ALFATROLL

A NEW KNOWLEDGE BASED TECHNOLOGY FOR UAS

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ABSTRACT

The development of autonomous UAV systems capable of operating in ordinary, non-segregated airspace, requires huge amounts of on-board knowledge. The alternative seems to be fully ground-controlled systems where ground-based pilot(s) operate the vehicle as if they were on-board. This alternative pose high expectations to communication between the UAS and the ground control, as well as to the air traffic control centrals. Yet, the UAS need to have autonomous alternatives in the case that the communication is lost.

Sooner or later, the requirement for fully autonomous operation of UAV systems will emerge. Given the rigorous requirements for airborne computer systems in general, the main challenge will be to produce such intelligent systems that apply to the strict regulations.

IQMotor is a Knowledge-based Reasoning Engine using a novel associative memory technology. The patent applied technology is entirely developed by Alfatroll. This paper describes the technology and its advantages when used in UAVs and UCAVs.

The technology is characterized by a shift away from high computational requirements using a firm data structure to the use of a storage and retrieval technology where data is stored and retrieved by using a new and innovative associative memory technique mimicking the physical phenomenon called “resonance”.

The Alfatroll technology enables users to build embedded Reasoning Engines, using small computational resources, and without having to build and maintain complex database structures, while still serving comprehensive knowledge bases.

This paper seek to describe why this is so.

1.0 IQMOTOR FEATURES AND BENEFITS

The IQMotor technology is characterized by its knowledge database does not having a firm data structure. Instead, the data are stored and retrieved by using an associative memory technique patented and developed by Alfatroll. This enables users to build large, embedded Reasoning Engines without having to also build complex systems and database structures. Another benefit from this is predictable and fast retrieval.

The Alfatroll IQMotor Reasoning Engine has the following properties:

FEATURES	BENEFITS
• A predictable and fast response time	• Makes it possible do design real-time systems that will work in any given situation • Lends itself to control and pilot autonomous systems • Scalable in terms of computing resources – can run on clustered, multiprocessor systems
• Simplified database structures	• Allows for simplified programming • Yields fast and predictable response times
• Small run-time footprint	• Can be used in embedded and mobile applications where there are limited computing resources, power availability and heat dissipation budgets
• Believed to be the only Reasoning Engine certifiable according DO178B, Level A	• Opens for that UAVs can operate in civilian airspace
• Certification to the DO178B, Level A standard is very expensive per line of code	• Definitely favors compact software with a small footprint, such as the IQMotor. • Reduces the cost of development and maintenance of UAV software.
• In the basic IQMotor technology, every instance of knowledge, i.e. a Knowledge Item, is stored in its own, separate location and will only respond with “resonance” if the values of each input sensors (Impression) also match with the value set that this particular Knowledge Item covers.	• Simplifies programming as the concept of “resonance” recognizes objects and situations rather than concerning itself with the variable types and complex database structures that usually follows. • Reacts to events or situations appearing “out of the blue”. • All complexity is limited to the off-line part, e.g. related to automatic creation of knowledge. On-board systems are always simple and standardized.
• On-line operation is carefully monitored by the Reasoning Engine. The Reasoning Engine monitor analyzes what Missions to perform and when to perform these, assigns and activates Tasks to perform the Missions, and supervises the execution of the Tasks.	• Fully flexible options for what to control, and how to perform the necessary actions. • Simplicity is the guiding principle throughout the design, thus leaving little room for error.

Table 1: Benefits of the IQMotor technology

2.0 UAV TRENDS

UAVs are, and will continue to be the most dynamic growth sector of the world aerospace industry in the next decade. A Teal Group market study from 2006 estimates that "UAV spending will more than triple over the next decade from current worldwide UAV expenditures of $2.7 billion annually to $8.3 billion, totaling close to $55 billion in the next ten years.

The most significant trend regarding the use of UAVs has been the enormous growth of interest in UAVs by the US military, tied to information warfare and net-centric systems. UAVs are a key element in the intelligence, surveillance, and reconnaissance (ISR) portion of this revolution, and they are expanding into other missions as well with the advent of hunter-killer UAVs".

Forecast International, however, estimates that the "annual UAV market will top $13 Billion by 2014".

