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Simulation of Optical Waveguide on Communication Signal Wave Delivery Between Airplane and Airport Through Tower

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Abstract

Optical waveguides have become essential in modern telecommunications and sensor technologies, offering light confinement and guidance efficiency. This article provides a comprehensive review of recent advances in the application of optical waveguides to aircraft sensors in sending navigation signals to airport signal-receiving towers, taking into account comparisons based on the GLB (regular straight motion) formula to determine how fast the time for signals from FAA and ICAO moves in units of seconds. Calculation of the signal time to the tower by comparing the maximum distance traveled with the average signal speed, the advantage of signal speed can be utilized by companies to display products and expand products owned by aviation companies to get additional benefits. In this case, there are several things that we examine with the method: (1) Searching for comparative reference data between FAA and ICAO, (2) Collecting additional data on FAA user companies that will expand, (3) Calculating the speed comparison between FAA and ICAO, (4) Visualizing supporting company data to ascertain whether the company has healthy finances to expand, In this case the comparison of signal speeds carried out by each aircraft to each tower to prepare a framework that can be used to support the company's expansion. Considering several possible factors that will occur if business expansion is carried out, this simulation examines the transmission of communication wave signals between aircraft and airports through towers using optical waveguides. The simulation results show that optical waveguides can send communication signals between airplanes and airports safely and efficiently.

Keywords: aircraft, ICAO, optical waveguides

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INTRODUCTION

The optical waveguide is a critical component in optical communication technology that transmits light signals with shallow losses (Yu et al., 2023). In the growing digital age, the need for greater bandwidth and higher data transmission speeds is becoming increasingly important (Huang et al., 2020). This simulation examines the transmission of communication wave signals between an airplane and an airport through a tower using optical waveguides. Optical waveguides were chosen because they offer several advantages over traditional methods such as radio frequency (RF), such as higher bandwidth, lower electromagnetic interference, and higher security (Chen et al., 2023). This simulation uses an optical wave propagation model to calculate the attenuation and distortion of the signal in the optical waveguide. Optical waveguides have become the backbone of modern communication infrastructure, enabling the transmission of large amounts of data quickly and efficiently (Mooshammer et al., 2024). Optical waveguide has various vital applications that include:

1. Telecommunications is one of the critical areas where optical waveguides find practical application. They are used in the backbone of telecommunication networks to transmit data signals over very long distances with minimal loss, a feat that traditional methods struggle to achieve.
2. Optical waveguides are not just limited to telecommunications. They also find use in various sensors for industrial, medical, and environmental applications. Their high sensitivity and precision make them ideal for these applications, where accurate data collection is crucial.
3. Imaging Systems: Used in microscopy and other imaging systems to transmit high-resolution images.

Although optical waveguides have made a lot of progress, some challenges still need to be overcome (Sun et al., 2024). These include signal loss reduction, modal dispersion handling, and improved resistance to extreme environmental conditions. Telecommunication is sending or conveying information from one place to another using a particular medium (Farahnak-Ghazani et al., 2019). Telecommunication is transmitting, sending, and receiving any information in the form of signs, signals, writing, pictures, sounds, and noises through wire, optical, radio, or other electromagnetic systems.

