OBJECT TRACKING USING MULTI-SOURCE PERSISTENT SURVEILLANCE

Richard L. Barrett  
Christopher M. Camp  
Nicholas W. Knize  
Richard L. Landis  
Raytheon, Intelligence and Information Systems  
Garland, Texas 75042  
Richard_L_Barrett@raytheon.com  
Christopher_M_Camp@raytheon.com  
Nicholas_W_Knize@raytheon.com  
Richard_L_Landis@raytheon.com

ABSTRACT

Tracking moving objects through remote sensing using Doppler shift is a well-established technique of radar technology. Once the moving objects that are of interest are identified, revisiting every few seconds allows tracking the objects’ paths. Similarly, video imagery can be used to track objects of interest using electro-optical change detection to identify and track moving objects. However, tracking an object by maintaining continuous surveillance of each object by a dedicated sensor is a very expensive use of sensor resources. Techniques are presented that support persistent surveillance by using multiple sources and types of remotely sensed data to track objects of interest. Longer gaps in remote sensor observations are possible using electro-optical change detection and by automatically determining revisit rates. Techniques are presented for improving geolocation and track fusion using pre-existing geopolitical information and object characterization, in addition to the current remotely sensed data. Temporal geolocation techniques support forensic analysis for law enforcement, traffic management, and military intelligence applications.

BACKGROUND

As early as the civil war, balloons were used for aerial photography of the battlefield. Later, aircraft and finally satellites improved on the technology. Photography is used to make and update maps more quickly and provide many new types of cartographic products. Since remote sensing can also provide operational intelligence over denied land masses it became a key technology for military and political strategists. In the news today, we hear about information warfare, and new military spokesmen speak of the “ops tempo” of modern warfare. In these rapidly changing environments, timely intelligence is critical. As a result, we have seen the amount of reconnaissance information explode by orders of magnitude. This creates a problem of sifting through all the data to find information related to an operational intelligence problem.

In the case of reconnaissance, we wanted to know about things that change slowly: roads, bridges, and disposition of forces. In addition, political maps provide insight to the environment in which we operate. Remote sensing can look at crops, industrial output, construction and other factors and supply economic information.

In contrast, surveillance requires timely updates to information to track activity. Detecting and tracking the activity level of an object can be very difficult to achieve over large areas. The question is how much information is enough and can we get sufficient information to monitor targets based on the level of activity of each target. This introduces the idea of persistent surveillance. In this paper, we define persistent surveillance as the ability to revisit targets based on the activity level of each individual target within a given area of interest. If you want to follow a vehicle as it moves across the countryside, through a town and finally to where it stops you can just have an aircraft follow the vehicle with a video camera and maintain constant surveillance of the target. Unfortunately, there are many more potential targets than collection resources, so one collector per target is not practical. However, there are massive amounts of information collected by various remote sensing systems. If this information can be used, that may provide a way to achieve some of this capability. Finally, if sensors can get direct feedback on what data collection is needed, that would...
speed responsiveness and increase the effectiveness of the collection process.

Our problems include how to take existing remote sensing resources and use them more effectively, improve the tasking of those resources, and automate as much of the process as possible to meet the short timelines necessary to achieve our tracking goals.

ASSURED TRACKING WITH VARIABLE RATE MULTI-SOURCE IMAGERY (AT-VRMI)

Figure 1 presents a functional flow of the assured tracking processing chain. The assured tracking chain takes EO, IR image and SAR MTI inputs convert these inputs into observations and feed them into a Multi-Hypothesis Tracking (MHT) function that fuses the data into Moving Target Tracks (MTTs) for display.

Figure 1. Data Flow Graphic.

The Change detection function generates moving target indicators (MTIs) from pairs of electro-optic (visible and IR) images acquired at short time intervals. For example, frames of video, still images from a sensor taken sequentially, and (with the right corrections) images from two different sensors or sensor types. The outputs of the EO change detection are moving target indications, each with geolocation, speed, and direction. Each potential target may need further characterization to improve tracking of that target moving among other targets.