Many sources state that the success of using UAVs in Kosovo and Iraq are the direct reason for the clearly increased usage and investment in the area. Also new in the recent years is the high growth in micro UAVs, such as the US made Raven.

A report by *Frost and Sullivan* said that "the war in Iraq has driven recent successes in the UAV market. The UAVs are being purchased by all services in the U.S. military as well as abroad.

"The demand for a lot of these UAVs, especially the smaller ones, has gone through the roof," Nelson said. (Bruce Nelson, deputy director of the Air Force's intelligence, surveillance and reconnaissance programs).

The U.S. UAV manufacturers earned $2.14 billion in 2005. Sales by 2011 are estimated to reach $17 billion. Northrop Grumman and General Atomics Aeronautical Systems dominate the UAV market. Northrop Grumman has produced the Global Hawk and General Atomics, the Predator."

Most UAVs today rely on remote control via high-performance satellite or radio links, thereby both requiring additional personnel on the ground, and a vulnerable link for its maneuvering and control. If systems become more autonomous – or intelligent – the requirements for high-performance links will be considerably reduced, while the vulnerability for sabotaging the operation of the is reduced.

The use of robots and intelligent systems will increase dramatically in the next few years

The assumption is that none of the UAV's using traditional software technologies will be allowed in civilian airspace, due to the safety constraints connected to such activity. There is a need for systems with new properties, and Alfatroll believes that systems that can handle the required safety in commercial use will take UAV operations into new application areas.

3.0 SOFTWARE REQUIREMENTS BY THE AUTHORITIES

From Wikipedia on "Avionics Software", "Regulatory issues":

"Because of the safety requirements, most nations regulate avionics, or at least adopt standards in use by a group of allies or a customs union. The three regulatory organizations that most affect international aviation development are the U.S, the E.U. and Russia.

In the U.S., avionic and other aircraft components have safety and reliability standards mandated by the Federal Aviation Regulations, Part 25 for Transport Airplanes, Part 23 for Small Airplanes, and Parts 27 and 29 for Rotorcraft. These standards are enforced by "designated engineering representatives" of theFAA who are usually paid by a manufacturer and certified by the FAA.

In the European Union the IEC describes "recommended" (mandatory!) requirements for safety-critical systems, which are usually adopted without change by governments. A safe, reliable piece of avionics has a "CE Mark." The regulatory arrangement is remarkably similar to fire safety in the U.S. and Canada. The government certifies testing laboratories, and the laboratories certify both manufactured items and organizations. Essentially, the oversight of the engineering is outsourced from the government and manufacturer to the testing laboratory.

To assure safety and reliability, national regulatory authorities (e.g. the FAA, CAA, or DOD) require software development standards. Some representative standards include MIL-STD-2167 for military systems, or RTCA DO-178B for civil aircraft.

The regulatory requirements for software can be expensive compared to other software, but they are usually the minimum that is required to produce the necessary safety."

3.1 DO 178 B Level A certification requirements

By requirement from the FAA, RTCA DO-178B (In Europe: ED-12B) has become the international standard to which such systems and system components must be certified[1].

No knowledge-based systems (Artificial Intelligence, Neural systems) have yet, to our knowledge, been certified for use as a reasoning engine in civilian airspace.

IQMotor has the potential to achieve this. This is possible because of its small run-time footprint and its unique organization of the knowledge database.

We believe that the first provider of a verified and certifiable system[2] can obtain a favorable position in the market, and Alfatroll AS is aiming for that position.

The DO-178B defines five safety levels. The software levels A & B below are relevant for UAVs in civilian airspace (Source: Wikipedia):

A. **Catastrophic** - Failure may cause a crash.

B. **Hazardous** - Failure has a large negative impact on safety or performance, or reduces the ability of the crew to operate the plane due to physical distress or a higher workload, or causes serious or fatal injuries among the passengers.

1 Source: http://www.windriver.com/solutions/aerospace-defense/

2 'Verified' means it has been developed according to a specific standard, e.g. DO-178B. 'Certified' is done by the FAA or similar body in each country, and can only be done for the total vehicle. Verified is a prerequisite for certification.

