# SIIA: A KNOWLEDGE-BASED ASSISTANT FOR THE SAFT ULTRASONIC INSPECTION SYSTEM(a)

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## INTRODUCTION

SIIA(b) is a knowledge-based system designed to assist in making the operation of the Synthetic Aperture Focussing Technique (SAFT) Ultrasonic Inspection System more reliable and efficient [1]. This paper reports on our effort to develop a prototype version of SIIA to demonstrate the feasibility of using knowledge-based systems in nondestructive evaluation (NDE).

One of our prime motivations for developing SIIA is to provide a means for insuring that the SAFT system is used correctly and consistently and to assist in interpreting the results of a SAFT inspection. Our initial formulation of the problem was to develop a system to assist in the interpretation of the images resulting from a SAFT inspection. As we started to identify the structure of the inspection problem, however, we realized that a more effective application of the knowledge-based system technology would be to develop a system that is in essence an on-line procedure generator that guides a user through a SAFT inspection. Such a system assists in proper setup of the inspection equipment for each of the steps in a SAFT inspection and in interpreting the inspection results for each step.

The first section of the paper describes the structure of the problem and our conceptual design of the knowledge-based system. The next section describes the current state of the prototype SIIA system and relates some of our experiences in developing the system. The final section discusses our plans for future development of SIIA and the implications of this type of system for other NDE techniques and applications.

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(a) This work was supported by the United States Department of Energy under contract DE-AC06-76RLO 1830.

(b) SIIA stands for the SAFT Image Interpretation Assistant. Our original intention was to build a system to assist in interpreting inspection results. As we explored the problem our objectives were reformulated as described in the paper.

## The SAFT Inspection Problem

The SAFT ultrasonic inspection system has been developed, under U.S. Nuclear Regulatory Commission funding, for inspecting primary pressure boundary weldments in nuclear reactors or similar facilities. The system scans an area of material and produces a three-dimensional view of the entire volume of material scanned. Flaws and other reflectors are interpreted by an operator viewing the three-dimensional image or cross-sections thereof.

In practice there are three modes of inspection for the SAFT system: Normal-Beam, Pulse-Echo, and Tandem Mode scanning. In normal-beam scanning the ultrasonic beam is normal to the inspecting surface. This mode is generally used to characterize the weldment by locating the weld-root and the counter-bore regions. In the case of ferritic materials in pressure-vessels it might also be used for the first attempt at flaw detection.

The second step in scanning is to perform a pulse-echo inspection. In this mode a shear or longitudinal wave is used at a 45 or 60 degree angle. A single transducer is used as both transmitter and receiver. The objective of pulse-echo scanning is always oriented to flaw detection and characterization. If the quality of data is high enough then a decision about the presence or absence of a flaw may be made using the pulse-echo data. Otherwise, a tandem mode scan is performed.

In tandem mode scanning two transducers are used, one for transmitting, the other for receiving. There are three different configurations for the transducers. In addition the operator must choose between shear and longitudinal waves at a 45 or 60 degree beam angle. Like the pulse-echo scan the tandem mode scan is intended to detect and characterize flaws.

In all three modes the operator must choose the appropriate transducer(s) center frequency, bandwidth, and diameter. In some cases he must also choose the type of transducer, contact vs. booted-shoe, or the coupling technique, immersion vs. direct contact.

In each of the inspection steps described above the operator must make a number of choices in setting up and performing the inspection. In addition to those mentioned above he must also decide what type of SAFT processing if any will be done on the data. The operator's choices are determined by the characteristics of the specific inspection he is performing. The most important parameters are the type of material being inspected and the components of the weldment (i.e. a pipe welded to a valve or a nozzle to pressure vessel weld).

Conceptually the SAFT inspection problem breaks down into two components: procedural and interpretive knowledge of how to perform and interpret an inspection, and description of the physical objects that are combined to represent a specific inspection situation.

Procedurally we have broken the problem into subproblems or steps. The three primary steps are the normal-beam, pulse-echo and tandem mode scans. Within each primary step there are secondary steps of setup, determination of desired transducer characteristics, initial transducer selection, transducer checkout with respect to signal-to-noise ratio, the scanning itself, and data interpretation.

