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Dependable Computing

V0.4 1/30/2024

Behavior Description

Zone Alert Service

Abstract

This document provides behavior descriptions of the zone alert service designed to inform the end user and stakeholders of the services behavior with respect to its provided services.

Changes

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| --- | --- | --- |
| **Version** | **Date** | **Change** |
| V0.1 |  | Initial draft |
| V0.2 |  | Updates based on behavior validation from stakeholders |
| V0.3 | 1/30/2024 | Modified behavior specification based on the lack of vehicle radius in route planning, replaced behavior semantics with concept of buffered keep-out and keep-in zones and consistent semantics of zones with Route Planning Service. Fixed typos. Discussed alerts only for zones in a vehicle’s operating region. |
| V0.4 | 1/30/2024 | Clarified when one or both projected or current violation is reported for a given vehicle and zone. |
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1. Introduction

The Zone Alert Service is a stand-up service that can be activated as part of an OpenUxAS instance. Its purpose is to alert subscribers to when vehicles associated with the UxAS instance in one of two states:

1. Are in current violation of a zone
2. Are in danger of violating a zone within a future time window.

These cases are more carefully defined in the next sections.

1. Service Parameters

The service is parameterized by

* ~~Vehicle collision radii,~~ **~~R~~~~V~~**
* Iteration period **IT**
* Path deviation tolerance **ED**
* Lookahead time window **TW**

These values are defined, more specifically as follows:

## ~~Vehicle Collision Radii, R~~~~V~~

*~~Vehicle Collision Radii~~*~~: The radius of a circle, defined in meters, for a given vehicle, defining a circle in the horizontal plane (of OpenUxAS) centered on the vehicle’s reported position. The radius of the circle is the distance around the aircraft within the vehicle is circumscribed on the horizontal plane. In other words, when looked at from above, the vehicle must always “fit” in the circle based on the vehicle’s reported position.~~

**VP**

**RV**

~~The figure to the right shows a vehicle at position~~ **~~V~~~~P~~** ~~with collision radius~~ **~~R~~~~V~~**~~.~~

*~~Source~~*~~: Vehicle configuration record in OpenUxAS. It is assumed that this radius is currently defined in the OpenUxAS vehicle configuration data sent out by OpenUxAS as the beginning of operation during vehicle announcement.~~

~~This radius forms the basis for determining how close a vehicle can get to the edges of a keep-in or keep-out zone without violating it. See the figure to the right.~~

## Iteration Period, IT

**Iteration Period**: The amount of time that should pass between iterative executions of the Zone Alert Service.

The Zone Alert Service executes iteratively. Each iteration, it computes current and potential future violations of zones by vehicles.

**The defined rate of iteration is best effort and is neither hard nor soft-real time, as the hardware on which the service is performed is not defined at the service behavior level.**

## Path Deviation Tolerance, ED

*Path Deviation*: The **closest distance,** defined in meters, from a vehicle’s reported position to its ***currently*** assigned path.

**ED**

*Path Deviation Tolerance*: A **maximum path deviation** for a vehicle relative to the vehicle’s path and current position.

An example maximum path deviation is defined to the right. It defines a corridor around a vehicle’s planned path, see the figure to the right, that if a vehicle position remains within, projected zone violations within the defined time window are not reported.

**path**

Given that vehicles may follow paths in performance of their mission, and it is a given of path finding services of OpenUxAS that computed paths for vehicles will obey all keep-in and keep-out zones, then it is useful to not alert when a vehicle is approaching a violation but is currently following a path. This allows paths to properly approach zone boundaries without resulting in superfluous warnings.

Note, if a vehicle DOES violate a zone, an alert will occur regardless of path distance.

## Lookahead Time Window, TW

*Lookahead Time Window*: A time window, defined in seconds, within which the service will project the last reported linear trajectory of the vehicle into the future to see if it violates keep-in/out zones.

*Linear Horizontal Velocity*: The velocity of a vehicle projected into the horizontal plane of OpenUxAS.

