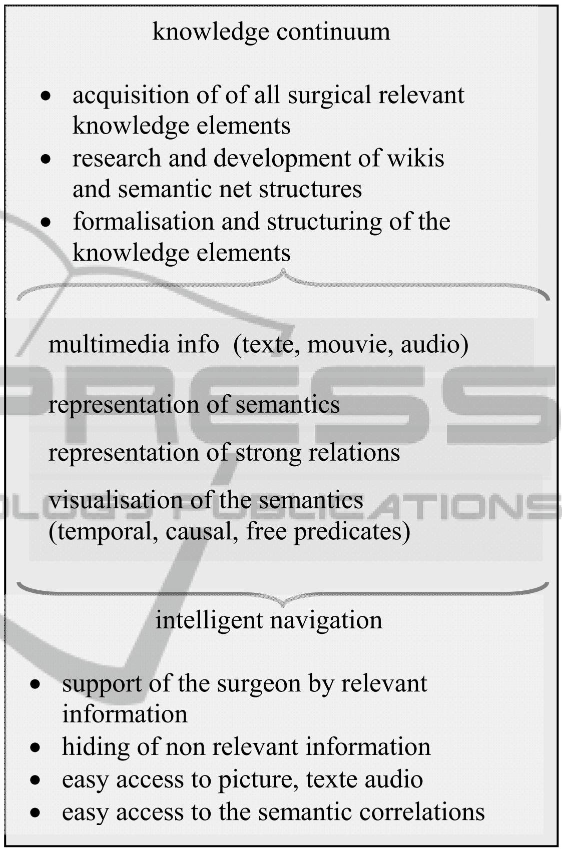

Figure 4: The path from the knowledge continuum to intelligent navigation.

The basic fundament and starting point for modelling the layer 1 through layer 4 is the knowledge continuum with the features in the upper part of Figure 4. In layer 1 to layer 4 the different knowledge representations are shown.

The frames represent the static multimedia information (text, pictures, and audio) including the source information (i.e. http-addresses, literature, and links). The context and associatives represent und describe the semantics between the different information items by *weak links*, i.e., the *associations*.

The final aim and the arrived advantage of this modelled knowledge approach are demonstrated in the lower part of Figure 4. Based on these features, this tool is responsible for an intelligent context sensitive navigation.

5 REALISATIONS

The presented approach is realized by using the system KnowWE (Baumeister et al., 2011b). KnowWE is a semantic wiki, i.e., a web-based knowledge system, extending textual and multimedia information by ontological annotations and strong-problem solving methods. Following the idea of the knowledge formalization continuum (Baumeister et al., 2011a), all types of knowledge (formal knowledge but also text and multimedia) are considered to be part of the knowledge base. In general, a semantic wiki allows for the collaborative authoring of the included knowledge base and its collaborative use.

At the beginning of the project, the ontology was defined for describing the relevant terms and actions of the cataract domain. In the next step, the relevant chapters of an established German textbook for cataract surgery were transferred to the wiki system in order to provide suitable information of the domain.

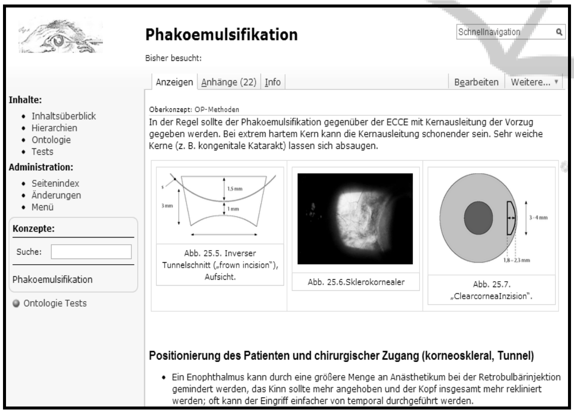

Figure 5: The WISSASS wiki system (original German screenshot).

Consequently, the textbook corpus was enriched by ontological annotations populating the initially defined ontology. In all project phases, different domain specialists (surgeons) and knowledge engineers were actively involved. Due to the nature of the wiki system, the domain specialist is able to extend the current body of knowledge by further elements, when necessary.

From the user's view, the wiki distinguishes *restricted knowledge acquisition pages* and *public system pages*. The restricted knowledge acquisition pages are only accessible by the knowledge engineers and the surgeons and include the formal knowledge definitions. The public pages are accessible for everyone and they include the textbook knowledge and the interfaces for browsing the cataract ontology.

Figure 5 depicts a public page, where the concept *Phakoemulsifikation* is described, i.e., a special method of surgical intervention. The text describes the requirements and consequences using this method but also practical advices for implementing it. From this description, the ontological neighborhood of the concept can be browsed and the user can navigate to interesting concepts easily. Figure 6 shows an excerpt of the visualization for the concept *Phakoemulsifikation* with neighboring ontological concepts having a refining relation.

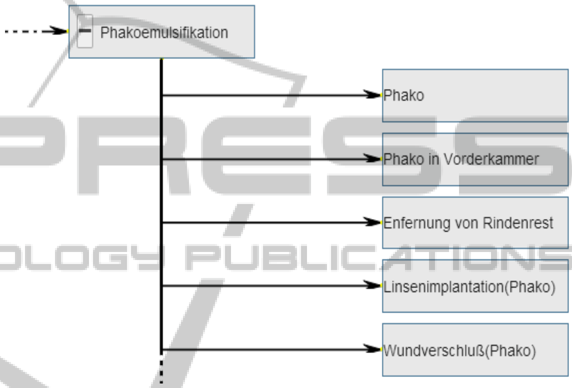

Figure 6: An excerpt of the ontology visualization (in German language).

In the future, we are planning to extend the range of visualization methods to provide more appropriate navigation structures for the specific browsing requirements of the users. At the current state of development, the system includes about 400 pages providing the textbook knowledge, annotated by about 360 concepts with about 430 relations. At the moment, clinical partners evaluate the system for the last three months.

6 CONCLUSIONS

The most important advantage of the knowledge-based assistance is the intelligent navigation of the user (surgeon) through the knowledge continuum. Based on the visualized network of the semantics (knowledge elements and their correlations) the surgeon gets exactly the information that is useful and necessary for him in the instantaneous situation. The semantics is of higher order because of representation of weak and strong links to the associated knowledge domains. In contrary to classical information systems the expert system is easy to extend by graphical knowledge acquisition features. Also the reasoning process for decisions can be explained by the visualisation of the logical path. This assistance yields a better human decision process and improves the results of the cataract operation.

ACKNOWLEDGEMENTS

The research and development of the proposed cataract surgical assistance system is funded by the national economical government of Germany. It is proposed to install a commercial clinical system based on the results of the presented prototype at clinical partners. The authors also thank the project executing organisation AiF in Berlin, which is responsible for the allocation of the budget to the research centre and the commercial company.

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