Application Note: KEEL® (Knowledge Enhanced Electronic Logic) Technology for Interpreting Image Features

Objective:

A common concept in the use of Vision Systems is to extract a series of features from an image.

These features can be exposed as values that fall within a range of acceptable values, or they can be used to adjust the perspective of the image so other filters can be used. For example, some features may be used to detect the orientation of an object. Once the orientation is known, other features can be extracted for further evaluation.

Once features have been extracted and measured from an image, the next step is to interpret them.

The interpretation process attempts to determine what to do with the observations.

The features themselves are, at least sometimes, independent values, even if they are the result of rotations or extrusions of a part of the overall image.

When interpreting the features one might be looking for specific patterns. The objective would be to search an image for something. When interpreting an image, however, it is not sufficient to look for features justifying a specific interpretation. One must interpret features that would negate any specific interpretation.

In this light, interpretation is a combination of including reasons supporting an interpretation and at the same time including reasons not supporting an interpretation. This is a balancing act that maps well with the capabilities of KEEL Technology.

When interpreting image features it may be appropriate to include external knowledge or information in the interpretation process.

KEEL provides a mechanism for fusing information from multiple sources when making judgmental decisions about an image.

Some of these external sources may include an assessment of "risk", which could be used to adjust the thresholds for certain decisions or actions.

Another case would integrate "trust", which could be an assessment of external information. It could also be the result of the interpretation of image information.

One of the key outputs of the interpretation of the image information could be the formal establishment of a "trust" value or a confidence value associated with the interpretation of a specific feature set.

To summarize, KEEL Technology can be used to fuse information from various sources along with the features extracted from an image to validate information and determine courses of action.

Because the KEEL model will be completely explainable and auditable, any model created using KEEL Technology will be correctable and extensible.

This is assumed to be important as new "image features" will be added to image processing systems over time and the effort required to keep the systems up to date must be minimized.

Market:

The market for image interpretation systems covers homeland security and surveillance systems as well as industrial automation systems where process quality needs to be maintained.

Business Drivers

Reduced Maintenance Cost & Time

Increased product quality can help companies reduce their maintenance costs and down time. When a company cannot ship their own products because their internal systems are down is inhibiting their ability to do business.

Reduced Support Cost & Improved Global Support Responsiveness

Companies benefit from partnerships with their suppliers when the suppliers participate in the management of support costs. Companies cannot offer their own products and services if their internal manufacturing systems are broken. When their suppliers can assist in assuring that these systems are running, the company can reduce their own costs for providing these services.

Reduced Project Risk

Tools and techniques that reduce project risk can help avoid major disasters that can have a major business impact.

Improved Delivery/Logistics - Performance & Reliability

By improving delivery and logistics a company can be more efficient in moving products through their system. Improvements in delivery and logistics directly impact the bottom line by reducing the cost of doing business.

Increased Machine Performance/Speed - Production Rates

By increasing machine performance, a company can get more output from existing resources thus reducing the cost of doing business.

Improved Internal Efficiency - Reduced Fixed Expense

By improving internal efficiencies, a company can do more with less. The "lean enterprise" concept addresses this issue.

Improved Access to Information

Almost all business understanding is developed by obtaining a better view of internal processes. This is commonly accomplished by automating the access to information. This is accomplished by acquiring information from all points in the system and by integrating automated decision-making into the process so the entire enterprise can automatically react to its environment. Compsim's Knowledge Enhanced Electronic Logic can play a significant role in automating the operation of the enterprise or Command and Control system.

Reduced Engineering Design Cost & Time

Companies that develop their own products can benefit from technology that shortens development time. By introducing products faster than the competition allows those companies to command increased market share and higher margins.

Reduced Start-up/Commissioning Cost & Time

Delays in production startup directly impact the company’s bottom line. If they cannot ship products they cannot reap the rewards. Tools and services that reduce the start-up and commissioning time directly impact the company's bottom line.

Optimization of Product Performance/Life to the Task

By extending the life of capital equipment and by increasing the performance of that equipment, a company can avoid or delay replacement of that equipment and thus reduce added expenditures.

Increased Differentiation of Their Products

As products become commoditized, the suppliers cannot demand the same margins since their products are just like the products of their competitors. Features and services that differentiate their products from the competition allow increased margins. Anything that demands higher margins and thus higher profits directly impacts the bottom line.