Associated with the change detection, the 3D model matcher looks at object shape and color to associate moving targets between previous detections and across gaps in time. This is not target recognition in the classic sense, but may be thought of as looking for unique signatures for each candidate target, perform a comparison to that unique signature on the next predicted observation, then refine and build on that unique signature in subsequent observations.

After associating a target through two or more frames, the output is now a visible/IR MTI. Like radar MTI, it identifies a target of interest with geolocation, speed, and direction. The Raytheon Precision Ground Tracker function then uses a Kalman filter to predict which MTI observations are tracking the target, then creates or updates tracks using whatever data is available.

The final block performs sensor retasking. The addition of more information can improve the prediction of when to collect more data. The targets also have behaviors that can be used. For instance, is the target on a road or off road? If the target is on road and the target has several miles to another intersection it may not be necessary to revisit as often. The time when the target is expected to be at the next intersection is an ideal time to look for the target again. What is of interest is whether the target took a turn or continued ahead. So, by combining road knowledge, acquired from map data, with the track data, the Retasker can make intelligent predictions of where the targets will be at some point in the future. The automatic sensor retasker then sends retasking messages to the sensor’s planning software.
SYSTEM ARCHITECTURE

Generalization of the system goes beyond the specific implementation used to integrate the separate components. First, it would be desirable to be able to insert new technology into the processing chain. Second, it should be possible to have more than one processing path. This implies the need to store intermediate data in an organized way. This is accomplished by incorporating a knowledge base (a knowledge data repository) in the design, which is shown below in figure 2.

![Figure 2. Assured Tracking System Architecture.](image)

The knowledge base keeps track of available data during the processing and also has metadata on what data is available from the external sources. When relevant EO data is detected by the tasking agent, it retrieves the images from the repository (e.g., an Image Product Library (IPL)) and spawns a task to the EO Change Detection function, which returns Observation Data to the Knowledge-Based Operations (KBO) database.

Depending on the nature of the observation, a task may be initiated to send the data to the 3D Model Matcher to further characterize the observation. When the 3D Model Matcher is finished processing, observation data with color model information is sent to the tracker to build track data. This information is then displayed on the user’s workstation. The track data also is sent to the retasker where road knowledge is used to determine when the next collection is needed and in what area to collect based on the expected position of the target. The output of the retasker is sent to the sensor planning software, which is external to the Assured Tracking system.

This architecture offers several advantages. The observations can be sent to different EO change detection processors allowing parallel processing during peak data periods. The EO change detection can also be optimized for one data type and the processor selected based on the input data. Trying to build a general EO change detector that handles large stereo pair images and standard resolution video equally well is not required if we can select the best EO change detection processor for the data. It is also possible to add additional characterization functions. For example, consider a LIDAR sensor in an aircraft or UAV. We could use high fidelity models and compare directly to the shape of the object detected by LIDAR. Just as the change detection could be optimized, another tracker could be integrated into the system. They could be run in parallel and work assigned to the best tracker based on the nature of the observation data. Multiple trackers could interoperate dividing a large area into smaller regions, allowing a larger area of interest or handling a larger number of targets in an area.
All of this is possible because a standard for observation data is defined that includes the geolocation information, speed, and direction of a target. Many other sources can provide this information such as ELINT collectors to allow for tracking ELINT hits.

ALGORITHMS

In addition to the architecture created in the Assured Tracking effort, we set out to make five improvements to existing algorithms.

1. **EO MTI** – In the initial work an existing change detection tool based on a static camera model was updated to allow it to handle a moving camera. It worked but clearly had limitations. Later work was based on a more sophisticated algorithm that was designed for a moving camera and moving targets.

2. **Behavior Pattern Analysis** – Group behavior is analysis of the behavior of targets and identifying groups. Groups of vehicles, or convoys, can pass each other head-on, overtaking and intersecting. Identification of targets and assignment to a group allows the operator to recognize groups and monitor unexpected changes.

3. **3D Color Reacquisition** – The original 3D model matcher recognized a target by shape and color to make a target stay locked in cluttered environments. The later goal was to add capability to handle articulated targets, for instance tractor-trailer trucks, and partial obscuration of targets.

