KNOWLEDGE BASED CONCEPTS FOR DESIGN SUPPORT OF AN ARTIFICIAL ACCOMMODATION SYSTEM

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Abstract: When conceiving medical information and diagnosis systems, knowledge based systems are used to diagnose failures based on specific patient data. The knowledge is evaluated based on statistical data from the paste and the present information is derived by statistical approaches (Bayes theorem) and analogues cases to interpret the individual patient related situation. An analogue methodical situation is that of the conceptualisation of a new technical system, where the system components with the properties will be configured in such a manner, that a target function is guaranteed under consideration of any constraints. In both situations, the system (human being, technical system) has to be described in a natural language and must be formalised. Based on these formulas logical conclusions can be drawn. Useful representations are formalised knowledge representation methods. For logical conclusions the predicate calculus of first order is used. For information access by both experts and users, comfortable natural language based concepts and the employment of graphical tools are very important to manage the complex knowledge.

1 INTRODUCTION

Concerning reconstitute the vision quality for presbyopes human eyes, a novel artificial accommodation system (AAS) will be investigated and developed. This is essential to guarantee life quality at an advanced age. In the course of this preliminary research and development vast information will be generated in this context which must be further processed, deleted, extended and changed during the current process. To do this, it is necessary to generate and dispose of software structures for storing and processing the information used in a consistent manner (Scherer et al., 2006). Formal representations have to be designed such, that the information is accessed in a natural language. Based on this acquired expert knowledge, new knowledge can be produced and hypotheses can be validated or disproved. The important topic in this proposal is the presentation of frame based concepts, where an inference engine starts with logical methods. Furthermore, causal relations and interactive effects between the different components of the accommodation system have to be regarded in the design process.

2 BIOLOGICAL BACKGROUNDS

From the biological and medical points of view, a mechatronic system is developed for implantation into the capsule bag of a presbyope human being after a cataract disease (Bergemann et al., 2006). This mechatronic system must be self sustaining. Consequently it needs an independent energy supply system to reproduce the refraction power needed.

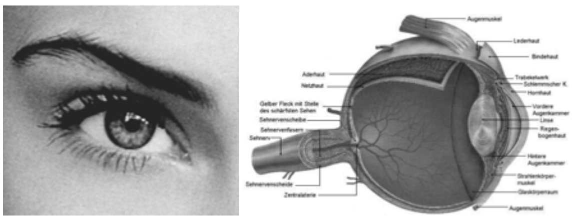

Figure 1: Human eye and a lens model with capsule bag.

Fig. 1 shows a natural eye (left side) with a capsule bag and an intraocular lens system (right side) before starting the cataract operation. After extraction of the human lens, the empty capsule bag should be filled with the miniaturised complex self

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sustaining accommodation system, which is nowhere existent at time.

When developing such a new complex mechatronic system, much information is produced, which is partially wrong, uncertain and contradictory. In spite of various constraints, the information should be processed logically. The management of such a complex information system requires the use of software methods to solve the following problem:

Are there any energy supply methods for such a self sufficient implant, taking into account the smallness, biological compatibility and the absolutely necessary energy to guarantee the refraction power needed?

In this problem following information entities are involved:

The patient or human being, undergoing the operational intervention to insert the implant.

The type of energy supply, which has to be selected from many possible physical, chemical and biological components.

The refractive lens system, which has to be implanted and needs also different volumes depending on the different actuator principles. Such a refractive system consists of different partial subsystems (optics, haptics, actuators, sensor components) with their own functionality. To provide the patient with refraction power, the energy level must be greater than a special conditioned value.

The sensor systems, which are responsible for the active control of accommodation, must also be implanted into the patient specific capsule volume. This results in a domain specific semantic network with different class structures.

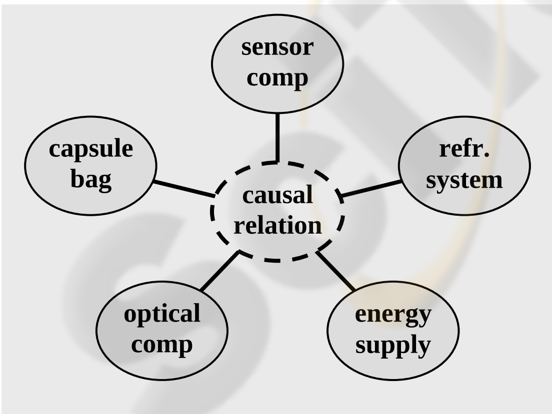

Figure 2: Different domain specific classes with relations.

So, the above mentioned aspects of the information entities and their subcomponents give rise to the following question:

Are there special conditions and is there a special parameterisation of the mechatronical components to reach the patient specific refraction power desired.

The first very important requirement refers to the volume of the different hardware components. It decides whether a special refractive system can be implanted with a special parameterised energy unit of adequate power. Related former aspects, following conditions have to be considered.