Buying Factors

Ease of Use

Time to Market

Flexibility

Extensibility / Scalability

Desire for Special Features

Performance

Options

Complex Systems

Enterprise Connectivity

Standards

Product Availability

Availability of Support

Quality

Lowest Installed System Cost

Lowest Lifecycle System Cost

Safety

Expectations of the Future

Efficiency

Reduce or Eliminate Other Costs

Form Factor

Explainable / Auditable

Considerations:

The schedule for evaluating the data

When complex cognitive systems are being created, the designer needs to consider the time sensitivity of input and output data.

In human systems, humans may try to postpone decisions until all the relevant data is available. When pressed, however, humans can react to demands that drive them to make instant decisions. In a KEEL system, the designer may need to have the system "adapt" to changing demands.

The flexibility of the KEEL system design allows for normal conservative operation and still adapts to emergency situations.

The system designer needs to consider when the data should be evaluated. Options could be to trigger the evaluation on a scheduled basis; it could be polled by a higher level authority; it could operate on a change of state from one of its sensors; or it could be continuously running.

Human interaction with the solution

In cases where KEEL engines participate with humans as part of an overall system, consideration should be given to the human interface characteristics of the system.

KEEL engines can trigger the dialog, or the dialog can be initiated by the human.

KEEL engines can provide continuous analog output which can be translated into human readable form or as stimulation to HMI tools.

KEEL engines can accept input from any source, as long as it is translated to the normalized format required by the KEEL engines.

The system designer will consider how and when the dialog between the human and the KEEL engine will be scheduled.

The ability to create complex cognitive solutions in a timely manner

Using the KEEL toolkit, it is possible to develop complex cognitive solutions in a short timeframe.

Software features are built into the toolset that allow the cognitive design to be structured in a manner that makes it easy to integrate the KEEL engine(s) into a variety of architectural models. In many cases, these tools allow the glue logic to be created once and be able to support changes to the cognitive model.

The KEEL-FBD tool allows the staged development of complex models in a manner that automatically creates the glue logic. This is another feature that supports rapid development of complex systems.

Performance of the system

Different applications require different levels of performance for the KEEL engines.

Some real time control applications may require that information is constantly being evaluated and operated upon.

There will be other times when information changes relatively slowly and therefore does not merit constant evaluation.

There are a variety of techniques to balance performance and system complexity when creating KEEL based solutions.

Architecture Independence

KEEL engines are discrete information processing engines.

In many cases they will be part of a larger system.

Just like humans in a factory, in an army, or on a team, there is interaction between individuals and between devices and equipment. Computer protocols and network architectures have been developed in a manner that somewhat duplicates the development of human language.

People developed different languages to satisfy different needs: voice for people to communicate verbally; sign language for those that cannot hear; telephone and video conferencing for distance communication.

Computer based protocols have been developed to satisfy different needs: ASCII for simplicity; XML for structure; asynchronous / synchronous / isochronous for flexibility, speed, and time determinism.

KEEL engines can participate with any of these linkages, as long as the data can be normalized to meet the needs of the KEEL engines.

KEEL engines can sit at any point in any architecture. In this way KEEL engines can be integrated into almost any architecture. The simple API enables this valuable attribute.

The "importance" of information

A key aspect of any KEEL based system is the dynamically changing importance of information.

In simple systems, there may be no changing importance of information. These types of systems might be built with hard-coded solutions or discrete logic.

Cognitive solutions, however, usually deal with complex relationships where information is being interpreted in different ways; in different parts of the same problem.

Cognitive problems often deal with both strategic (future) and tactical (now) problems at the same time. Questions about what to do now and not destroy future opportunities are often addressed. This requires a balancing of information to obtain the best outcome.

Diagnostics and prognostics require that a system adapts its operation to performance variables. For example, if you have difficulty breathing, then breathing becomes more important.

The evolution of the KEEL engine over time

KEEL engines are often developed over time. New pieces of information are added to the design when it is apparent that they contribute to the interpretation of the data provided.

Compsim's KEEL Toolkit provides a number of services to enable enhancements to the engine over time without impacting the glue logic. This saves software development effort.

