Effectively Utilizing a 3rd Party 3D Visualization Component in a Discrete Event Simulation Environment for Joint Command and Control (JC2)

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ABSTRACT: *A 3rd party 3-dimensional visualization tool (developed by the Council for Scientific and Industrial Research (CSIR)) is being used to visualize and assist with the development of a synthetic environment for joint command and control technology research. The visualization tool is based on the OpenSceneGraph toolkit and dynamically linked to a discrete event simulation environment. The visualization interface allows the visual scene to be efficiently and effectively updated from simulation events. A graphical user interface is also incorporated to manage the visual scene. The 3D visualization tool has recently been used to develop a simulated joint air picture display console towards the realization of automated decision support. This paper will report on the various techniques investigated for visualizing the air picture, sensor fusion and track management information from a Quantized Discrete Event Simulation Environment. Experiments were also done with various techniques for real time user interaction with the display console. The resulting joint air picture display console has already been successfully demonstrated during defence force interoperability exercises.*

1 Introduction

Joint Command and Control (JC2) requirements have brought about the need for research into developing systems to perform Command and Control (C2) operations as discussed by Le Roux [1]. This paper describes the integration of simulation and visualization to realise a single JC2 system which is a stepping stone to achieving automated decision support.

3D visualization has become a critical tool for use within modelling and simulation (M&S). Even more critical is the need for real time visualization as discussed by Holmes et al [2] which is of importance in C2. 2D displays should not be left out of the JC2 equation as there are inherent needs of JC2 which require both 2D and 3D visualization. It has been shown by Smallman et al [3] that both 2D and 3D displays provide complementary advantages in providing information which is available to the user. Smallman et al [3] concludes that 3D displays provide realism while a 2D display can provide more intuitive information without the ambiguity 3D displays can produce. Utilizing a visualization component effectively can produce a system which will aid a commander to make effective decisions.

The main aim of visualization must be to present the data to maximize the effective information transfer so as to support decision makers and to increase their situation awareness. Ultimately it must speed up the OODA (Observe, Orient, Decide, and Act) loop. This is a not a trivial problem. Summers et al [4, 5] speaks about the possible complications in a visualization display for commanders when used for decision support:

- inadequate or poor – quality information,
- misinterpretation of information,
- conflicting information or choices,
- too much information [4]

Summers et al [4, 5] goes on to show that 2D and 3D applications are typically handled in separation from one another. This is evident as separate systems are being developed which address either 2D or 3D in isolation. 2D and 3D display is integrated in our system to maximize information availability and address the display complications shown above. Real time user interaction with the live air picture display is another requirement. These concepts when coupled with a discrete event simulation provide the developer with various challenges. The system was created with the following functionality:

- joint air picture display
- visual scene management user interface
- real time aircraft track selection
- sensor fusion visualizations
- instant switching of 2D/3D visualization
- incident management

The Background and Related Work sections of the paper show how the simulation requirements expanded from a Ground Based Air Defence (GBADS) Simulation capability as discussed by Naidoo and Nel [6] to Joint Command and Control (JC2) capability. A use case of the application is given which is utilized throughout the paper. Requirements and challenges for Joint Command and Control are shown. The integration of visualization and M&S is presented after which the visualization results, solutions and features that were produced from the system are shown. The system was used in interoperability exercises. Lessons learnt from these exercises are discussed. How visualization performance was in turn improved from the lessons learnt is then discussed.

Finally future work is discussed. A conclusion on how to effectively use a visualization component in simulation is drawn. This sets up a basis for further research and development towards automated decision support.

2 Background

The modelling and simulation capability has been shown to be very successfully in previous applications. The main focus in the past was GBADS [6], [7]. Due to the large success of those implementations further requirements have been realised towards interoperability and joint command and control [1].

2.1 Viewer Interface

The previous simulation viewer interface was time based XML [7]. This protocol was however limited to being from simulation to the viewer and not from the viewer to simulation. For a commander to effectively interact with the display and provide feedback back into the simulation the latter link (from viewer to simulation) formed a critical requirement.

2.2 Gateway

A gateway was developed to provide the simulation with the capability to route and filter information into and out of the simulation. The gateway also caters for logging, playback of simulation events, connecting to GBADS [6] simulation and other external simulations for computer generated forces. This provides sensor information from external systems (real world) and simulations and also connecting to other simulation nodes.

3 Related Work

3.1 Discrete event simulation

Discrete event model representations have found application in many software simulations. The models' (entities') behaviours are simulated as a series of events at points in time [8, 9, and 10].

Schriber and Brunner [11] provide detailed study into the inner workings of discrete event simulation. The simulation utilized in this paper is described by Duvenhage and Duvenhage [12, 13]. It explains the evolution of a distributed parallel discrete time architecture to quantised discrete event architecture.

3.2 3D Viewer

Duvenhage et al [7] describes the development, requirements and initial application of the visualization analysis tool. Requirements from Command and Control and other Competency Areas of CSIR have initiated further support of the viewer features. These are as follows:

- 2D map view
- 2D heads up display (HUD)
- 3D-Shape and 2D-Icon support
- Mouse, key call-back functions
- Geographic Information System (GIS) feature support
- Multi Layer Terrain support
- Terrain overlay support
- Switching between Terrain view and GIS–only view

4 Joint Command and Control Simulation Requirements and Challenges

The urgency of requirements to be realised necessitated the rapid development of systems to occur. Figure 1 shows the requirements of the desired system for JC2.

