Dispersed Cyber-Physical Coordination and Path Planning Using Unmanned Aerial Vehicle

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Abstract –

In recent years, drones have been used exclusively for military missions, but with the advent of new characteristics in UAV technology, more industries are now moving to add this new element to their practices. Engineers and analysts use UAVs to monitor projects, scan the ground, find out its dimensions and reduce the incidence of costly errors. The Drones improved the world over the next years and its use becomes a general trend in all areas, including industrial. Technology can be said to have a way of breaking down barriers and making impossible. The emergence and spread of a technological event is one of the key features that ensure the continuation of technological progress, and also guarantees us the creation of best products that the future holds. In this paper, we analyze a close coordination between dispersed cyber-physical system parts; aiming to mount pre-casted concrete pergola sections on rooftop of a building. The system consist of a manipulating robotized crane, moving the sections of pergola to the top level and positioning them according to a predefined shape. For better positioning of the sections, the trajectory of the manipulating system, in terms of lifting altitude, and two-dimensional positioning, is coordinated using unmanned aerial vehicle.

Keywords –

Cyber-physical system; UAV; Robot path planning

1 Introduction

In the past few years, the importance of unmanned aerial vehicles can be clearly defined in different techno-social fields. The application of autonomous systems is not anymore strictly related to military applications. Nowadays, unmanned platforms are used in medical, construction, rescue and cinematography business. Despite the relative success and the development of market share, the integration of these platforms in our quotidian life cycle is endangered by physical isolation of these solutions from direct contact with end-users, the absence of regulations and laws and relatively late development in human-machine interfaces.

Focusing on the UAV, the challenges are more serious than the ground-based autonomous platforms. The reason might be the importance of skies in military and civil aspects. Hence, the integration of the UAV in day-to day applications is limited due to the aforesaid reasons.

Pertaining to the construction market, the presentation of UAV is limited to photogrammetry and BIM. Researches about these topics are plenty: bridges, light poles, high-rise building and facades inspections are some of them.

In this paper, we would like to take the discussion further more and use the aerial capabilities of the UAV to guide and lead trajectory planning for dispersed cyber-physical system, the goal of which is to install heavy-weight roof mounted pergola.

This research will be composed in three main paragraphs:

- Description of the cyber physical system;
- Odometric approach and calculations of trajectory planning;
- Formation of control tasks and generation of results.

2 Dispersed Cyber-Physical System

By cyber-physical system, we understand the concept of reliable fusion between computational and physical platform embedded within the same body [1], however, enabling better interaction capabilities with the surrounding (world and human operator) though many modalities and processes. In light of that, the terms of interaction, integration and enhancement are key areas where the research of cyber physical systems is occurring.

Traditionally, the physical system is a consolidated system and not dispersed over selected area. Recently, with the introduction of Internet of things (later IoT), the probability of designing distributed physical systems became achievable, as it overcame the disadvantages of radio systems and the huge cost related to GPS and GLONASS integration in navigation platforms, which made these solution not optimal techno-commercially. In this paper, we introduce the cyber-physical system consisting of the following levels:

- Aerial: a UAV scanning the roof and generating the positioning tasks for the subsequent component of the pergola;
- Cybernetic: analyzing the video-input of the UAV and generating trajectory for the manipulator using visual odometry algorithm;
- Ground: a Mobile robotic crane, receiving the coordinates from the cyber system and performing the laying-out of the pergola blades.

A concept of the solution is illustrated in fig.1 according to which, the UAV will dictated the following parameters as a potential control task to the cybernetic system: the swing angle ϕ, the luff angle θ, the hoist elevation h and the mobility across axis OX and OY, which can be replaced by the angle formed by the hoist and the luff axis [10].

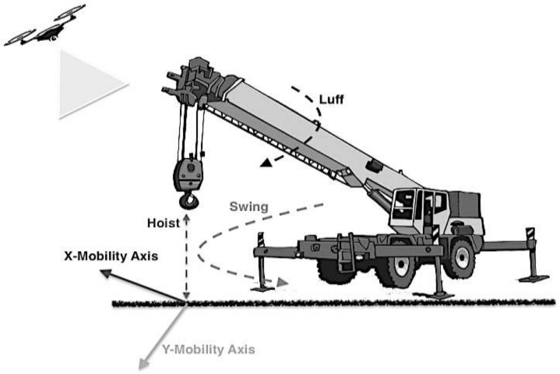

Figure 1. Concept of dispersed cyber-physical system

3 Trajectory Identification

3.1 Optical Odometry

The task of global planning is to fly through checkpoints [2]. This approach has already been applied in determining the position of the UAV and managing altitude using color or shape identification [9]. The difference between the proposed algorithm and the known control methods using machine vision algorithms is that for autonomous localization, the autopilot determines the distance traveled by calculating the rotor speed and rotation axis and establishes the relationship between the pixel system and the associated coordinate reference system (Body-axis). Usually, to determine the location of the UAV, information from the global localization system and the onboard sensors are used. Here, it is proposed to solve the problem using a machine vision and the method of optical odometry, which allows determining the location and orientation of the movement based on the sequence of optical information (images) in each time step. Figure 2 shows the relation between different references systems.

