A Generic Fusion Tool on Command Control of C4ISR Simulations

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ABSTRACT

We present a generic high-level fusion tool that is a part of a novel C4ISR M&S system based on the HLA being developed by TÜBİTAK MAM BTE. The main objective of our fusion tool is to execute a generic, user-friendly information fusion process via a database using rules, which can be defined during run time.

1.0 INTRODUCTION

Every tactical military commander desires to know all of the information about both cooperative and non-cooperative armed forces in a battle space. Due to the large amount of information, computer-aided decision making and threat assessment methods are required to help the tactical commander. The advances in the information technology in the areas of command and control (C2); intelligence, surveillance, and reconnaissance (ISR) are dramatically reshaping the conduct of future warfare. The full application of these principles will accelerate the decision cycle by linking sensors, communications networks, and weapon systems. Nowadays, the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) framework as an integrated military structure attracts more attention in parallel to developments on information technologies and knowledge engineering. Being an integrated and complicated domain, the problem of C4ISR concept development as well as staff training generally require experimenting on complex scenarios. Modeling and Simulation (M&S) plays a critical role for improving the decision process significantly. Simulating the complex scenarios in virtual environments and coupling them to real C4ISR systems and staff are notably cost-effective solutions for the problems at hand [1].

In modern combat systems, information coming from several sensors is fused in order to overcome the uncertainty in a battle space. The main purpose of fusion is to provide an overall picture of the military significance of the information collected by different platforms to classify/identify the targets and to show the locations and movements of all entities. The need for a general-purpose sensor fusion tool has already been pointed out in a previous work [2].

Ahlberg *et. all.* [3] described a reusable demonstrator system for the C2 system of the future network-based defense. The Swedish Defense Research Agency (FOI) developed a concept demonstrator called

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Information Fusion Demonstrator 2003 (IFD03). The main purpose of this project was to provide a research platform. Similarly, in 1998, DSO National Laboratories started to develop a common simulation test bed to facilitate scenario generation and testing of data fusion systems. FOI and DSO have agreed to work on the common M&S test bed framework to collaborate on research activities in sensor, fusion and decision support [4].

The aim of our work is very similar to FOI's and DSO's studies by developing a simulation framework. In this work, we present a generic high-level fusion tool that is a part of a novel C4ISR M&S system based on the High Level Architecture (HLA) being developed by The Scientific and Technological Research Council of Turkey Establishment (TUBITAK) Marmara Research Center (MAM) Information Technologies Institute (BTE) [5]. In our structure, different sensor types produce various types of data from different geometries. Each sensor is only a contributor to a composite decision process that provides an overall picture of the military significance of the information collected by different platforms. A tactical picture of the environment provides information about the position, velocity, direction and identity of targets within a certain area. Our fusion tool combines evidence to determine platform's position, velocity, direction, and identity parameters.

2.0 C4ISR SIMULATION TOOL

The main motivation for C4ISR simulation systems is to be able to merge many individual and interoperable components into a common integrated virtual environment. Briefly, C4ISR M&S environments offer realistic resemblance to its corresponding real world operational counterparts.

TUBITAK has already developed an open, reusable, modular and interoperable simulation system for modeling and executing C4ISR architectures [6]. The simulation system has an open architecture on two points. The first point is generating a distributed infrastructure consisting of reusable components. The other point emphasizes openness to new developments by having modular and well-interfaced component architectures.

Our C4ISR Simulation framework, which is called Agent driven Simulation Framework (AdSiF), has been developed by combining a novel simulation engine solution and agents as decision makers and planners [7]. It also combines all implementations, decision process, knowledge management of agents and behavior, time and event managements of entities under a common language.

The simulation environment consists of the following main components:

- Scenario Design,
- Scenario Engine,
- Analysis,
- Optimization,
- Autonomous Forces,
- Communication,
- Sensors,
- Fusion,
- Mapping and Visualization.

Each scenario will be a different HLA federation running on RTI (Run Time Infrastructure) middleware. To support this structure; sensors, communication model, platforms, staff and C2 components are represented as federates [8]. Modeled sensors are radar, electro-optic imaging sensors (day and infrared cameras), synthetic aperture radar (SAR) and buried sensors (seismic, magnetic etc.). The architecture of the simulation structure is given in Figure 1.