The KEEL FBD tools allow a complex system to be developed in stages and integrated and tuned as separate components.

The KEEL toolkit incorporates the idea of merge-able objects or decision-making modules.

There are other cases where the model doesn't need to expand, but only needs to be tuned when relationships between information change.

KEEL engines can be created as "classes" in some languages.

The value of "explainable actions"

Many systems can benefit from an engine that creates explainable decisions and actions.

This allows the systems to be audited for their performance in order to tune them over time.

It is possible to have KEEL engines monitor other KEEL engines and potentially provide a feedback mechanism to achieve optimal operation.

There are other cases where there are demands for the creation of explainable actions. This insures that a code of ethics is integrated into the design. Without the ability to decompose every action and every decision, there is the ability to create a system that does not meet the needs of society.

So, KEEL based systems, because they are rule based, can explain why any action was taken or decision was made.

Even though the rules are defined graphically, by inserting a snapshot of the inputs back into the design, the reasoning can be displayed.

Who and how the KEEL actions are monitored

KEEL based systems offer several methods for monitoring their performance.

First, because all KEEL actions are visible and explainable in the development environment, they are available for analysis within the tool environment.

Second, because a KEEL engine is a rule based system, it will always respond the same way to an input. An XML schema exists that defines the format for an XML file produced by the real-world device or software applications. If the device or software application logs the input data in this format, it can be read back into the KEEL Toolkit where the reasoning can be reviewed and explained.

The system designer has the responsibility for determining when and how the data is logged and reviewed.

Certain applications may demand more auditing to insure that performance is satisfactory.

It is also likely that new data will enter the application space. This may trigger reviews of performance.

As in human systems, novice operators or players may require closer review than experienced operators or players. The same is true with a KEEL engine.

Consideration for how the KEEL engine(s) fits in the "chain of command"

In some cases KEEL engines will participate as components of a larger system.

They can perform administrative roles by interpreting information in a consistent manner and responding with consistent command decisions.

They can perform subservient roles by accepting direction from above and adapting the commands to modify their actions.

They can sit in the middle of a chain, by accepting commands from above and reviewing status from below. They can modify their own strategy according to the rules provided to them and the information they observe on their own.

They can make requests to humans and devices above them in the chain-of-command, and can deliver commands to humans and devices below. They can collaborate with their peers according to the rules that dictate responsibility.

Should it be appropriate, the KEEL engines can develop their own levels of trust in collaborative environments. The system designer will determine the communication protocols and the flexibility of the system.

The level of "trust" attached to input information

Many judgmental decisions are made by including a level of trust to validate the information. When the level of trust is diminished, then the information may be given a lower level of importance in the overall solution.

KEEL engines can include the level of "trust" as an input to the system. How this is interpreted, is the responsibility of the system designer.

The concept of risk associated with the decisions and actions associated with the system

Many cognitive decisions need to incorporate risk into the decision-making model.

Risk can be included as an input to a KEEL engine.

It is the responsibility of the system designer to determine how risk participates in the decision-making model.

How time and space relationships might contribute to the solution

Time and space often impact the importance of information when making cognitive decisions. KEEL supports these concepts with its "clipper" features.

This allows decisions and actions to be tuned for different times and locations.

In cases where an optimal solution is being targeted, such as the time to send a message or the time to shoot at a moving target, then tools to support these kinds of decisions are required. They are built into the KEEL toolkit and they are available to the system designer.

Normalizing the data

KEEL engines normally operate on normalized data (0 to 100) values that can be either integer or floating point, as defined by the KEEL project. Any normalization scheme can be used.

While this suggests a linear range of normalized input data, the inputs can drive a curve which allows the data to be interpreted in almost any way.

In this manner a single normalized input value can be interpreted according to any number of independent curve relationships.

Much of the development work in architecting a KEEL solution is spent defining the relationships between information. Because this is all done graphically, there is no need to write "code" to see the results of the analysis.

The responsibility for the overall system remains with the solution architect

The system architect is responsible for the overall architecture of the system.

This will include segmentation of the system, determining when and how the KEEL engines will be scheduled.

The cognitive model for interpreting the input data and causing decisions and actions to be promoted is also the responsibility of the system designer.

System architecture

The system architecture is the definition of the relationships between all system components.

