Maximum Activation 3D Cube Transition System for Virtual Emotion Surveillance

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***Abstract*— The concept of barrier coverage has been utilized for with various applications of surveillance, object tracking in smart cities. In barrier coverage, it is desirable to have large number of active barriers to maximize lifetime of UAV-assisted application. Because existing studies primarily focused on the formation of barriers in two-dimensional area with limited applicability, it is indispensable to extend the barrier constructions in three-dimensional area. In this letter, a cube transition barrier system using smart UAVs is designed for three-dimensional space. Then, we formally define a problem whose goal is to maximize the number of cube transition barriers by applying a two-dimensional theory to a three-dimensional spaces. To solve this problem, we propose two algorithms to return the number of barriers and evaluate their performances based on numerical simulation results.**

***Index Terms*— UAVs, barrier, surveillance, cube, virtual emotion.**

I. Introduction

RECENTLY, *virtual emotion surveillance* have gained much attention of researchers. Thanks to significant technology development, *virtual emotion surveillance* were enhanced with unmanned aerial vehicle (UAV) devices in aerial side. With clear advantages of rapid movement and strong collaboration capability with relevant frameworks, the tendency to use UAVs for *virtual emotion surveillance* is increasing more and more today at numerous applications including industrial Internet of Things, 5G communication, surveillance, tracking, criminal prevention, maritime transportation stations [1], [2], [3], [4]. Originally, UAV devices were used in military applications; however, recently, they were used to enhance the operation of various applications, such as environment monitoring, vehicular network monitoring, wildfire management, remote sensing, farming, search and rescue, emergency communications, epidemic prevention, and infrastructure monitoring [5], [6], [7], [8], [9]. It is highly appropriate that a group of smart UAVs enables a fast speed of UAVs to carry out virtual emotion surveillance to achieve specific goals and given missions.

On the other hand, the concept of barrier proposed by [10] has attracted much interests of researchers due to its wide rage of applicability in industrial area and academic field [11]. However, current research focusing on two-dimensional environment for virtual emotion-assisted barrier construction and formation is not enough to monitor not only the ground but also other floors in practical circumstances. It's because, the air space unlike the ground is monitored in units, not one limited floor. Moreover, various areas may contain permitted access zone and unpermitted or unprotected sub-area when a fleet of UAVS are operated. Different from previous studies, we make a transition to virtual emotion surveillance in three-dimensional (3D) space because 3D virtual emotion surveillance has a great potential and provides advanced services for terror threat prevention, disaster management, intelligent virtual emotion-enabled smart infrastructures with ground and underground spaces, etc. Hence, the novel strategies and approaches of virtual emotion-enabled barriers for three dimensional areas with unprotected sub-regions are needed to be developed with a consideration of maximizing the system lifetime and activation in energy-efficient smart cities.

Based on the above observations and clear motivations, the leading contributions of the letter are summarized as follows.

- A cube transition barrier system using smart UAVs for three-dimensional environment with unprotected sub-area is designed to provide virtual emotion surveillance by transition from two-dimensional environment.
- We formally define the problem whose main objective is to maximize the number of cube transition barriers as well as represent the problem with ILP (Integer Linear Programming) formulation.
- Also, two different approaches with divided planes and minimal distance among pairs of UAVs are developed to resolve the problem. Then, their performances based on numerical outcomes through extensive simulations are analyzed for various scenarios and settings.

The rest of the letter is organized as follow. Section II introduces the proposed cube transition barrier system with problem definition of ILP representation. Then, to solve the defined problem, two methods are specified in Section III. Moreover, according to outcomes through simulations, the devised algorithms are analyzed in Section IV. Lastly, this letter is concluded in Section V.

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TABLE I
NOTATIONS

notations	description
T	the whole three-dimensional surveillance area
S	a set of smart UAVs
C	a set of cube transition barrier in T
n	the total number of smart UAVs
r	a detection range for smart UAVs
d	a distance value for dividing plane
p	a specific potential point in T
i	identifier of smart UAVs, where $i \leq n, s_i \in S$
j	identifier of positions, where $p_j \in T$
k	identifier of cube transition barrier, where $k \leq n, c_k \in C$
δ	the total number of activation cube transition barriers

II. Cube Transition Barriers for Virtual Emotion Surveillance

In this section, the basic terms are explained as well as the main research problem are represented with ILP formulations.

A. Problem Definition

First, we show the essential definitions that are used in the developed framework.

