Networked Adaptive Interactive Hybrid Systems (NAIHS) for multiplatform engagement capability

Leon Kester

TNO Defence, Security and Safety
Oude Waalsdorperweg 63, 2597 AK The Hague, The Netherlands
[1]leon.kester@tno.nl

***Abstract*— Advances in network technologies enable distributed systems, operating in complex physical environments, to coordinate their activities over larger areas within shorter time intervals. Some envisioned application domains for such systems are defence, crisis management, traffic management and public safety. In these systems humans and machines will, in close interaction, be adaptive to a changing environment. Various architecture models are proposed for such Networked Adaptive Interactive Hybrid Systems (NAIHS) from different research areas like (networked) sensor fusion, command and control, artificial intelligence, robotics and human machine interaction. In this paper an architecture model is proposed that combines the merits for a multiplatform engagement capability application. The NAIHS model focuses on the 'hybrid mind' that is layered in several dimensions defining specific functional components and their interactions.**

I. INTRODUCTION

Since the introduction of the NAIHS model [1], this model is considered for applications in various domains. In this paper we investigate in more detail how this model relates to other models and recent developments therein. In chapter 2 the high level model is discussed. In chapters 3 different decomposition principles are proposed. In chapter 4 the applicability of the NAIHS for multi-platform engagement capability is considered and chapter 5 concludes this paper.

II. HIGH LEVEL MODEL

The NAIHS under consideration is a system of networked entities or components that strive to co-operate to cause an effect in the outside world according to a certain system goal. The first distinction is therefore between system and outside world. As the expression 'hybrid' already suggests, one would be tempted to decompose the system in a human and machine. Although different in nature, both can perform similar tasks like, sense the outside world, recognise, act on the outside world and reason how to reach certain goals. Therefore, the approach taken here is to focus on modelling the system according to specific functional components, irrespective of whether they are performed by a human or machine.

In figure 1 a schematic picture is given for such a system. One can characterise the system as a distributed set of hybrid functional components (or hybrid mind) that interacts with collectors (sensors, observers or other information sources), effectors (actuators or actors) and a (distributed) service that takes care of communication between the distributed functional components.

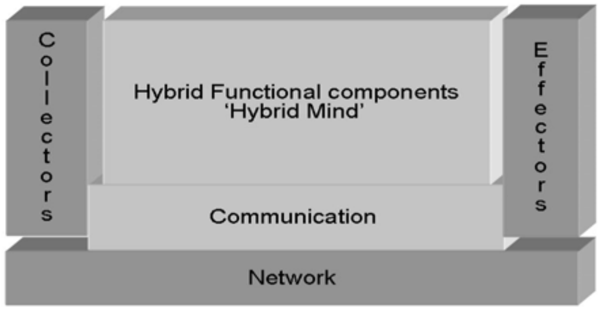

Figure 1 : High level System Model

A common approach is to decompose the system in the chain from collector to effector. In this 'dimension' a well established model is in use, the Observe Orient Decide Act (OODA) cycle [2]. According to the OODA cycle, functional components can be identified that are engaged in creating situation awareness and components that are engaged in deciding which effects to generate. This view is depicted in figure 2.

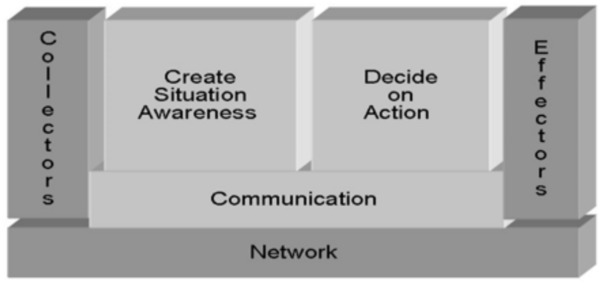

Figure 2 : Separation of the hybrid mind in creating situation awareness and decision making

The goal of such a system is to grasp that part of the situation, defined as the system in its environment, based on which the most effective actions can be taken.

III. PRINCIPLES OF ABSTRACTION

An important problem that has to be addressed now is what principles should be used to further decompose 'create situation awareness' and 'decide on action' into more specific functional components. Three principles can be distinguished: Information abstraction hierarchy, physical structure of the situation and time scale at which decisions have to be made. In the next paragraphs these principles are discussed.

A. *Information abstraction Hierarchy*

The most well known model that uses a decomposition based on a information abstraction hierarchy is the JDL model [3], depicted in figure 3.