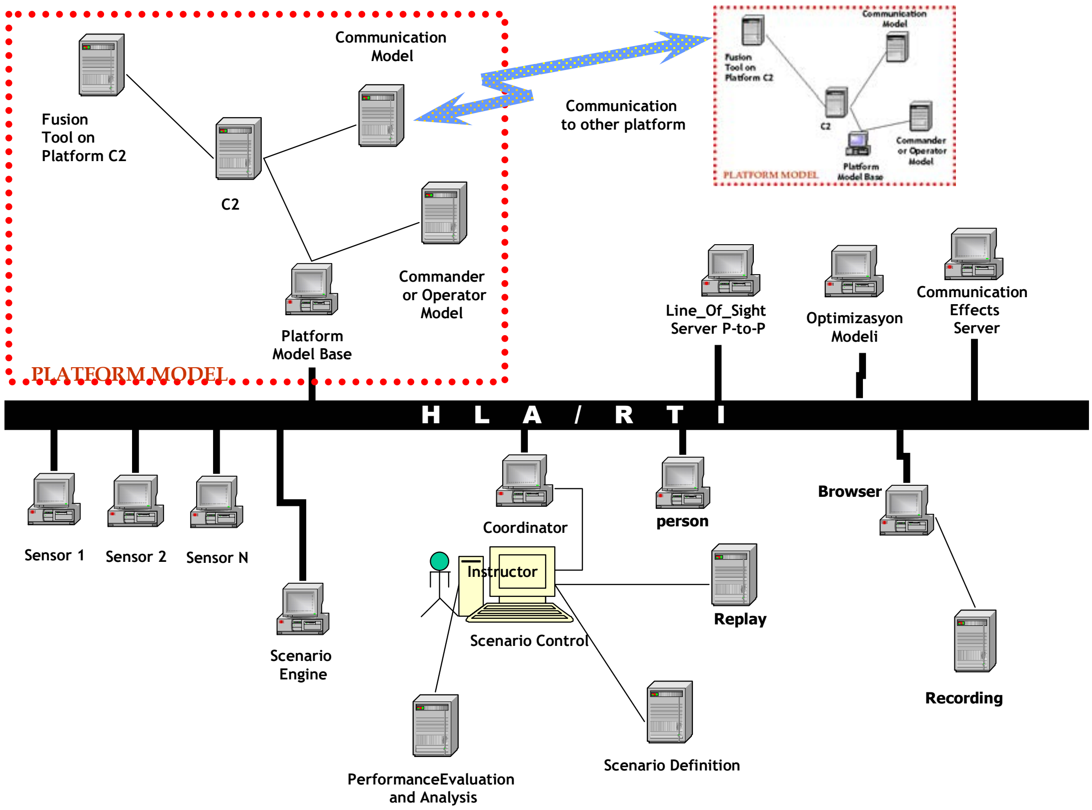

Figure 1: The architecture of the simulation structure.

All of the C4ISR simulation and simulation framework are developed by using C++, just with the exception of Prolog as interpreter in Fusion and autonomy parts.

3.0 RULE BASED FUSION TOOL

Sensor information is stored in a local C2 site and the C2 database information is transmitted from local to the global C2 center via the communication tool. Information fusion tool is executed on the C2 center and fused information is shown on the Tactical Picture.

Simulation contains different kinds of target models including moving land vehicles, air vehicles, and persons. For sensor models, we construct realistic sensor simulations instead of probabilistic models. Sensors collect data from the environment, and these data sets contain information about an object of interest. Since, this information is hidden in the data in many cases, artificial intelligence methods like data mining or knowledge-based fusion can extract the required information. Powerful methods are necessary to examine the data by applying various techniques of filtering, correlation, inference, and so forth. [9].

The main objective of our fusion tool is to execute a generic, user-friendly information fusion process via a database using rules, which can be defined during run time. The general execution flow diagram is shown in Figure 2.

