Open Architecture of a Counter UAV System

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ABSTRACT

Government agencies and military are seeing a rise in drones used for terrorism, destruction and espionage. As recently as a decade ago, UAV technology has been used only by US military. Today, dozens of countries manufacture and operate military-grade drones. Drone technology has been made available around the world. Anyone can purchase a drone from an online retailer. Western military operations as well as critical infrastructure protection agencies experienced multiple drone incidents in the last years, ranging from the use of weaponized drones by ISIS to drones flying over airports or drones breaching airspace of other critical infrastructure.

The emergence of threats caused by unfriendly or hostile drones requires a proactive drone detection in order to decide on appropriate defence actions.

In this contribution, an open architecture of a UAV detection system including decision support for counter-action is presented. The system is composed of multiple deployable sensor stations, an operation center comprising the operational picture display and the decision support component, and a communication bus consisting of a message-oriented middleware connecting the sub-systems and components.

The architectural design specifies the sub-systems, their constitutive components, the information and control flow between the components, the protocols used for data and information exchange, the functionality and responsibility of each component, and the functional parameters.

The designed architecture provides a blueprint for a UAV detection and defence actions decision-making system which will allow public protection agencies and military to react timely against threats caused by hostile drones.

Keywords: Drones, UAV, Counter-UAV, System Architecture, Open Architecture

1. INTRODUCTION

The commercial availability of small, remote-controlled or semi-autonomous aircraft - so-called "drones" or "UAVs" (unmanned aerial vehicles) - has increased dramatically in recent years. Smaller systems are now available in every toy store, larger (with a load capacity now up to 10 kg) can be built from kits by oneself or obtained via the Internet.

From pure toys and carrier platforms for professional film cameras to larger material handling systems, a wide range of civilian drones are available - and they are being used more and more often.

Companies are beginning to use them for various logistics tasks; police and rescue teams are using drones for achieving a better situational awareness or are planning to introduce them. In addition, there are various uses for science, agriculture, construction, art, inspection and monitoring tasks, etc.

At the same time, the rapid increase in the availability of drones to almost everyone also led to the emergence of new threats caused by unfriendly or hostile drones[1]. The threats are ranging from drones used to invade privacy, to smuggle drugs and weapons into prisons or across borders[2], drones flying over airports and thus jeopardizing aviation, breaching airspace of other critical infrastructure to weaponized drones used for terrorism[3], destruction and espionage.

In order to tackle these threats, a counter UAV system is needed, which contains as two main parts a drone detection component and a decision support component for counter and defence actions.

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The paper at hand describes an open architecture of a UAV detection system including decision support for counter-action. The architectural design specifies the sub-systems, their constitutive components, the information and control flow between the components, the protocols used for data and information exchange, the functionality and responsibility of each component, and the functional parameters.

The rest of the paper is structured as follows: Section 2 presents the use cases, which an operator may encounter when, using the system. An overview of the system is provided in section 3 and in section 4 the main components together with the main information exchanges between the components are described. Finally, in section 5 a brief conclusion is provided

2. USE CASES

Starting point of the architecture design has been the definition of a set of use cases for the counter UAV system.

The following use cases have been defined (**Fehler! Verweisquelle konnte nicht gefunden werden.**):

- Definition of air space control zones
- Observing and assessing consolidated tracks
- Assessing fusion results
- Receiving alarm
- Making an action decision