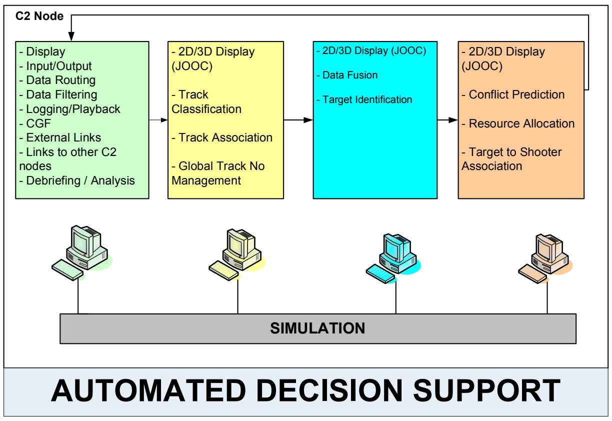

Figure 1 Simulation system requirements for JC2

4.1 Application Use Case

The simulation via the gateway discussed in Section 3.3 currently displays aircraft track information (position, velocity, hostility, etc.). Each aircraft (simulated and real) is detected by a number of sensors (simulated and real). A particular aircraft may then be associated with multiple aircraft tracks. An operator dynamically identifies and groups tracks which may belong to the same aircraft. These groups are then visualized as higher level 'fused' tracks. Suggested associations are provided as a guideline for the commander. Further enhancements include an incident tracker and a basic collateral damage estimator. These features will be touched on within this paper.

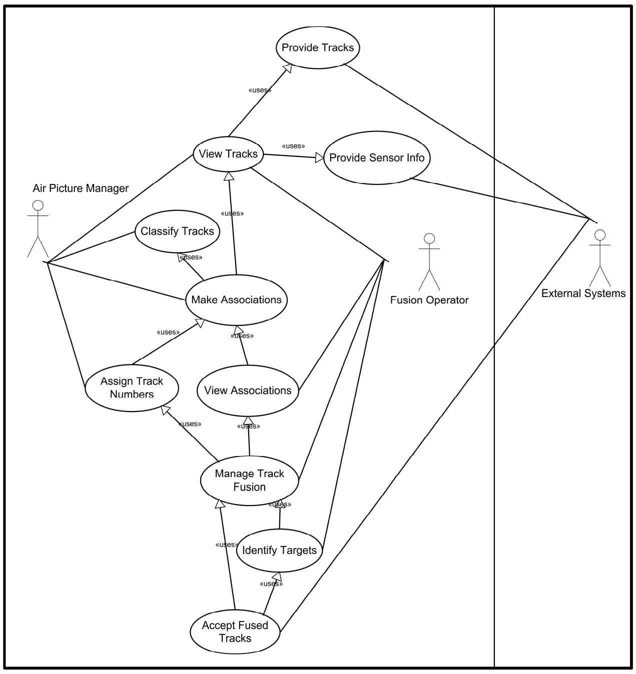

Figure 2 Use case for JC2

4.2 Situation Awareness and the Vision towards Automated Decision Support

A novel system is presented which addresses the issues of visual uncertainty and information availability. The main aim is to aid JC2 personnel in terms of decision support by facilitating situation awareness. The larger challenge is automated decision support: techniques need to be developed to address data validation, classification and identification at all levels within the JC2 structure. Table 1 shows the list of joint functions. The highlighted item is the one initially addressed by the system presented here. An initial effort is made in terms of suggested association for sensor fusion. A joint air picture display coupled with user interaction and 2D/3D visualization provides the capability to handle these challenges. The system is flexible and configurable by means of an Extensible Markup Language (XML) scenario file.

Table 1: Joint Functions (Le Roux [1])

Function	Description
J1	Personnel
J2	Intelligence
J3	Current Operations
J4	Logistic Support
J5	Future Operations
J6	Communications and Information Systems
J7	Training and Exercises
J8	Civil Military Cooperation
J9	Host Nation Support

4.3 Feature/System Integration

Existing systems made use of multiple displays and consoles to achieve the joint command and control tasks. Figure 3 shows features of previous systems. One of the requirements for JC2 was a single flexible integrated system which incorporated all of the previous system features together with the current visualization and real time user selection requirements.

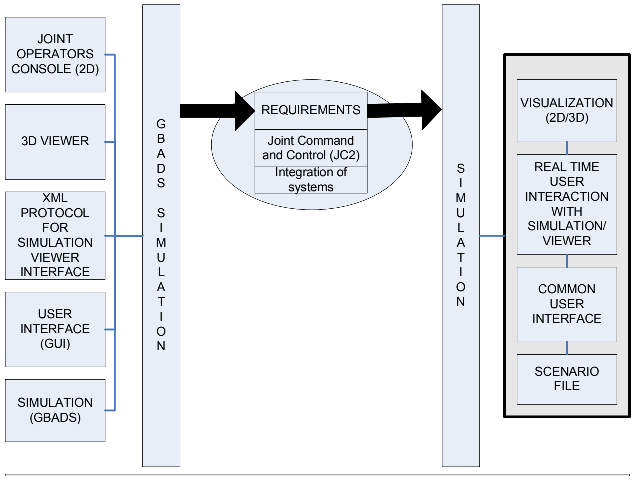

Figure 3 Feature and system integration/addition of previous systems

4.4 Visualization Goals

Visualization provides a different way of analyzing data to collect information. 2D and 3D displays offer various views of the information and when combined effectively within a display can allow a user to achieve the required level of situation awareness to aid in decision support. The following has been identified by Summers et al [5] as some of the crucial features which visualization should have:

- fusion of data,
- improve estimates by enhancing simulation output by using visualization as opposed to going through arrays of data as shown by Holmes et al [2],
- combine multiple information sources,
- reduce uncertainty,
- show alternate views of the same situation,
- notational symbolism (2D symbol or 3D model),
- available and interpretable information as discussed by Summers et al [5].