In the setup step we must decide what type of SAFT processing is appropriate -- line-SAFT, full-SAFT, or to not use SAFT processing. In addition for normal beam scanning we must decide whether the inspection objective is weld characterization or flaw detection.

In determining transducer characteristics we primarily consider the type of material being inspected and for ferritic welds the type of cladding, if any. In doing so we determine a desired transducer center frequency, bandwidth, and diameter. We follow this by matching desired transducer characteristics with actual transducer descriptions and select a specific transducer for the inspection.

Before the scan is performed the system requests a check of signal to noise ratio. In this step the back surface signal is compared to the overall noise from grain structure and other material characteristics. If the ratio is less than 6dB then a different transducer is selected and the check performed again. This process continues until an acceptable signal to noise ratio is achieved.

## The Current Status of SIIA

We have chosen to implement SIIA on a Symbolics Lisp Machine using the KEE knowledge-based system development software (a). KEE provides the ability to describe the problem in terms of object-class hierarchies with procedural attachments, lisp functions, and If-Then rules. It provides both forward and backward chaining as control strategies for the rule bases. For a discussion of frame based knowledge representation systems such as KEE see [2]. For an introductory level coverage of knowledge-based systems see [3].

For the purposes of developing the SIIA prototype we have concentrated on representing the structure of the physical components of the problem and then on the normal beam scanning step without data interpretation. We have created the base level structures for the rest of the problem, but have not supplied the procedural know-how.

The physical components related to the problem are described in object-class hierarchies. For example, Fig. 1 shows a graphical representation of the object-class hierarchy for materials. Starting at the left a KEE unit for materials is shown. This unit contains slots for descriptive parameters common to all materials of interest. In this case these parameters are grain-shape, grain-size, and sensitization. Moving to the right we see the next level breaks down into ferritic steels and stainless steels. There is no further breakdown of ferritic steels, but stainless steels breaks down further into cast and wrought stainless steels. At the lowest level, connected by dashed lines, we have specific instances of materials. For example A533B is a specific ferritic steel and SS304 is a specific wrought stainless steel.

In a similar manner other physical entities are described including reflectors, primary system components, and transducers. The object class hierarchies have been defined for each of these classes. As with materials these definitions begin with a generic description and proceed with increasing detail to specific descriptions. For example, primary system components are broken down into vessels, components, and pipes. Vessels are further broken into pressure vessels, pressurizers, and steam generators. Components are broken into elbows, pumps, valves, and a catch all other category. There is no further breakdown of pipes.

Flow of control in solving the problem centers around a description of the "inspection problem". Figure 2 shows the menu that is used to collect

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(a) Symbolics is a trademark of Symbolics, Inc. KEE is a trademark of Intellicorp, Inc.

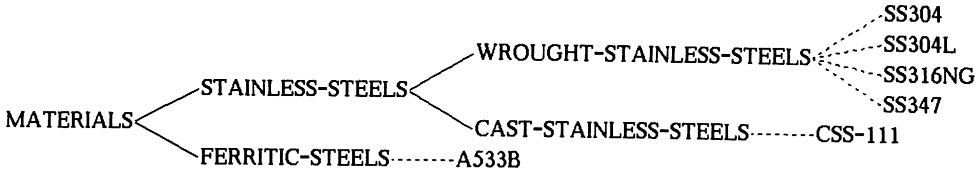


Figure 1. Object-Class hierarchy for description of Materials

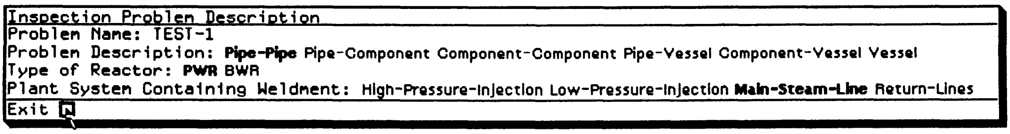


Figure 2. Initial problem description menu. User enters problem name from keyboard. Other items are entered by selecting an item using a "mouse". In this illustration the selected values are shown in boldface.

information about the problem. This basic information determines what other information to collect. For example if we are inspecting a weld on a pressure vessel then we only have one material to consider, whereas if we are inspecting a weld between a pipe and a pump we need to ask what type of material each piece is made of. Associated with each inspection problem is one or more "inspection worksheets". The worksheet is filled in with intermediate information that further describes the problem or is derived from information about the problem. For example the desired transducer characteristics are entered into the worksheet when they have been determined. A problem may have one or two worksheets associated with it. A problem has two worksheets when two separate scans will be required to complete the inspection. This occurs primarily with bimetallic welds, such as cast to wrought stainless steel, where material characteristics require that two different transducers be used.