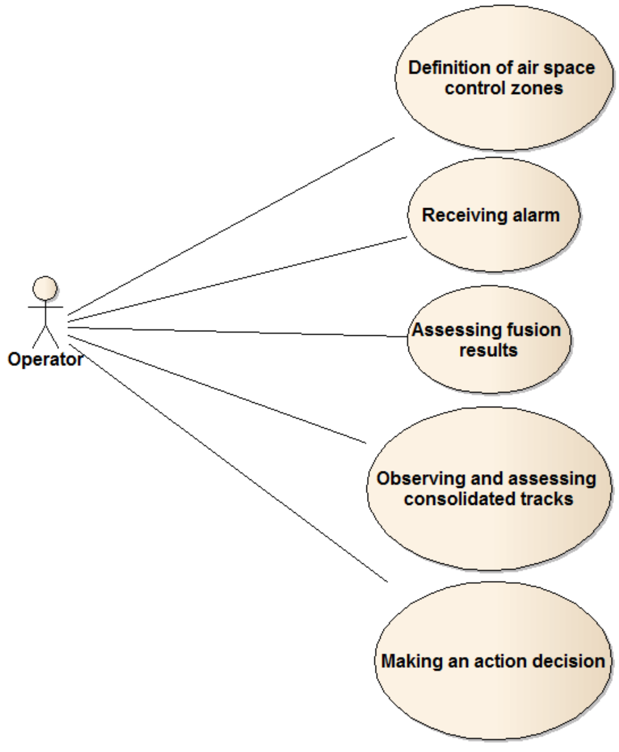

Figure 1: Use Case Diagram

Within the use case “Definition of air space control zone” the operator defines the zones, sections or sectors which shall be surveilled by the system and defines the surveillance task. For each zone or sector, the sensitivity and alarm generation parameters are defined.

Within the use case "Observing and assessing consolidated tracks" the operator observes and evaluates the tracks consolidated across multiple sensor sources. The track evaluation is fed into the fusion component.

The fusion results (i. e. the results of the fusion of tracks with other available information) will be displayed in a situation display. The operator may verify and evaluate them by cross-checking with the live video stream. These actions are performed within the "Assessing fusion results" use case.

Alarms generated by the system are provided to the operator in the "Receiving alarm" use case.

The fusion results as well as the alarms are forwarded not only to situation display, but also to a decision support component. This component generates a list of options for action and a suggested course of action and presents them to the operator. Based on the situation displayed, the generated alarms, and the suggested course of action, the operator makes a decision on how to react to the threat. These actions are performed within the use case "Making an action decision".

3. SYSTEM OVERVIEW

The system is composed mainly of two components; the sensor station and the operation center (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). These two components are themselves composed of a series of sub-components. The communication between the sub-components is performed via a communication bus (see Figure 3). The communication bus provides a publish-subscribe pattern and logical communication channels via so-called topics. In addition and depending on the implemented middleware and underlying network technology, different quality of service parameters may be configured.

