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Time Varied Self-Reliance Aerial Ground Traffic Monitoring System with Pre-recognition Collision Avoidance

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***Abstract*—In this paper, we introduce a time varied self-reliance aerial ground traffic monitoring system which provides pre-recognition collision avoidance among mobile robots and smart UAVs for virtual emotion security. Then, with ILP (Integer Linear Programming), we make a formal definition of the problem whose objective is to minimize a total spent time by smart UAVs (Unmanned Aerial Vehicles) and mobile robots without conflicts on condition that the demanded number of self-reliance security barriers are formed. To solve the defined problem, we develop two approaches, time-differentiated pre-stop movement and approximated equal segments movement. Then, those schemes are implemented through expanded experiments and are evaluated based on numerical results.**

***Index Terms*—self-reliance, mobile robots, UAVs, virtual emotion, barriers.**

I. INTRODUCTION

As original feature of human beings, the emotion recognition has been categorized with audio information, motion detection, facial expression, physiological signal, wireless signal and its reflection [1]. The concept of virtual emotion was introduced by Kim et al. [2] because it will take a critical role of numerous applications such as public security, secure patrol and monitoring, emotion-based services, etc. [3].

Recent advancement of mobile robots with improved task completion capabilities expedites intelligent services to citizen in 6G-assisted smart cities [4]. UAVs with rapid movements will be utilized for numerous missions to support emergent tasks, operations in harsh environment [5], [6]. So, a cooperation between smart UAVs and mobile robots in aerial side and ground side is indispensable to achieve high-reliable, minimal delayed, successful task completions rather than individual operations of smart UAVs and mobile robots. And, the traffic forecast based on estimation of traffic monitoring and traffic volume is necessary for intelligent transportation [7], [8], [9]. On the other hand, since the barrier concept has been proposed by Kumar et al. [10], its usability is enlarging to various industrial and academic areas. Also, the concept of barrier using mobile robots and UAVs can be used for traffic monitoring or security reinforcement at intersection for both aerial and ground sides.

However, when the cooperation of smart UAVs and mobile robots is performed, the collision issue among them should be considered as one of critical issues [11]. In particular, it is observed that the strategy of pre-stop or pre-recognition will alleviate those collisions so that the system reliability can be elevated. Therefore, the reliable operation without any clash among system components should be executed properly.

According to the above motivations, the primary contributions of the paper are specified.

- A time varied self-reliance aerial ground traffic monitoring system is introduced to provide pre-recognition collision avoidance among mobile robots and smart UAVs where time varied slots or time moments are considered as variables for security barrier construction.
- A problem of minimizing a total spent time for time varied self-reliance security barriers is formally represented with ILP formulation.
- Two different schemes are proposed to solve the problem. Also, we compare their performances based on the obtained results through expansive simulations with various settings, practical parameters and scenarios.

The rest of the paper has the following structure. In Section II, the proposed framework's description, problem definition with ILP formulations are demonstrated. Then, in Section III, two devised methods are described followed by their evaluations based on extensive simulation results in Section IV. Then, this paper is ended in Section V.

II. TIME VARIED SELF-RELIANCE AERIAL GROUND SURVEILLANCE FRAMEWORK

In this section, the key definitions and the defined problem by ILP formulation are specified in the devised framework.

A. Problem Definition

We formally describe essential definitions in the system.

Definition 2.1 (time varied self-reliance security barriers): Assume that the traffic monitoring framework includes a set

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TABLE I
NOTATIONS

notations	description
S	the whole surveillance area
U	a set of UAVs
R	a set of mobile robots
F	a set of time varied self-reliance barrier in S
B	a set of potential positions
UD	a set of detection ranges for smart UAVs
RD	a set of detection ranges for mobile robots
n	the total number of smart UAVs
m	the total number of mobile robots
t	the required number of time varied self-reliance barrier
p	the assigned speed of UAVs
q	the allocated speed of mobile robots
i	identifier of UAVs, where $i \leq n, u_i \in U$
j	identifier of mobile robots, where $j \leq m, r_j \in R$
k	identifier of potential position, where $k \leq n+m, b_k \in B$
l	identifier of potential position, where $l \leq n+m, b_l \in B$
$\overline{a,b}$	line segment between a and b
$euc(a,b)$	euclidean distance between a and b
τ	the total spent time

of UAVs U and a set of mobile robots R within the surveillance area S with the assigned speed of UAVs and mobile robots. Then, *time varied self-reliance security barriers*, called as *TVRelianSeBar*, is the surveillance-oriented barrier using virtual emotion detection, which are formed by time varied, separated movements of UAVs, mobile robots.

