Energy Minimization of Unmanned Aerial Vehicle in Site Monitoring

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Abstract

In this paper, we studied the unmanned aerial vehicle (UAV), which are emerging with powerful utilities. Wireless connection and huge reachability make the UAV versatile in nature which in turn open the possibilities to deploy in different scenarios with various applications. Remote site monitoring is one of the main utility of UAV but this application posses various constraints such as battery consumption, need a strong backhaul connection, and interference avoidance. We analyzed the case of UAV deployment in a remote area for site monitoring, where battery consumption is one of the highlighted constrained and various perspective of research is undergoing to improve in this area of UAV. In our approach, we study the battery consumption of UAV with an optimal path planning. Our objective was to deploy the UAV on its track for remote site monitoring while minimizing the energy consumption. Our simulation results showed the optimal trajectory of UAV while monitoring.

I. Introduction

Unmanned Aerial Vehicle is one of the emerging technology in the modern era. It has many utilities i.e, i) UAV surveillance is utilized to gather information by pictures and recordings of diverse things, people, and regions [1] from which useful data can be extracted [2]. It helps in getting data from various elevation and difficult terrains. UAV flight can cover the troublesome surroundings which couldn't open by people. ii) The development of groups and things starting with one spot then onto the next with the methods for different bearers. Diverse transportation implies contains flight, railroad, transport, metro, and taxi are essential necessities of clients day by day life. And yet in the event that they would not oversee legitimately, at that point cause trouble for the clients. Consequently, the idea of brilliant transportation come in the field to run this framework securely and productively. iii) Climate determining application used to identify the present natural parameters and predicts the status of the environment of things to come in a specific area. iv) Squander the board managed approaches for different sorts of waste age, accumulation, partition, treatment, and transfer. Waste has diverse classifications i.e, business, private, rural, institutional, sewage slime, modern and so on. v) UAV has an inconceivable impact in enterprises office, empowering boundless ethereal view. UAV has an effect in different areas, for example, overwhelming businesses, seaports, oil, gas, mining, and substance plants [3]. vi) Building destinations around the globe depend upon assessments and reviews to accomplish a far-reaching comprehension of a fabricates advancement and to ensure that wellbeing norms are being met inside the technique. With the most recent UAV innovation, models can basically and rapidly perform estimations, mapping, and investigations in a minimal effort and effective way, while also dealing with laborers expelled from perilous conditions. vii) An agrarian UAV is utilized to increase in the generation of harvests and watch out for their development. UAV give an unmistakable picture of harvests to the ranchers to genuinely detect their properties in a better viewpoint and can settle on choices in like manner [4]. viii) The developing innovation of UAV and their utilization cases expanding exponentially. So also, it's a possible apparatus in the cataclysmic event the board, not just confined to looking over of destinations [5], in addition, it can use as a wellspring of communication between restorative guide supplier and casualties of debacles [6]. It can also be utilized as a sink node for IoT network [7].

II. System Model

In our system, we have a construction site in which work is continuing. To estimate the material and work progress on site, a UAV has been deployed to traverse the site for live images or videos from the terrain. UAV has to traverse the horizontal plane path between initial and final positions at a constant altitude. But, UAV has limited battery power so to optimally utilize this power, UAV has the need to choose their traversing path which spends less amount of battery power and complete the track. UAV in this system model can be imagined as a discrete-time linear dynamical system which has a state vector for position and velocities. Moreover, this system has a