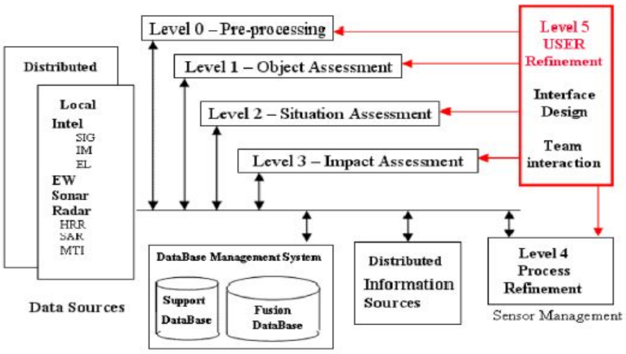

Figure 3: JDL model

We can match this model easily with the high level model of figure 2 for the part of situation awareness.

The JDL model distinguishes four levels of information abstraction:

Level 0: Estimation of States of Sub-Object Entities (e.g. signals, features)

Level 1: Estimation of States of Discrete Physical Objects (e.g. vehicles, buildings)

Level 2: Estimation of Relationships Among Entities (e.g. aggregates, cueing, intent, acting on)

Level 3: Estimation of Impacts (e.g. consequences of threat activities on one's own assets and goals)

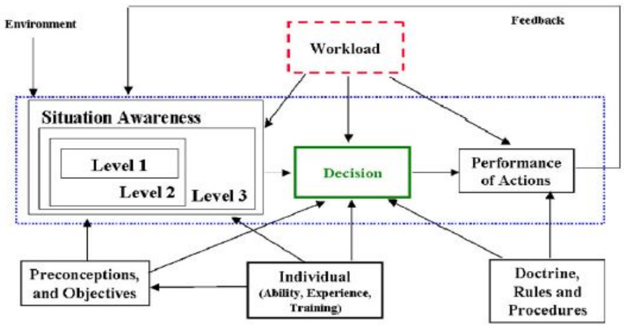

Figure 4: Endsley's situation awareness model

A model very similar to that but more from the human perspective is the model of Endsley [4] depicted in figure 4. While the JDL model is confined to creating situation awareness the model of Endsley includes decision making and performing actions.

Inspired by these models is the decomposition that was adopted for the NAIHS model is:

F1: Signal (Pre)-Processing – generating the feature space from the collector raw data

F2: Filtering in Feature Space – selecting phenomena from the feature space likely to originate from objects (detection)

F3: Filtering in Time – associating detected phenomena in time and estimate state, tracking

F4: Recognition – classification and identification

F5: Situation Assessment – Relationships among entities, similar to level 2 of the JDL model.

F6; Relevance Assessment – threat evaluation, risk assessment, similar to level 3 of the JDL model.

F7: Action Assessment – decide on what actions to take

F8: Execution – execute the actions

In figure 4 the interacting functional components are shown.

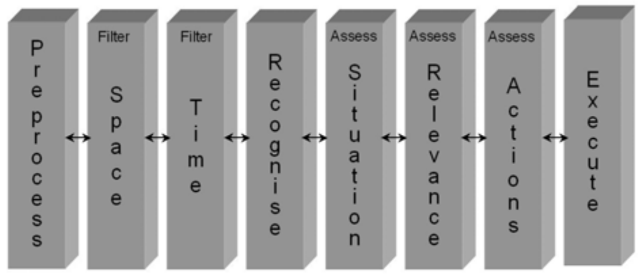

Figure 5 : Functional components of the process cycle and their interactions

As mentioned before, each component may be artificial, human or hybrid.

B. *Decomposition based on Physical Structure*

A second principle on which decomposition can be based is physical structure. This is the primary principle the Rasmussen adopted in his abstraction hierarchy [5]. The application he had in mind was the control of power plants. In systems considered here the physical structure is due to the network of platforms and the various collectors and effectors. An example of such a decomposition is depicted in figure 6 where the abbreviations correspond to the components in figure 5.

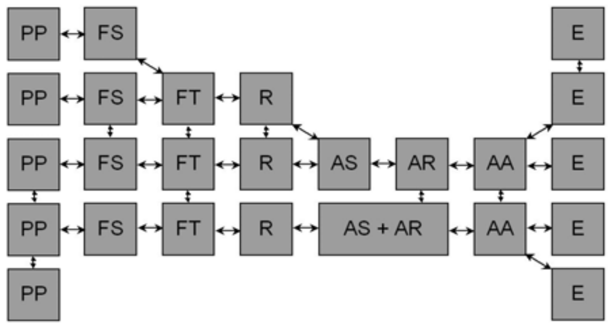

Figure 6 : Interacting functional components in the networked system of dissimilar collectors and effectors.