C. **Major** - Failure is significant, but has a lesser impact that a Hazardous failure (for example, leads to passenger discomfort rather than injuries).

D. **Minor** - Failure is noticeable, but has a lesser impact than a Major failure (for example, causing passenger inconvenience or a routine flight plan change)

E. **No Effect** - Failure has no impact on safety, aircraft operation, or crew workload.

DO-178B Level A represents the strictest standard, governing situations where a software defect would result in a catastrophic accident. Alfatroll is planning for Level A, since there is no viable backup in an unmanned aircraft.

Certified software has restrictions regarding the development process:

- Choice of hardware is limited
- Compilers are limited to certified ADA or C,
- Operating system limited to certified versions (RTOS)
- No surplus code is allowed, only net usable code.

There are also other requirements to software developed under DO-178B. A number of plans need to be worked out and documented, and the software must be systematically tested against specs and its operational envelope.

Alongside the development process goes a verification process with internal and external participants. They verify that the plans, documentation and testing processes are followed as specified in the DO-178B standard.

A development and verification process according to a standard such as DO-178B affects the entire company. The benefits of such a process usually is, not only that the quality of the software goes up, while the development time is less than when the development process is badly managed.

Certification to the standard is expensive, costing, at a minimum, ***$40-50 per line of code*** according to Windmill Software and others. This favors compact software with a small footprint, such as the IQMotor.

4.0 IQMOTOR SYSTEMS ARCHITETURE

IQMotor consist of a run-time module, which may be part of an embedded on-board system in a UAV, and an off-line module used to prepare the Knowledge Database.

The major modules of the IQMotor are:

- The Edit & Load Module
- The Knowledge Database
- The IQMotor Run-time System and Application

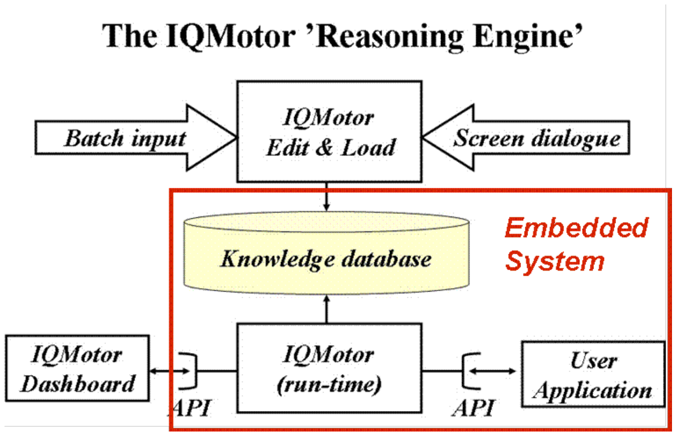

Fig. 1. IQMotor Modules

The Knowledge Database, IQMotor run-time system, and the application connecting it to the sensors and control may constitute elements of an ***embedded solution***.

4.1 The Edit&Load Module

This module is used for entering knowledge into the Knowledge Database. Knowledge can either be entered manually through an interactive tool set, or automatically through a batch entry input. If the knowledge has been generated from a separate software system, then batch entry may be used. Still, the data can be inspected, tested, and adjusted through the interactive interface.

The Edit&Load module incorporates functions to define Variables, Knowledge Items, Actions, Tasks, and Missions. Existing knowledge may be entered, removed or altered without interfering with already existing knowledge.

In IQMotor, all possible situations that may occur within the UAV's operational envelope must be pre-loaded in the knowledge database in order to cope with any foreseeable situations. What if the Knowledge Database is not complete? What if situations occur where there is no Knowledge?

- The most common approach to this situation is to invoke an emergency procedure, in order to not jeopardize other air traffic. This procedure may be e.g. 'return to the base', 'stop the engine and release the parachute', 'self destruct', or similar – depending on the situation.
- Optionally, these situations are saved for an off-line study and learning process at a later stage.

4.2 The Knowledge Database

The organization of the IQMotor Knowledge Database and the way knowledge is invoked are patent applied and unique properties of the IQMotor. The IQMotor's Database differs from other known Knowledge Based Systems (KBS) in that every instance of knowledge, i.e. a Knowledge Item, is stored in its own, separate location.