Definition 1 (Three-Dimensional Virtual Emotion Surveillance): Suppose that there is three-dimensional protecting area to be monitored where unprotected sub-area is included. Also, a fleet of smart UAVs equipped with wireless transmitter and receiver are randomly positioned in the three-dimensional protecting area. An *three-dimensional virtual emotion surveillance*, referred as *3DVEmoSurv*, is a surveillance using the detected virtual emotion information provided by smart UAVs.

Definition 2 (Cube Transition Barrier): Given that three-dimensional protecting area with unprotected sub-region and a group of smart UAVs with initially inactivated status, the cube transition barrier, referred as *CubeTranBar*, is to reinforce virtual emotion surveillance by detection in cube-shaped area.

Definition 3 (Maximum Activation Cube Transition Barrier Problem): It is given that we have three-dimensional protecting area for *3DVEmoSurv* and a fleet of smart UAVs with initial random locations. The maximum activation cube transition barrier problem, called as *MaxActCubeTranBar*, is to maximize the number of activation cube transition barriers so that *3DVEmoSurv* is achieved with maximum system lifetime.

B. ILP Formulation

In the presented ILP formulation, the defined notations and their explanations are summarized in Table I.

Also, integer variables are defined as follows.

$$W_{i,j} = \begin{cases} 1, & \text{if a UAV } s_i \text{ moves to point } p_j \text{ in plane} \\ 0, & \text{otherwise.} \end{cases}$$

$$X_{i,j,k} = \begin{cases} 1, & \text{if } s_i \text{ is a member of cube transition } c_k \\ & \text{when } s_i \text{ moves to position } p_j \text{ in plane} \\ 0, & \text{otherwise.} \end{cases}$$

$$Y_k = \begin{cases} 1, & \text{if a cube transition barrier } c_k \text{ is created} \\ 0, & \text{otherwise.} \end{cases}$$

For three-dimensional virtual emotion surveillance, an objective function is to maximize the the number of activation cube transition barriers so that *3DVEmoSurv* is achieved with maximum system lifetime in T. Then, we make that the objective function (1) of *MaxActCubeTranBar* problem is to:

$$\textbf{Maximize } \delta \tag{1}$$

$$\text{Subjectto}: \sum_{j=1}^{n} W_{i,j} \leq 1, \quad (\forall i) \tag{2}$$

$$\sum_{j=1}^{n} X_{i,j,k} \geq 1, \quad (\forall i, \forall k) \tag{3}$$

$$X_{i,j,k} \leq Y_k, \quad (\forall i, \forall j, \forall k) \tag{4}$$

$$\sum_{k=1}^{n} Y_k = \delta \tag{5}$$

The variable δ in (1) represents the total number of *CubeTranBar*. At constraint (2), it is forced that every UAV s_i is relevant to at most one specific point in planes. From constraint (3), it is required that the movement between initial position of UAV s_i and specific position p_j is connected to at most one cube transition c_k. Also, constraint (4) restricts that the s_i is included in cube transition barrier c_k at most once. Through constraint (5), it is confirmed that the total number of cube transition barriers to be formed within T should be δ.

III. The Proposed Algorithms

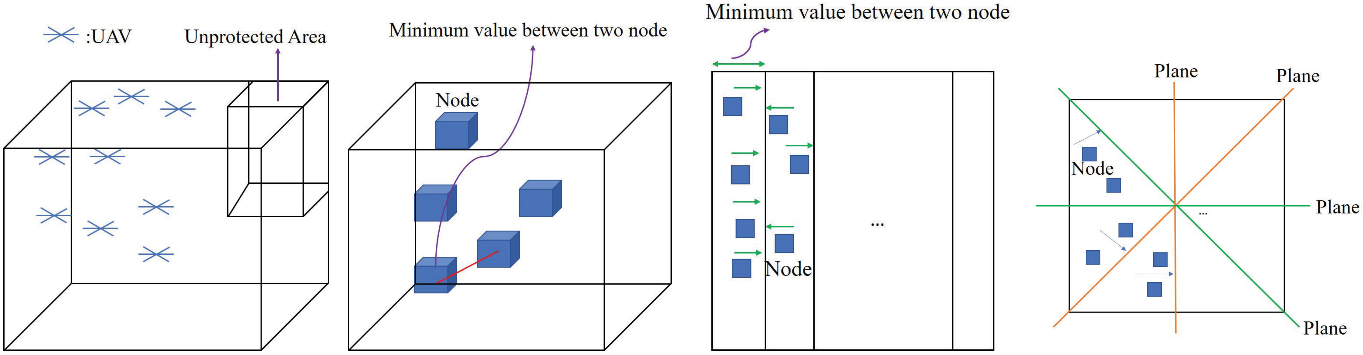
In this section, the proposed schemes, *Minimum-Distance-Transition* and *Divided-Planes-Cube-Transition*, are presented.