The view of the NAIHS model is here that the two principles of abstraction are in most cases related in the sense that the higher the information abstraction level usually there is less of a necessity to distribute the processes. This is also shown in the 2D structure of figure 6. However, their may be exceptions and in the design phase there must be possibilities to accommodate this.

C. *Hierarchies in Temporal Abstractions*

The effects the system would like to generate in the situation (system and environment) can widely vary in time. A decomposition of the process cycle in this dimension has been adopted in various application domains. In the military field a strategic, operational and tactical level is in use. For (business) planning the same levels in use, however, contrary to the military case the operational level acts on a shorter time scale than the tactical level.

In the AI domain Brooks [6], who discards the decomposition of the process cycle, proposes a hierarchical composition of process cycles based on reaction or cycle time.

The need for decomposition into temporal abstractions is also acknowledged in the case of decision making processes in complex situations [7].

The time scale may be very different for various applications. A suitable decomposition therefore depends on the application.

D. Integrating Abstractions

Most models use only one type of abstraction, there are some that distinguish these different principles but integrate them in one abstraction hierarchy [8,9]. Although it is a tempting thought to do so the NAIHS model considers the three principles on which decomposition can be based independent and results therefore in a three dimensional decomposition of the 'hybrid mind'. The reason for this is that it is well imaginable that information processing at a high information abstraction level is very fast and relevant for short term decision making or that information processing from one sensor at one platform needs to be decomposed in many components at the higher information levels. In the NAIHS model we want to keep the freedom of choosing the decomposition depending on the particular application.

IV. DISTRIBUTED BEHAVIOUR

The question that remains to be addressed is how to organise the distributed behaviour of the functional components in such a way that the interaction and or dependency between these functional components is minimal while at the same time they operate in a most effective way. In the NATO NEC roadmap four levels of maturity are characterised (figure 6): Deconflict, Coordinate, Integrate and Coherent.

The three levels identified in the figure correspond well with the three levels identified in the high level model depicted by figure 2. For the higher maturity levels the functional components need to act as services on a service oriented architecture platform and as self organising/orchestrating applications with semantic capabilities.

Besides this for the interaction between the networked components the issue of interoperability is considered. A common model for interoperability is the LISI model [10] that distinguishes five interoperability levels:

Level 0: no interaction or unintelligible data/information

Level 1: unstructured representation of data/information

Level 2: a common representation of data/information (syntactic level)

Level 3: a common understanding of the data/information (semantic level)

Level 4: common methods, procedures, algorithms to use or process the data/information (behavioural level)

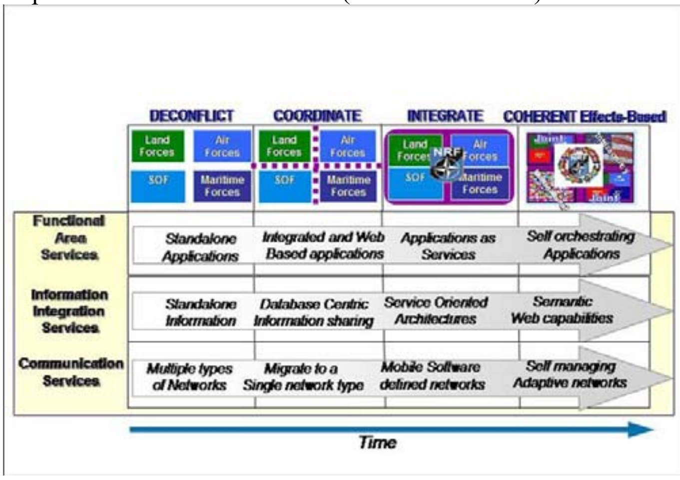

Figure 6 : NATO NEC maturity roadmap

The highest level of interoperability offers the best perspectives for coherent behaviour.

In the NAIHS model [1] a detailed example is described how in a service oriented approach and with interoperability 4 adaptivity to changing needs in information can be accommodated in a distributed setting.

Given the description of the components and the nature of their interactions at the higher maturity levels of NEC the NAIHS model considers the components as hybrid agents. The behaviour of the agent is determined by its place in the three dimensional hierarchy structure of the 'hybrid mind' analogous to the idea of the society of mind [11]. For these agents the NAIHS model distinguishes five different interactions; with agents higher in the information hierarchy, with agents lower in the information hierarchy, with agents similar in functionality/behaviour, with agents higher in temporal hierarchy and with agents lower in the temporal hierarchy. The behaviour of the agent can therefore be influenced by these interactions.

The adaptability of the system to changing goals and environment is therefore directly related to the capability of the agents to successfully adapt their behaviour and learn new behaviour.

