WITAS

Wallenberg Laboratory for
Information Technology and Autonomous Systems
at Linköping university, Sweden

PM 1999:02

1999-05-04

Erik Sandewall

WITAS Phase II Proposal

Executive Summary

Related information can be obtained via the following WWW pages:

Linköping university:	http://www.liu.se/
WITAS Project:	http://www.ida.liu.se/ext/witas/
Author's Department:	http://www.ida.liu.se/
The author:	http://www.ida.liu.se/~erisa/

The WITAS project has been planned for 3+4 years: phase I for 1997-1999 and phase II for 2000-2003. The plan for phase II was approved by the WITAS Board on April 22, 1999; the present memo is a brief summary of the plan.

Project Goals

Disciplinary goal and system goal

The project has two goals with equal dignity:

- Construct a particular kind of system – the onboard IT system whereby an unmanned aerial vehicle can "think" for itself – for demonstration by the end of the year 2003.
- Conduct disciplinary research on topics that are of importance in the international research community, and that are relevant for the system being built. This research involves both theory and methodology.

It is this combination of building a complex system and doing disciplinary research that gives the WITAS project its special character.

The WITAS developed system must then consist of the following essential components or subsystems:

- On-board computer system
- Computer vision system (video and IR cameras, camera housing for stabilization, etc)
- Other on-board sensors
- Communication with an operator on the ground, or in another vehicle.

Such a flying vehicle is usually called a UAV, for Unmanned Aerial Vehicle. The UAV in our project is intended for a particular operational environment, namely, for *roads carrying automobile traffic.* It is therefore required to "understand" what happens on those roads - conventional maneuvers of individual cars and other road vehicles, dangerous or otherwise exceptional maneuvers, structure of the traffic e.g. congestion. It is also to perform tasks that are assigned by the operator or triggered by the observations it makes itself, for example to follow a certain car that flees from the scene of an apparent crime, or to assist a certain car so that it can make it through difficult traffic and get to a particular destination as quickly as possible, or to deliver a particular parcel to a particular point.

The UAV is supposed to perform these functions autonomously, that is, without the direct intervention of a human operator. It is therefore not sufficient to design it for remote control of its maneuvers and other detailed operations: the operator is only supposed to communicate general commands, often using a combination of a phrase in natural language, and pointing to a map or video image. The most important capabilities for such a system are therefore (1) to form a model of ("understand") scenes and events that it observes on the ground, and (2) prediction, planning, and autonomous decisions using that model.

System Behavior Goals

For a project of this kind it is important to have a clear definition of the system one intends to build. The system can be defined in various ways (physical characteristics, what are the major subsystems, and so on), but the most important is the specification of the *behavior* that the developed system is required to exhibit and the *scenarios* that it is required to master. These definitions were made already in the original project proposal from 1996, where they were stated as follows:

- Fly over a congested highway system (typically in a city) and detect traffic accidents by the pattern of how cars are standing and/or moving
- Fly over a congested highway system and find the best route for an emergency vehicle (avoiding traffic jams)
- Fly over roads in a segment of countryside where there have been hostilities (but fighting has stopped), identify how roads have been blocked (by obstructing vehicles, destroyed bridges, etc), and identify a route where trucks can pass
- "Watch that car" – fly over a particular car (for example a high-value transport) and supervise what happens around it. If there seems to be any trouble, then fly down and take close-up photographs; also report back to a communication center.
- "Follow that car" – if there has been an incident in the activity of the previous item, then follow a particular fleeing car and check where it goes. If the people in it switch to yet another car, then watch what happens and follow the (a) car that moves rather than (the) one that stays.
- Interception analysis: In the context of the car-watch and car-following activities, do lookahead across the road network to predict if the watched car or the fleeing car will be forced to stop because of an obstacle. Also, identify ways of stopping it using available, cooperating vechicles (police cars, etc).

The original project proposal continued as follows:

"The proposal, then, is to develop an IT system (sensors, computer hardware and software, radio communication) where all of these functions are performed automatically: the on-board vision sensors observe the roads and situations under the aeroplane and analyze the images, and the decision system specifies where to fly and which communication to have with the base. (...)"