The service is based on an iterative projection of the current linear horizontal velocity of a vehicle from its reported position to determine if the vehicle violate keep-in/out zone definitions in the horizontal plane.

1. Zone Definitions and Interpretation Consistency

The service operates to warn when vehicles are in violation of a zone or may soon be, based as determined by current trajectory. Given that OpenUxAS using floating-point precision data to describe zones and aircraft position in the range of meters, it is possible that OpenUxAS will apply small and intricate zones where aircraft size relative to zone boundaries is critical. In other words, for some applications, it matters if, for example, the wing of an aircraft enters a zone rather than the center of the aircraft (its reported position). This would matter, for example, if zones are tight boundaries around buildings and there is a risk of physical collision.

However, OpenUxAS does not generally compute geometry of zone violations based on aircraft size and form. Instead,

* Aircraft are treated as point-like objects.
* Zones are defined as closed, simple polygons with a ‘buffer size’. Keep-in zones are shrunk, and keep-out zones are grown by the buffer size.

The notion of buffering zones requires that zones be defined with an initial size, or with a buffering size, that accounts for all the semantics under which zones are defined. Operational restraint, safety, etc., and accounts for aircraft size as well as other factors, in one combined padding value.

For example, a keep-out zone might be defined for a neighborhood with a padding value that grows the zone to account for safety of the aircraft as well as staying well-clear of the neighborhood for operational and civilian safety purposes. Such padding is a ‘ceiling’ on padding as required by all combined factors.

The result is that all zone alerts are based on

1. Correct interpretation of zones with their padding
2. Point-like aircraft potentially violating such padded zones.

## Semantic Consistency with Other Zone Services

The semantics of zone padding can differ. For example, a padding method might bezel edges of grown keep-out zones. Another might leave flat edges on grows zones. This example of interpretative difference has been observed in the two existing route planning service implementations of zone padding.

Therefore, it is critical that the Zone Alert Service consistently interpret announced zones with padding in the manner of other services. Otherwise, operational inconsistency and advice can occur between services. For example, if a Route Planning Service and a Zone Alert Service pad zones using different edge semantics, Zone Alert Service might alert to violations of keep-out zones on paths planned by the Route Planning Service.

**As a result, the Zone Alert Service will rely on a Route Planning Service’s definition of zone construction and padding from zones announced to the services.**

## Only Considering Zones of a Vehicle’s Assigned Operating Regions

Zones are defined independent of **operating regions**. An operating region is a collection of zones and and an prescribed region in which vehicles can operate. Each vehicle is defined as operating within such a region. However, different vehicles can be defined to be operating in different, overlapping regions. Furthermore, zones are defined globally and potentially shared between regions. As a result a Zone Alert Service must be aware of what operating region a vehicle operates within, as the vehicle is only concerned with those zones applied to its assigned operating region, and should ignore any other zones not part of its operating region, even if its path intersects them.

1. Basic Behaviors

## Case 1: Report Potential Zone Violations Based on Current Linear Trajectory

### Each iteration of the Zone Alert Service will alert subscribers when a vehicle is projected in a future time to violate a zone applied by the vehicle’s operating region.

### The prediction approach is based on the last reported position and linear velocity of each aircraft. This basic algorithm is meant to match the linear projection models used for DIADLUS [cite].

### Projected Violation Model

Violations are detected from the last received vehicle state report, **Ts**, to a future time limit **Tw**, in the parametric range for time, **t**, as **Ts**<=**t**<=**Ts**+**TW**. . **TP** is the current time at which the algorithm is computing. It is assumed that **TS**<**TP**<=**TS**+**TW**.

Ts+Tw

Ts

Tp

Keep-Out Zone

Start of Projected Future

Violation

Tv

The model of projected violation is based on the linear projected trajectory of the vehicle from its last state-reported position to the final position in the time window along vector **Pv**, which has length **TW**\***VS** and where **Sv** is the current speed of the vehicle with direction **Vn** (the normalized velocity vector), both from the state report at time **Ts** and the assumed position of the vehicle at the present time is calculated based on the above linear equation.