Finally associated with each worksheet is an "inspection procedure." The inspection procedure contains the information required by the operator to proceed with the scan. A specific transducer is identified along with the type of SAFT processing to be performed and other information such as beam angle and wave propagation mode. A portion of the generic form for an inspection procedure is shown in Figure 3.

## Knowledge Representation

Knowledge is represented in the system through the object-class hierarchy descriptions and through the use of If-Then rules. If-then rules set reference parameters associated with objects in the system. For example in determining how many procedures will be required one of the rules looks at the type(s) of material joined by the weld. If one is wrought stainless steel and the other cast stainless steel then the rule concludes that two inspection procedures will be required.

**(Output) The INSPECTION-PROCEDURES Unit in SIIA Knowledge Base**

Member slot: NORMAL-BEAM-INSPECTION-OBJECTIVE from **INSPECTION-PROCEDURES**
Inheritance: **OVERRIDE.VALUES**
ValueClass: (ONE.OF FLAW-DETECTION PROFILING)
Cardinality.Max: 1
Comment: "The purpose for the normal-beam scan."
Values: PROFILING

Member slot: NORMAL-BEAM-SCANNING-MODE from **INSPECTION-PROCEDURES**
Inheritance: **OVERRIDE.VALUES**
ValueClass: (ONE.OF NO-SAFT LINE-SAFT FULL-SAFT)
Cardinality.Max: 1
Comment: "The scanning mode to be used in normal-beam."
Values: NO-SAFT

Member slot: NORMAL-BEAM-TRANSDUCER from **INSPECTION-PROCEDURES**
Inheritance: **OVERRIDE.VALUES**
ValueClass: **TRANSDUCERS**
Cardinality.Max: 1
Comment: "The transducer selected for use in normal beam scanning."
Values: Unknown

Member slot: PULSE-ECHO-BEAM-ANGLE from **INSPECTION-PROCEDURES**
Inheritance: **OVERRIDE.VALUES**
ValueClass: (ONE.OF 45 60)
Cardinality.Max: 1
Comment: "The beam angle desired in the material being inspected"
Values: Unknown

Member slot: PULSE-ECHO-MODE from **INSPECTION-PROCEDURES**
Inheritance: **OVERRIDE.VALUES**
ValueClass: (ONE.OF SHEAR LONGITUDINAL)
Cardinality.Max: 1
Comment: "The transducer mode to be used in pulse-echo scanning"
Values: Unknown

Member slot: PULSE-ECHO-TRANSDUCER from **INSPECTION-PROCEDURES**
Inheritance: **OVERRIDE.VALUES**
ValueClass: **TRANSDUCERS**
Cardinality.Max: 1
Comment: "The transducer selected for use in pulse-echo scanning."
Values: Unknown

Member slot: TANDEM-MODE from **INSPECTION-PROCEDURES**

Figure 3. A portion of a generic inspection procedure form showing the information for normal beam and pulse-echo scanning. Default values are shown for the normal beam inspection objective and scanning mode.

Figure 4 shows the "external" form of a rule that determines desired transducer characteristics for a ferritic steel pressure vessel weld with multiple wire cladding. The rule is entered into the system in a quasi natural language form. The KEE system parses this form and resolves references to objects in the system and their parameters.