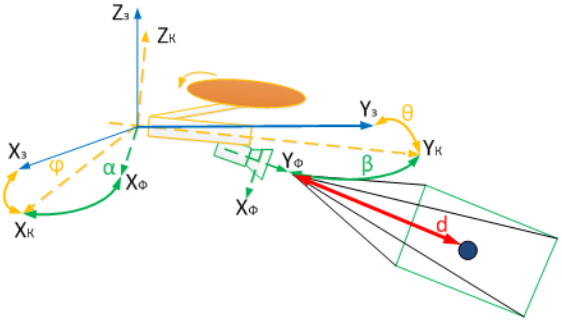

Figure 2. Axis and reference systems

To change the UAV position in relation to the Earth, using camera frames, it is necessary to find geometric relationships between different coordinate reference systems. We consider AR DRONE as UAV, which has a diaphragm deviation diagonally within 64 degrees. Using the laws of trigonometry, we obtain the angles of vertical and horizontal deviations, equal to 43.18 degrees and 51.62 degrees, respectively. The definition of the angles of inclination of the UAV with respect to the fixed axis of coordinates, and the roll, pitch and flight altitude, which are needed to determine the position of the camera in relation to the Earth are as follows: the aperture deviates by 51.62 degrees from the horizontal coordinate system i.e. from the origin of the roll angle (φ), therefore, the deviation of the projection of the image on the horizontal axis of the diaphragm can be computed according to equation (1):

$$\varphi = (51.62 - \alpha), \qquad (1)$$

Where $\alpha -$ is the horizontal polar angle in the aperture coordinate system. In the same way we find the vertical projection by the formula:

$$\theta = (43.18 - \beta), \tag{2}$$

Where $\beta -$ vertical polar angle in the aperture coordinate system.

A geometrical representation of the deviation of the diaphragm from a fixed coordinate system is presented in Figure 3.

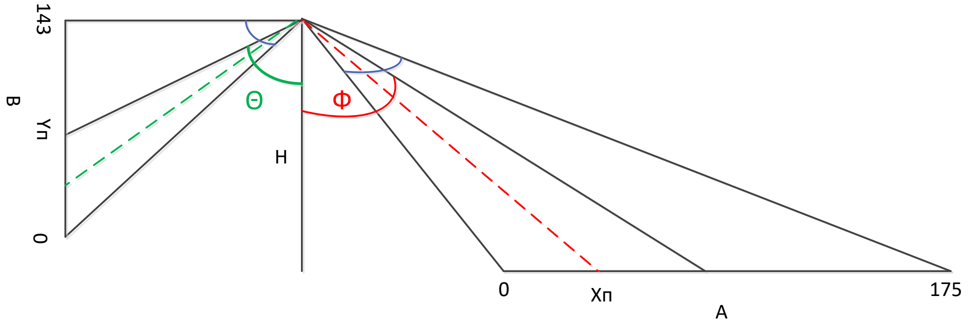

Figure 3. Geometric relationship between the associated coordinate system and the camera reference system

The distance from the camera to a specific coordinate (Earth-axis) is computed using the following equations

$$d(x) = H_{\text{г}} = H * \tan(\varphi + \alpha); \tag{3}$$

$$d(y) = H_{\text{В}} = H * \tan(\theta + \beta), \tag{4}$$

Using equations (3) and (4), we can identify the transformation formulas between different reference systems.

$$\begin{cases} X_{\text{п}} = \dfrac{x}{\Pi x} . \cos\left(\arctan\left(\dfrac{H_B}{H_{\text{г}}}\right)\right) \\ Y_{\text{п}} = \dfrac{y}{\Pi y} \sin\left(\arctan\left(\dfrac{H_B}{H_{\text{г}}}\right)\right) \\ \rho_x = \sqrt{{X_{\text{п}}}^2 + {Y_{\text{п}}}^2} * \cos\left(\arctan\left(\dfrac{H_B}{H_{\text{г}}}\right)\right) \\ \rho_y = \sqrt{{X_{\text{п}}}^2 + {Y_{\text{п}}}^2} * sin(\arctan\left(\dfrac{H_B}{H_{\text{г}}}\right)) \end{cases} \tag{5}$$

Where $X_{\text{п}}$ and $Y_{\text{п}} -$ are the pixel coordinates, x and $y -$ are the body axis coordinate and ρ_x and ρ_y are the angular pixel coordinates.