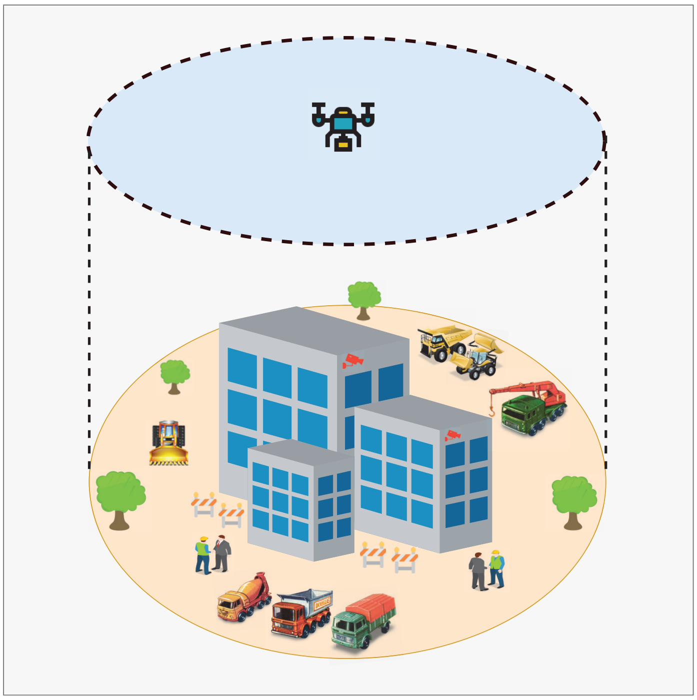

Fig. 1: System Model

driving force which is acting like acceleration for the UAV to fly in the region.

III. Problem Formulation

Our system model is based on a discrete-time linear dynamical system, which contains the sequence of vector $\vec{x} \in \mathcal{R}^n$ for different states of UAV which is indexed by time $t \in \{0, ..., M-1\}$. So the general form of a linear dynamic system is the following,

$$\vec{x}_{t+1} = \boldsymbol{A}\vec{x}_t + \boldsymbol{B}\vec{u}_t, \tag{1}$$

here, $\vec{u}_t$ is representing the control input to UAV while their flying time period, matrix $\boldsymbol{A}$ is showing the state conversion of UAV and matrix $\boldsymbol{B}$ is representing the input states to the UAV while the flying time span.

According to our objective, we have to optimize the $\vec{u}_0, ..., \vec{u}_{M-1}$, because it derives UAV state to the desired state at the ending position which is $x_M = x_{des}$. So the required optimization problem for the minimum energy controller will be formulated by finding the optimal $\vec{u}_t$.

$$\begin{aligned} \underset{u}{\text{minimize}} \quad & \sum_{\text{t=0}}^{\text{M}-1} ||\tilde{\text{u}}_{\text{t}}||^2, \\ \text{subject to} \quad & x_M = x_{des}, \\ & \vec{x}_{t+1} = \boldsymbol{A}\vec{x}_t + \boldsymbol{B}\vec{u}_t. \quad t = 0, ..., M-1 \end{aligned} \tag{2}$$

Equation (2), represents the control forces minimization for starting point to the ending point. Additionally, we have the constraint to reach UAV at the destination and discrete-time linear dynamical system. According to our system model, the state vector of UAV consists of four states, so the vector $\vec{x} \in \mathcal{R}^4$, in which first two states represent the coordinate system for movement of UAV in a horizontal plane and remaining two states representing the velocity of the UAV in 2D plane. Moreover, controlling forces of UAV is represented by $\vec{u}_t \in \mathcal{R}^2$ which is responsible for thrust force to move UAV on their respective two coordinate axes.

Our goal is here to modify the optimization problem to that category which can be solvable by any technique of optimization solvers. So we will transform this minimum energy control problem into the basic least norm problem by performing some mathematical operations.

$$\vec{x}_t = \boldsymbol{A}\vec{x}_t + [\boldsymbol{A}^{t-1}\boldsymbol{B} \quad \boldsymbol{A}^{t-2}\boldsymbol{B}....\boldsymbol{A}\boldsymbol{B} \quad \boldsymbol{B}] \begin{bmatrix} \vec{u}_0 \\ \vec{u}_1 \\ . \\ . \\ . \\ \vec{u}_{t-2} \\ \vec{u}_{t-1} \end{bmatrix}, \tag{3}$$

Equation (3), implies that, the UAV states vector is affine function of UAV control force $[\vec{u}_0, ..., \vec{u}_{t-1}]$. Therefore, at the ending position when $t = M$, it implies that

$$\vec{x}_t = \boldsymbol{A}\vec{x}_t + \underbrace{[\boldsymbol{A}^{t-1}\boldsymbol{B} \quad \boldsymbol{A}^{t-2}\boldsymbol{B}....\boldsymbol{A}\boldsymbol{B} \quad \boldsymbol{B}]}_{\text{G}} \begin{bmatrix} \vec{u}_0 \\ \vec{u}_1 \\ . \\ . \\ . \\ \vec{u}_{t-2} \\ \vec{u}_{t-1} \end{bmatrix}, \tag{4}$$