A 3D display does this by presenting the data spatially. Smallman at al [14] reports that 3D perspective views may be less useful for information availability than a well designed 2D display in certain command and control (C2) tasks.

Le Roux [1] states the 2D and 3D visualization capabilities which should be considered for this simulation system. He also adds that a “mix of 2D and 3D visualization” be supported. Switching between 2D/3D easily creates additional mechanisms for operators to understand a given situation. The visualization goals specific to our scenario are as follows:

- aircraft track display,
- icon representation,
- GIS features mixed with multi layered terrain,
- track history,
- visual scene management,
- instant 2D/3D switching,
- sensor fusion control and display,
- suggested association display for sensor fusion,
- text track information.

4.5 Real Time User Interaction

An operator requires the ability to manipulate information (aircraft tracks in this scenario). This needs to be performed in a timely manner so as not to hinder the operators’ decision.

Aircraft Track Selection Challenges

Live exercises can produce a large number of tracks which result in display clutter. To aid the commander’s selection a track filter is required. Another issue involved with track selection is track overlap. This is seen in the 2D display where multiple tracks are viewed as one track or as overlapping tracks which makes selections difficult.

4.6 Incident Management

Incident management does not form a substantial part of the visualization requirements. It does however bring about critical JC2 requirements. Live operations (See Section 7 Interoperability Exercises) have resulted in this requirement. The visualization offers the commander a live joint air picture which would be used to select tracks and assign them as an incident or/and a resource assigned to an incident.

5 Integration of Visualization and Simulation

The viewer was dynamically linked to the simulation. An interface file was used to utilize the display functions. This method provided flexibility in terms of the use of the virtual simulation.

5.1 Real time visualization and discrete event simulation

The critical requirement in terms of C2 is that the information needs to be trusted, well defined and clear.

Some of the main difficulties are:

- Events are time driven. For each time interval several events may be occurring simultaneously. [2].
- Single behaviour-based actions (like selections) can set off multiple simultaneous responses [2].
- Computer graphics should provide the user with multiple world views which may contain many simulated objects and events [2].
- There is no industry standard for display frame rates unlike the movie industry which uses 24 frames per second. An unofficial standard frame rate of 30 frames per second [2] is used which places constraints on hardware and software for real time visualization.
- Smooth motion requires that visual components be shown at the correct position and orientation a number of times per second. [9]

5.2 Updating the Display from Events

A service was created to handle the interface between viewer and simulation. The simulation stored the state data from events in temporary structures which were parsed continuously through the simulation current time updating the viewer. The use of multiple structures catered for several events occurring simultaneously. This was evident as long as the simulation did not lag behind time. These structures were updated on events. The need for an alignment service was realised because the state of an entity is given at discrete but possibly random sets of points in time from the simulation. This becomes important when different external sources are used to get information to the simulation. Thus the events would not produce an accurate representation of the actual visual scene without the alignment. The viewer contains key and mouse callbacks. These were created to enhance the real time user interaction with the visualization. Callback functions enable user selection response times to be real time as the callbacks are independent of the objects trigger frame used in the simulation. The final result was a successful real time simulation with 2D/3D visualization output and real time user interaction with the display scene.

5.3 Alignment Service

Alignment was a required service in the simulation. Temporal alignment is a must when working with multi sensor fusion applications and real time applications as discussed by Mitchell [15]. *T (t)* can be referred to as the transformation which maps local sensor time *t* to a common time axis. The following simple algorithm was used to time align all tracks from multiple sensors (simulated and real):

- $TargetTime = CurrentSimulationTime + SimulationTimeIncrement + TrackOffsetTime\ (Specified\ in\ Scenario\ File)$
- North, east and down (ned) orientation axes are used.
- $nedVelocity = nedVelocity * (TargetTime + TimeStamp\ (Sensor\ Observation\ Time)$
- The new position of the aircraft track is then calculated using its ned spatial reference model (SRM). The original position of the aircraft track in latitude, longitude, altitude (lla) is used as the reference point for the ned SRM.
- $SRMConvertPosition(lla, ned, lla)$
- The track is then time stamped with the new target time.
- $NewTimeStamp\left(\begin{matrix} Aligned\ Sensor \\ Observation\ Time \end{matrix}\right) = TargetTime$

This service also allows online prediction of the future positions of the aircraft tracks. This feature gives a commander the ability to access a future predicted display. In command and control this adds great value to the decision making process. A user interface was utilized to perform this on the live/simulated air picture.

6 System Application and Results

The following sections show the results of the system. These results were taken from simulated exercises as well as live exercises.

