An Approach to Knowledge Acquisition for the Hull Form Design of Fishing Crafts
2nd Report: Object Oriented Methodology for the Rapid Development of Procedural Tools and Interactive Elicitation for Hull Selection

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Summary

The problem of acquiring procedural knowledge for hull form design and construction of a knowledge base for hull form selection is addressed in this paper. An object oriented methodology involving creating classes, state diagrams and data flows for parametric hull form design was undertaken. An interactive graphical tool for the production of hull designs from a parent design was developed based on knowledge acquired from domain experts and the technical literature. Hull variation was accomplished by changing common design parameters including CB, CP, LCB and parallel middle body. Dependent and independent variation of design parameters was allowed and the tool produced variants of the parent hull rapidly with a high degree of flexibility. The resulting forms then serve as input to a selection tool for constructing the knowledge base. The tool was based on rating grids and involved the elicitation of decision elements, traits and ratings from users to build a set of rules for selection. Sample selection sessions illustrate the applicability of the system.

1. Introduction

As part of an effort to develop an expert system for hull form design, several tools and methodologies are being utilized in the development of a knowledge base. A previous paper described a tool for constructing a database of hull forms which provide geometric data for the design system. Knowledge acquisition was then conducted to derive more knowledge about the problem domain.

Knowledge of a person is defined as a "system of related facts, abstractions, theories and models or procedures existing in that person's mind, enabling one to interpret, predict, respond in a manner consistent with a general goal". A knowledge base is a systematically organized collection of stored knowledge and could be defined into two; declarative and procedural.

Declarative knowledge includes the general heuristics or facts explaining system components or what is true regarding a certain system. General relationships between facts and constraints that exists on the facts and relationships are included. Declarative knowledge answers the question "what" and is very useful in initial stages when concepts about the domain are being constructed. Conventional database are sometimes regarded as a collection of declarative knowledge.

Procedural knowledge includes the skill of the expert in performing a task as well as decision making expertise and problem solving techniques used in moving from step to step along a defined task path.

Procedural knowledge also includes automatic response to stimuli, strategies, knowledge in the use of algorithms, tools and logical explanations. Answering the question "how to", procedures for the inference of new facts or relationships and heuristics for finding solutions to specific problems within the environment are classified under this type. Defined as consisting of several levels, the lowest level consists of modular procedures which are applicable to restricted problem classes. The next level consists of knowledge of when and how to apply the low level procedures and are termed "control" or "meta" rules for a specific domain. The highest level consists of general domain independent control procedure or heuristics that may be applied to a variety of tasks (Fig. 1).

Sources of domain specific knowledge may consist of documented rules and procedures, written text, existing

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databases or undocumented knowledge in the minds of human experts. Knowledge acquisition is considered as the most difficult aspect in constructing any knowledge based system. Most notable researchers in AI have acknowledged the complexity of transferring knowledge from a human to the computer. What has proven to be especially difficult to encode is the heuristic problem solving knowledge required in controlling and regulating the various subsystems or chunks of procedural knowledge. Such difficulty results from a lack of understanding of the nature of human expertise, the methodology of a human being in using knowledge and the process of knowledge acquisition in general.

For the intended system, a combination of reference to databases, interview of experts, the technical literature and existing learning or knowledge acquisition tools is being utilized in the construction of the knowledge base. Early efforts in knowledge based systems focused on the capture of knowledge using "knowledge engineers" employing a variety of structured/unstructured tools and techniques. More recently, advances in automatic knowledge acquisition and machine learning have been successfully employed to lessen the time and effort required in building a knowledge based system. It also has been more common to combine all three for the development of the entire knowledge base or its components. As applied to fishing boat design, the process of knowledge acquisition is conducted using several methodologies and tools for deriving both declarative and procedural knowledge.

(Fig. 2)

2. Methodology

The techniques used for tapping knowledge from experts was a combination of interviews, process tracing, protocol analysis and a tool based on grid rating technology for selection of finite elements or choices. Process tracing involved recording the expert's methodology, tactics and strategies in coming up with solutions to problems or the completion of a task. Protocol analysis was then used to identify points where decisions were made; actions leading to such decisions and alternatives.

Based on interviews with experts of various design departments, a methodology for the implementation of procedures in design was developed and subsequently implemented as a tool for the creation of hull form variants from a parent ship. Implementation in an object oriented system greatly facilitated the rapid prototyping of the system. Aside from knowledge gathered from domain experts, technical references providing the mathematical background and algorithmic details of the process. (Fig. 3)

Instead of constructing rules or other forms of knowledge from interview sessions with experts, the development of a tool was intended to directly encode procedural knowledge existing in the design experience of experts as well as in the technical literature. The decision to do so was based on the nature of the problem where the system for determining hull forms has been established and proven to be very reliable.