Given the above, zone violations are reported for relevant zones for a vehicle as follows:

* **Predicted Keep-Out Zone Violations:** A projected violation of keep-out zone by a vehicle is reported if the zone is part of the vehicle’s operating region and any point on the parametric path during the forward time window from time **TP** time **TS+TW** intersects the edge or interior of the keep-out zone. This is illustrated in the above figure.
* **Predicted Keep-In Zone Violations:** A projected violation of a keep-in zone is reported for a vehicle and zone if the zone is part of the vehicle’s operating region and any point on the projected linear path of the vehicle from present time **TP** to time window end **TS**+**TW** lies outside of the keep-in zone.

The above definitions is consistent with the edge of zones being considered part of zone area.

If a violation is projected to occur, a notification is sent to all subscribers for the given vehicle. The notification presents the following data to subscribers:

1. The ID of the violating aircraft
2. The ID of the violated zone
3. The zone type (keep-in or keep-out)
4. The position, **P**Tv, and time, **TV**, of the first moment of projected violation.

### Past Projected Violations Are Not Reported

Note that this vector does not include positions along the vector for **t**<**Tp**. We will not report projected violations that only occur in the past relative to the current iteration time of the service. Below is a figure showing two example projections of violation, but one is in the past from **Ts**<=**t**<**Tp**. Because it occurred before this iteration only, it is not reported.

It is important to note this behavior. If the last reported state position is in the distant past relative to the rate of iterative reporting of the Zone Alert Service, then it is possible that a projected violation will be projected to start and end before the current iteration of the Zone Alert Service (e.g., a vehicle is projected to have passed completely over a keep-out zone before the current Zone Alert Service iteration.) The service will not report such events. It reports only events in the future of the current computation time.

### Repeating Reports

Each iteration of the algorithm will report violations it computes. Therefore, subscribers will receive notifications at each iteration of the service for each future predicted violation of each predicted violated vehicle and zone.

This may generate significant network traffic.

### Potentially Report While Following a Route

When a vehicle has filed a path route and is currently executing it, it will only have projected zone violation warnings sent out if it believes the current projected position of the aircraft deviates too far from its planned route.

TS+TW

TP

Keep-Out Zone

Projected Violation

Ignored

The figures to the right show the expected behavior of this feature. A vehicle is approaching a keep-out zone but is following its current filed path route closely. So long as its current projected position at time **TP** is close enough to the planned route the projected future keep-out zone violation will not be sent to subscribers. This rule does not apply if the vehicle has no current planned route that it is currently meant to be following.

Projected position at time **TP** is within distance **Ed** of planned route.

TS

However, should a vehicle’s projected current position be too far from the vehicle’s current assigned route, a future predicted violation will be reported. The distance is calculated as the shorted distance, d, from the planned route to the current projected position of the vehicle at the present time TP. Reports occur if **d** >= **Ed**, where **Ed** is the defined route displacement as defined at the beginning of this document.

Projected position at time **TP** has closest distance **d** to planned route greater than **Ed**

Projected Violation

Reported

d

TP

TS

Ts+Tw

Keep-Out Zone

The application of the projected position of the vehicle at the present time is deliberate. The last reported position of the vehicle can be stale relative to the curvature of a route. It is deided that conservative reporting based on curvature relative to age of state reports is preferred behavior of the service.

### Behaviors of Service with Noise in Vehicle Entity Report Measures

OpenUxAS is currently applied to the AMASE vehicle simulator. If OpenUxAS were to be used with real-world reporting and there is noise in vehicle position data over time, then the behavior of the violation alerting behavior is undefined.

## Case 2: Violation of a Zone Boundary

If during an iteration of the Zone Alert Service, projected **current location** of a vehicle, **PTP**, at the present iteration time, **TP**, is computed to be in violation of a zone defined for the vehicle’s operating region, the service will alert subscribers to the current zone violation. The graphical example to the right shows a current violation of a keep-out by a vehicle. In the example of the figure, even though the last reported state of the vehicle at time **TS** is not in violation, the current projected position is in violation.