Waveguides are essential for communication and computing applications because they resist electromagnetic interference and induce cross-talk and diffraction (Yang et al., 2024). Next-generation high-end information processing (bandwidth > 1 Tb/s and speed > 10 Gb/s) is very challenging using copper-based interconnects. Optical interconnects transmit data over optical wave channels and offer a potential solution to improve data transmission (Fang et al., 2022). There are two classes of optical waveguides: those in which "classical optical elements, placed at regular intervals along the direction of wave propagation, serve to confine the waves by sequential redirection around the optical axis (laser resonators and many lens waveguides); and those in which the guidance mechanism is a mechanism of multiple total internal reflections from interfaces parallel to the optical axis" (fiber optical waveguides, plate waveguides, and resonators). Various examples of EM wave-based computing structures have been recently reported, such as optical networks capable of performing computational operations such as matrix inversion, transverse electromagnetic (TEM) pulse switching with waveguide networks, and analog computing with dielectrics (Yang et al., 2023). In analog computing for signal processing, derivative calculation is a critical task as it enables edge detection, an important first step in image/signal recognition tasks (Zong et al., 2023). Different EM wave-based analog processors have been reported to perform first-order differentials in space and time domains, including structures designed by fitting the permittivity distribution or reflection/transmission spectra of metamaterial blocks/metamaterial surfaces (Fu et al., 2024). In practice, this often requires fine adjustments to some design parameters, such as the dielectric layer length in multilayer structures or the permittivity of pixels in 2D grids. In this case, we focus on comparing the signals generated by aircraft using different aviation; for example, the FAA focuses on aviation regulation and oversight in the United States with a more stringent and direct approach, while ICAO seeks to create global standards that member states can adopt to ensure international aviation consistency and safety. Both aviation organizations are essential in creating a safe and efficient aviation environment at national and international levels. Analyzing the design and development of high-quality filters is closely related to selecting the appropriate transmission line or waveguide technology. Depending on the specific frequency range desired and the application's relative frequency bandwidth, metallic waveguides, coaxial lines, planar structures, or hybrid forms of those different geometries can be used. Different hardware technologies present different electrical and physical features and characteristics, which directly impact the filter's performance, size, and cost (He et al., 2023). The transmission of data from transmitter to receiver over a considerable distance always experiences a decrease in power or power loss; the loss of power can be called attenuation caused by several factors, including cable attenuation, splice attenuation, connector attenuation, bending, light reflection, absorption, scattering, and Fresnel reflection (Zhao et al., 2023). Damping values exceeding the standard can interfere with the data transmission process, causing delays and loss of information sent due to losses along the fiber optic cable (Zhang et al., 2023). Data delays or loss of information are also due to dispersion (overlapping of wave pulses) and the number of corrupted bits (bit errors) (Garrett & Tong, 2021). Several different approaches to modeling flight data communication demand have been identified.

First is synthetic modeling, which creates a constant or repetitive data stream and is independent of the aircraft's flight path and operational status, such as that used to model APC data communications. Second, proprietary inputs, which could be communication records or statistical evaluations of current flight data link usage, are used by relevant ATS or AOC stakeholders, such as communication service providers operating the current flight data communication network. This modeling approach may include, for example, the dependence of data communication behavior on airspace user type and airspace type. In addition, some works base the modeling of aviation data communication demand on a comprehensive assessment by FAA and EUROCONTROL of the expected aviation data communication demand, including a list of relevant services depending on the flight phase and airspace type and the sequence and size of messages. The results of this assessment are intended to be used as technical guidelines for developing related technologies and procedures. A further possible approach is recording actual flight data communications as already done or using data link performance reports for flight data link communications provided by the ICAO North Atlantic office and deducing a representative data communications demand model. In addition, the flight data communication demand model can be supplemented with technical standards for flight data link applications, such as the safety and performance standards published by EUROCAE, which provide a sequence of messages in service and performance requirements. Its application in an agency can be seen from the following data.

