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How to assess the capacity of urban airspace: A topological approach using keep-in and keep-out geofence

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ABSTRACT

The anticipated proliferation of small Unmanned Aerial Vehicles (sUAVs) in urban areas has garnered greater interest in capacity estimation of the low-altitude airspace. As a first step to assess such capacity, we propose a topological analysis framework to identify *free* versus *usable* airspace in a 3D environment filled with abundant geometric elements. To incorporate the underlying geospatial complexity as well as vehicle operational requirements, two types of geofence – *keep-out* and *keep-in* – are utilized. The keep-out geofence defines a boundary around static objects to keep sUAV out. The keep-in geofence is a 3-D sphere to keep a vehicle in. While the keep-out mainly focuses on public assurance as a mitigation measure against collision and privacy risk, the keep-in mainly concerns the operational feasibility of a vehicle. Three scenarios of keep-out, keep-in, and dual geofencing were applied and compared in a hypothetical case study as well as in the real 3-D environment of Seoul, South Korea. The results show that the keep-in usability is an upperbound of the keep-out, due to its unique capability to identify corridor segments using the alpha shape method. The dual scenario demonstrated tradeoffs between two types of geofence in a built-up environment, in which the keep-in exhibited more robust behavior than the keep-out. It is evident that both geofencing methods need to be considered in parallel in urban areas. In addition, decisions on the geofence parameters should be made in accordance with the geospatial complexity and flight purposes, rather than relying on fixed values. The proposed framework is not only capable of evaluating airspace availability in an adaptive and intelligent manner, but also has the potentials to identify departure/arrival locations and design ascent/descent routes.

1. Introduction

The anticipated proliferation of small Unmanned Aerial Vehicles (sUAVs) in urban areas has garnered greater interest in capacity estimation of the low-altitude airspace. Unlike the high-altitude controlled airspace with few obstacles, the low-altitude airspace needs to take into account the geospatial complexity derived from geometric variability of existing static obstacles such as buildings and terrain. Currently, several states have imposed sUAV operational restrictions based on proximity to population and man-made structures. In Table 1, the UAV flight restrictions of eight countries are summarized: Australia, Canada, Hong Kong, Japan, Singapore, South Korea, the United Kingdom, and the United States. Restrictions generally include (a) flight purpose and the UAV weight category, (b) minimum distance from people, (c) minimum distance from a building or structure, and (d) altitude limit. Where

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Table 1
State-wise operational requirement on the minimum distance from people and man-made structures.

State	Flight purpose	Weight category	Minimum distance from people	Minimum distance from a building or structure	Altitude limit[a]	Reference
Australia	Recreational	100 g up to 25 kg	30 m	30 m	120 m AGL	(Civil Aviation Safety Authority of Australia, 2002, 2016)
	Commercial	100 g up to 25 kg[b]	30 m	Unspecified		
Canada	Recreational	250 g up to 1 kg	30 m	Unspecified	90 m AGL	(Transport Canada, 2017a)
		1 kg up to 35 kg	75 m	Unspecified		
	Commercial[c]	250 g up to 1 kg	30 m	30 m		(Transport Canada, 2016)
		1 kg up to 25 kg	150 m	150 m		
Hong Kong	Recreational	7 kg or less[d]	Unspecified	Unspecified	90 m AGL	(Civil Aviation Department of Hong Kong, 2017)
	Commercial		30 m	30 m		
Japan	Recreational/commercial	200 g or more	30 m	30 m	150 m AGL	(Ministry of Land, Infrastructure and Transportation of Japan, 2015)
Singapore	Recreational/research	7 kg or less[e]	Unspecified	Unspecified	60 m AMSL	(Civil Aviation Authority of Singapore, 2017)
South Korea	Recreational/commercial	25 kg or less	Unspecified	Unspecified	150 m AGL	(Ministry of Land, Infrastructure and Transportation of Republic of Korea, 2014)
United Kingdom	Recreational/commercial	20 kg or less	30 m	50 m	120 m AGL	(Civil Aviation Authority of United Kingdom, 2016)
United States	Recreational/commercial	25 kg or less	Unspecified	Unspecified	120 m AGL	(U.S. National Archives and Records Administration, 2016)

[a] Above Ground Level (AGL); Above Mean Sea Level (AMSL).
[b] Remote Pilot License (RePL) and RPA Operator's Certificate (ReOC) are required for commercial RPAs over 2 kg.
[c] Special Flight Operations Certificates (SFOCs) or an exemption is required for non-recreational use.
[d] Permit is required for UAV over 7 kg.
[e] Activity Permit is required for UAV over 7 kg or commercial use.