6.1 System Outline

The system as configured for the joint command and control use case accepts aircraft track information. This is presented in the visualization using military symbolism (MIL2525b). 2D map view is the default view used. 3D perspective view is available via the GUI. The user interface presents online display features to the user.

6.2 The Scenario File

The system scenario file is in XML format. The file specifies the simulation services which will be utilized. Viewer configuration data (Terrain, GIS and default settings), network settings (addresses) and Gateway routes and filters are also specified within this file. The configuration of this file allows instances of the same system to be effortlessly used on multiple nodes.

6.3 Visual Scene Management

Visualization needs to be managed. Tolk [16] talks about a common graphical user interface when using simulations as decision support systems. He says that the roof of the architecture of requirements for simulation systems used for decision support is a common graphical user interface.

The GUI has a window for each required service of the system (Display, Gateway, Alignment and Incident Tracker). The display window is used to manage the visual scene. The GUI features were provided directly from the JC2 requirements. The current display window contains 2D/3D switching, multi level GIS layer switching and multi layer terrain mixing as well as switching(on/off) time based track history, track filtering, and track history filtering based on track selection/s.

2D Map and 3D Perspective View

Instant switching of 2D map view and 3D perspective view allowed a user to get clarity of track information. One example is track altitude. When a number of tracks are fused it is difficult in a 2D map view to identify which tracks are contributing towards the track altitude.

Track History

Track history gives the trail of the aircraft and show where the target came from. A large amount of tracks can be present on screen at any given time. The track history selection filter allows the user to view the history for the relevant tracks only. This contributes to solving one of the possible complications discussed in the introduction, which is 'too much information'. Figure 4 displays track history when seen from both the 2D map view and the 3D perspective view. 2D view portrays where the tracks came from. 3D is useful here to view the altitudes of the tracks.

GIS Feature and Terrain Layer Switching

The GIS feature layer switching together with the terrain mixture provided an intuitive feel for location. Having GIS data displayed without terrain gave a familiar radar type screen to the commanders. Figure 5 shows how the use of a mixture of terrain layers (satellite, spot data) and GIS features improves the user's location awareness.