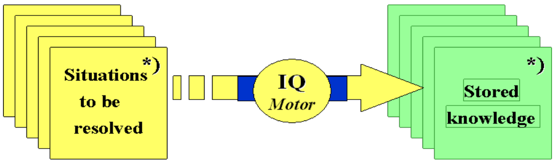

Fig. 2. For each situation or object to be recognized and reacted upon, knowledge exists.

The Knowledge Item itself contains instructions of what to do next, once a situation is recognized. When "resonance" occurs, the task simply executes the instructions found in the Knowledge Item.

If the system is used to control tasks normally performed by a pilot in a UAV, this may require a few thousand Knowledge Items, each covering specific parts of the total knowledge.

IQMotor allows selected variables to be tested for "resonance" on one level, and the outcome of that level may be input to higher levels. This may continue for an unlimited number of levels, i.e. for as long as it takes to establish useful knowledge that can be acted upon on the relevant higher level. This allows for complex knowledge structures, where knowledge is aggregated up to ever higher levels.

4.3 The IQMotor run-time system

The runtime system supervises input variables and presents these to a defined set of Tasks. These Tasks are scheduled for execution in regular intervals by the internal Monitor, or may be triggered by external or internal events.

A Task utilizes IQMotor's patented "resonance" principle to identify knowledge that can be applied to the situation or object that is described by the input variables. When "resonance" occurs, the Task looks up the corresponding Knowledge Item and performs the Actions stored with that particular item.

Tasks can be executed in separate processors, allowing for expansion into computer clusters, if needed.

4.4 A flight operation example:

Assuming that the IQMotor is responsible for piloting an expensive UAV or UCAV and that the unmanned vehicle comes under attack or enters a major turbulence, and winds up spinning towards the ground, the IQMotor is facing two immediate challenges:

- How do you detect the spin?
- What do you do about it?

In IQMotor, all that needs to done is the following: Define the criteria that recognize a spin situation, according to the characteristics of the actual UAV/UCAV.

These can be [3]:

Yaw, ➔ any position 0-360 º
Roll ➔ any position 0-360 º
Yaw rate ➔ 180 º -360 º /sec.
Roll rate ➔ 180 º -360 º /sec.
Pitch ➔ -30 º to -60 º
Pitch rate ➔ -30 º to +30 º /sec.
Speed ➔ Stall speed +/-20 kph
Altitude ➔ any altitude above minimum
Flight Mode ➔ Level flight intended

Once the actual parameters are within the limits above, IQMotor immediately triggers the relevant Knowledge Item, and thereby initiates recovery through a series of tasks.

These tasks will take the UAV/UCAV out of the spin by applying opposite rudder and down elevator, wait for the rotation to stop, then level out and resume level flight, after which it will resume its original heading and intended altitude. The recovery operation is supervised by a series of re-usable tasks that are chained together until the recovery has been completed.

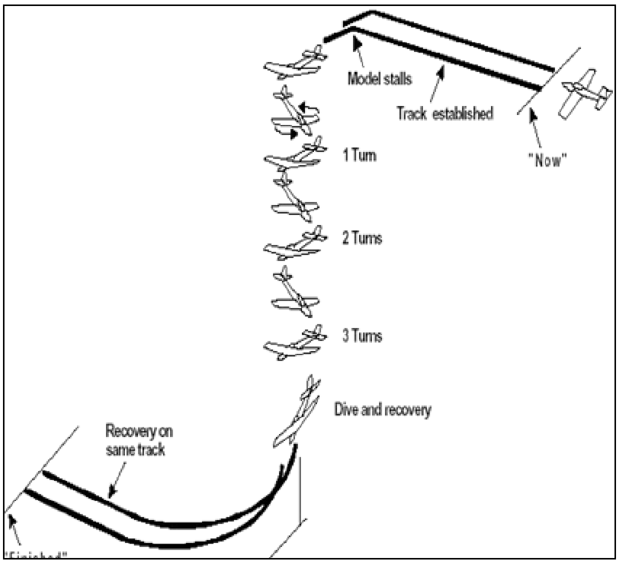

Fig. 3. How do you recognize that your airplane is spinning?