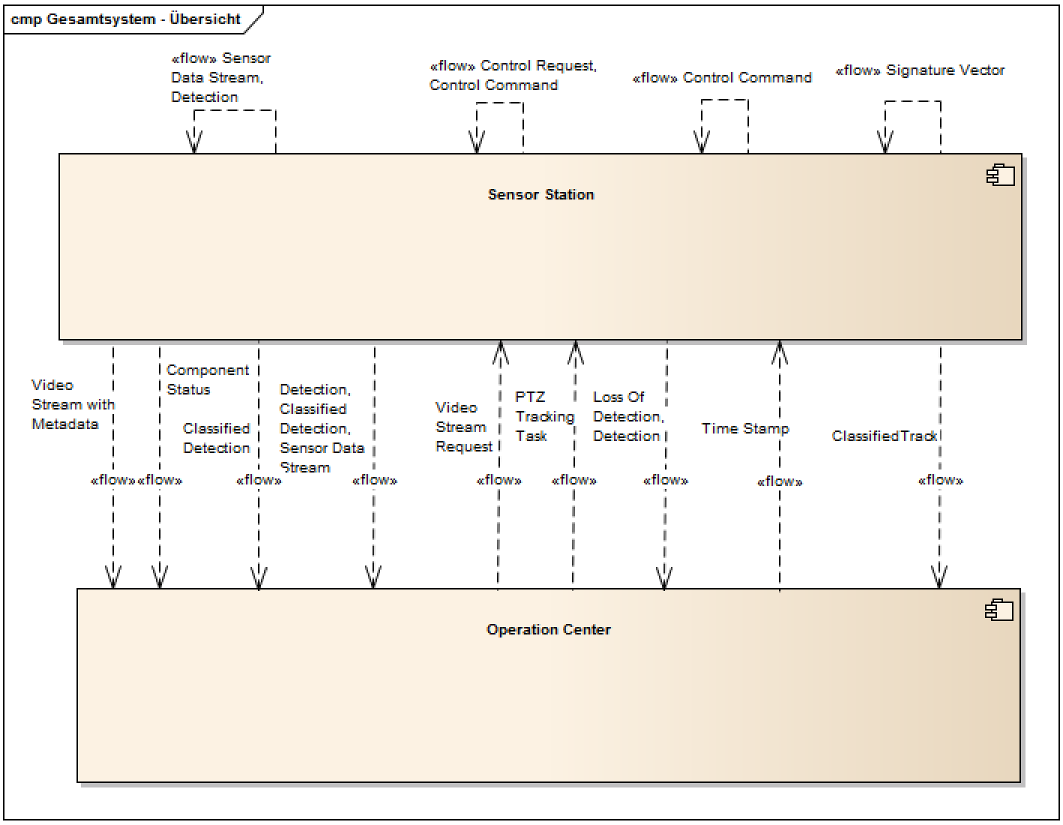

Figure 2: System overview.

Within each sub-component, a communication module is responsible for connecting the sub-component to the communication bus in order to send and receive messages. The communication module prescinds from the used underlying network technology and uses the IP protocol as the common layer for data and message exchange between sub-components. As an example, the communication module may use either an Ethernet or a WiFi network for message exchange.

The communication module is agnostic with regard to the used middleware (i. e message oriented middleware, web services, or CORBA).