Definition 2.2 (TSpenTime problem): For traffic monitoring, it is given that a set of UAVs U and a set of mobile robots R with the allocated speed of UAVs and mobile robots, the given minimum detection accuracy c, the required t number of *TVRelianSeBar*. The *TSpenTime* problem is to minimize the total spent time by self-reliant UAVs and mobile robots without any crashes from movements such that the required t number of *TVRelianSeBar* are constructed satisfying with the detection accuracy c.

B. ILP Formulation

For ILP formulation, the summary of the notations and their explanations is represented in Table I.

Also, the integer variables are specified as follows.

$$T_{i,k} = \begin{cases} 1, & \text{if } u_i \text{ shifts to position } b_k \text{ in } B \\ 0, & \text{otherwise.} \end{cases}$$

$$V_{j,l} = \begin{cases} 1, & \text{if } r_j \text{ shifts to position } b_l \text{ in } B \\ 0, & \text{otherwise.} \end{cases}$$

$$W_k = \begin{cases} 1, & \text{if the position } k \text{ serve as a part} \\ & \text{of } \textit{TVRelianSeBar} \\ 0, & \text{otherwise.} \end{cases}$$

$$H_l = \begin{cases} 1, & \text{if the position } l \text{ serve as a part} \\ & \text{of } \textit{TVRelianSeBar} \\ 0, & \text{otherwise.} \end{cases}$$

$$X_{i,j,k,l} = \begin{cases} 1, & \text{if self-reliance without collision is met} \\ & \text{when } u_i,\ r_j \text{ shift to position } b_k,\ b_l \\ 0, & \text{otherwise.} \end{cases}$$

$$Z = \begin{cases} 1, & \text{if the number of } \textit{TVRelianSeBar} \\ & \text{is established entirely in the area } S \\ 0, & \text{otherwise.} \end{cases}$$

The goal of the *TSpenTime* problem is to minimize the total spent time by self-reliant UAVs and mobile robots without any collisions on condition that the requested t number of *TVRelianSeBar* are built with satisfying with the detection accuracy. Then, the objective of *TSpenTime* problem is to minimize τ.

Subject to:

$$\sum_{k=1}^{|B|} T_{i,k} \leq 1, (\forall i) \tag{1}$$

$$\sum_{l=1}^{|B|} V_{j,l} \leq 1, (\forall j) \tag{2}$$

$$T_{i,k} \leq W_k, (\forall i, \forall k) \tag{3}$$

$$V_{j,l} \leq H_l (\forall j, \forall l) \tag{4}$$

$$\prod_{i=1}^{n} \prod_{j=1}^{m} \prod_{k=1}^{|B|} \prod_{l=1}^{|B|} T_{i,k} \cdot V_{j,l} \cdot W_k \cdot H_l \cdot X_{i,j,k,l} \geq Z \tag{5}$$

Constraint (1) imposes that the UAV member u_i takes own role at most one position in *TVRelianSeBar*. For constraint (2), it is restricted that the mobile robot member r_j also takes own role at most one position in *TVRelianSeBar*. And, constraint (3) verifies that when the position b_k is occupied by u_i, it should be a part of *TVRelianSeBar* as well as constraint (4) confirms that if the position b_l is taken by r_j, it must be a member of *TVRelianSeBar*. Finally, constraint (5) identifies that the required number of *TVRelianSeBar* is made with self-reliance movements within S.

III. THE PROPOSED ALGORITHMS

In this section, we propose two different algorithms for working out a solution of the *TSpenTime* problem. Note that while Algorithm 1 utilizes the pre-stop strategy, Algorithm 2 applies the equal segment strategy.

A. Algorithm 1: Time-Differentiated-Pre-Stop-Movement

We introduce *Time-Differentiated-Pre-Stop-Movement*. Its processing steps are described as follows.