(Output) The EXTERNAL.FORM Slot of the CLADDING-RULE-3 Unit

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Own slot: EXTERNAL.FORM from CLADDING-RULE-3
  Inheritance: SAME
  ValueClass: (LIST in kb KEEDATATYPES)
  Avunits: (RULEPARSE in kb RULESYSTEM2)
    Facet Inheritance: UNION
  Values: (IF
          ((?WORKSHEET IS IN CLASS INSPECTION-WORKSHEETS) AND
           (THE INSPECTION-PROBLEM OF ?WORKSHEET IS ?PROBLEM)
           AND (THE TYPE-OF-REACTOR OF ?PROBLEM IS PWR) AND
           (THE SYSTEM OF ?PROBLEM IS PRESSURE-VESSEL) AND
           (THE INSPECTION-TECHNIQUE OF ?PROBLEM IS
            DIRECT-CONTACT) AND
           (THE CLADDING OF
            (THE WELDMENT-TO-BE-INSPECTED OF ?PROBLEM) IS
            MULTIPLE-WIRE)) THEN
          ((THE DESIRED-TRANSDUCER-CENTER-FREQUENCY OF
            ?WORKSHEET IS 2.25) AND
           (THE DESIRED-TRANSDUCER-DIAMETER OF ?WORKSHEET
            IS 0.375)))
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Figure 4. A typical rule from the SIIA system. The rule is shown in a quasi-natural language form. It is entered into the KEE system in this form.

## User Interface

In operation the user starts the system by using the mouse to activate the process of "generate an inspection procedure." The system begins by asking the user to fill in the menu previously shown in figure 2 that describes the basic inspection problem. Based on the values indicated on the menu a second menu is presented that asks for more specific information about the problem.

The system then forward chains through rule bases corresponding to the steps in solving the problem as described earlier. If necessary two worksheets are created. During the forward chaining through the rule bases displays can be activated that show the user which rules are being considered and when they are fired. This is primarily useful for debugging but not for day-to-day operation. In the final version of the system we will likely not use these displays, but provide an indicator of what step the system is working on to show the user that something is happening.

When an inspection procedure has been filled in for the current inspection step the signal-to-noise ratio for the chosen transducer must be checked as described above. At this point the user is asked to make a single point measurement and report the signal-to-noise ratio to the system. If it is acceptable then the system will clear the user to perform the scan, if not then it will determine a new transducer and ask for another signal to noise ratio measurement.

## Interpretation of Scanning Results

At this point we have not implemented any rulebases for interpreting the results of a scan. We are planning that the first version of this part of the system will advise the user on what to look for in color displays of scan results and ask him questions about what he sees. Based on the users responses the system will recommend other data displays that might be useful and attempt to determine whether there is a flaw displayed in the images. If there is a flaw it will assist the user in characterizing the flaw.

Complexity of SIIA

As it stands today the SIIA knowledge base consists of approximately 130 KEE units. Included in this count are 25 rules. As a given problem is solved from four to six additional units are created describing the problem and its associated worksheet(s) and inspection procedure(s). Figure 5 shows a graph of most of the current knowledge base. Notice that the rules are broken into subsets corresponding to the steps in performing a SAFT inspection. At this point there are only rules related to general problem description and normal beam scanning.

## CONCLUSIONS

Designing and implementing SIIA has been a valuable experience. From an expert systems point of view it is an interesting problem because it is fairly complex and required the use of a variety of types of knowledge to solve the problem. From an NDE point of view it has caused us to consider what role knowledge-based systems should have in the NDE inspection process.

For the most part the NDE community has not developed detailed procedures for optimized inspection or procedures for analyzing the results of inspections. There are ASME code or other requirements that provide procedures for making a weld and tell how often to inspect it, but generally there is very little that tells how best to inspect it.

Even with an advanced computer based system such as SAFT, the margin for misapplication still exists. Furthermore, the vast amount of data generated by such a system can be overwhelming and will increase inspection times unless optimized analysis procedures (based on expert knowledge) are employed. We were motivated then to find a way to guide a SAFT user through the proper use of the system in order to produce consistent high quality results and to reduce the time to perform a thorough analysis of the data. One option is to require extensive training and qualification for SAFT operators. This, however, is an expensive option. We are optimistic that by integrating a knowledge-based system with the rest of the SAFT system that we can achieve the same result with lower cost to the end user.

In determining the structure of the SAFT inspection problem we realized that there are many parallels with conventional ultrasonic inspection and with other techniques such as eddy current inspection. As with SAFT the other techniques require that the proper transducer be used and that other aspects of the inspection be set up properly. The other techniques also require that data be properly interpreted in the context of the specific inspection. Knowledge-based systems can assist with consistent solution to all of these problems. We expect to see more knowledge-based systems for NDE in the future. This will help reduce the sensitivity of NDE inspections to variation between individual inspectors.