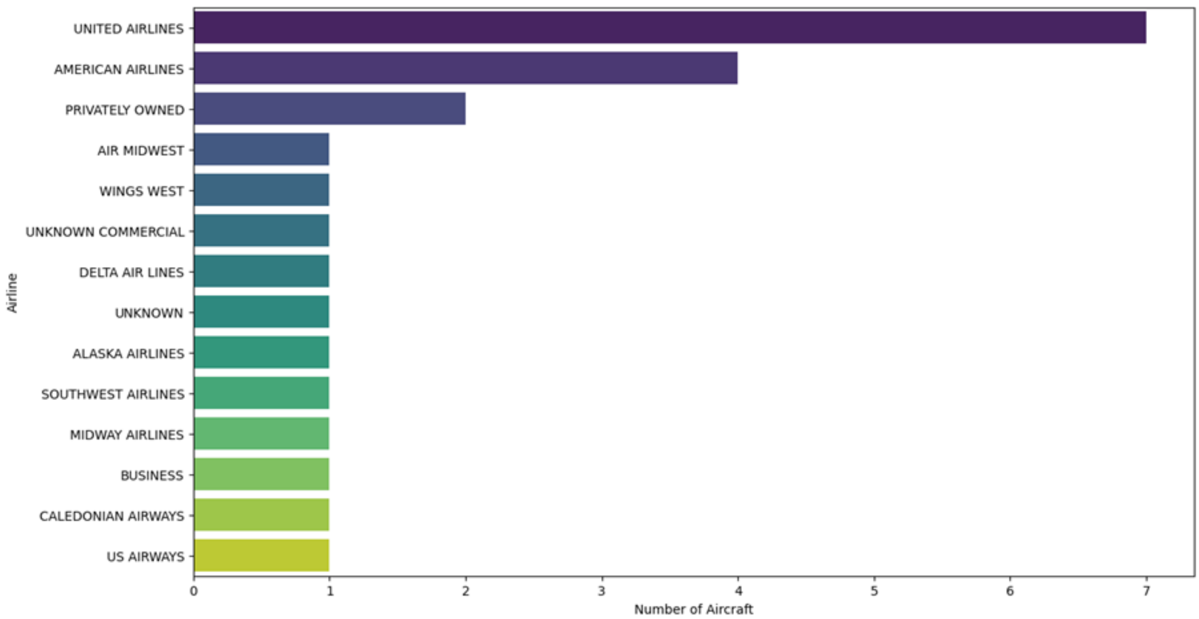

Figure 1. Number of Aircraft per Airline

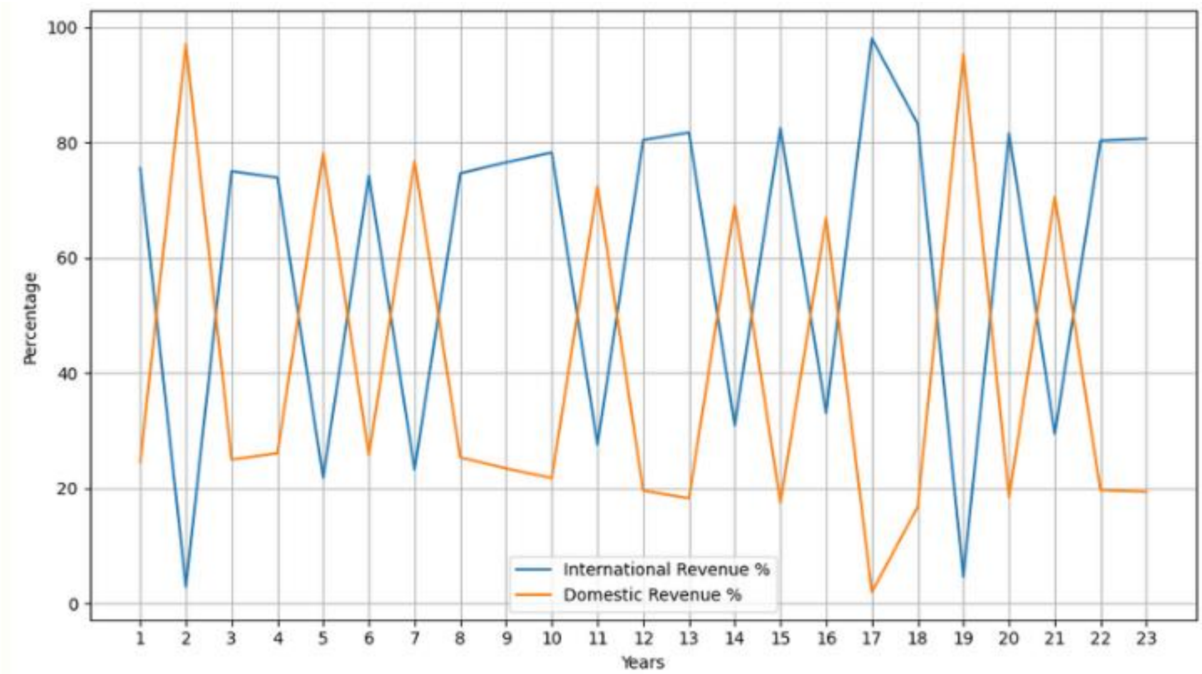

Figure 2. International and Domestic Revenue as %of Total Revenue

The first table clearly demonstrates the potential profitability of companies that utilize FAA aviation, attracting a significant client base. This promising outlook, as indicated by the second graph, suggests that the benefits of FAA aviation on aircraft are substantial. However, before embarking on this journey, it's crucial to thoroughly research and consider several key factors, ensuring that we are well-prepared for the challenges ahead.