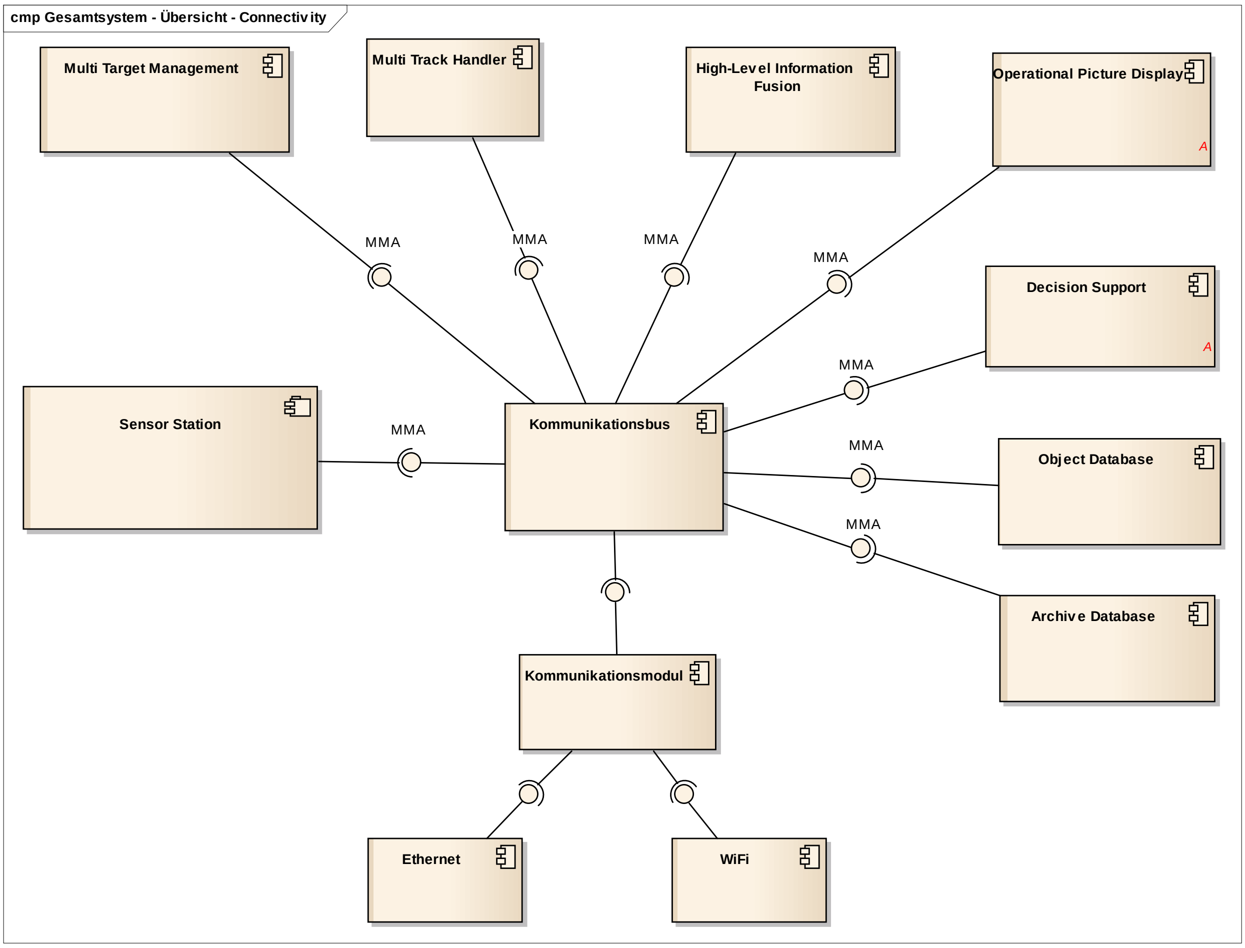

Figure 3: Communication bus.

4. SYSTEM MAIN COMPONENTS

4.1 Sensor Station

The Sensor Station component consists of the following sub-components (Figure 4):

- OmniCam
- OmniCam Detector
- PTZ Sensor Device (PTZ: Pan Toilt Zoom)
- Radio Sensor
- Video Stream Management
- PanTiltUnit Control

- LRF Control (LRF: Laser Range Finder)
- Audio Detection Control
- Radio Detection Control
- Track Controller
- Optical Detection
- UAV Classification (multisensory)
- Signature Database
- Tracker
- Local Archive