3.2 Minimum Jerk Trajectory

The pixel coordinates calculated in equation (5) has to be fed to the crane as a desired trajectory for its manipulator. In light of that, the obtained coordinates and rotational angels have to be transformed to metric again in terms of swing and luff angles, elevation and 2D mobility. We will assume that the height of the building is known and the influence of the wind is negligible; hence the elevation parameter will be considered as an input value and the dragging coefficient of the pergola blades will be neglected aerodynamically.

The remaining four parameters can be directly correlated with received by computing equation (5) and interchanging equivalence. The difficulty remains in generating a trajectory that achieve minimum jerk to the manipulator as it might cause risks, false positioning of the moved piece and possible abortive works [5,6]. To achieve an optimal trajectory to the manipulator, the movement will be posed and solved as quadratic programming using multi-segment Chebyshev orthogonal collocation for transcription.

Using the two dimensional Chebyshev-Gauss collocation method to obtain possible numerical solution of differential equation by partially is differentiating it in time and discretizing it using finite difference method [4]. Taking into consideration that the trial or candidate trajectories $f_k(x)$ will be set on homogenous Dirichlet boundary conditions [3], the approximate solution can be presented in the following equation

$$U^N(x,t) = \sum_{k=0}^{N} a_k(t)\, f_k(x) \tag{6}$$

In the collocation approach, the differential equation has to be satisfied by the approximate solution at the collocation points in the assigned domain [8]. The derivative at each node can be found by multiplying the value at any Chebyshev point by a differentiation matrix.

3.3 Results

Implementing the equations in sections (3.1) and (3.2), and running the quadratic programming listing on Matlab, the result of multi-segment trajectory simulation based on the aforementioned modeling constraints is depicted in Figure 4.

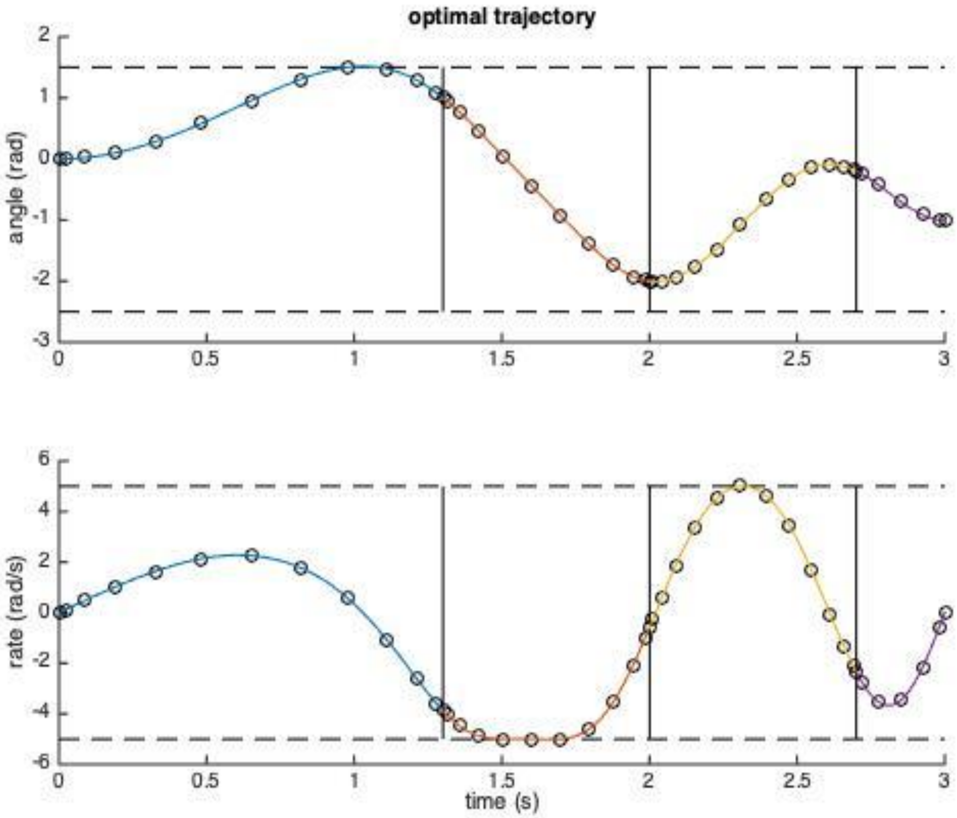

Figure 4. Results of multi-segment trajectory

In figure 4, we can clearly see, that the trajectory is passing by all the Chebyshev node points, where the initial an final velocity rated in rad/s is zero and the angle of the final trajectory is almost negligible.