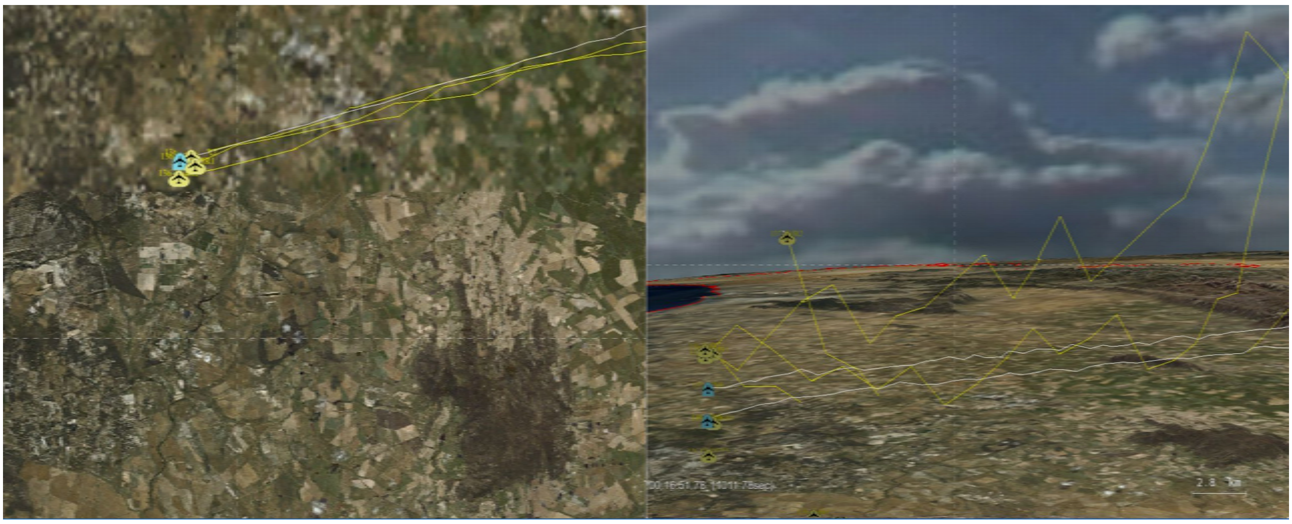

Figure 4 2D map view and 3D perspective view of tracks and track history

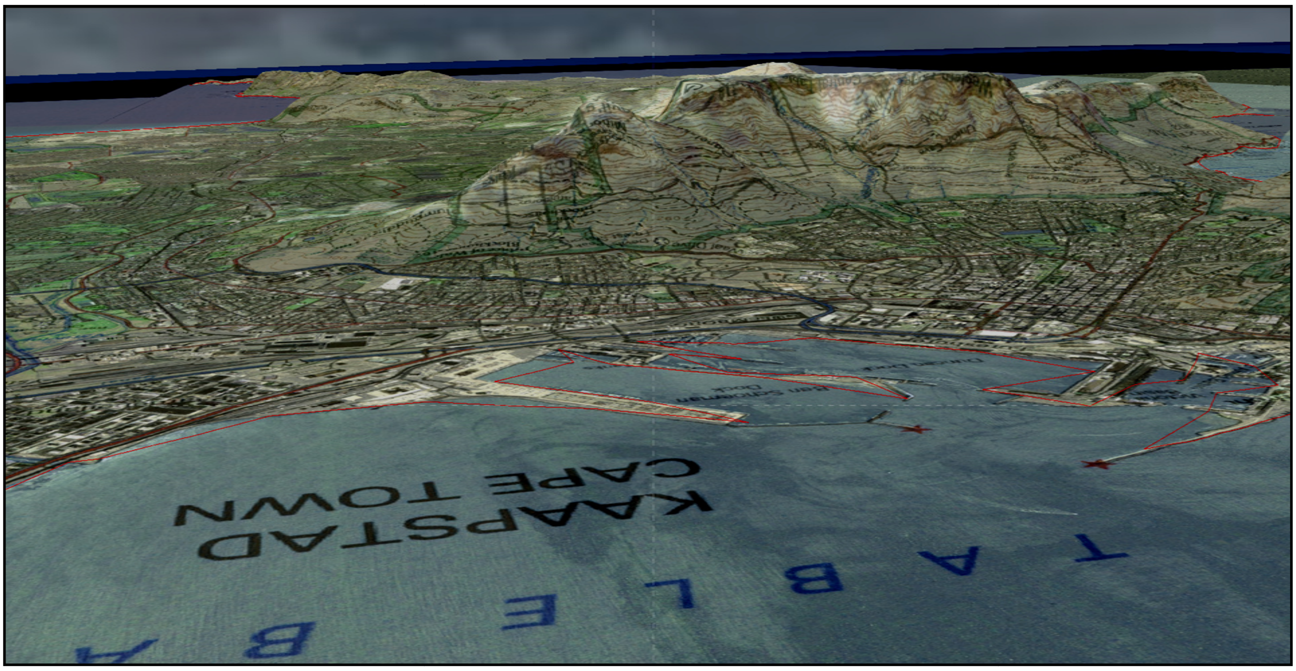

Figure 5 Mixture of terrain layers and GIS features

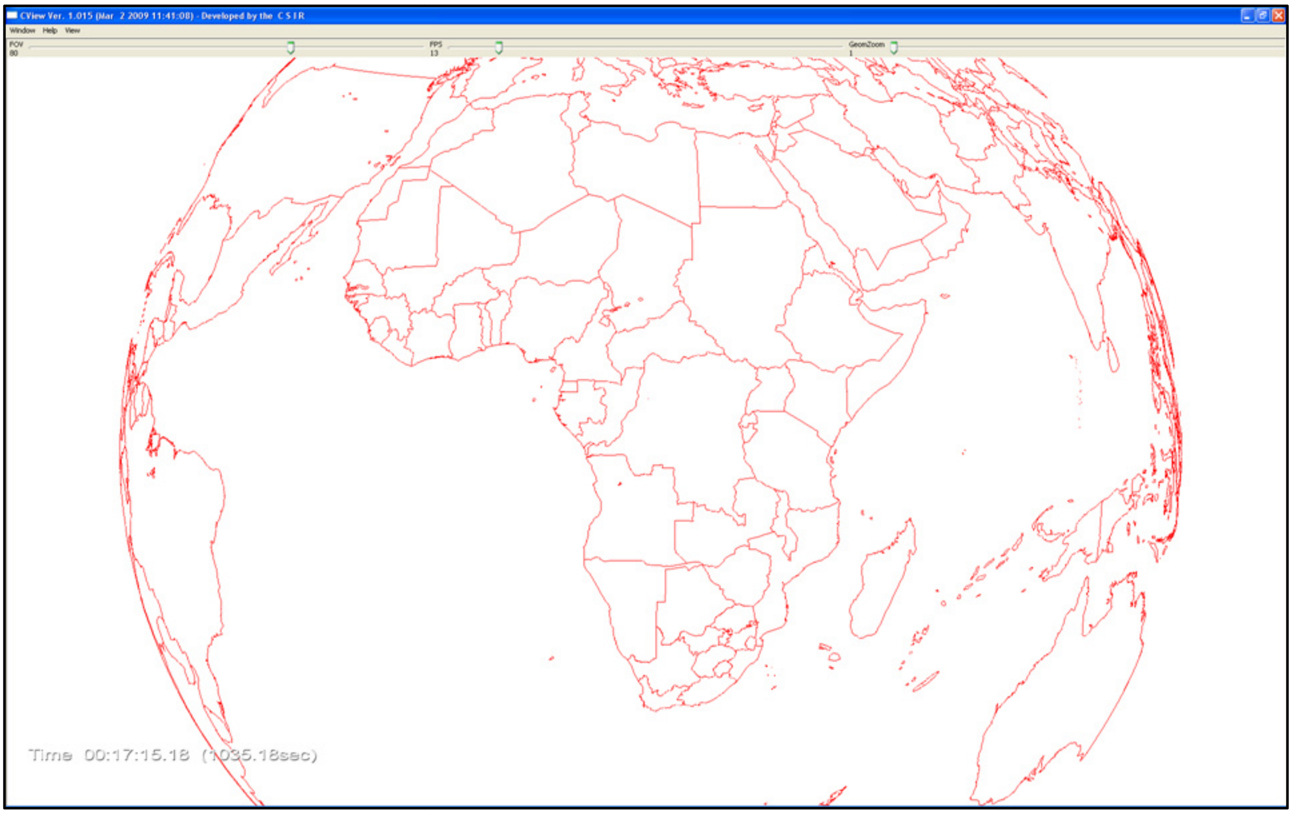

Figure 6 GIS features without terrain (White background shown (normally black) to emphasis GIS)

Track Filtering

Track filtering was a large requirement which resulted from use of the system in live exercises. An example that shows the need for track filtering is when a commander is assessing a live joint air picture and hostile aircrafts enter the picture. One part of incident management (See Section 7 for a discussion on incident management) consists of tracking the hostile aircraft along with assigning possible friendly aircraft tracks. At this point the rest of the aircraft tracks can distract and block the visual scene. The filter allows the commander to only view the current incident which increases the situation awareness.