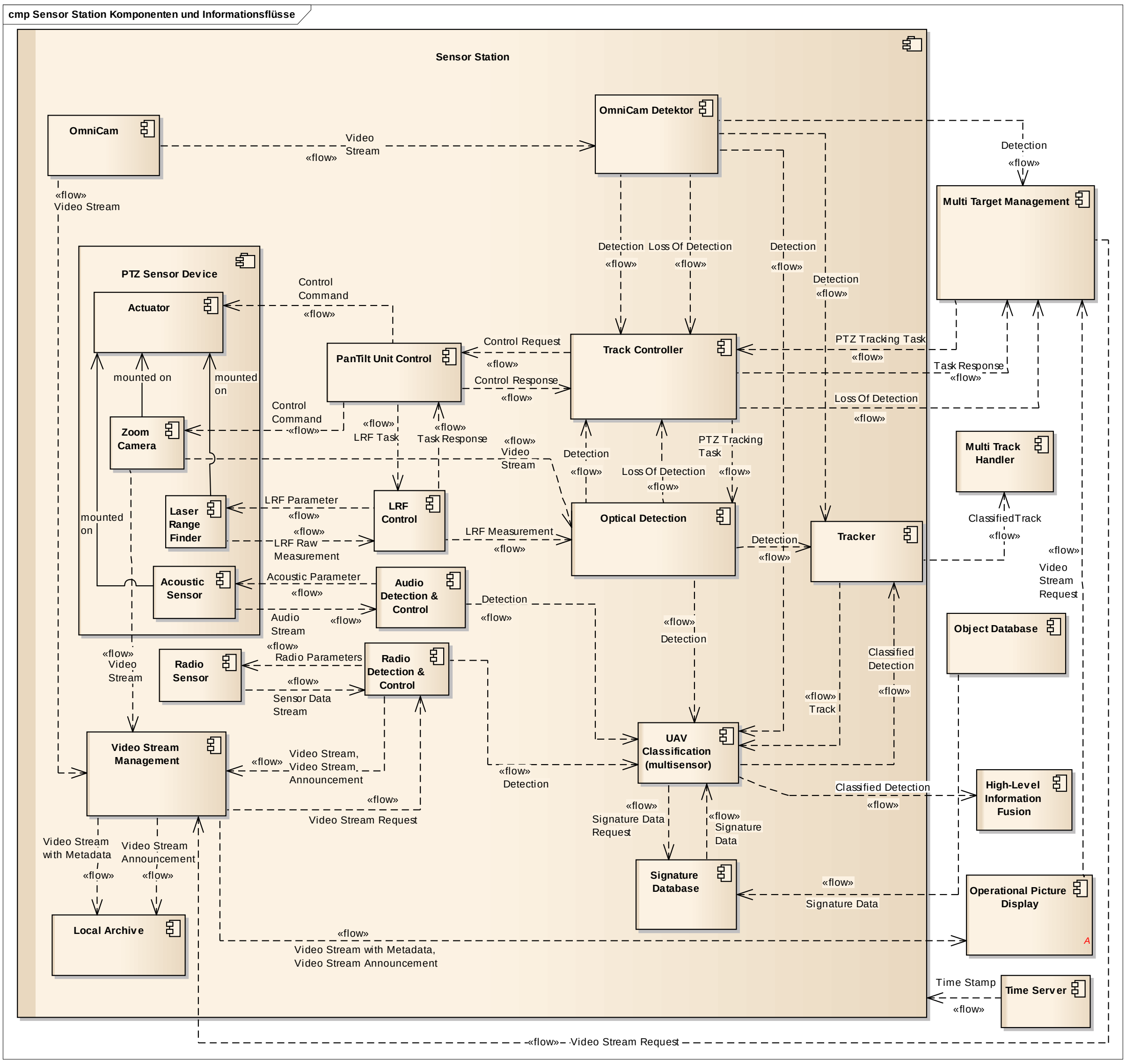

Figure 4: Sensor Station component and its sub-components.

The **OmniCam** is a static (no PTZ) high resolution wide-angel camera. It records movements in the sky and delivers the video to the OmniCam Detector and to the Video Stream Management. The **OmniCam Detector** is responsible for detecting in the video stream delivered by the OmniCam UAVs. It assigns to each detected UAV an initial Id. The OmniCam Detector delivers the generated UAV detections to the Track Controller.

The **Track Controller** is a stateful sub-component. It is responsible for selecting the detected UAV detections (tracks) and sending these to the PanTiltUnit Control as a Control Request. Initially, the Track Controller receives a control request for an UAV Id from the Multi Target Management sub-component of the Operation Center. This Id specifies the UAV to be tracked until a new track request is generated by the Multi Target Management. As long as the selected UAV is within the detections generated by the zoom camera and the Optical Detection sub-component, the Track Controller does not change the Control Request. However, when a detection gets lost, the Track Controller selects another UAV detection provided by the OmniCam Detector and generates a Control Request for this UAV. In case that for all UAV detections of the OmniCam Detector the PTZ Sensor Devices loses them, the Track Controller reports a Loss Of Detection to the Multi Target Management.

The **PanTiltUnit Control** is responsible for receiving the Control Requests from the Track Controller and transforming them into Control Commands for the Actuator and Zoom Camera of the PTZ Sensor Device and LRF tasks for the LRF Control. The PanTiltUnit Control computes based on the UAV’s last known positons the most probable UAV position and the lead-lag and triggers the hardware, the PTZ Sensor Device.

The **PTZ Sensor Device**, which consists of a series of sensors, like a zoom camera, a laser range finder, an acoustic sensor like directional microphone and an actuator for moving the sensors to the requested direction, delivers the sensor detections to the sensor data processing sub-components. Video streams from the zoom camera are forwarded to the Optical Detection and the Video Stream Management sub-components, audio streams are forwarded to the Audio Detection & Control. The LRF measurements are forwarded via the LRF Control to the Optical Detection sub-component.