The cognitive segment is usually just part of the system. The system architecture defines the layout for performance, flexibility, extensibility, cost, resources, etc.

The system architecture is often the result of a balancing act: balancing time to market, resources, performance, and cost. The system architecture is driven with an objective where the features are defined. The objective is addressed by identifying potential solutions: selection of components and methods of tying them together.

KEEL technology can be integrated into the architecture from the beginning, or it can be an "add-on". Because individual KEEL engines are architecture neutral, they can be integrated into an overall architecture at different times; even after a program is completed.

The potential for autonomous operation

Because KEEL engines can interpret information in a human-like manner, and direct relative actions to be taken based on that interpretation, KEEL based systems have the potential to operate without human intervention.

Alternatively, KEEL based systems can operate as either backups to human operators, giving advice or recommendations, or they can provide the primary decision-making engines that are backed up by humans.

The outputs from the system

The outputs from a KEEL engine are normalized values between 0 and 100. This information may have to be transformed into other forms for use by the external controls or monitoring equipment.

KEEL could generate control signals.

KEEL engines interpret information and provide outputs that represent a balancing of the inputs. These values can be used to generate complex commands in the form of control signals to other equipment.

KEEL could generate information for other KEEL engines.

A common practice is to segment a system into multiple KEEL engines. It is likely that one KEEL engine will provide data to the input(s) of other KEEL engines.

The KEEL FBD tool assists in connecting KEEL engines into a single solution.

KEEL engines could also be distributed across a network or in multiple tasks where messaging or data sharing could provide the mechanism for one KEEL engine to feed others.

KEEL could provide inputs to other systems (non-KEEL).

The outputs from a KEEL engine could be supplied to other non-KEEL subsystems for further processing.

KEEL outputs could be part of a local feedback loop.

KEEL engines can be part of a feedback loop, where the output of the system is connected back to the input through some other circuitry.

KEEL outputs could be part of a distributed feedback loop.

KEEL outputs could be fed to other external devices which, in turn, feed data back to the input of the KEEL engine. The other devices could be local or remote to the KEEL engine.

Warning messages could be triggered.

The outputs from the KEEL engine could be used to trigger warning messages. The warning messages could use other outputs to describe the warning in relative terms.

Information messages could be triggered to indicate status. Analog values could be included to explain subjective interpretation.

KEEL engines can used to supply variable information in the form of informational messages. Complex messages could be structured from multiple variable output signals.

Commands to operators could be generated.

KEEL engines interpret information and provide outputs that represent a balancing of the inputs. These values can be used to generate complex commands to an operator.

Logging of information could be triggered. KEEL could log its own decisions or it could log other inputs and outputs.

The outputs from KEEL engines could be logged for historical records or for audits.

The inputs to the system could also be logged. If the log format is in XML compliant with the KEEL Input Schema, then the data could be used in the development environment to recreate the decision-making model for exact interpretation.

KEEL could cause state changes of the system to take place based on subjective evaluations.

KEEL engines interpret input information and drive outputs. These outputs could drive an external state machine that could cause the equipment holding the KEEL engine (or any other system with or without the KEEL engine) to change state. In this case, the KEEL engine is supplying inputs to the state machine.

KEEL could generate diagnostic interpretations.

Beyond just generating processed / interpreted information, KEEL engines can interpret diagnostic information and explain the interpretation in detail.

In addition to explaining the interpretation, it can provide the information to explain why other diagnostic interpretations are not considered.

The sources of input data

KEEL engines can accept inputs from almost any type of data source, as long as the data can be transformed into the normalized data format required by the KEEL engine.

When the input is textual or verbal, it will have to be transformed into the normalized format.

Sensors

Sensors of all types can be used as inputs to a KEEL system. As long as the information can be transformed into one or more normalized input values, it can be interpreted by a KEEL engine.

Sensors exist to detect and measure almost all physical states. For example: time, temperature, pressure, torque, speed, acceleration, distance, density, color, edges, shapes, counts, volume, etc. There are probably sensors to measure anything for which a value can be assigned to it.

Collections of sensors can also detect and measure non-physical information: stress, truthfulness, pain. These values are determined with some algorithm that synthesizes the information.

Human operator

In systems where the human operator is part of the system there is the potential that the operator will be providing input data to the system.