The focus then was shifted to a tool for the rapid creation of hull form variants such that the resulting forms could be used as input to a selection type knowledge acquisition system. The resulting knowledge base was used for decision making in conjunction with the hull variation system to select the best design. Users of the tool were then provided with advice on the combination of parameters which are best for a particular problem. Also, it was observed that the procedure in the visited design departments using the 1-CP method was mainly manual and batch processing used to develop the lines, showing a need for an interactive, knowledge

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**Fig. 1** Types of knowledge

**Fig. 2** Knowledge base development system.
based system for hull form variation.

Sessions with very helpful design departments resulted in the compilation of declarative knowledge and some procedural knowledge in fishing boat design. Although the knowledge learned was limited in depth, it provided enough reference to procedures which are available in the technical literature.

From the interview sessions and research on the literature, the process described in Fig. 3 was followed and a state diagram of the system constructed for hull form design based on a parent and using the CP curve or 1-CP curve techniques. The design procedure for hull form variation as employed in one ship yard is shown in Fig. 4.

2.1 Implementation 1: Hull Variation Tool

As the CP curve and 1-CP technique was the sole criteria for determining the hull form, research was conducted on the literature of the field. Changes in hull form was achieved by moving the sections of the parallel middle body in the transverse direction and adjusting the fore and aft part to derive the desired CP. Based on the work of Lackenby\textsuperscript{5)}, the following implementation was derived and subsequently coded in an object oriented system. The following relationships are defined (also known as the 1-CP) technique: (Fig. 5)

\[ \frac{\Delta x}{1-x} = \frac{\Delta \phi}{1-\phi} \]  \hspace{1cm} (1)

where:

- \( \Delta x \) = necessary longitudinal shift of the section (fraction of halfbody)
- \( x \) = actual station position (as a fraction of length of halfbody)
- \( \Delta \phi \) = required change in the prismatic coefficient of the halfbody

\[ \frac{\Delta p}{1-p} = \frac{\Delta \phi}{1-\phi} \]  \hspace{1cm} (2)

where:

- \( \Delta p \) = change in parallel middle body (fraction of halfbody)
- \( p \) = fractional parallel middle body (fraction of halfbody)
- \( \Delta \phi \) = required change in the prismatic coefficient of the halfbody

![Fig. 3 Methodology for rapid production of a tool implementing procedural knowledge.](image1)

![Fig. 4 State diagram for preliminary hull form design.](image2)

![Fig. 5 Halfbody and terms.](image3)
Based on equation 2, it can be seen that the parallel middle body is dependent on the prismatic coefficient. Limitations of the 1-CP method in this regard include the lack of control over the range of parallel middle body; it is not applicable to ships without parallel middle body. With maximum longitudinal shift limited to the parallel middle body, there is no control over the longitudinal distribution of added or removed displacement. In resistance experiments of a series, there is also the difficulty of relating experimental results with independently varied parameters. To add flexibility, Lackenby developed the following mathematical technique which allows the various parameters to be varied independently of each other. Given a basis ship with any length of parallel middle body:

\[ \text{ax} / (1 - x) = \phi p / (1 - \phi) + (x - p) / A (\phi - \phi p / (1 - \phi)) (1 - \phi) \]

where:

\[ A = \phi (1 - 2cx) - p (1 - \phi) \]

where:

\[ cx = \text{distance of halfbody centroid to midships} \]

The lever \( h \) or the distance of the centroid of the added area to midships is approximated by:

\[ h = \phi B / (1 - \phi) \phi p / ((1 - \phi) / (1 - \phi)) + \phi p (1 - 2cx) / (\phi - \phi p / (1 - \phi)) \]

where:

\[ B = (\phi (2cx - 3k - p (1 - 2cx))) / A \]

where:

\[ k = \text{radius of gyration of the area} \]

The practical limits of \( \phi \) is defined as:

\[ \phi = \phi (1 - \phi) + A (1 - \phi p / (1 - \phi)) / (1 - \phi) \]

As implemented in Prograph, the various parameters are defined as attributes of objects shown in Fig. 6.

The preceding theory allows for the independent variation of the following parameters: CB-block coefficient; LCB-longitudinal center of buoyancy; Parallel mid body-aft; Parallel mid body-fore. As implemented, direct variations on the fore and aft Prismatic coefficients were also allowed. The state diagram of the system is given in Fig. 7. The system consists of three windows: CP curve, waterlines and control curve. The various elements of the CP curve window are shown in Fig. 8.

Varying the parameters involved selecting the parameter and sliding a slider in the control window. Instead of directly working on the values of the parameter, the change (\( \phi \)) in parameter is directly controlled. Aside from independently varying \( \phi \) CB, \( \phi \) LCB, \( \phi \) aft, \( \phi \) fore, it was also possible to change the parameters at the same time. For example in Fig. 9, \( \phi \) LCB is varied after \( \phi \) CB is varied and the effects are shown.