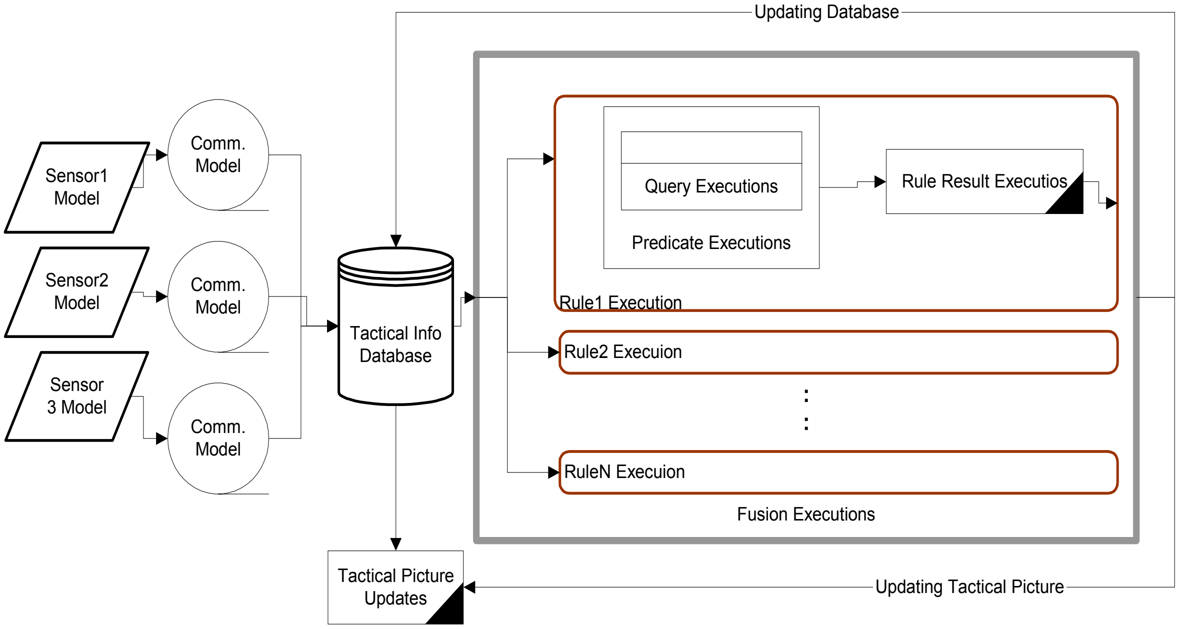

Figure 2: The general execution flow diagram.

The proposed solution has a design appropriate for three different usage possibilities.

- **Operator Level:** The end-users can apply any rule defined through the user interface to the database and they can also process these rules on a database and display the results on the user interface.
- **Rule Development Level:** It addresses the end-users who want to define new rules using the existing predicates and apply these rules to the database.
- **Predicate Development Level:** If a rule cannot be defined with the existing predicates, user-defined predicates can also be introduced to the system. The predicates used to define the rules are Prolog statements; therefore the system takes Prolog statements and executes them.

A rule consists of three components:

- Query and Alignment,
- Predicate,
- Result definition.

These three components of a rule are in interaction with each other. It means that the result of a rule depends on the resulting value of the predicate. The variables that are passed to the predicate at execution time are acquired from the data obtained by queries.

The fusion process is executed on pre-defined rules. In this process, predicates use all of the possible inputs from the Tactical Info Database (Command Control Database). All of the required information is extracted from the database via defined queries. The execution process on the system can be customized as listed below.

- Rule execution order can be changed.
- New rules can be added.
- New predicates can be added.
- Required predicate queries can be defined.
- New database can be used.

According to this structure, the selection of the predicates to be used constitutes the first step of rule definition. The next step is to make the query definitions in order to determine the contents of the predicates. In query definition, all of the database fields can be attained and the required comparisons can be made. After the definition of the required queries, the query results that will be the parameters of the predicates can be selected. Here, a query output field corresponding to the each predicate input value should be selected. After the assignment of the predicate input values, with the definitions related to the predicate results, the rule definition process is completed. The assignment of the operations at the end of the execution of the rules could be made in different ways. Surely, these decision rules are based on the subject matter expert's input. Detailed block diagram of the fusion tool is illustrated in Figure 3.