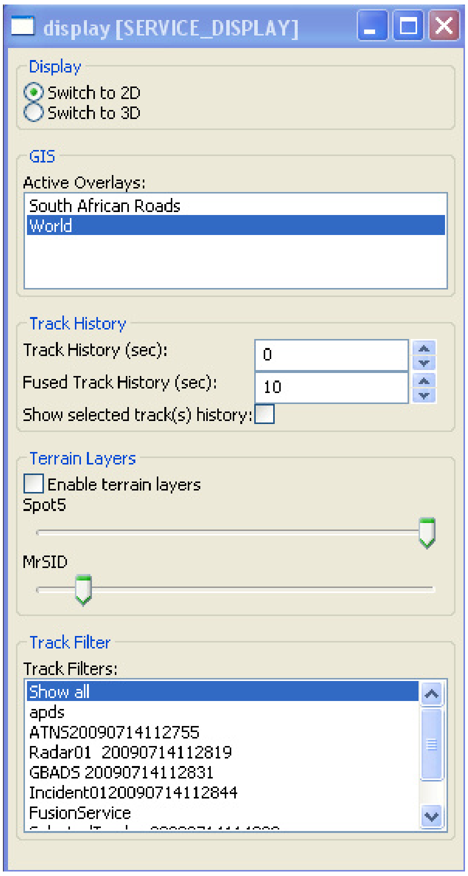

Figure 7 Visual scene management GUI

6.4 Decision Support

This section presents the results of the simulation. Results are in the form of screenshots taken during lab testing and live exercises and operations. This shows how the system has successfully implemented the initial requirements for a JC2 system. The use case discussed in Section 4.1 of this paper is applicable to the results shown. A joint air picture is formulated. Tracks which appear to belong to the same aircraft are grouped and selected. A *fused* track is then shown. To assist with track selection decisions, suggested associations are shown as hints to the commander. Tracks may be filtered to show only fused tracks. Figure 8 and 9 show the suggested associations and fused picture respectively.

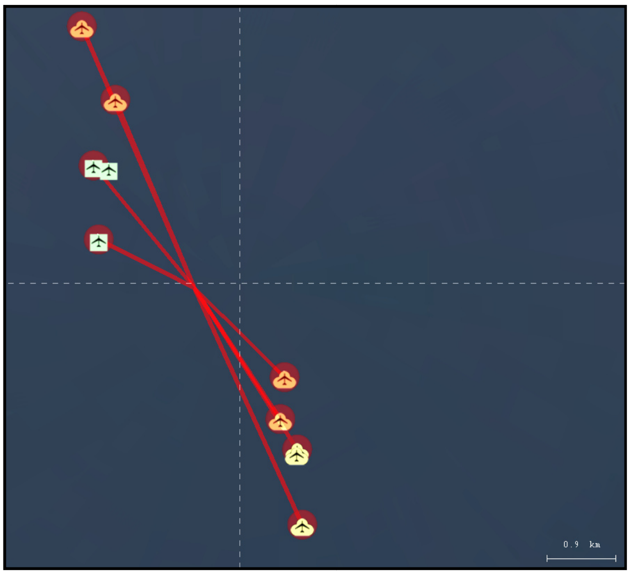

Figure 8 Suggested associations

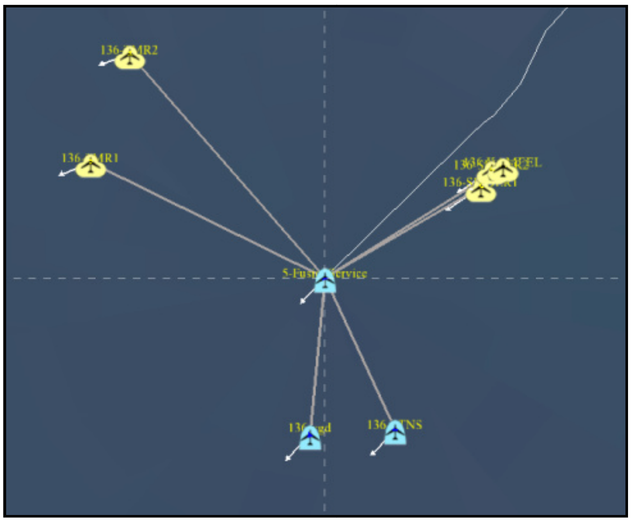

Figure 9 Sensor fusion showing selected tracks and fused track

6.5 Track Selection Techniques

Four track selection techniques were investigated:

- Fuzzy selection, a fuzzy distance (user configurable) is used to select all tracks within that fuzzy distance from a reference point.
- Point and drag outline (Windows Style), All tracks within the outline box are selected.