Not clicking on the buttons for \( \phi \) CP aft and \( \phi \) CP fore was equivalent to setting the prismatic coefficient constant. Varying the aft and fore prismatic coefficients was seen to result in different CB and LCB as well as \( \phi \) aft and \( \phi \) fore. The limits as shown in the figures were calculated using equation (6) and was found to be quite reasonable.

A later version of the system incorporated a waterlines view for the simultaneous changing of waterline values given the change in the coefficients. The plotted lines are quite rough because in order to speed up the system, straight lines were used. The following figure describes the process of changing a parameter and reflecting the change in station position on the water-
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The tool directly changed parameters which are mostly commonly employed in further calculations such as resistance. It provides a capability for the rapid development of new designs based on existing hull forms. Although at present, the modification is limited to the longitudinal variation of stations, further capabilities are being developed to provide more flexibility and usefulness.

2.2 Implementation II: Selection Tool

Choosing the right curve or right design involves experience and knowledge. Given the set of curves, which one is the best? For an expert, such decision making probably comes readily but for inexperienced users, an advisory system is assumed to be very helpful. Even for expert users, such advice could be helpful in the decision making process such as in cases where the design is of unfamiliar nature. One way to develop the knowledge base for such an advisory module is to use a tool for construction a selection knowledge base that would construct rules and advice on selecting the best design.

The Selection Tool methodology is based on the popular grid construct technology which has been used by many knowledge base development systems. Grid construct technology is based on psychology and is called Kelly’s Construct Theory. This theory says that people classify and categorize their environment and experiences and individuals are capable of expressing their ideas by means of constructs or opposing ideas (for example: good or bad, comfortable or not comfortable, safe or not safe) termed as the left and right hand poles.

Grid rating technology has been used successfully in the field of diagnostics, classification, selection and other analysis type problems. Its use in finding solutions lines. (Figs. 10 and 11).

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Grid rating technology has been used successfully in the field of diagnostics, classification, selection and other analysis type problems. Its use in finding solutions
to synthesis problem has been quite limited and some authors express doubts about its applicability in this domain. For some areas of the knowledge acquisition process for design, grid technology, in conjunction with other tools and techniques has proven to be helpful in defining declarative knowledge particularly facts and some relationships. It has been found to be useful in determining built-in hierarchies among similar attributes describing an element set.

As shown in the state diagram of Fig. 12, the Selection Tool starts by asking for decision elements from the user. Decision elements consist of choices or alternatives from which the best or most applicable element is selected. It is assumed that the given choices are at the same level of hierarchy. For example if the selection is between hull types A, B and C, each one must not be a subclass or superclass of the other, they must be at the same level of classification.
After decision elements are given, traits which are the basis for selection are entered. Traits are given as a set of opposing pairs and the element rating is based on whether the user judges the element to be nearer one pole or the opposite pole (examples of opposing poles include good and bad, tall and short, expensive and cheap). The system allows the interactive input of traits. As traits may be hidden or may be difficult for the user to declare, a comparison of three elements allows the elicitation of characteristic traits. One element is compared with two other elements and the user is asked for the difference between the element and the other two, giving one pole (an example pole is high speed). Then the user is then asked for the opposite trait (low speed) and the opposing poles (high speed—low speed) constitute one trait pair for selection. Again, it is assumed that the traits do not have any inherent hierarchical structure.

After traits and elements are given, elements are rated from 5 to 1 depending on the correspondence of the element with each pole. Ships or elements with characteristics nearest the right hand pole (high speed) are given ratings of 4 or 5 while elements nearest the left hand pole (with low speed) are given ratings or 1 or 2. This process is continued for all the trait pairs.

The system then calculates the implications of the traits or how closely traits are related to one another. Various options are available for processing and viewing the results of the rating process. The rating list can be viewed or a clustering of traits conducted to determine the classification of elements and traits. The process of deriving a set of rules for selecting from a set of elements is iterative in nature and the user is allowed to change the ratings according to the results of the output window. Elements and traits may be added in addition to the modification of ratings.

Once the user decides that the set of traits and element ratings is satisfactory, a knowledge base consisting of rules and element objects is derived. Intermediate rules determine the internal structure and relationships of the traits. Traits are also rated according to importance in the decision making process and conclusion rules that recommend the best element from the given choices are derived.

As an example, suppose that 5 hull forms have been created using the given tool; ships A, B, C, D and E. (Figure 13) Ships A and B had their CBs varied with Ship A near the maximum CP and B near the minimum CP. Ships C and D had their fore and aft CPs respectively varied towards the maximum. Ship E had its parallel midbody increased both fore and aft. Which one is better? Such knowledge exists either through further analysis of the form, or through experience from previ-
ous designs. The Selection Tool is used to create a knowledge base for choosing the proper hull.