A. Minimum-Distance-Transition

Now, as the first algorithm, we specify the *Minimum-Distance-Transition* including applied strategy, execution procedures and output. Then, the *Minimum-Distance-Transition* implements the essential procedures below.

- Identify the whole three-dimensional virtual emotion surveillance area T with unprotected sub-region and a group of smart UAVs S with their detection ranges R are deployed randomly in T.
- Find the minimum value p of the distance between two nodes or UAVs among randomly deployed nodes. The value d becomes the criterion for dividing the plane.
- Divide continuously into a plane with a difference of that value d among planes.
- If the plane overlaps with the unprotected area, it approximates the plane of the next distance.
- Next, create a cube transition barrier with nodes approximated by each plane.
- Add the number of cube transition barriers generated for each plane.
- Calculate the total number of cube transition barriers and return it as outcome.

Fig. 1(a) depicts the given three-dimensional system environment with unprotected sub-area. And, Fig. 1(b) shows the minimal distance value among a pair of smart UAVs which is utilized to divide plane by *Minimum-Distance-Transition*.



(a) Three-dimensional system environment with unprotected sub-region (b) The execution status of Algorithm 1: *Minimum-Distance-Transition* (c) The plane view of Algorithm 1: *Minimum-Distance-Transition* (d) The execution status of Algorithm 2: *Divided-Planes-Cube-Transition*

Fig. 1. System environment and descriptions of the proposed algorithms.

Algorithm 1 Minimum-Distance-Transition Input: T, S, r, Output: δ

set $C \leftarrow \emptyset$;
identify T with unprotected sub-region;
verify a set of UAVs S with their detection ranges R;
estimate the minimum distance value d between UAVs;
divide T into several planes with the term d;
while a new cube transition barrier is found in divided planes **do**
  add the new cube transition barrier c_k to C;
end while
update $|C|$ as δ;
return δ;

Also, Fig. 1(c) presents the continuously divided status with plane view. Then, the pseudocode of *Minimum-Distance-Transition* is shown in Algorithm 1 formally.

B. *Divided-Planes-Cube-Transition*

Next, we describe *Divided-Planes-Cube-Transition* covering essential idea, fulfilment steps as follows. The implementation strategy of *Divided-Planes-Cube-Transition* is to create more spaces to allow each UAV to be included so that the better relaxation is provided.

- Verify three-dimensional virtual emotion surveillance area T with unprotected sub-region and a set of smart UAVs S with their detection radii R are positioned randomly within T.
- Make four sides by dividing them into four equal parts based on cube center.
- Ten planes are created by combining four divided planes, six outer surfaces and are divided into eight spaces.
- Each node is placed in eight new spaces. The randomly deployed nodes are moved to the divided planes and approximated to the plane.
- If the plane overlaps with the unprotected area, it approximates the plane of the next distance.
- Next, generate a cube transition barrier with nodes approximated by every plane.

Algorithm 2 Divided-Planes-Cube-Transition Input: T, S, r, Output: δ

set $C \leftarrow \emptyset$;
recognize T with unprotected sub-region;
confirm a group of UAVs S with detection ranges R;
make four sides based on the center of the cube;
create ten planes by combining the four divided planes and 6 outer surfaces and divide it into eight spaces;
locate each UAV into 8 new spaces;
while a new cube transition barrier is sought in divided planes **do**
  add the new cube transition barrier c_k to C;
end while
update $|C|$ as δ;
return δ;

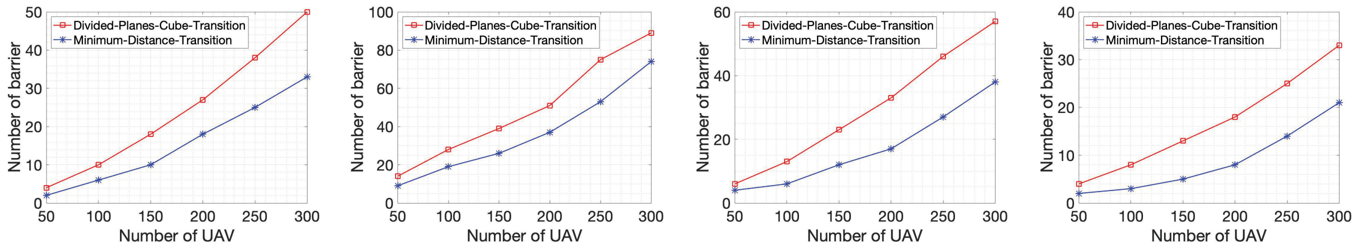
- Return the number of cube transition barriers which are built in each plane.
- Estimate the total number of cube transition barriers and return it as result.