1) A patient specific quantitative volume of the capsule bag is available for the AAS. But the installation space is limited by an upper and a lower value.

2) Different physical, chemical and biological energy supplies posses different power densities depending on their activity principle and the degree of efficiency.

3) The regarded refractive system consisting of the optical component itself, the haptics and the actuator component needs space, which is described not only by the pure volume, but also under morphological aspects (it may be compact, cliffy, cylindrical and so on) and affects other hardware components.

4) Apart from to the optical component itself the sensor component (measuring and control unit) has to be installed. The following parameters are introduced to describe the basic situation:

- *Vol_P*: the volume of the capsule bag in the eye
- *Vol_E*: volume of the energy supply unit needed
- *Vol_S*: minimal volume of the sensor component
- *Leistdichte_S*: power density for the energy
- *Vol*: installation volume of the optical component
- *Leist_O*: needed power for the refraction desired

3 SEMANTIC NETWORKS FOR KNOWLEDGE REPRESENTATION

The information embedded into the class structures and the attributes, are correlated to formalise the knowledge about patients, energy supply and the refractive system (requirements see chapter 2). The main information entities (patient, energy supply, refractive system) are regarded as classes with variable objects (Fig. 3). The additional slots about these classes are the two relations “has properties” and “consists of”. The properties are inherited from super classes along the relation path “is a”. For the information system a frame based approach is constructed for the classes themselves, which will be extended further to so called concepts (concept = frame with attributes including restrictions).

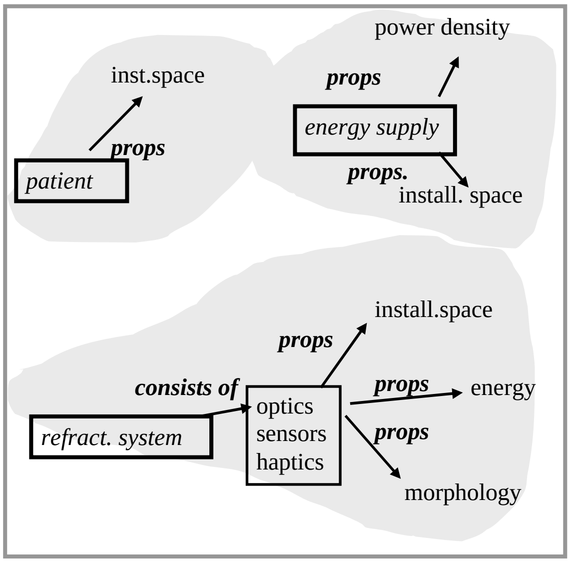

Figure 3: Class components with relations and attributes

For the overall correlated information a rule based approach is applied with the known Boolean operators of the predicate calculus of first order. The evaluation of the attributes in the classes *patient*, *refractive system* and *energy supply facilities* form the symptom tree, otherwise any information about fit accuracy of the participating components in the capsule bag compose the diagnostic tree. The relations between this hierarchical organised knowledge are performed by rules with functions and interpretations. (Fig. 4).

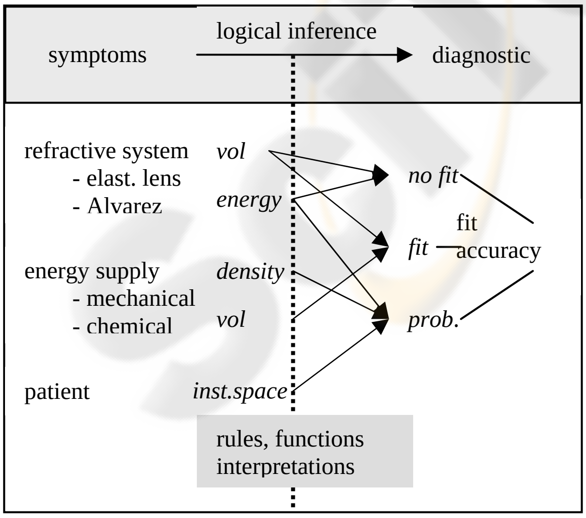

Figure 4: Semantic network of class and object relations.

4 FRAME BASED KNOWLEDGE REPRESENTATION

The modelling of the natural information about mentioned semantic topics means the development of structures, which are formulised in class-subclass-element-relations. Along the relation “is a” between classes and subclasses and elements an inheritance mechanism is available. For the attribute slots, constraints can be formulated. These frame based approaches form a well defined hierarchical tree structure for the new information system and are a prerequisite for starting logical conclusions.

4.1 Class Structure of the Refractive Systems

The class of the refractive optical systems is subdivided into five classes, each distinguishing by the actuator principle and the physical principle. In the following application only one class will be considered, namely the elastic lens system. Other principles and optical systems are ignored in this stage of knowledge engineering. The elastic lens itself is studied and the aspect “consists of”. Each of the resulting two classes of optical device (optics) and sensor device (sensors), has “installation space” (volume) as an attribute. Along the relation “consists of” no inheritance is available.