- Circle Selection, Selections are made by use of circle whose size is controlled by the mouse scroll wheel. All track/s within the circle are selected. Holding down the control key allows for multiple selections/de-selections.
- Individual Select, A cursor placed onto the current mouse position for individual selecting. Holding down the control key allows for multiple individual selections. The system finally used a mixture of Circle Selection and Individual selection.

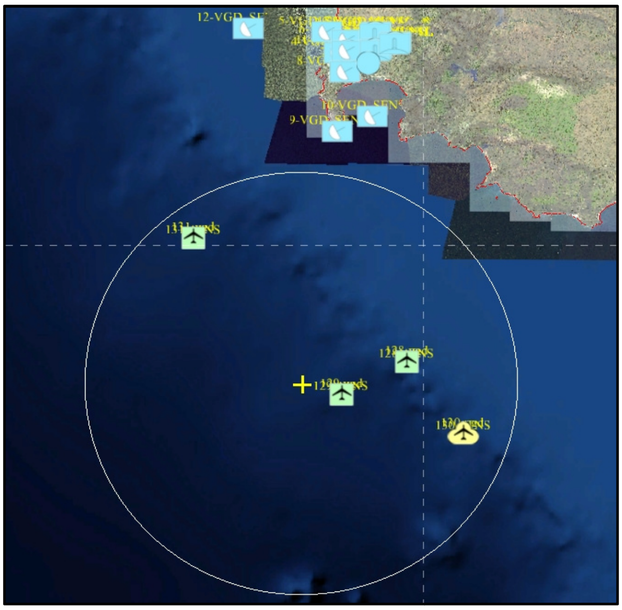

Figure 10 Track selection circle showing selected tracks

6.6 Track Overlap in 2D display

As discussed in Section 4.5 track display ambiguity of selection can occur. Track selection needs to be a quick decision and one must consider that the tracks positions are continuously updated. The following methods have been identified as possible solutions to the problem.

Auto Zoom

The viewer (in 2D mode) will automatically zoom into the display scene thereby allowing more screen space per track to view the tracks at their individual terrain locations. The issue identified here is the sudden change in view space which would be automated. A commander might find this change confusing and thus time consuming and delaying the decision making progress.

GUI Track List Popup

The popup is a GUI naming the track numbers/details and selection can be made from the GUI listing. The issue identified here was with achieving separate GUI windows to be embedded in the same view window as the viewer.

Track Source Filter

Within the display User Interface a track filter which filters tracks on source and incident (Incident Management). The one issue identified is that the tracks in some cases may all come from one source. Figure 4 shows the track filter.

Individual Unique Selection

Tracks will temporarily stop being updated. Using a basic spread algorithm tracks will be spread out in a uniform circle around the reference point where the overlapped tracks occur. The issue identified here was the radius calculation of the temporary circle.

The two most effective solutions which covered the issues were the track filter and the individual unique selections. Figure 11 and 12 show the overlap issue and the individual unique selections.

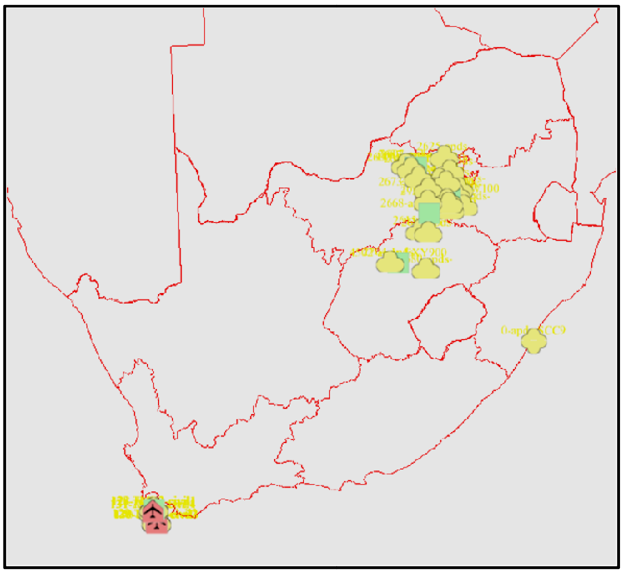

Figure 11 Track Overlap Issue

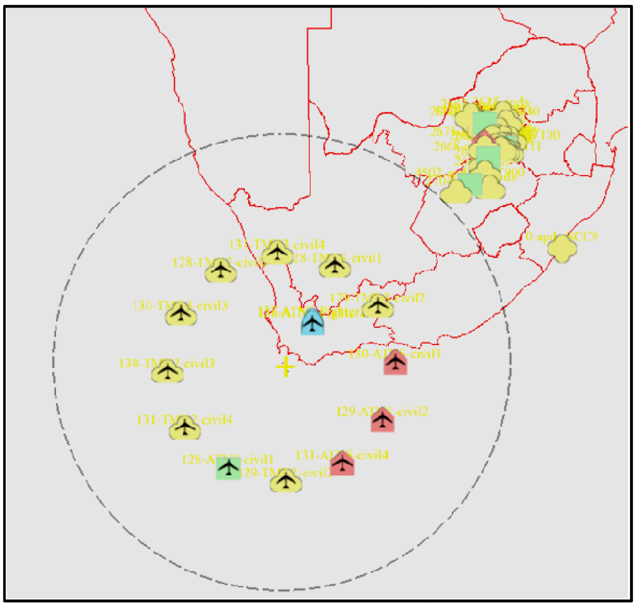

Figure 12 Unique Track Selection provides a solution for the track overlap in Figure 11