V. MULTI PLATFORM ENGAGEMENT CAPABILITY

We have applied this model to the case of multi-platform engagement capability. In this case there are multiple ships with multiple dissimilar sensors that have to cooperate to counter common threats like incoming missiles and hostile fighters. This case is primarily focussed on the tactical level. For this application the time hierarchy, physical structure and information abstraction organise in the same way. It is therefore reasonable to combine the NAIHS model concepts with the proposed abstraction hierarchy in [8]. This has resulted in a model shown in figure 7. In this model the upper four layers correspond to the levels 0 to 3 of the JDL model. The model is also symmetric in generating situation awareness and decision making similar to figure 2.

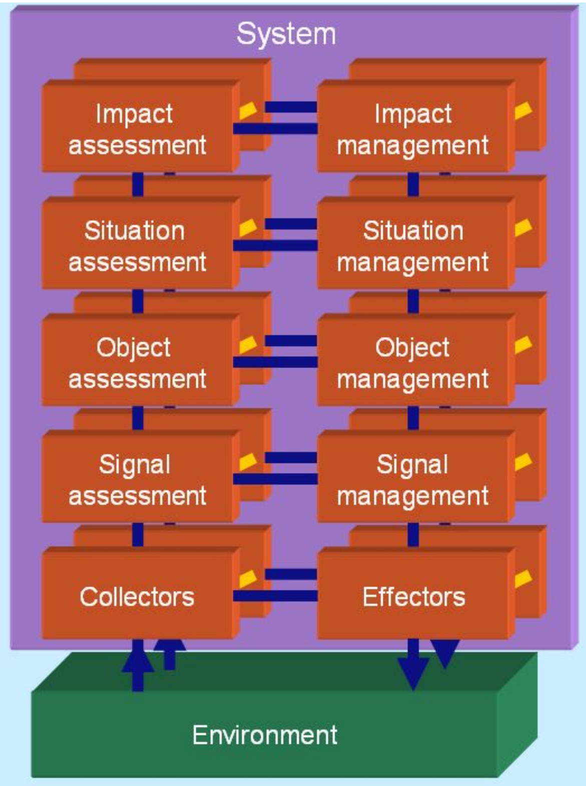

Figure 7: Cognitive system model

For this application we have focused on interacting tracking algorithms at object assessment level. These tracking algorithms are capable of fusing information from radar and electro optic sensors. A detailed description how from a service oriented approach in which the higher levels indicate their information need based on which the tracking algorithms can optimize their behaviour and minimize communication is described in [1].

We have tested the principles of this in a demonstration environment where radar and electro-optic sensors were simulated but the real tracking and information management functions were implemented.

The scenario that was considered was a manoeuvring fighter in a cluttered environment. For this scenario two cases were compared. One in which all contacts between the platforms were exchanged and one in which operational criteria were used to evaluate how much contacts contribute to the operational information need before exchanging them. A first qualitative result is shown in figure 8. This research and results from this are discussed in more detail in [12].

In general results will off course be greatly dependent on the operational need for information, available bandwidth, and sophistication of fusion and evaluation algorithms. Future research will be focussed on satisfying operational information need at minimum (communication) cost.

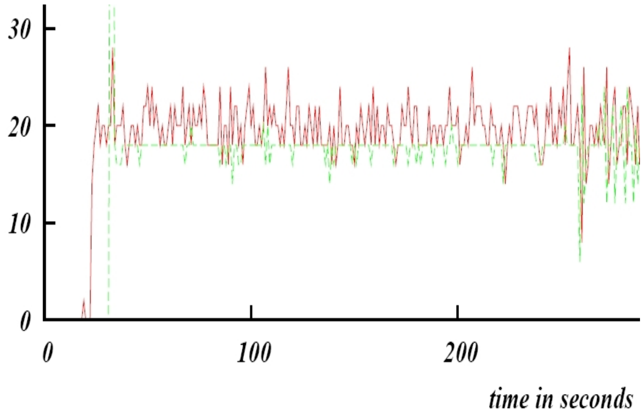

Figure 8: Number of contacts exchanged with (green) and without (red) information evaluation.

VI. Conclusions

In this paper we have compared the principles of decomposition used for the NAIHS model with that used by other models. It can be concluded that three types of abstractions can be distinguished in different models. There maybe a correlation between the three abstractions but for optimal designing freedom, the can be considered independently in the NAIHS model.

Since the NAIHS model considers the components to act as services to maximise the effect and as agents with a certain level of autonomy that can be controlled in a well defined way. In this paper some preliminary results are shown how this model can be used for satisfying operational information need at minimum (communication) cost for multi-platform engagement capability applications.

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