- First, the *system initialization* with sub-procedures are achieved below.
  - Verify initial random locations of UAVs and mobile robots in the whole surveillance area S.
  - Generate potential positions B for the given number of *TVRelianSeBar* within S where potential positions satisfy the minimum detection accuracy c.
  - From initial locations of UAVs and mobile robots, search for the closest pairs (u_i, b_k) or (r_j, b_k) between UAVs or mobile robots and potential positions.
- After *system initialization*, the pre-stop strategy is implemented with the following procedures.
  - Among the found pairs for movements, estimate the spent time for movement with p and q.

Algorithm 1 ***Time-Differentiated-Pre-Stop-Movement***

Inputs: S, U, R, m, n, t, c, Output: τ

```
1: set $B = \emptyset$;
2: set $F = \emptyset$;
3: set $\tau = 0$;
4: identify initial locations of $U$ and $R$;
5: create potential positions $B$ to satisfy $c$ and $t$ in $S$;
6: while TVRelianSeBar is formed without crashes do
7:     seek the closest pairs $(u_i, b_k)$ where $u_i \in U, b_k \in B$;
8:     find the closest pairs $(r_j, b_k)$ where $r_j \in R, b_k \in B$;
9:     if there is potential collision among pairs then
10:        apply time-differentiated pre-stop movement;
11:    end if
12:    calculate every spent time by each founded pair;
13:    add it to $\tau$;
14: end while
15: return $\tau$;
```

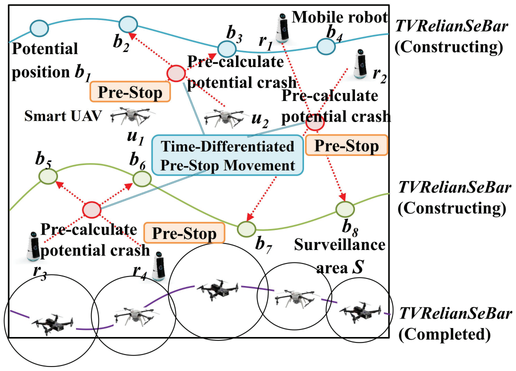


Fig. 1. A description of *TVRelianSeBar* construction and Algorithm 1 applicability.

  - Check the possibility of potential collisions by considering straight trajectory of the pair movement.
  - If the pair with potential collision is identified, apply time-differentiated pre-stop movement.
  - Estimate all spent time of UAVs and mobile robots after the required number of *TVRelianSeBar* is built in S completely. Then, add the total spent time to τ.
- Return τ as the total spent time by self-reliant UAVs and mobile robots without any crashes.

The pseudocode of *Time-Differentiated-Pre-Stop-Movement* with formal processing steps is demonstrated in Algorithm 1 in detail. Also, Fig. 1 shows the construction of *TVRelianSeBar* and the applicability of *Time-Differentiated-Pre-Stop-Movement* scheme. As seen in Fig. 1, there are potential positions $b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8$ within a surveillance area S to build *TVRelianSeBar*. When smart UAV u_1 and u_2 in the aerial side should move to b_3 and b_2, the potential crash is pre-estimated so that *Time-Differentiated-Pre-Stop-Movement* strategy can be utilized. Similarly, when mobile robot r_1 and r_2 on the ground move to b_8 and b_7, Algorithm 1 can be applied with pre-stop movement so that such a strategy will take a critical role to achieve successful surveillance using virtual emotion security in time-varied environment.

Algorithm 2 ***Approximated-Equal-Segments-Movement***

Inputs: S, U, R, m, n, t, c, Output: τ

```
1: Execute system initialization in Algorithm 1: line 1 - 5;
2: while TVRelianSeBar is built without collisions do
3:     find the closest pairs $(u_i, b_k)$ where $u_i \in U, b_k \in B$;
4:     seek the closest pairs $(r_j, b_k)$ where $r_j \in R, b_k \in B$;
5:     Check if there are equal line segments $\overline{u_i, s}$ and $\overline{r_j, s}$
       at potential collision spot $s$;
6:     if there is equal segment then
7:         apply approximated equal segment movement using
           pre-allowed time difference for movement between
           $u_i$ and $r_j$ among found pairs;
8:     end if
9:     estimate every spent time by each founded pair;
10:    add it to $\tau$;
11: end while
12: return $\tau$;
```