7 Interoperability and Operational Exercises

A Joint Command and Control Test Facility is currently being established [1] within South Africa. From this live exercises have been held to test and showcase systems from research and industry. South Africa is also receiving attention from the global scene regarding hosting of international events. This has allowed the system discussed in this paper to be utilized in live operations. Preceding these exercises the system had to be tested in the lab. An air defence simulator [6] (GBADS simulation) was used to inject simulated computer generated forces into the system discussed within this paper.

7.1 Interoperability demo/exercise

This exercise demonstrated the use case discussed in Section 4.1 of this paper. Five nodes with the system discussed within this paper were setup to receive aircraft tracks. Three of the nodes received air, ground and maritime tracks respectively. The fourth node was used to visualize the higher level fused tracks (See section 6.4 Decision Support for Sensor Fusion results). The fifth node was used to route and filter all aircraft tracks from external and simulated systems. This was done via the gateway (see Section 2.2 of this paper) and a tactical data link.

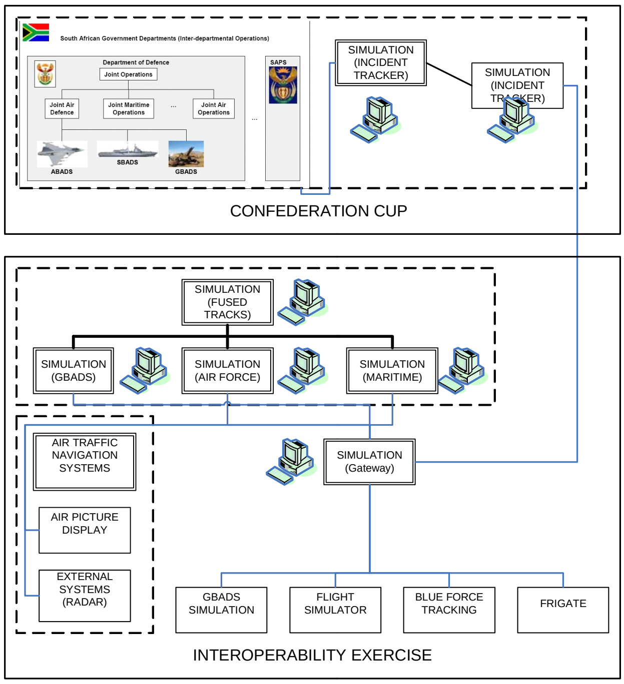

Figure 13 Interoperability Exercise and the Confederation Cup. South African Government Departments diagram from Le Roux [1].

Figure 13 shows the how the systems were connected during the respective exercises and operations. The computer icon represents a node.

7.2 Confederation Cup

The Confederation Cup is a football tournament hosted by FIFA (The Fédération Internationale de Football Association). It was held in South Africa in June 2009. Joint Command and Control is vital in events of this nature. JC2 includes include stadium protection and airspace control. The system was used as an Incident Management Tool to track and log incidents using a live air picture display together with a user interface.

7.3 Lessons Learnt

Lab testing and live exercises provide feedback from the use of systems and allow developers to modify/optimize the system according to requirements. Staying in context of this paper the lessons learnt were as follows:

Viewer performance

Large amount of data (aircrafts tracks, track history, large GIS sets, large Terrain databases) coupled into one viewer can put a strain on hardware and software. This caused the simulation to lag behind time.

Viewer integrated into common user interface

The viewer is shown within its own window. Some difficulty was noted when one screen is used and the viewer windows has to be minimized.

Tactical data link used to connect nodes

Tactical data link used to connect the simulation presented challenges in time management and data distribution. This work will be presented in a separate paper.

7.4 Scope Timing of Display Functions

Scope timing of the visual/display functions has allowed the optimization of the viewer so as to prevent the viewer from causing the simulation to lag behind in time. The timing output showed number of times that each function was called during the simulation along with mean time, min time and max time of the call. From this timing output code optimization was successfully applied.

8 Future Work

This research into JC2 development was the initial phase of the establishing a JC2 national test facility. Le Roux [1] has identified the high-level requirements for JC2 test facility. From the successes of live exercises and operations further research will continue towards the goal of automated decision support. Other concepts to be developed in conjunction with the present system include resource allocation, conflict prediction and shooter to target association.

9 Conclusions

The JC2 simulation presented within this paper is initial phase of the JC2 interoperability requirements. Visualization has been identified as a must have in a JC2 simulation system. A mix of 2D and 3D visualization has been identified as an importance concept of providing information availability to the commander.

Results have demonstrated successful realisation of JC2 requirements within a single integrated system. This has been a critical achievement as it strengthens the confidence of the team as moving in the right directions towards fulfilling all the JC2 requirements needed for the JC2 national facility

This console can be used as a standalone viewer or as a tool whereby a live operator influences the real world air picture from the virtual environment. The value of such a joint air picture in achieving situation awareness and complementing decision support may now be evaluated.

10 Acknowledgements

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