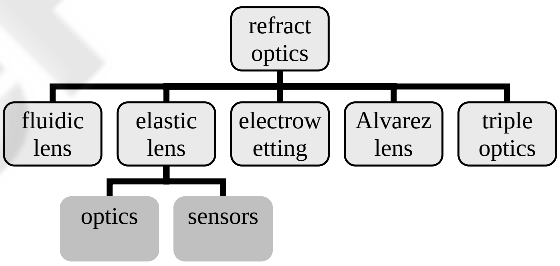

Figure 5: Class hierarchy of refractive optics (excerpt).

4.2 Class Structure of Energy Supply

For the development of the AAS different energy supply units are analysed. A representation of four energy supply classes is needed. The attributes of these classes have both numerical and also linguistic values. Here it is focussed on a single energy supply class, namely the mechanical one, that is based on “vibration generators”. The attributes of interest are the power density and the volume needed.

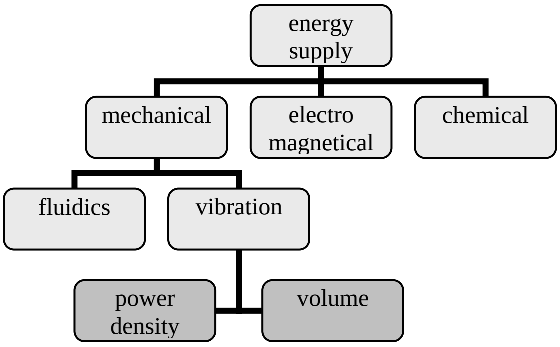

Figure 6: Class hierarchy of energy supply units (excerpt).

4.3 Class Structure of Patients

A third important class in connection with the fitting accuracy in the capsule bag is the set of all patients. At the moment, the volume value is the only numerical feature that describes the installation space of interest. Other also important features like the biological compatibility and other medical constraints are added in time.

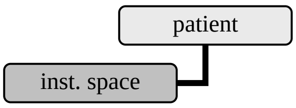

Figure 7: Class patient with the attribute installation space (volume).

5 RULE BASED STRUCTURES

The rule based structures refer to the domain dependent part of the knowledge base. They reflect the causal relationships between the diagnostic part of fitting accuracy in the human capsule bag and the prerequisites, formulised by the frame based classes *patient, energy supply and refractive system*. A simple rule is following:

if
Vol_O < 107 mm^3
then
energy supply fits into capsule bag

Figure 8: Simple rule without Boolean operators

The rule only describes the dependence status and has no active function in knowledge processing contrary to a rule interpreter. This will be realised in the inference engine.

As an extension of the former rule a complex rule consists of atomic preconditions associated by operators of predicate calculus of first order.

if
AND Vol_O < 107 mm^3
AND Vol_S < 20 mm^3
AND Leist_O > 15 mW
AND Vol_P > 320 mm^3
AND Leistdichte_S > 80 mW/mm^3
AND Vol_E < 190 mm^3
then
energy supply fits into capsule bag

Figure 9: Complex rule with AND conditions.

In the next stage, structured rules are complex rules with exception conditions being specified.

5.1 Rule Extension with Interpretations

Sometimes, the numerical values of attributes are not input directly for logical conclusions. Before final conclusion, an algorithmic evaluation of the attributes must be performed to reason with the condensed information.

As shown in figure 10 first the sum of all parameter values has to be calculated before a conclusion can be drawn with respect to the fitting accuracy. Also the product of energy power density and the volume results in the power, which is one of the two AND conditions for the conclusion process.

if
AND Vol_O + Vol_S + Vol_E < Vol_P
AND Leistdichte_S x Vol_E > Leist_O
then
energy supply fits into capsule bag

Figure 10: Rule extension with interpretations

6 ARCHITECTURE OF THE KNOWLEDGE BASED SYSTEM

A knowledge based system is mainly a computer application, which performs a special task, which would be performed usually by human experts. These systems are part of the general category of artificial intelligence applications and capture an expert's decision making knowledge, such that it can be disseminated to others. The knowledge based systems differ from conventional programs by performing tasks using decision making logics under constraints and other conditions. The kernel of such a system exists of the two main components the knowledge base (subdivided into the two parts "fact base" and "rule base") and the inference engine, which uses the parameterised facts and rules of the knowledge base to draw conclusions concerning a special given problem. Additionally a comfortable explanation component and a consistent knowledge acquisition tool complete the architectural structure. A special feature of the knowledge based architecture is the strongly logical division into the passive knowledge base and the active strategic part of making logical conclusions (Puppe et al., 2001).