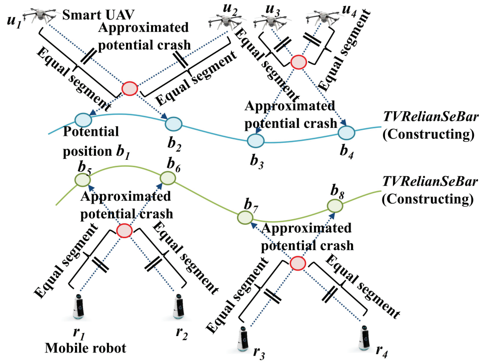


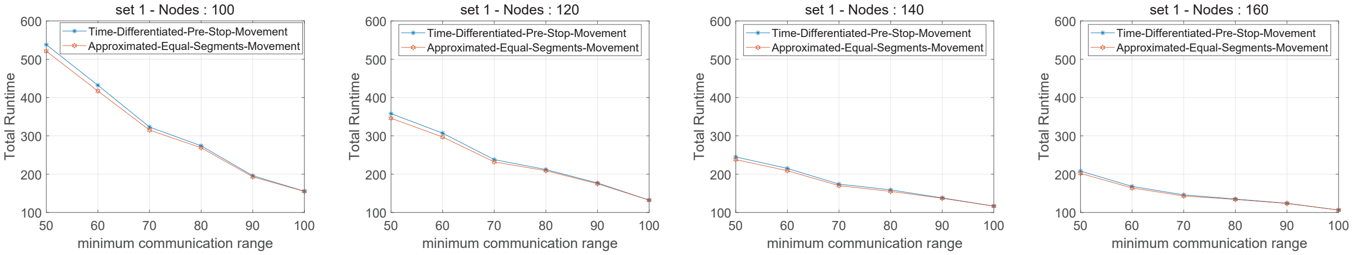
Fig. 2. A description of Algorithm 2 using approximated equal segment movement.

B. Algorithm 2: Approximated-Equal-Segments-Movement

Next, we describe the proposed *Approximated-Equal-Segments-Movement*. Its procedures are specified as follows.

- Similar to Algorithm 1, the sub-procedures of *system initialization* are executed first.
- After *system initialization*, the equal segment strategy is executed with the below procedures.
  - Check if there are equal line segments $\overline{u_i, s}$ and $\overline{r_j, s}$ at potential collision spot s by movement trajectories among the found pairs.
  - If equal segment is verified, the approximated equal segment movement using pre-allowed time difference between u_i and r_j for movement is applied.
  - Calculate all spent time of UAVs and mobile robots after the requested number of *TVRelianSeBar* is constructed in S
  - Then, add the total spent time to τ.
- Return τ as the total spent time by self-reliant UAVs and mobile robots without any collisions.

The pseudocode of *Approximated-Equal-Segments-Movement* is described in Algorithm 2 in detail. Furthermore, Fig. 2 depicts the applicability of Algorithm 2. There are potential locations $b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8$. If smart UAV



(a) n = 100 (b) n = 120 (c) n = 140 (d) n = 160

Fig. 3. Performance comparison of different number of mobile robots and UAVs n with their various communication ranges for the total runtime to form the required number of *TVRelianSeBar* t = 6 by the proposed schemes in 1000×1000 surveillance area.

u_1 and u_2 move to b_2 and b_1, the *Approximated-Equal-Segments-Movement* scheme firstly check if there is equal line segment of the movement. For example, $\overline{u_1, b_2}$ and $\overline{u_2, b_1}$ are equal line segment, which may lead to potential crash spot. Similarly, when mobile robot r_1 and r_2 move to b_6 and b_5 to form *TVRelianSeBar*, the trajectory may cover equal line segment of $\overline{r_1, b_6}$ and $\overline{r_2, b_5}$.

IV. PERFORMANCE ANALYSIS

In this section, the devised schemes are analyzed for performance through expansive experiments. For simulation settings, the system members including mobile robots and UAVs range from 100 to 160 and their communication ranges are established between 50 to 100 in the whole surveillance size of 1000×1000. Also, the number of *TVRelianSeBar* is assigned as 6. It is remarked that every numerical outcome of τ are an average value of 10,000 different implementations.