The **Optical Detection** sub-component receives the video stream from the zoom camera and the measurements of the laser range finder. It is responsible for detecting in the video stream the UAVs with the id provided within the PTZ Tracking Task generated by the Track Controller. The Optical Detections forwards the detections to the Tracker and the UAV Classification sub-components.

The **Tracker** aggregates the sensor specific detections into tracks and assigns the tracks to the detected flying objects. In addition, it computes the direction vector and the velocity of the UAV.

The **UAV Classification** sub-component determines, based on the detections delivered by the Optical Detection, Audio Detection, and Radio Detection sub-components, the entries in the signature database and the track properties delivered by the Tracker whether the detected flying object is a UAV and in the positive case the type of the detected UAV. The output of the UAV Classification is a Classified Detection, which is forwarded to the High-Level Information Fusion sub-component and the Tracker sub-component.

4.2 Operation Center

The Operation Center component is composed of the following sub-components (Figure 5):

- Multi Target Management
- Multi Track Handler
- Own Asset Identification
- Object Database
- Archive Database
- High-Level Information Fusion
- Operational Picture Display
- Decision Support
- Time Server

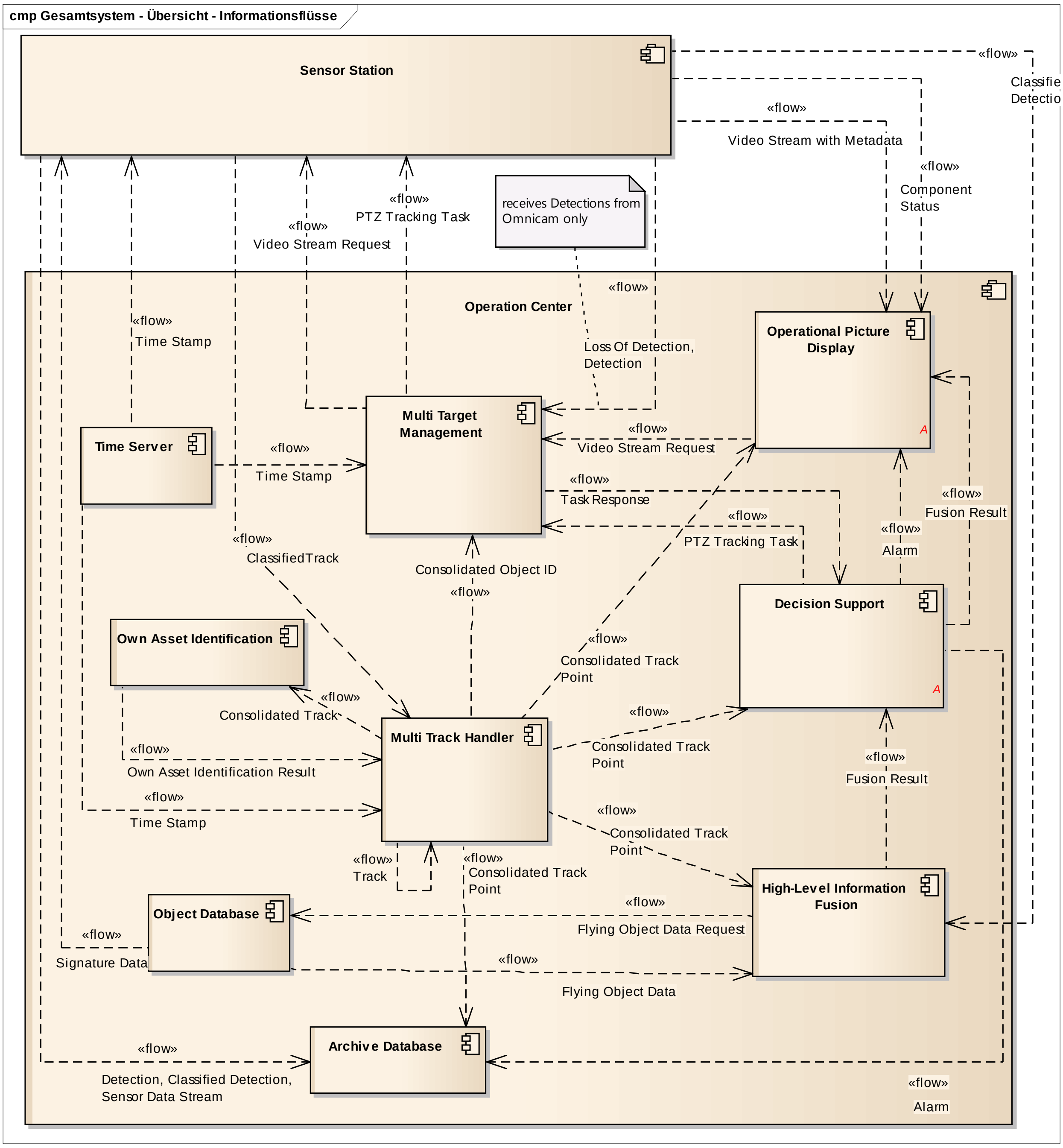

Figure 5: Operation Center component and its sub-components.

The **Multi Target Management** sub-component is responsible to manage the tracking of different UAVs in accordance with the priorities assigned by the decision maker. In the case that multiple UAVs penetrate the surveilled air space and not all can be tracked continuously by a zoom camera, the operator or decision maker in the operation center must prioritize, which UAVs shall be tracked by the PTZ Device sensors. In the case that a tracked UAVs can no more be detected (Loss Of Detection), the Multi Target Management decides which UAV shall be tracked instead. It receives a PTZ Tracking Task from the Decision Support sub-component or generates one itself. In both cases, it forwards the task to the Track Controller in the Senor Station.

The **Multi Track Handler** receives Classified Tracks from the Tracker sub-component of the Sensor Station. The Multi Track handler ensures that for each identified UAV only one single track exists among all sensor stations. If needed, it merges two or more tracks to one or it separates one track into multiple ones. The result is a Consolidated Track, which is forwarded to the sub-components High-Level Information Fusion, Decision Support, Operational Picture Display, and **Own Asset Identification**. The latter sub-component identifies whether a consolidated track concerns an own asset or not. The result is fed back to the Multi Track handler and improves the results for the decision support and operational picture display.