For example, the operator could be supplying input data to the system as part of the job function. The operator could be reading values or recording physical observations about characteristics of the problem domain. This could be a doctor that records physical symptoms of the patient or of the environment that may contribute to the symptoms.

In other cases, the operator could be directed to take specific measurements. An example might be an automotive service technician that could be directed to take readings in an automotive electrical system to try and isolate the problem.

Inputs from human operators are commonly gathered through some kind of Human Interface Device that will transform the information from human terms to formats more conducive to digital processing. This might be via a keypad, a pushbutton, or in some cases it might be voice input. It could also be in some form of visual form where information is generated by physical movement. It is possible that any of the human senses could trigger inputs to a KEEL system.

Databases

Databases are used to store historic and synthesized data. This data can be manipulated by any number of mathematical processes to provide running averages, identify trends, detect shifts, etc.

The result of database queries can generate numeric information that can be used as inputs to KEEL engines.

Databases that are constantly updated have the ability to send evolving data to KEEL engines and thus tune the KEEL engines with new data.

External Data Sources

In addition to databases, external data sources can be any device or software application that generates information.

For example, machine tools may have counters embedded in them that count completed operations or completed orders. This information is gathered as the equipment operates and can provide input information to KEEL engines.

A clock or calendar is another example of an external device that can generate information for a KEEL engine. These devices generate time related information.

A communication network might generate traffic information.

Other KEEL Engines

KEEL engines may be components of a larger cognitive system. In these cases it is likely that one KEEL engine will feed other KEEL engines.

The KEEL FBD tool provides a mechanism for integrating multiple KEEL engines in a single application.

A more loosely coupled solution would be to connect KEEL engines across a network or some other connectivity approach.

Locally accumulated data

A KEEL engine will be embedded in a device or software application.

It is likely that the device or software application will be performing functions in addition to the cognitive process associated with the KEEL engine. In these cases other values generated by the application may be used as inputs to the KEEL engine. Certainly diagnostic and prognostic data generated by a device might be used to drive a KEEL engine.

Preprocessed data

Preprocessed data can exist anywhere in a system. This preprocessed data could have gone through a validation process or a transformation process. It could carry with it confidence data or some other biasing information that could be used in conjunction with the preprocessed data. It could be accumulated locally or it could exist anywhere in the system where it could be move to the KEEL engine for interpretation and processing.

Control Signals from Other Devices

Control Signals from pieces of equipment or software applications can be used as inputs to KEEL engines.

In some cases KEEL engines are parts of autonomous devices. They react to their surroundings and decide what to do for themselves. In some of these cases, the KEEL engine could intercept control signals from another device that are directed to perform operations for that other device. This information could provide intelligence for the device containing the KEEL engine.

Feature Extraction Systems

A variety of systems expose "features" from raw data.

Artificial neural nets extract features based on trained patterns.

Vision systems extract features by determining outlines of graphical features and calculating geometric shapes based on pixel count and color.

Audio processing systems extract features from wave forms.

These systems may or may not include an interpretation function that preprocesses the features.

Connectivity

The ability to install KEEL engines at any point in an architecture makes this a valuable attribute where components of the system are likely to be distributed across different pieces of equipment in different locations.

KEEL engines can be connected by any media and in any format as long as the data is converted to the normalized format before triggering the KEEL engine to process it.

Directly wired to source

In its simplest form a sensor can be directly wired to an input pin on a microprocessor where the signal is transformed to a normalized data format used by the KEEL engine.

The same is true for the output. In its simplest form the normalized data output from the KEEL engine is transformed before sending it out a pin on the microprocessor where a wire carries the signal to an actuator (control point).

A direct wire is the simplest form of network.

Network connected - any topology

Connectivity to and from KEEL engines can be accomplished with any type of network with any topology.

Some wired networks might be termed point to point, multi-drop, token passing, star, web, loop, trunk, etc.

Messaging techniques might include: Broadcast, Store and Forward, Directly Addressable, Group Addressable, All-call.

Any message packaging technique might be used: structured or unstructured, packed, block mode, etc.

Any character encoding can be used: ASCII, Async, Bisync, Isochronous, or any other.

The data can be encrypted or non-encrypted.

The choice of network connectivity is left to the system designer.