For simulations, *Time-Differentiated-Pre-Stop-Movement* scheme and *Approximated-Equal-Segments-Movement* are executed in 1000×1000 in Fig. 3. For every result graph, X-coordinate presents the minimum communication range as well as Y-coordinate demonstrates the total runtime of τ. Fig. 3(a) and Fig. 3(b) depict a performance of the developed two approaches when n = 100 and n = 120 with t = 6. Then, Fig. 3(c) and Fig. 3(d) show the results if n = 140 and n = 160 with t = 6. As it can be verified in Fig. 3, the total runtime of τ decreases as the minimum communication range increases for both *Time-Differentiated-Pre-Stop-Movement* scheme and *Approximated-Equal-Segments-Movement*. And, we can check the total runtime to build *TVRelianSeBar* increases as the whole surveillance area S covers the increased number of system member n because more system members of mobile robots and UAVs allow more relaxation if it is selected as a part of *TVRelianSeBar* from initial positions. Furthermore, it is demonstrated that as the minimum communication or detection range of system members decreases, the performance difference between *Time-Differentiated-Pre-Stop-Movement* scheme and *Approximated-Equal-Segments-Movement* increases. It follows that the smaller detection range shows the better results *Approximated-Equal-Segments-Movement* than *Time-Differentiated-Pre-Stop-Movement*.

V. CONCLUSION AND REMARKS

In this study, the time varied self-reliance aerial ground traffic monitoring system was introduced to support pre-recognition crash avoidance. With ILP formulation of the *TSpenTime* problem, two schemes were developed and they were executed through expansive simulations with various scenarios. Then, based on obtained experiment results, the performance of those proposed approaches was evaluated with detailed discussions. As future works, we plan to study aerial ground traffic surveillance system with irregular obstacles without collisions. Moreover, the obstacle-aware low energy traffic monitoring system should be developed.

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REFERENCES

[1] M. Zhao, F. Adib and D. Katabi, "Emotion recognition using wireless signals," *Communications of the ACM*, vol. 61, pp. 91-100, 2018.

[2] H. Kim, J. Ben-Othman, S. Cho and L. Mokdad, "A framework for IoT-enabled virtual emotion detection in advanced smart cities," *IEEE Network*, vol. 33, no. 5, pp. 142-148, 2019.

[3] H. Kim, J. Ben-Othman, L. Mokdad, J. Son and C. Li, "Research challenges and security threats to AI-driven 5G virtual emotion applications using autonomous vehicles, drones, and smart devices," *IEEE Network*, vol. 34, no. 6, pp. 288-294, 2020.

[4] J. Li, J. Wu, J. Li, A. K. Bashir, M. J. Piran and A. Anjum, "Blockchain-based trust edge knowledge inference of multi-robot systems for collaborative tasks" *IEEE Communications Magazine*, vol. 59, pp. 94-100, 2021.

[5] Y. Wang, Z. Gao, J. Zhang, X. Cao, D. Zheng, Y. Gao, D. W. K. Ng and M. D. Renzo, "Trajectory design for UAV-based internet of things data collection: A deep reinforcement learning approach" *IEEE Internet of Things Journal*, vol. 9, pp. 3899-3912, 2022.

[6] N. Ansari, D. Wu and X. Sun, "FSO as backhaul and energizer for drone-assisted mobile access networks" *ICT Express*, vol. 6, pp. 139-144, 2020.

[7] A. Ramadan, A. Elbery, N. Zorba and H. S. Hassanein, "Traffic forecasting using temporal line graph convolutional network: Case study," *Proc. of IEEE ICC 2020*, pp. 1-6, 2020.

[8] C. Zhang, M. Dong, K. Ota, "Employ AI to improve AI services : Q-Learning based holistic traffic control for distributed co-inference in deep learning," *IEEE Transactions on Services Computing*, vol. 15, no. 2, pp. 627-639, 2022.

[9] R. Imran, M. Odeh, N. Zorba and C. Verikoukis, "Quality of experience for spatial cognitive systems within multiple antenna scenarios," *IEEE Transactions on Wireless Communications*, vol. 12, pp. 4153-4161, 2013.

[10] S. Kumar, T. Lai and A. Arora, "Barrier coverage with wireless sensors," *Wireless Networks*, vol. 13, pp. 817-834, 2007.

[11] H. Kim and J. Ben-Othman, "A collision-free surveillance system using smart UAVs in multi domain IoT," *IEEE Communications Letters*, vol. 22, no. 12, pp. 2587-2590, 2018.