Rule definition is given as follows:

```
Rule_X :   IF    {
                 Predicate1_X[Alignment1_X(Query1_X)]
                       Operator1
                 Predicate2_X[Alignment2_X (Query2_X)]
                       Operator2
                 :
                 :
                 PredicateN_X[AlignmentN_X (QueryN_X)]

                 }

           THEN Result_X
```

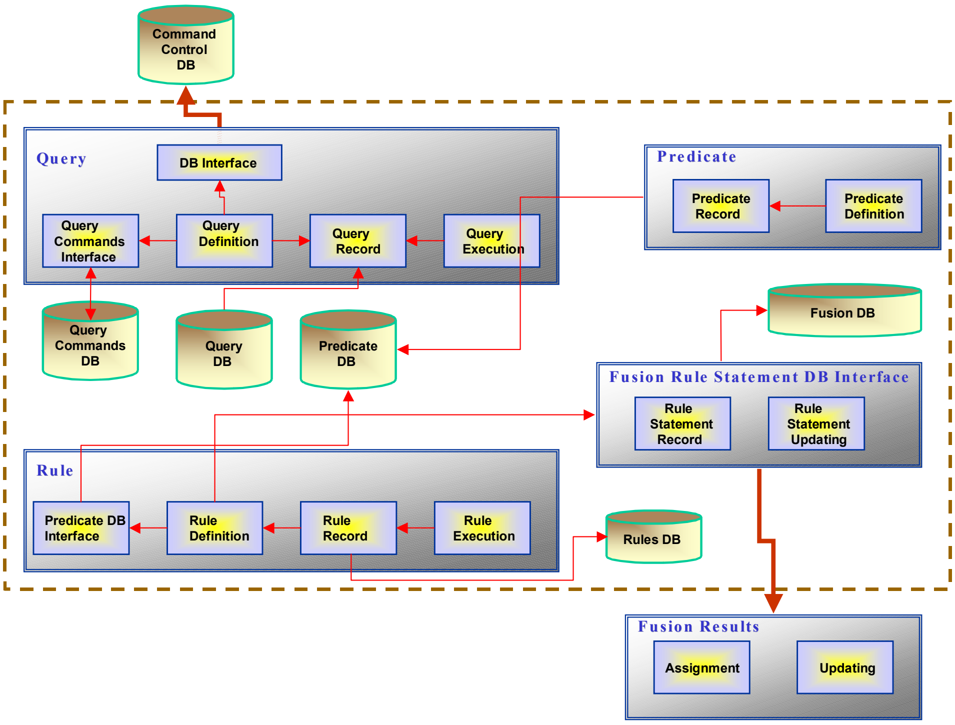

Figure 3: Detailed block diagram of the fusion tool.

4.0 TEST SCENARIO

In order to demonstrate our Fusion Tool, we work on a simple example. Some platforms with sensors, targets, C2 center, and communication device for sending detections to the C2 center are deployed. We assume that all of the platforms send their detections to the central C2 center via communication devices. The test scenario architecture is depicted in Figure 4.

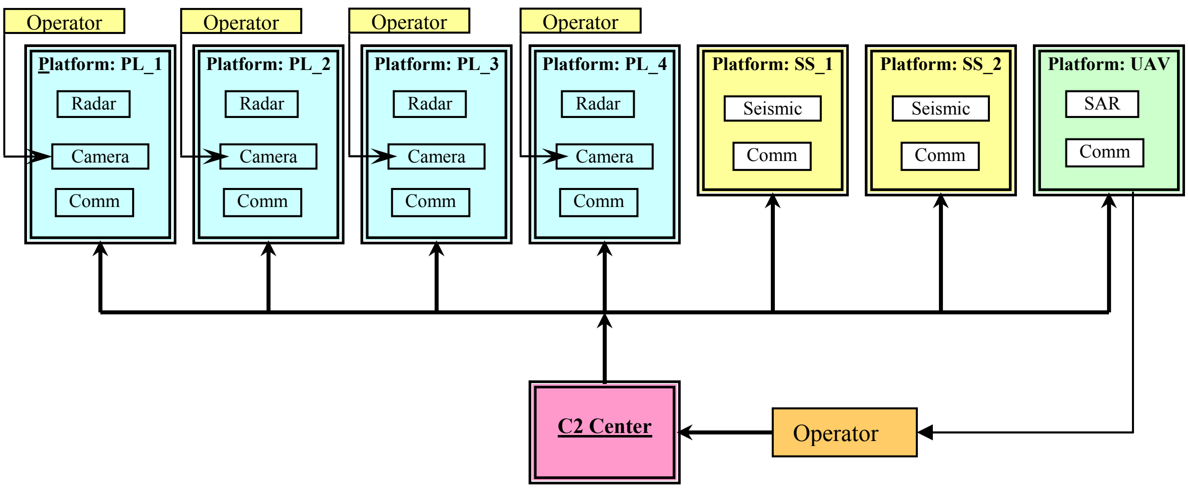

Figure 4: The test scenario architecture.