Infrared connection

The KEEL engine is not restricted to any specific connectivity to its inputs and outputs. Infrared links can be used.

Supplied by the same processor running the KEEL engine

Because some data sources and data sinks for KEEL engines will be within the same microprocessor, input and output data can be generated and consumed locally.

Radio Frequency

KEEL engines are independent of the connectivity between inputs and outputs and the KEEL engine. Radio frequency connectivity is appropriate for some applications where wired and infrared connections are not appropriate.

Development Process:

Determine where KEEL engines might be located in the system and what information will be exchanged

This is where the number of KEEL engines will be identified to satisfy the system need.

This is also where the information model will be defined: What input information is needed at each KEEL engine and how that information will flow through the system.

Define the information hierarchy which includes how and when information is accumulated

Some systems will fit in a "chain-of-command". The concept of authority needs to be considered in these types of systems.

This will dictate who is a supplier of information and who is a receiver of information.

This is where the concept of trust needs to be included in the model.

The concept of risk may also be considered.

Plan for staged introduction

In systems that might require multiple KEEL engines, consideration for a staged introduction might be appropriate.

Since KEEL engines operate autonomously, this is primarily an issue that is driven by other parts of the system.

If cognitive technology is to be included in the overall system, then it should be scheduled for introduction when it can be tested with the availability of its inputs and outputs.

Evaluate KEEL segmentation

KEEL engine segmentation is an issue that is required with distributed systems. It should also be considered with complex cognitive situations.

The KEEL FBD tools provide support for the integration of multiple KEEL engines into a single compile for a localized solution.

There is also the potential for integrating multiple independent segments into a signal KEEL engine. In situations where one is dealing with simple cognitive processes, it might be appropriate to include several of them in the same engine.

For each KEEL engine, define the expectations (outputs) from the system

The outputs of the system can drive external controls, provide information or logging data, drive external logic, provide warnings or triggers, or drive other processing engines (like other KEEL engines) or hard coded logic.

The outputs of the system define what the KEEL engine is trying to accomplish.

For each KEEL engine, identify the sources of information

The sources of information are the inputs to the system as viewed from the outside of the KEEL engine. They can come from sensors, databases, human operators, other KEEL engines, other control systems, or internal logic (like self diagnostics and prognostics or internal calculations).

KEEL General:

This section identifies the general benefits that could be derived from a KEEL based solution.

Situations where there is an advantage to be able to create one design and execute it on multiple platforms: device, software simulation, web

When the small memory footprint of a KEEL engine is an advantage

Where architectural issues may prohibit other solutions (KEEL technology is architecture independent: localized, distributed, web based, multiprocessor, etc.

Human experts are required to interpret information to make the best decisions or take the most appropriate actions

Devices must operate autonomously and make judgmental decisions on their own

Devices can make control decisions when human operators are not present

Repetitive judgmental decisions are prone to error

Judgmental decisions by trained operators are potentially "tricked" into overlooking critical attributes

Human experts take too long to make judgmental decisions

Applications where the judgmental decisions must be explained

Complex situations where it is uneconomical to develop and maintain straight line code (IF, THEN, ELSE)

Situations where the environment is dynamic and the importance of information changes and the system must react to change

Summary:

The interpretation of image "features" is a judgmental action when performed by humans. The same is true when this process is to be performed by an automated or semi-automated system.

KEEL Technology provides a mechanism for creating a process for judgment that operates similar to the way that a human expert might balance the reasons for interpreting data. Because the process can be completely explained and audited, it can be refined over time to optimize performance and take into account new information.

Because the interpretation of image data can also be supplemented with information from other sources, it is important that the ultimate solution is also extensible to include other information sources. KEEL Technology supports the creation of a cognitive model that can include data from multiple sources. The model can also support the need to change the rules as the situation changes. This could be the result of changing overall system "risk" or by other external intelligence factors.

The small footprint solutions may allow intelligence to be distributed to the vision sensors themselves and provide a way to reduce the overall network load by processing information locally rather than centrally.

Disclaimer

This application note suggests the potential for KEEL technology to respond to certain market needs. The end users are totally responsible for assuring that the technology performs as expected.

The application note may also assume that certain external technology exists to support the KEEL engine in an effective manner. This may or may not be accurate in all cases.