In generalized form, it will become following,

$$\vec{x}_M = \boldsymbol{A}\vec{x}_M + \boldsymbol{G}\vec{u}, \qquad \vec{u} = [\vec{u}_1^T.....\vec{u}_{M-1}^T]^T \tag{5}$$

By performing basic operations on an optimization problem, the modified form is following,

$$\begin{aligned} \underset{u}{\text{minimize}} \quad & ||\text{u}||^2, \\ \text{subject to} \quad & \boldsymbol{G}u = x_{des} - \boldsymbol{A}^M x_0. \end{aligned} \tag{6}$$

The modified optimization problem in equation (6), is basic least norm problem, so we can find the optimal control for UAV as matrix G is full row rank, it showed us the condition for controllability which has normal utilization in most of the control theory problems.

IV. Simulation

For the simulation of the system, we construct a discrete-time linear dynamical system for UAV. The values for state vector in initial and final position are declared in the following parameters table.

TABLE I: Simulation Parameters

Parameters	Values	Parameters	Values
Initial x position	x_0=10	Initial y position	y_0=-20
Final x position	x_0=100	Final y position	y_0=50
Initial x-Velocity	v_{x0}=30 m/s	Initial y-Velocity	y_0=-10 m/s
Final x-Velocity	x_0=0 m/s	Final y-velocity	y_0=0 m/s
No. of Time-steps	n=1000	Time	T=50

Simulation parameters were set according to the table. The modeled linear dynamical system in the form of least squares optimization problem in was simulated in python platform. Firstly we declared the placement of UAV in both cases i.e, initial and final position for monitoring the construction site. After declaring the positions, we run our code for the 1000 time-steps along with time which has the limit of $T = 0, ..., 50$. After, traversing the declared trajectory by UAV with constraints, our solution has deduced this optimal results for UAV trajectory with energy minimization as shown in Fig. 2.

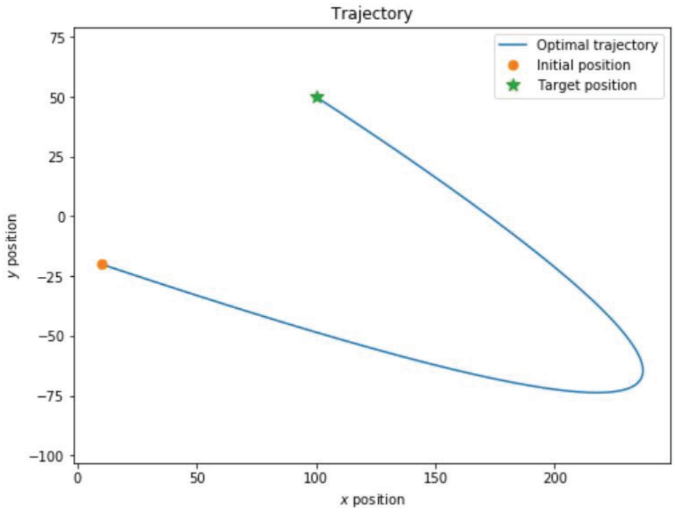

Fig. 2: Energy Minimized Trajectory

V. Conclusion

In this paper, we studied a discrete-time linear dynamic system in the form of UAV motion over a particular region for monitoring and minimizing the energy by controlling the driving forces of UAV. Firstly, the system was modeled as a linear dynamic system and then their input vector $\vec{u}$ was presented as an optimization variable for this system. Afterward, the system's equation was modified to make the overall problem solvable by least norm optimization. Results showed the optimal path for UAV while considering the constraints into account to minimize the energy of UAV. In future work, we will extend our model for minimizing UAV energy by considering different points stay in space to collect data from deployed sensors on the ground.

Acknowledgment

This research was partially supported by the MSIT (Ministry of Science and ICT), Korea, under the Grand Information Technology Research Center support program (IITP-2018-2015-0-00742) supervised by the IITP (Institute for Information & communications Technology Promotion)" and by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1D1A1B01015320) *Dr. CS Hong is the corresponding author.

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