As it can be seen in Fig. 1(d) for *Divided-Planes-Cube-Transition*, each UAV or node is located in eight new spaces after ten places are generated by combining four divided planes and six outer surfaces. Furthermore, the pseudocode of *Divided-Planes-Cube-Transition* is found at Algorithm 2.

IV. PERFORMANCE ANALYSIS

In this section, we evaluate the performances of proposed algorithms by experiments using different settings and parameters. Every earned numerical value through simulations is average value by 100 different settings and parameters.

Our simulations are composed of four different groups according to various settings and scenarios to compare *Minimum-Distance-Transition* with *Divided-Planes-Cube-Transition* to return the objective value δ of the total number of activation cube transition barriers. Fig. 2 shows the entire performances. The first set of simulation uses the scenario of detection range $r = 120$ in $1000 \times 1000 \times 1000$ surveillance area. and the second set of experiment follows $r = 240$ in $1000 \times 1000 \times 1000$. Also, the third sub-group of simulation



(a) r = 120 in 1000 × 1000 × 1000 (b) r = 240 in 1000 × 1000 × 1000 (c) r = 240 in 1500 × 1500 × 1500 (d) r = 240 in 2000 × 2000 × 2000

Fig. 2. Performance evaluations of the total number of activation cube transition barriers by the proposed methods with different number of UAVs in various sizes of three-dimensional surveillance areas.

not only utilizes $r = 240$ in $1500 \times 1500 \times 1500$ but also deliberates on $r = 240$ in $2000 \times 2000 \times 2000$. As it can be seen for the first set of experiment in Fig. 2(a), it is checked that as the number of smart UAVs is increasing, both *Minimum-Distance-Transition* and *Divided-Planes-Cube-Transition* generate the increased number of cube transition barriers and *Divided-Planes-Cube-Transition* has better performance than *Minimum-Distance-Transition* when more UAVS are allowed. As shown in Fig. 2(b), we verify that the number of UAVs increases, the proposed schemes create more cube transition barriers in in $1000 \times 1000 \times 1000$ as well as *Divided-Planes-Cube-Transition* returns the better performances than *Minimum-Distance-Transition*. Similarly, as seen in Fig. 2(c) and Fig. 2(d) for $r = 240$ in $1500 \times 1500 \times 1500$ and in $r = 240$ in $2000 \times 2000 \times 2000$, we could confirm that the number of UAVs increaes, both *Minimum-Distance-Transition* and *Divided-Planes-Cube-Transition* construct the increased number of cube transition barriers because more UAVs improves the connection among UAVs so that it leads better relaxations to build cube transition barriers. As a whole, we can see that *Divided-Planes-Cube-Transition* outperforms *Minimum-Distance-Transition* finally.

Furthermore, if we firstly estimate the complexity of *Minimum-Distance-Transition*, it finds the minimal distance value p between the pairs of UAVs and divide so that planes are made given that the set of UAVs V and the set of neighbor edges between UAVs is equal to the set of edges E. Then, search for possible cube transition barrier formation by maximum flow If so, the total number of operations will be $O(V^2) + O(1) + O(VE^2)$. Hence, its complexity of is $O(VE^2)$. Secondly, if we calculate the complexity of *Divided-Planes-Cube-Transition*, it makes four sides with ten planes after cube center is determined. The deployed nodes are moved to the divided planes. Then, seek possible cube transition barrier formation by maximum flow. If so, the total number of operations is $O(1) + O(1) + O(VE^2)$. Therefore, the complexity of *Divided-Planes-Cube-Transition* is $O(VE^2)$.

V. Concluding Remarks

With the 3D cube environment for virtual emotion surveillance, in this study, we introduce the cube transition barrier system covering smart UAVs for three-dimensional environment. And, the maximum activation cube transition barrier problem is formally addressed with ILP formulation. As solutions for the defined problem, two different methods of *Minimum-Distance-Transition* and *Divided-Planes-Cube-Transition* applying divided planes and minimal distance among pairs of UAVs are proposed. Through the numerical experiment outcomes with various scenarios and settings, the performance evaluations are accomplished with discussions. As future works, we plan to expand the virtual emotion surveillance by 3D transition to various applications covering theme park, military areas, ground and underground spaces.

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