1. Profit:
   As a new company in the country, how quickly do we get results (return on capital) if the company has good revenue and accuracy in a good percentage of profits, especially in the presentation of international flights obtained? The company is seen to have the ability to expand abroad and has fulfilled its needs.
2. Competitors
   See how and what competitors' components already exist in the destination country that has used ICAO as an institution that has worked together. Consider how the company can adapt to the new environment in the face of competitors by making developments or changes to the aircraft aviation section by prioritizing the latest quality and using entry fragments to process revenue results and market analysis to survive in the destination country.
3. Market
   By carefully assessing the market potential and strategically planning for sustainability, the company can confidently navigate the challenges of the destination country, ensuring a successful expansion.
4. Risk

Of course, expanding will incur charges, especially fixed costs in case of disaster or failure. Before marketing expansion, the company must also determine whether the destination country is good and healthy enough for cooperation.

5. Achievement
   When considering expansion and international cooperation, it's essential to plan carefully. This involves calculating potential profits, estimating the duration of fixed profits, and recording fixed expenses. The potential for significant profits can instill a sense of optimism and hope in stakeholders, reassuring them that the company's shares will retain or even increase in value.

Implementing expansion carried out by a company can be achieved if all factors can be carried out properly, provided that the company can work to adjust and follow the provisions in the destination country.

METHOD

In our simulation, we conducted several methods, such as methods to analyze the difference in waves emitted by FAA and ICAO that can be used as a reference for expansion, and there are also methods in making simulations of transmitting waves of communication signals between aircraft and airports through towers. Some of the steps we took to analyze the differences in waves emitted by the FAA and ICAO that can be used as a reference for the expansion of a company:

Searching for comparative reference data between FAA and ICAO

So, to compare two aviation organizations: the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO). The need to look for comparative reference data between the FAA and ICAO means that we are trying to understand the fundamental similarities and differences between two important aviation organizations: the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO). With good comparative baseline data, you can see the whole picture of their responsibilities, authorities, and how they affect the world of aviation.

By finding good comparative benchmark data, we can better understand how these two organizations work together to ensure the safety of civil aviation around the world. The resources we use to find this comparative data will depend on the level of detail we need.

Collecting additional data on FAA user companies that will be expanding

Our research involved a comprehensive understanding of the profile and needs of companies looking to expand their flight operations under FAA regulations. This in-depth and targeted data collection process instills confidence in the thoroughness of our study, enabling the FAA to better understand the needs and challenges of companies looking to expand their operations under FAA regulation.

Ultimately, the goal of our study is to create an environment conducive to the growth of the aviation industry in the United States. Our findings are significant as they provide valuable insights into the differences in waves emitted by the FAA and ICAO, and the needs of companies looking to expand their operations under FAA regulation, all while ensuring the safety and security of civil aviation.

Calculate the speed comparison between FAA and ICAO.

$$\vec{v} = \frac{d\vec{x}}{dt} \tag{1}$$

$$\int_{x0}^{x} d\vec{x} = \int_{t0}^{t} \vec{v}dt \tag{2}$$

$$[\vec{x}]\, {}_{x0}^{x} = \vec{v}\,(t)_{t0}^{t} \tag{3}$$

$$\vec{x} - \overrightarrow{x0} = \vec{v}(t - t0) \tag{4}$$

$$\overrightarrow{x0} = \vec{v}.\Delta t \tag{5}$$

Comparasion for FAA and ICAO

- For **FAA** (maximum distance 10 km) :

$$t_{FAA} = \frac{10\ \times 10^3 m}{v} \tag{6}$$

- For **ICAO** (maximum distance 8 km) :

$$t_{ICAO} = \frac{8\ \times 10^3 m}{v} \tag{7}$$

This formula defines velocity as the derivative of the position vector concerning time. That is, velocity is the rate at which the position of an object in space changes concerning time. This shows the relationship between the position integral and the velocity integral. The position integral is the difference in the position vectors at two different points in time. In contrast, the velocity integral is the difference in the total distance traveled during that period. This formula shows that the position integral is equal to the velocity integral multiplied by the time difference in the relationship between the position vector at two different time points and the average velocity vector over that period. This equation states that the difference of the position vector is equal to the average velocity vector multiplied by the time difference.