The simplicity with which IQMotor recognizes this fairly complex situation is the single demonstrates the power of the IQMotor. All that has to be done is to describe the situation through the variables that are at hand, and attach the instructions of how to perform the recovery to the relevant Knowledge Item.

The way these situations are solved by the IQMotor is exactly how a pilot would do it. That is why it is so simple. NO extra programming is necessary, except the entering of the necessary knowledge itself. No complex database structure, no mathematical formulae, and no complex program structures. It is all in the structure of the knowledge itself, and the tasks that supervise the operations!

3 Yaw: sideways offset, Pitch: nose up or down position, Roll: sideways rotation, Yaw/Pitch/Roll rates: the velocity of the offset, Speed: IAS= indicated airspeed, Altitude: altitude above the terrain or airport, Flight Mode: the momentary purpose of the flight, e.g. “fly from A to B at altitude xx”

4.5 Missions and Tasks

The missions to be carried out are described by the Edit&Load Module. Each mission is described through a set of variables and their 'target' values. A Mission can be split into a number of sub-missions. Each variable used in a Mission has been given a 'target' value, and is mirrored by a 'current' value. A Task is responsible for carrying out each mission, by comparing the current values with the target values and issuing the necessary actions as directed by the contents of the Knowledge Database.

A set of tasks systematically expose the input sensor data to Knowledge Items[4] stored in the Knowledge Database. All tasks are initiated by other tasks, except the Initial Task, and they may schedule themself for regular repetition at a frequency that gives the IQMotor sufficient control to react in ample time to the knowledge it unveils.

Each task has a specific focus area. It supervises a number of input values, as well as knowledge associated with these. Some tasks supervise Impressions that partly or completely consist of results (conclusions) from other tasks, such that knowledge on lower levels can be used to aggregate knowledge on a higher level.

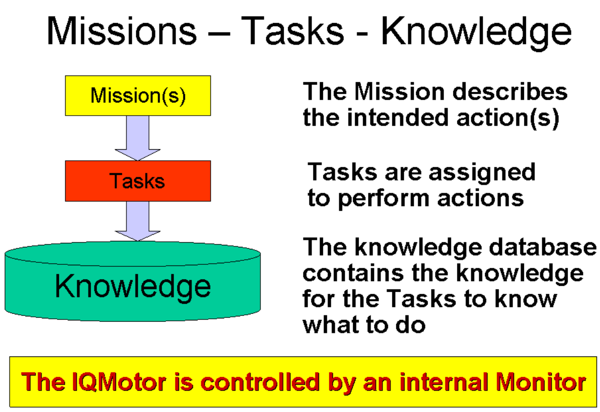

Fig. 4. How a Mission is described and carried out

The total number of tasks may be just a few, or several thousands, depending on the requirements and the available computational resources. The IQMotor is prepared for SIMD[5] or clustered multiprocessing, thereby allowing for very large decision-making capacity.

4.6 Installation and configuration

The IQMotor Run-time System is installed as an embedded system, and relies on external sensor inputs for analysis of the various mixes of Impressions that may occur, and on external control mechanisms for actions that invokes the knowledge commands.

[4] The term 'Knowledge Item' is here used for a piece of knowledge that is limited to dealing with a specific selection of input variables, and a limited set of values these variables may have. Input variables such as "the time is twelve o'clock", "today is a work day", and "I am at work sitting at my desk" may e.g. contain the knowledge: "it is lunch time".

[5] SIMD: Single Memory, Multiple Data

Accordingly, a project involving the usage of IQMotor involves installation of the system in the environment where it will run, and connecting it to the external sensor facilities.

The IQMotor demands little resources for itself, but these may grow with the requirements. Factors that influence the resource requirements are the complexity in the knowledge involved as well as the required

5 THE IQMOTOR IN UAVS AND UCAVS

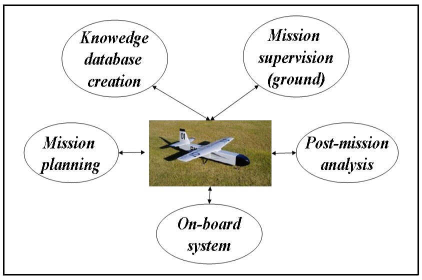

Fig. 5. An UAV and its support operations

A UAV/UCAV operational setup typically includes the functions outlined above. These must be present in some form or another. A closer look at each particular function with a special focus on the on-board activities follows.