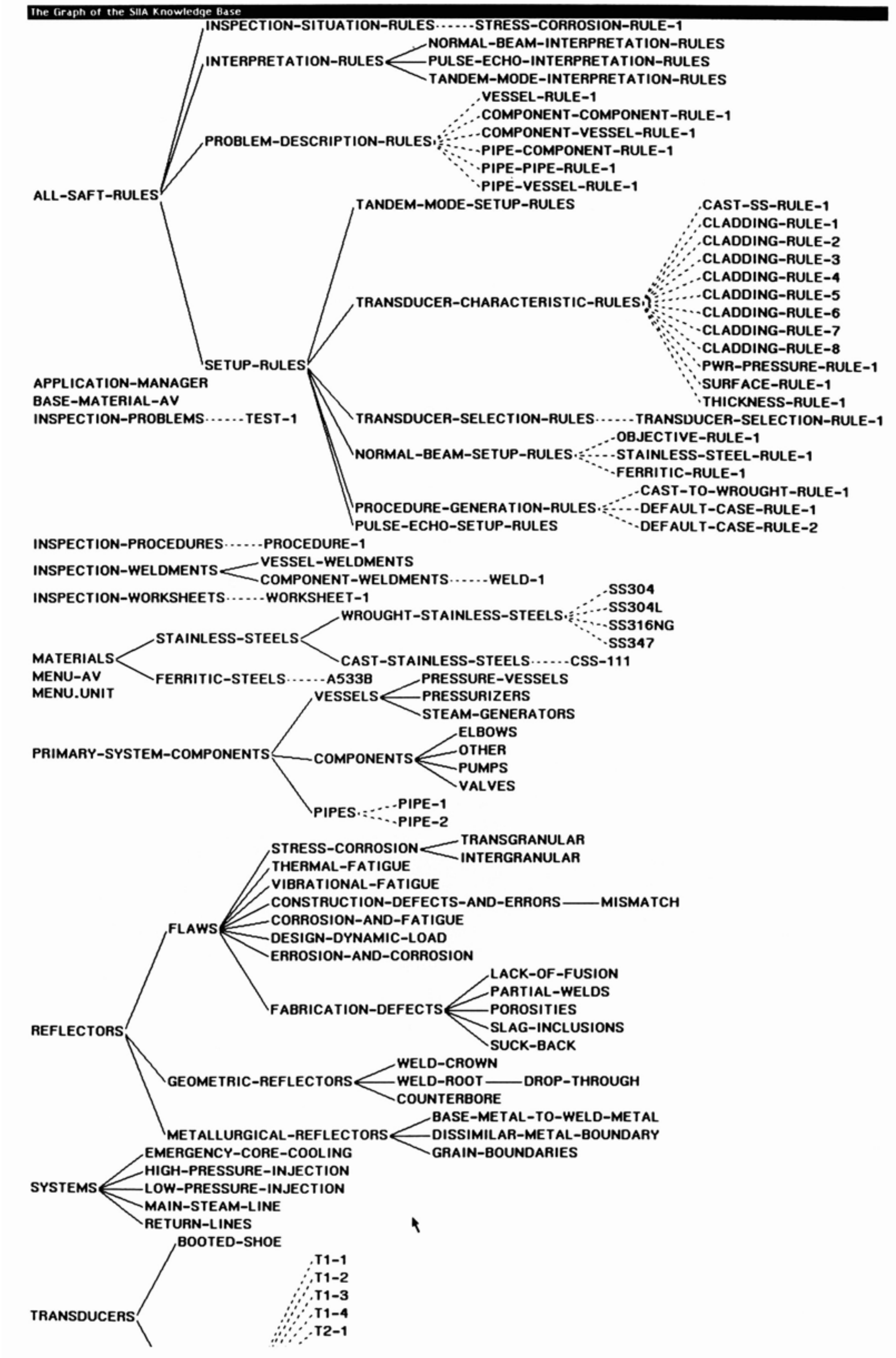


Figure 5. A graphical representation of the SIIA knowledge base. Solid lines indicate subclasses, dashed lines indicate members of a class or subclass, i.e. specific instances.

## REFERENCES


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