The scenario area region is 140 x 140 km square and is generated on a terrain data as a Digital Terrain Elevation Data (DTED) map. Sensors are carried by different kinds of platforms like land-based, air based, or they can be buried like seismic sensors. Targets (military truck, tank, person, etc.) can be mobile or stationary. The test scenarios have the following platforms:

- PL_1, PL_2, PL_3, and PL_4 are the platforms of the same type (fix land-based) and contain X-Band Surveillance Radar with Doppler capability, Day Camera and Communication device.
- Buried type seismic sensors (SS_1 and SS_2) are located in a fix location and communicate directly with the C2 center.
- We add an Unmanned Aerial Vehicles (UAV) platform to the scenario as Air Based type platform and a Synthetic Aperture Radar (SAR) is installed on the UAV.
- All of the targets have the following features: Radar Cross Section (RCS) values (for every 10 degrees), Length, Width, Height, Velocity, Direction, Weight.

Sensors measure various types of parameters, which are stored in the C2 center database. Radar measures range, bearing and Doppler velocity of the target depending on the related RCS and radar characteristics. Day camera gives azimuth and elevation information for the detected objects and an operator in land-based platform can interpret the images and can add information to the C2 center. In our scenario, SAR sends the imaging acquisition to the land operator who interprets the information and adds to the C2 center the information related with the size of the target, possible type, etc. Seismic sensors produce vibration caused by the weight and speed of the target. The coverage of seismic sensors are shown as circle area for a driving truck. Test scenario is given in Figure 5 with coverage areas, deployment of platforms and targets.

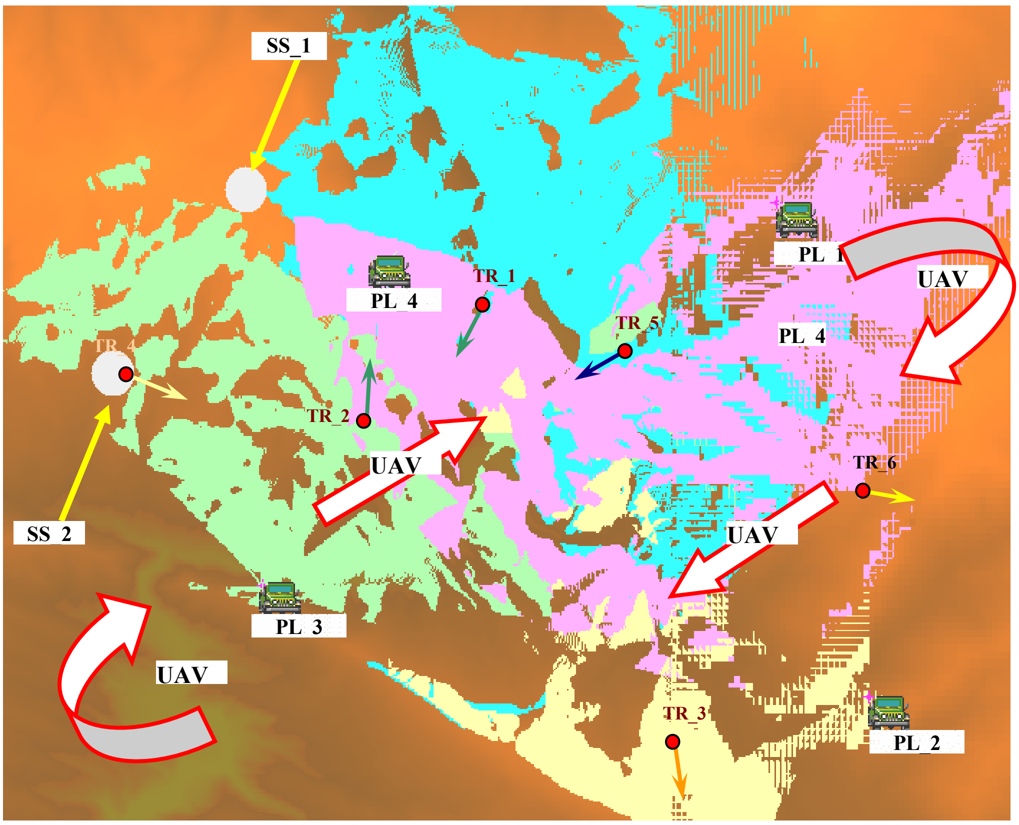

Figure 5: Test Scenario.