For Phase II we confirm this formulation of the goal, with the following amendments:

- that the achievement of this goal is to be demonstrated using a combination of flights with an actual UAV (most probably a helicopter rather than an aeroplane), and flights in a simulated environment with a high degree of realism;
- that actual UAV flights are used to the greatest extent possible, and that the use of simulation is restricted to demonstrating those aspects of the system where flights with actual UAV are not allowed.

Characterizing the project

Technologies That Combine

Does the WITAS challenge represent a product that can be built and marketed with a profit? Possibly, not necessarily. Does the WITAS challenge benefit research? Yes, absolutely.

The purpose of choosing this task was not to build a product; it was to create "pull" and "merge" effects on research in several areas of engineering science. By working jointly on the WITAS challenge, our groups develop technologies *in a number of different areas* that can safely be assumed to be relevant in the future. However, the *exact combination of these technologies* is difficult to foresee. Even if it were possible to foresee today what combinations of technologies will be the most important ones in the future, it may not be possible to go for them directly, since some of the elements of the future combination may not yet be operational.

The point is not to find the right combination of technologies today; it is important instead to *develop technologies in such a way that they do combine* when combination is needed. This requires, in particular, that the researchers work in an environment where they are required to see their own contributions in the context of a larger system. WITAS is organized so as to encourage development, right from the start, of technologies that combine in this sense.

The demonstration of results in December, 1998

The combinatory strategy has been pursued from the very start of the project. After the first two years, we can clearly see how the participating research groups have changed their mode of thinking and their way of solving their own problems, because of the requirements of making their solutions work in the context of the emerging WITAS Integrated Software System (WISS).

The results of the first two years were demonstrated to the WITAS Board on December 17, 1998. At this point our WISS system includes subsystems for computer vision, scene understanding, autonomous decision making, and visualization. We also showed how software techniques for computer vision had been transferred in a systematic way from a laboratory computer system to a compact system for on-board use in hard real time. All the subsystems require further work, of course, but the demonstration showed how we can combine the necessary subsystems into a working whole.

We also presented an extensive account of present system architecture as well as plans for how this work can be continued and broadened so as to achive the goals for the entire project. The present planning activity is based on the combination of current system concepts and continuing analysis of the achievements of related research projects elsewhere.

Synergy between fundamental research and complex systems development

The joint work on building a complex and advanced software system is an important part of WITAS, but it is not the only activity. The project has two goals with equal dignity, as mentioned above:

- Construct a particular kind of system – the onboard IT system whereby an unmanned aerial vehicle can "think" for itself – for demonstration by the end of the year 2003.
- Conduct academic research on topics that are of importance in the international research community, and that are relevant for the system being built. This research involves both theory and methodology.

It was our assumption that these two activities benefit mutually from each other: the WITAS system benefits from the results of the basic research within the project, as well as from the international contacts that it enables; the basic research also benefits from the insights obtained in the systems building activity. This initial hypothesis when the project started has been strongly confirmed by the course of events. The enthusiasm of the participants for this mode of working is very evident from our meetings and demonstration events.

The WITAS project is unique among Swedish research efforts in information technology in that it addresses *long-range* research issues in this *goal-directed* fashion where the construction of a large research system by interdisciplinary cooperation is a major part of the strategy.

Technical Directions for Phase II (2000-2003)

For the continuation of the project into Phase II we propose both a continuation of the work so far, and the addition of several activities which all contribute towards the overall goal for the end of 2003. The proposed annual cost for Phase II is roughly doubled compared to Phase I: 105 MSEK for 4 years, compared to 40 MSEK for 3 years. This is explained partly by increased equipment costs (12.9 MSEK in Phase II), but mostly by the additional activity areas. The following are the proposed major directions of the project in Phase II:

1. *Development of a full on-board IT system, the WITAS On-Board Computing System (WOCS), based on the existing laboratory system, WISS.* This requires, in particular, the use of and interface to the control system of an actual UAV, instead of the present system that is entirely based on our own mathematical model of the UAV.

   Some initial work for setting up the basic components of the on-board system shall begin already during 1999, as a preparation for Phase II.

   The overall system development goal of the project is to demonstrate an airborne IT system for an intelligent UAV before the end of the year 2003. It is the WOCS system that will be used for the concluding system demonstration.