Keep-Out Zone

Violation

TS

TP

TS+TW

The rules regarding detection of a current violation by zone type are as follows:

* **Keep-Out Zone Current Violation**: A vehicle is in current violation of a keep-out zone if the zone is part of the vehicle’s operating region and the current projected location of the vehicle at time TP is on the edge or within the area of the zone.
* **Keep-In Zone Current Violation**: A vehicle is in current violation of a keep-in zone if the zone is part of the vehicle’s operating region and any part of the position trajectory vector from the present time **TP** to the time window time **TS**+**TW** is outside of the area of the zone and not on its defined polygon edge.

**This is reported regardless of following a current route. There is no route-following tolerance computed for current violation detection.**

**Note that under this definition of service, if the last reported state of the vehicle is in violation of a zone and the current projected position would not be, no current violation would be reported.**

The service sends one notification for each zone and vehicle that is violated. The notification contains the following information:

* Violating aircraft ID
* Violated zone ID
* Zone type (keep-in or keep-out)
* Time of violation, **TP**
* Projected position of vehicle at present time, **PTP**

### An Impact of Computation Interval on Reporting

Notification occurs during the iteration of the service in which violation is detected by the latest state reports of the vehicles. It is **not** reported during an iteration when the vehicle will enter the violation before the next iteration. It **is** reported in the iteration in which vehicle position report satisfies violation conditions. For example, as seen in the figure to the right, if a vehicle quickly passes through a keep-out zone between iterations of the algorithm, a violation will **not** be reported.

Vehicle position at 2

successive iterations at times

**TP1** and **TP2**

Vector

TP1

TP2

Keep-Out Zone

No violations are reported

Again, if a vehicle’s projected position passes quickly through a zone between iterations of the Zone Alert Service, no current violation will be reported.

### Boundary-Skimming Behavior

If a vehicle’s flight path is erratic or a zone has a highly complex geometry, then it is possible that a vehicle skimming along a boundary may frequently enter and leave violation with a zone boundary. Such rapid oscillation of violation state in successive iterations is captured by this service and will result in a rapid succession of violation events.

### Position Noise Behavior

OpenUxAS is currently applied to the AMASE vehicle simulator. If OpenUxAS were to be used with real-world reporting and there is noise in vehicle position data over time, then the behavior of the violation alerting behavior is undefined.

## Case 3: Reports Failure to Be Able to Compute

The service will notify consumers when it is unable to compute for a given vehicle.

It is assumed that the service receives the necessary operating region definition and zone announcements. Any failure to get an operating region merely delays reporting until such a message is received and is not considered a failure of service.

However, if the present time of the iteration, **Tp**, is past the time window **Ts**+**Tw** for projection of the state vector of any vehicle, then the service is unable to compute any forward prediction. This is defined as the threshold for failure of service. This failure is reported to all subscribers to the given vehicle. Each successive iteration will repeat the message unless a new status, **TS**, of the vehicle is received. If that report is still stale for the projections time window, a new error report will be produced.

This may generate significant network traffic when the service fails to receive vehicles states in a timely manner, or if for any reason state reporting message receipt consistently lags present time by a sufficient amount.

## Case 4: No Reporting Regarding Operating Region Boundary

The system does not respond or care about operating region boundaries. Any vehicle entering or leaving an operating region outer boundary has no impact on the zone alert service.

1. Complex Behaviors

The service computes potential future violations of zones by aircraft. It also computes current violations based on predicted current position of aircraft. This section of the document clarifies when one or more of these computations compute violation with a given zone.

Detected current and future predicted violations are not separate service functions. The rules for messaging are as follows:

1. A detection of a current position violation by an aircraft for a relevant zone is always reported in the iteration it is detected.
2. A detection of a future position violation by an aircraft for a relevant zone with route deviation is reported if the aircraft is not also in current violation report for the same zone.

## Important Case to Consider

Under these rules, in the figure to the right, where the vehicle is predicted to be in current violation at time **TP**, the future violation at time **TV** would ***not*** be reported.

TS+TW

TP

Keep-Out Zone

TS

TV