Detection range of the radars and SAR are calculated in terms the parameters of sensor, target, environment and Line of Sight (LoS). LoS ranges of the land-based platforms are shown with different colors. We assume that UAV platform has a high altitude to cover the 75 x 75 km square area and its flight path has the form of a line with 50 minutes revisit time.

In this test case, we consider just the state fusion example because of the generic structure of the Fusion tool, which user can develop own rules for customization purposes. Positional fusion is required because more than one sensor may detect the same target. When each sensor sends the position of the same target, tactical picture will sense it as different targets.

In the first step, we normalize the data (data alignment) with respect to time in Query step. To fuse positions, we propose to cluster the targets by using the Euclidian distance. If the Euclidian distance is smaller than the desired threshold, the targets will be strong candidates to be the same. But clustering is not enough to decide that the targets in a one cluster are the same object. We recommend calculating the correlation of two feature vectors [10]. The correlation coefficient between two given vectors X and Y, can be expressed as following:

$$C_{xy} = \frac{X \bullet Y}{\left(X \bullet X + Y \bullet Y - X \bullet Y\right)} \tag{1}$$

where $X = \{x_1, x_2, .., x_n\}$ and $Y = \{y_1, y_2, .., y_n\}$ are the feature vectors and "•" denotes dot product. We define feature vector as $\{Latitde, Longitute, Bearing, Range, Speed, Direction\}$. The solution is summarized in Figure 6.

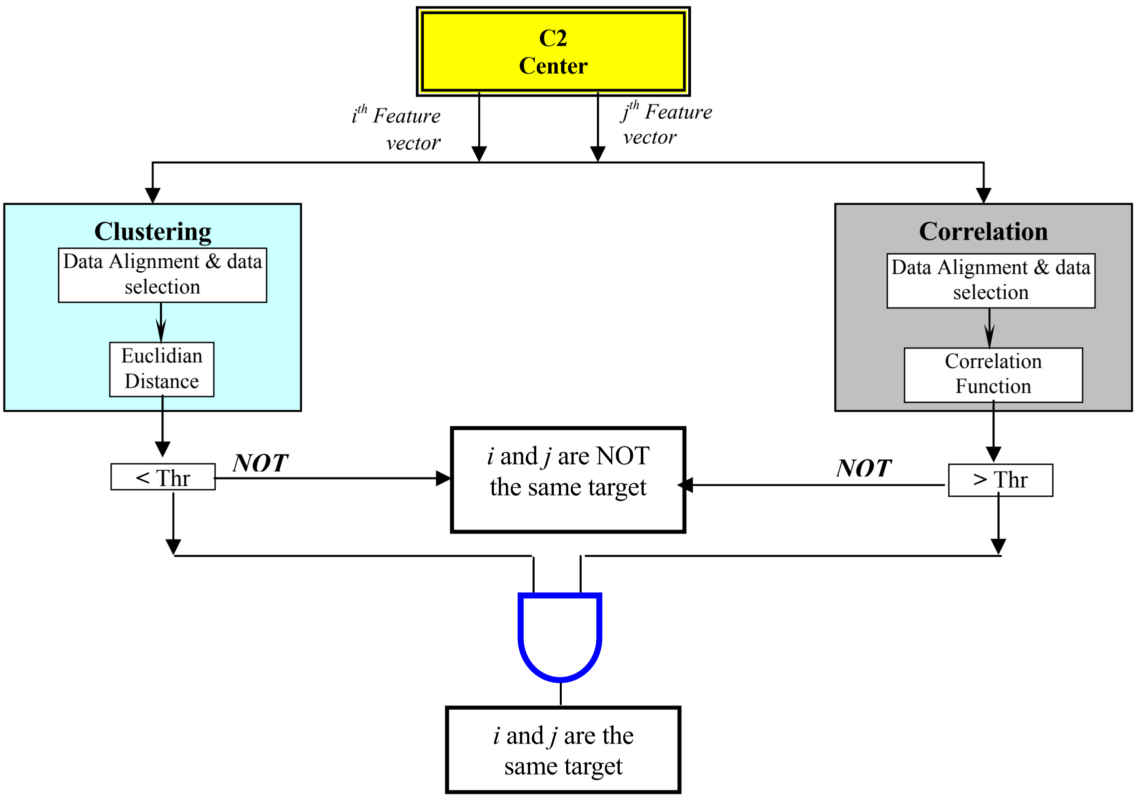

Figure 6: Proposed solution for position fusion.