The transition from the laboratory system WISS to the on-board system WOCS is to be done gradually. The timepoint of the first actual flights with an airborne vehicle containing the WOCS can be expected by late 2001.

2. *Gradual development and improvement of the facilities within the system architecture.* This includes the modelling and knowledge representation of the maneuvers, movements, and control of the UAV and its subsystems, including the video camera subsystem. It likewise includes the further evolution of the techniques for computer vision, and of the autonomous decision-making capabilities.

   One of the challenges under this heading is to extend the vision and scene understanding systems so that they are able to deal with close-up, sideways/ diagonal views of individual ground vehicles. So far we have only worked with top views of larger traffic scenes, involving a larger number of cars, where no details can be seen in the cars.

   This gradual development work will use the WISS system as its development tool. Results will then be successively transferred to the WOCS system.

3. *Development of a Fluent Library*, that is, a repository of archived recordings of signals, video streams, and high-level information streams during actual or simulated flights. The fluent library will be an important research tool for work on the higher levels of the architecture (representing the UAV's "intelligence"), and in particular it will vastly improve the possibilities of making repeatable experiments on higher levels of the system architecture.

4. *Development of a Geographical Dialogue System*, GDS, allowing effective, mixed-mode dialogue between an operator on the ground and a UAV, where the two can communicate in terms of text, speech, and pointing into maps, photographs, and videos. The GDS includes geographical databases and image archives, which are to be used by the autonomous navigation and planning systems as well.

5. *Methods for assuring safety and airworthiness.* The goals of the project are not limited to demonstrating the target UAV behavior in a couple of demonstration events; the goals also include the development of formal, systematic, and reliable techniques for validating the design for all possible situations that can arise within a specified 'envelope'. This goal subsumes work on formal validation techniques for both hardware, software, and knowledge representation aspects of the design.

The proosal also contains preliminary work on an additional topic, where the commitment is only the end of year 2000, and a final decision whether to continue is to be taken around mid-2000:

- *Development of a second, maintenance-oriented operating environment, namely, for those situations requiring mechanical manipulation of the UAV itself and/or other autonomous vehicles.* This operating environment complements the primary, flight-oriented one. The need for it arises in particular in order to create autonomous service stations where UAV's can go for refueling, loading and unloading of cargo, and possibly also for exchange of components and for minor repairs. The second operating environment will first be developed using the WISS, and will then be transferred to the WOCS.

The maintenance-oriented operating environment will require a new kind of modelling, besides what has been used in Phase I, and with a greater emphasis on three-dimensional mechanical structures. In this way it also has some connections to topics in aircraft design.

Towards a distributed project organization with international participation

At present the project is organized in terms of four subprojects, each one hosted by an existing research group or combination of two groups. The respective group makes an agreed contribution to WITAS as a whole, and obtains a corresponding amount of grant.

For phase II, I propose to open up the set of participating groups, so that we have both a set of *kernel groups* that take primary responsibility for the project as a whole, and a number of *associated groups* that make more specific contributions to the project in well defined areas. The associated groups may be either in Linköping or in other places ("outposts"), whereas the kernel groups must be in Linköping, in order to guarantee the necessary cohesion. Outposts will be located at first-class research institutions internationally. Efficient communication back to the kernel project can be provided using modern information technology.

The present trend towards international operations concerns research and research projects, just as much as it concerns industries and public administrations. In many ways research has always operated internationally. Also, international "big research" organizations such as CERN, and the consortiums that are required in European cooperation programs such as ESPRIT, are examples of how research projects can be organized in geographically distributed ways.

When we propose to operate some parts of WITAS in a geographically distributed fashion, we envisage yet another organizational model. For our purposes, it is important to retain the combination of goal-directedness and long-range research goals that has characterized the project so far. It is also important to retain and develop the cohesive factor of joint systems development. The planning and budget system that we have already established will be important in this respect: activities are planned and overseen by the WITAS Board as we proceed; and do not have to be specified in advance for the whole project period.

The distributed organization will also be facilitated by novel publication and communication techniques. We have been quite active in that area as well.

In general terms, we believe that the question of how to organize effective research projects on the international scene is a major challenge for the research community. The organizational structure used and proposed by WITAS represents a new approach in that respect.