The **Object Database** comprises the signature data and technical information about known UAV types, like size, maximum velocity, endurance, flight altitude, possible and maximum payload, etc. This information is used amongst others by the **High-Level Information Fusion** component for performing a knowledge-based classification of detected UAVs and fusing this classification with a sensor-based classification in order to improve the overall classification result and thus support the decision maker[4].

The **Decision Support** receives the results of the high level information fusion, which comprises all useful information about the respective UAV, like the type of it, technical data such as its weight, load capacity, max. airspeed, max. altitude etc. The Decision Support is responsible for analyzing the fusion results, performing a threat analysis, generating, if needed, an alarm, a list of options for action, and recommending a course of action. The alarm, the list of options for action, the recommended course of action as well as the fusion results are send to the Operational Picture Display.

The **Operational Picture Display** is the interface to the operator. It comprises and displays the information received from the Decision Support component, the air picture (i. e. the position of the detected and tracked UAVs in either 3D or polar coordinates), videos of the tracked UAVs, and the sensor position, including the sensor footprint, the functional status of the different components. In addition, it provides the ability to steer the sensors manually by selecting the respective objects in the display.

5. CONCLUSION

An open architecture of a UAV detection system including decision support for counter-action has been presented. The main components of the intended system are one or multiple deployable sensor stations, an operation center comprising the operational picture display and the decision support component, and a communication bus consisting of a message-oriented middleware connecting the components and sub-components.

The designed architecture provides a blueprint for a UAV detection and defence actions decision-making system which will allow public protection agencies and military to react timely against threats caused by hostile drones.

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