By applying the same concept to the both sections of the manipulator, with specific boundaries and input trajectory, we can see that the arm end-effector holding the bald is travelling smoothly, on the doted lines, shown in Figure 5, taking into consideration for joint 1 and 2, the initial velocity is zero (starting point of lifting task), and the resultant final velocity of the end-effector is also zero rad/s, which corresponds to discharge of the manipulator after laying task.

4 Conclusion

This paper presented an operational simulation of dispersed cyber-physical system performing a lifting and disposing pergola blades on certain rooftop of a building. The system consisted of UAV, the task of which is to analyze the surrounding and generate an optimal trajectory to a robotic manipulator (crane) considered as a Chebyshev orthogonal collocation points based on optical odometry. The task was formulated as a quadratic programming problem. The obtained results endorsed the theoretical approach and showed that both the joints of the lifting crane have followed the optimal trajectory, passing by all Chebyshev points with minimum jerk considering that the initial velocity of the joints is zero and the final velocity should be obtained zero rad/s with minimum to zero overshooting angles.

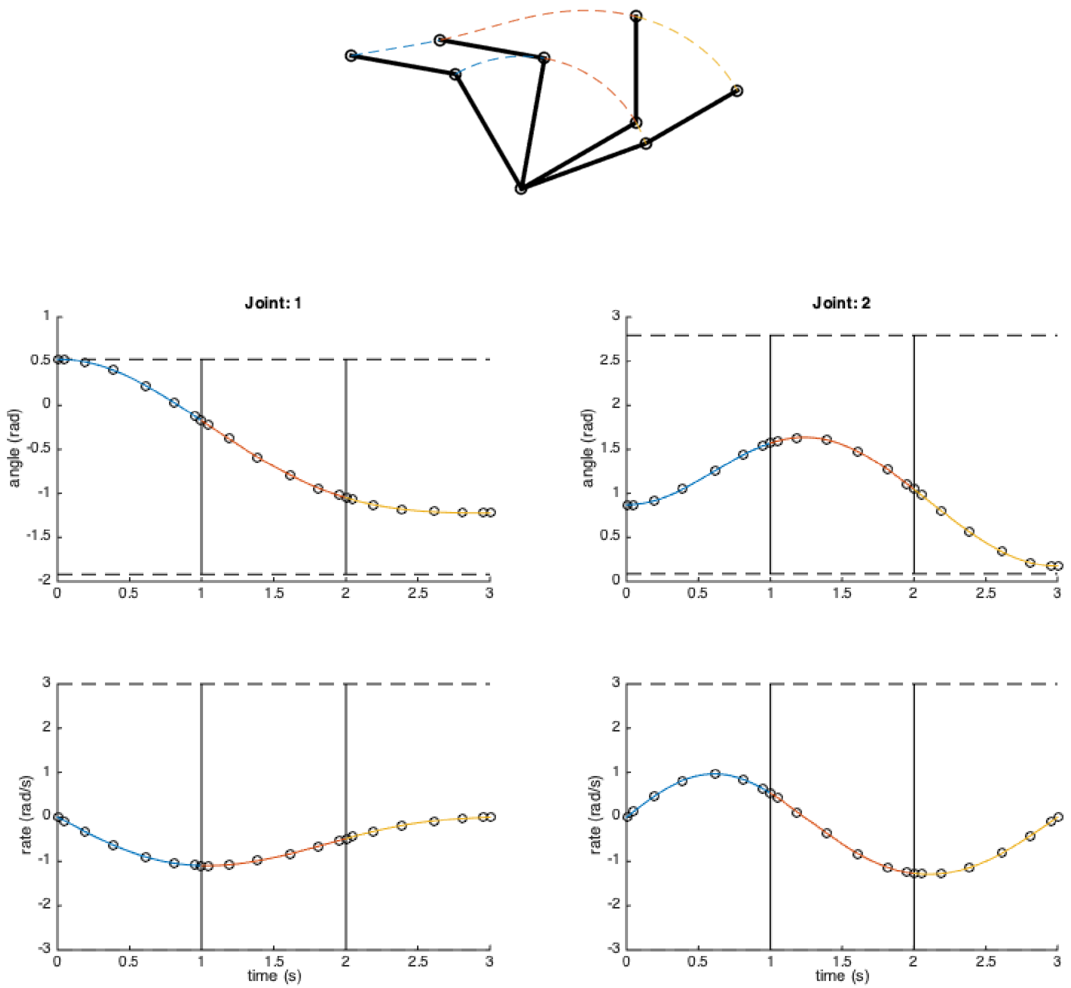

Figure 5. Minimum-Jerk Trajectory of the robotic manipulator corresponding to Chebyshev nodes

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