5.1 An Example of an UAV On-board system

If we assume that the system is to be used in non-segregated airspace, the mission need to be completed with at least the following Tasks:

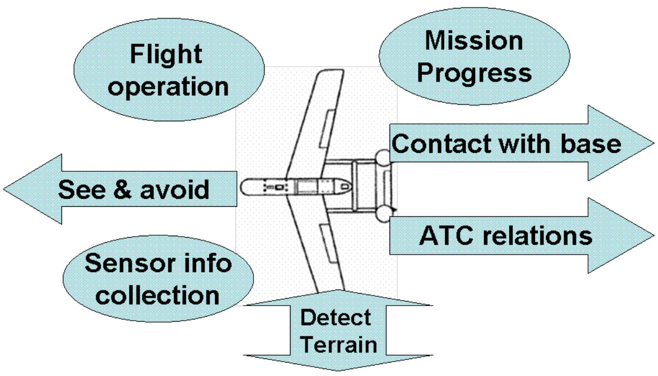

Fig. 6. Typical Tasks for On-board operation

As an example, one task for the UAV pilot can be to check the maneuvering altitude during flight. If the altitude over the terrain below, as well as for some time ahead, is judged to be sufficient for all possible corrective maneuvers, then the knowledge: “the current altitude over terrain is sufficient for all ordinary flight operations” can be established, and IQMotor knows that it has the liberty to make maneuvering decisions without taking extra measures due to low altitude problems.

If the altitude is low, however, it will clearly affect the decisions to be made. The same can be established for "flying velocity is OK/NOT OK for normal maneuvers".

Similarly, a pilot will always have these and other matters in the back of his mind at all times, and it will affect his decisions once a situation occurs.

Flying: The most obvious operational task is the supervision of the flight itself. The IQMotor reasoning engine then has the responsibility to act as the pilot of the UAV.

The tasks may vary, depending on the UAV itself, and may include:

> *Taxiing from the hangar to take-off position, take-off, climb to a designated altitude, following a predefined route to one or more targets, utilizing one or more waypoints, returning to the base, landing, and taxiing back to the hangar.*

These operations need to be defined in a carefully prepared mission description, as well as a set of "micro missions" to deal with any corrections whenever deviations from the prepared mission are detected.

Since various flight conditions may require different actions for similar situations, it is often best to establish a state vector driven system, such as this one (to the right).

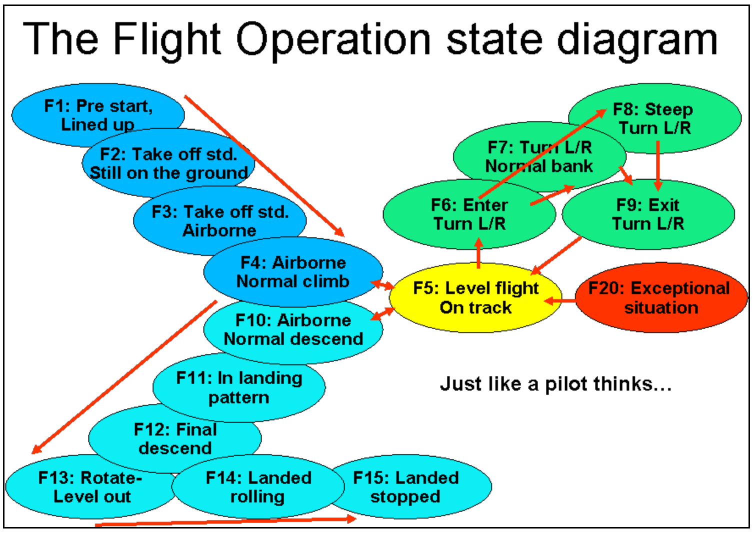

Fig 7: An example of a state diagram

If, e.g, the speed becomes too low in F4, a reduced climb angle may be the best decision (the engine is already running on high power), while in F10, more engine power can easily be applied instead for an increase in speed, since the engine is running on low power during descend.