The decision elements consisting of Ships A, B, C, D, and E are input into the selection tool using an interactive editing window. Traits are given that commonly reflect the basis for which selections are made. Since the variation is basically concerned with the fineness of whole form, fineness of the aft and fore sections as well as extent of parallel middle body, traits such as seakeeping, resistance, and internal capacities are affected. Also, because the hulls are based on an existing parent form where the stations are moved longitudinally, some effects on stability may occur.

Such set of traits serve as an example to the process and may differ from expert to expert, depending on the priority given to each particular trait. While such choices for traits and the subsequent ratings may seem inaccurate or strange to some, it just serves as an example of the process where selection from a set of previously known elements can be conducted based on a set of subjective traits that is commonly used to decide between the elements.

The output window for the selection tools shows four windows:
1. Rating Summary—numerical values of the element rating for each trait are given.
2. Cluster and Hierarchy window—the resulting dendrograms and classification of elements and traits are shown.
3. Elements window—shown a listing of elements
4. Traits window—traits are listed; both the right hand and left hand sides of the trait are also shown. (Fig. 14)

Cluster analysis was done using the Euclidean similarity distance and nearest neighbor clustering techniques. The scroll list adjacent to the clusters shows the classification of elements or traits in outline form. The tree diagrams provide the classification of elements and traits based on the ratings and clearly show hierarchical relations for both. Based on the resulting graph, the user can make modifications to the ratings to change the classification or if the user is satisfied, the set of rules for choosing the best choice among the decision elements can be constructed.

The resulting trait and element structures are then stored in an database to form a part of the session's knowledge base. Storage of the elements and traits in the database is also hierarchical where classes have subclasses that are instances of the element and trait classes which in turn can contain other such subclasses.

The traits window has an option for showing the clustering of elements based on a pair of traits. This allows the user to view relationships between elements and traits. Selecting the trait pairs to be clustered and viewing the resulting graph provides an additional tool for the user to decide whether to change the rating or construct the rule base. To show the relationships of the traits and elements for the given problem, all the possible combinations of traits were plotted and arranged in triangular format to provide a more informative view of each pair. (Fig. 15)

Conclusion rules are created from ratings in the grid; the relative importance of the trait (5 to 1 scale) for solving the problem is evaluated. The certainty factor is a measure of the strength of belief that a particular assertion is true. The uncertainty factor used in the system

![Fig. 14 Grid rating system](image-url)
is based on an existing system (KS-300/Mycin). These are combined to give the confidence factor that such a rule is true. Rules are stored as objects in a database. Prograph provides some primitive functions for the storage and retrieval of data using a B+ structure for disk based data storage. (Fig. 16)

It is also possible to test the rules using a simple rule firing window. Traits required are clicked on the traits window and the system searches the rule base for the rules to be fired. Rather than giving an outright recommendation or a specific choice, the output is a listing showing the ranking of elements based on the traits. Ranking is based on a computation of the certainty factors from the rules and the most positive value (topmost value) is the recommended choice. (Fig. 17)

Given the requirement for high speed, high capacity, good stability and good seakeeping, the system recommended ship E as the best choice. The ranking of the other ships is indicative of the rating given by the expert. After testing, the user can modify the ratings or accept the results of the session. The resulting set of rules can then be used for advise in making the choice between different hull forms.

3. Conclusion

At its present form, the Selection Tool is quite simple and does not have the rich suite of structuring and knowledge view tools that Aquinas, ETS, KSSO or Nextra all have. As a component of the knowledge acquisition system, its role was limited to the selection of elements that were explicitly known and where knowledge was well developed. Although it may be of limited use in the design synthesis and analysis stages, it would provide some convenience in the construction of advising rules for modules in the design spiral for which specific and readily enumerable decision elements exist.

The construction of a knowledge base for a design required an object oriented approach to tool development. This allowed a rapid modelling, analysis and implementation of a useful and knowledge based tool. The knowledge acquisition sessions was augmented by the technical literature where the necessary mathematical tools and techniques was be derived. When implemented, the tool effectively produced various forms from parent hulls and allowed the independent variation of design parameters.

Construction of a knowledge base was aided by an

![Fig. 15 Triangular arrangement of clusters.](image)
interactive elicitation tool making use of grid construct technology to derive rules for selection of decision elements. The selection tool determined the best hull form based on a rating of traits that are commonly used to select the forms. The combination of expert elicitation, knowledge acquisition techniques and object oriented methodology resulted in a useful approach for making advisory knowledge when solving selection type problems encountered during the design spiral.

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