The fusion results are shown on the fused tactical picture snapshot is given in Figure 7.

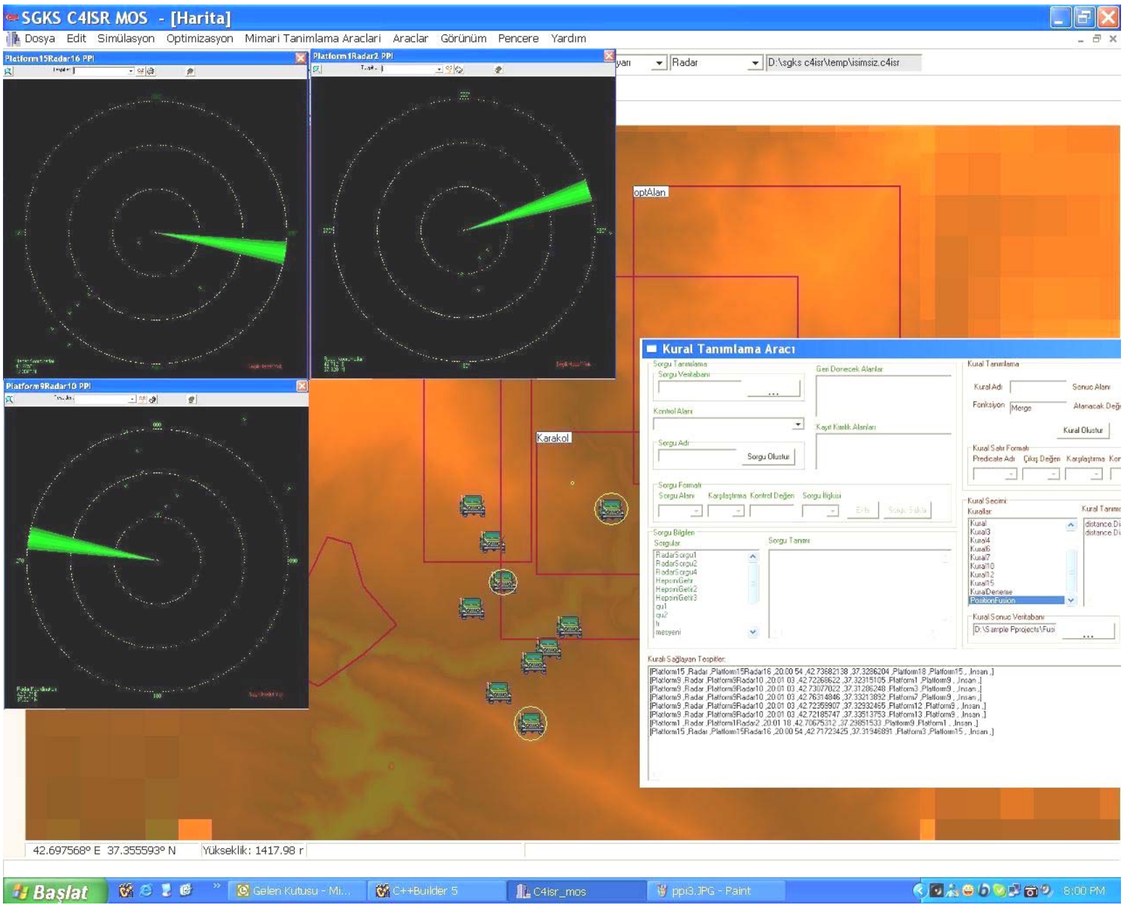

Figure 7: A fused tactical picture snapshot for the given test scenario.

5.0 CONCLUSION

In this paper, a generic and expandable rule-based fusion tool on a command control system is presented. In this high-level fusion tool, rules can be defined during run time and the whole system execution process can be customized.

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