4. **Improved Search Area** – Application of road knowledge to the tracking data can provide an improved probability to reacquire a target and track after a gap in observations. Road knowledge is used by the retasker to guess at the most likely locations to try to reacquire a target since the last observation.

5. **Improved Sensor Retasker** – The improved retasking algorithm makes the probability of finding a target better and can improve the speed of reacquisition, reducing false track ends and false track re-starts.

CHALLENGES

The greatest challenge in the development of this system is in the algorithm development for the EO change detection. The current technology is adequate under ideal conditions. The problem is that the real world conditions are not ideal. The decision to move to a moving camera model is correct, but these algorithms are not as far along in development. The next area with opportunity for dramatic improvement is the Target Characterization. As more multi-spectral and hyper-spectral information becomes available, the ability to identify specific targets and improve tracking could be achieved. The addition of high-resolution 3D technology, for example LIDAR, allows additional granularity to the existing model matching approach. Improvement is also needed in partial obscurations and articulated targets. In urban areas if a target is obscured by a building the system moves forward using the last known velocity and acceleration. Depending on what is happening when the target is not visible, target lock may be lost. When a tractor-trailer turns, it changes shape and the track can be lost.

On the tracking side the tracker is continuing to evolve. With this architecture we can also test other tracking implementations. Handling more targets at one time and improving the performance of the algorithm so it can be completed with less processing power at higher rates are the current approaches providing improved performance. The use of the knowledge base along with the application of intelligent agents can allow us to mine the data that is collected and to apply knowledge based prediction to some unique problems such as behavior pattern recognition.

Finally, for assured tracking to work in an operational environment, sensor system design has to account for the needs of the tracking system. The basic functionality is short notice retasking with areas of persistent coverage.

TESTING

Several problems are encountered in testing a system like this. First it requires a large amount of coherent data. Test data that is acquired frequently enough in time and located in the correct area of interest, to allow for EO change detection (for example), is difficult to come by. In addition, for testing and development of a target tracking system from multiple data sources, more than one type of data with common coverage is needed. Moreover, the content from
each data source needs to be consistent with the physical actions and events that took place in the environment. Simply “transporting” the data from one geographic location to another is not an option because the targets need to be in the same location when viewed from the different sensor sources.

An additional problem encountered is that the metadata available with existing test data is often inaccurate or non-existent, and is nearly always in a different format. Highly accurate and consistent metadata is required to properly develop and test the tracking function.

To solve the described problems, we developed the Situation Simulator (SitSim) which is shown below in figure 3. The situation simulation system is developed as a subset of the larger Enterprise Modeling and Simulation (EMS) system. The simulation environment allows us to create scenarios with moving vehicles and platforms along a pre-defined route, and obtain synthetic sensor data from multiple sensors as output. The simulated sensors include visible data, IR data, SAR data, and SAR MTI data. During 2005 work was done to improve and mature the Situation Simulator and develop an interface so data can be requested and retrieved for Assured Tracking.

![Figure 3. Situation Simulator.](image)

The portability of the Situation Simulator allows it to support many different tests and provides a consistent source of repeatable data to exercise and stress the Assured Tracking System. An environment with 1-meter imagery overlaid on DTED data creates the simulated terrain. The targets are 3D models that move across the simulated terrain. From the computer generated scene the various data collection types are simulated by the SitSim software tools.

### RESULTS

An example of output from the simulator is shown below (figure 4). The four quadrant example shows synthetic Electro-Optical (upper right), SAR (lower left), and IR (lower right) imagery with a three dimensional view of the platform performing its flight plan. The imagery products are used by the assured tracking algorithms to generate
tracks that are then overlaid on top of the synthetic imagery and displayed using electronic light table (ELT) software for further exploitation (figure 5). The project is still under development so only interim results are available. Right now we can track with gaps in data of tens of seconds, while longer gaps (e.g., minutes) are proving more difficult.

Figure 4. EMS SitSim Output.

The Assured Tracking system has been able to manage groups of targets, or convoys, and track the convoy in a fifteen-minute scenario as shown in the screen shot below. We are continuing to research improved methods to get the tracking data to support longer gaps. Our goal is 15 minutes.
Figure 5. Synthetic Panchromatic Imagery with Track Overlays.

REFERENCES