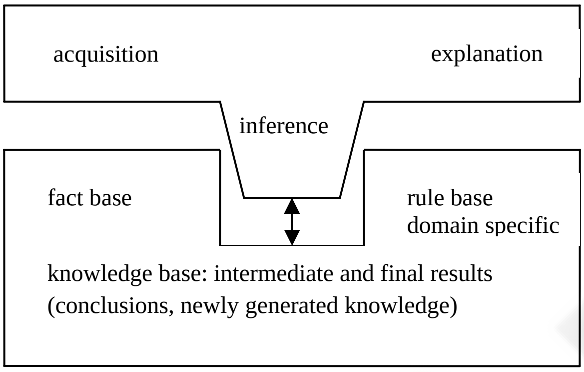

Figure 11: Architecture of the knowledge based system

6.1 Fact Base

The current situation is represented by the facts, i.e. the parameterised attributes of the classes and objects. The different facts are stored in the fact base. In the presented special application the situation is as follows:

Case specific knowledge

In this situation the following parameters are given:
A volume of the space for installing the optics
A special parameterised sensor component
A patient specific capsule bag
A special energy supply unit with attributes

Figure 12: Situation in fact base.

6.2 Rule Base

The different representations concern the rule base, describing the relations among the knowledge entities in the knowledge domain. Depending on a state (given by formulised "if conditions" as premises) new knowledge items are derived. In this case only categorical knowledge is used. The "if conditions" contain atomic formulas connected by predicate operators. This condition is sufficient for the declarative (hypotheses) and the procedural (actions) conclusion parts.

domain specific knowledge
set of causally connected information units

formal representation:

If
B1 op B2 op…satisfied
Then
actions A1, A2 ….
hypotheses D1, D2…

predicates conditions
procedural
declarativ

Figure 13: Domain specific rule base.

6.3 Inference Engine

The inference engine is the active part of the knowledge based kernel to process the given information and obtain new results. The conclusions result from the logical predicate calculus of first order. The definition is as follows:

An inference rule is an advice of how to generate a new formula in a logically correct manner by combining two (or any) given logical formulas. An important inference rule used in this application is the so called "modus ponens", given by the following method.

A (fact in fact base)
A >B (rule in rule base)
B (new fact generated as conclusion written into the fact base)

In this context, A, B and the implication itself are deterministic and without loss of certainty. A contains all parameterised preconditions concerning the patient's capsule bag, the refractive system with components and the energy supply unit.

B contains information about the fitting accuracy of the artificial accommodation system into the capsule bag. The instantaneous state of diagnostics is a binary valued statement "the system can be implanted" (based on value conditions) or "system cannot be implanted".

A weak uncertainty function of accuracy exists but has not been implemented so far.

6.4 Knowledge Acquisition

The human based knowledge (natural language) must be transformed into formal structures of the computer software components. The knowledge entities are inputted into the class-objects-attribute variables (see also frame based structures). Knowledge acquisition can be enhanced by consistence checking during the acquisition step. Consistence means a validation of values in a predefined numerical range or linguistic values within a predefined term set or the number of allowed values from the whole acquisition set.

AND 100 < Vol_O < 110
AND 15 < Vol_S < 25
AND Leist_O > 15
AND 280 < Vol_P < 330
AND Leistdichte_S in mW
AND Vol_E in mm^3

Figure 14: Frame extension to concepts (with facets).

This indirect constraint representation prevents formally correct conclusions from being drawn on the basis of data that are not allowed. Extension of the frames to the so called concepts is a useful representation of the knowledge schemes. An example is shown in Fig. 14.

6.5 Explanation Component

The explanation component is responsible for providing the user with explanations as to how the reasoning process was performed. It is essential to understand the reasoning process and to obtain new ideas for further advanced solution processes. In this way, confidence into the conclusion and the developed knowledge based system is enhanced.

Due to the probably very complex and wide solution paths (numerous conditions and constraints) the user specific results have to be analysed by backward chaining processes. This requires a comfortable capacity to interact with the system through text and graphics.

The explanation part together with the knowledge acquisition component are the dialogue components. Together with the inference engine they form the monitoring process, that is responsible for powerful navigation through the complex knowledge system.

7 CONCLUSION

The benefit and necessity of knowledge based structures in the research and development of a novel complex artificial accommodation system (ASS) are outlined. The acquired knowledge must be managed using refinement processes, because absolute information is lacking in the instantaneous state.

Original rules developed may be rewritten later and redefined. The complex knowledge is more circular than linear. Furthermore the knowledge always is only partly correct and not complete and has to be redefined gradually. In this meaning comfortable formulised structures and refinement mechanisms must be developed as well as comfortable decision making processes including their explanation.

Hence, the classical algorithmic based system has to be extended to a knowledge based system for developing the new complex artificial accommodation system.

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