The Reasoning Engine must also, during its flight operation supervision, be able to cope with situations that involve unexpected and even extreme flight situations, such as strong wind or turbulence, and failing controls or sensors.

The ground control may also have an optional possibility to override the reasoning engine's pilot function and take over via remote control.

Information collection is traditionally the most common task for a UAV, and involves the activation of equipment that collects information from the ground or sea level, as well as in the airspace at a given location. The information will either be stored onboard or relayed back to the base as required.

Tactical and Strategically: Some flight operational decisions are tactical in their nature. Examples:

Follow a predefined route at high altitude, or switch to low-level, terrain-following modus. Switch from 'report all sensor info back to the base' to 'collect all sensor info in own storage for analysis later, due to lack of communication links or the requirement for radio silence'.

If in civilian airspace, the UAV must be capable of receiving instructions from the air traffic control units (ATC), and respond to these as required.

There are few strategic activities going on in a UAV or UCAV, but some examples of what can be considered as strategic decisions are these:

- Abort mission and return to base, due to unexpected activity in the area.
- Make the UAV self-destruct, due to irreversible error on board and/or lack of ability to return to friendly side.

The ground based control unit may want to execute the following type of commands once a UAV is airborne:

- Follow mission progress, alter mission (route, or what tasks to execute), display all UAV/UCAV actions in the area on a 'theatre map', override onboard functions with manual control, download all collected information.

IQMotor allows the ground control to focus on the vital part of the missions, and relieve the operators from trivial tasks, such as the actual flying, etc.

5.2 IQMotor Competitive Advantages for use in UAVs/UCAVs

IQMotor is a unique reasoning engine for knowledge-based[6] decision-making in an on-board control unit for UAVs. This application is characterized by requirements for safe and continuous operation 24/7, as well as high problem solving capacity.

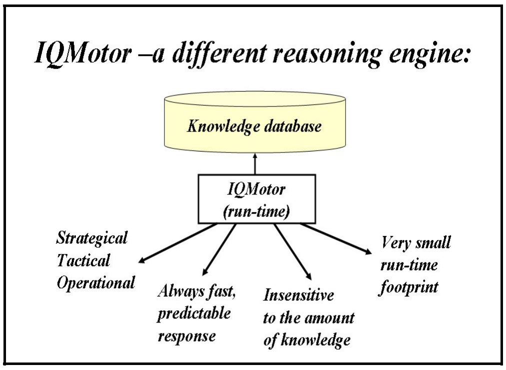

Fig 8: The IQMotor Run Time system

IQMotor can perform operational, tactical and even strategic reasoning. The need for special software to cover these highly different areas of responsibility can, through the use of IQMotor, simply be replaced by adding the necessary knowledge. However, the necessary sensors and control mechanisms still need to be in place.

Knowledge may be added as the tasks to be covered are defined and does not affect the already existing knowledge.

6 KBS => Expert system. For a Wikipedia definition: http://en.wikipedia.org/wiki/Knowledge_based_system

IQMotor is not more intelligent than other Knowledge based systems. Yet, there are only practical limits to how much knowledge – or intelligence – the system can cover.

It may not even be faster, although we believe it is among the fastest and most economical methods in the market.

The main benefits of the IQMotor system, compared to other systems, are:

- The extreme simplicity of the embedded software system itself.
- The minimal footprint of the embedded software system.
- The predictable response time, and the deterministic behaviour of the system.
- All logic decisions are made on the basis of knowledge based in a knowledge database. New or additional knowledge may be added without altering or affecting already established knowledge.
- The systems ability to be certified according to the strictest rules.

5.3 IQMotor, current status

IQMotor currently exists as a prototype. The system is used to pilot a flight simulator within a PC under Windows. The work has been supported by the Norwegian Government Innovation Fund and the shareholders.

Not attempt has been made to meet the DO178B Level A standard at this time, albeit much consideration has been made to convert the system in order to meet the standard. The costs for converting are known and reasonable.

Alfatroll AS is a privately owned, small company in Norway. The IQMotor is its only product, and the IQMotor patent belongs to the company.

Cooperation with other companies are desirable, and we are open for discussion of alternative forms of cooperation.