Visualize supporting company data to ascertain whether the company is financially sound to expand

I was visualizing the company's supporting data to ascertain whether the company has sound finances to expand means presenting the company's financial information concisely and easy-to-understand through graphs, charts, and other visual indicators. The goal is to help decision-makers assess the company's financial health and determine whether it is ready to expand. By visualizing the company's financial data clearly and concisely, stakeholders can quickly:

- Understand the company's current financial condition.
- Assess the company's financial trends over some time.
- Identify areas of the company's financial strengths and weaknesses.
- Make predictions about the company's future financial performance.
- Determine whether the company has sufficient financial resources to fund expansion.

Visualizing financial data is about more than just creating attractive graphs and charts. It's about choosing the right visualizations to convey essential information and help decision-makers make informed decisions about the company's future.

In addition to data visualization, it is also essential to consider other qualitative factors, such as:

- **Market conditions**: Assess the market conditions in which the company operates and identify potential opportunities and risks.
- **Business plans**: Review the company's business plan for expansion and assess its feasibility and profit potential.
- **Management team**: Evaluate the experience and expertise of the company's management team in leading a successful expansion.

By thoroughly considering all these factors, stakeholders can make an informed decision about whether the company is financially sound and ready to expand.

Create a visualization of how the speed difference between the signals given by FAA and ICAO.

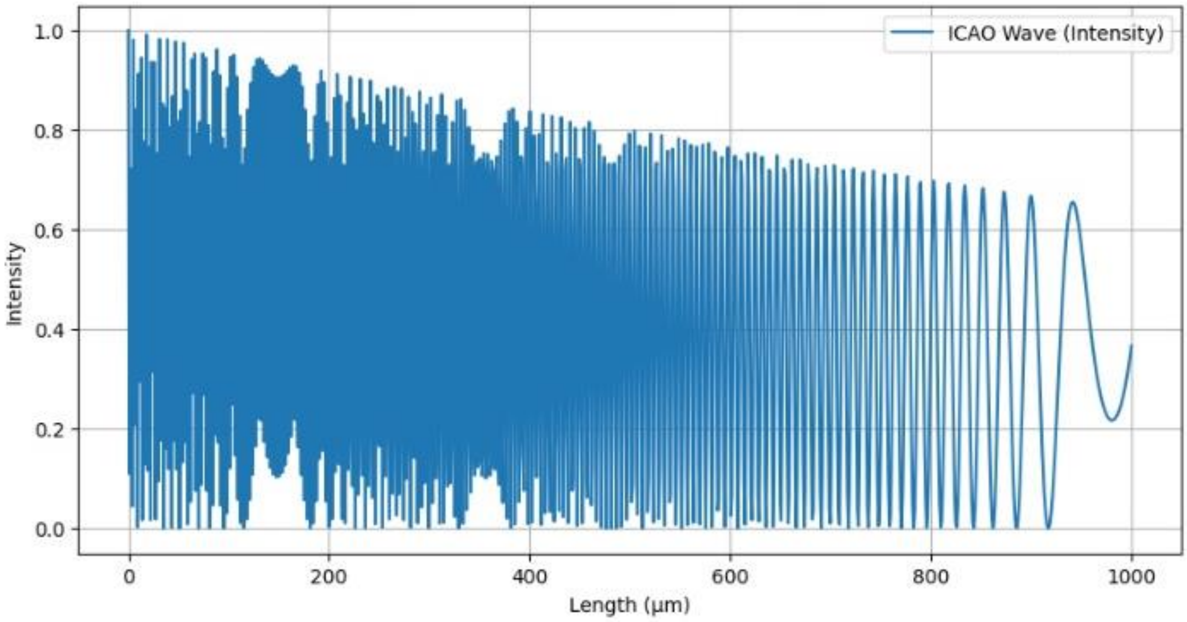

Figure 3. Optical Waave in ICAO Optical Waveguide

The figure shows a graph of optical waves using the ICAO method. Optical waves are electromagnetic waves that propagate through space. An optical waveguide is a structure used to direct optical waves. Wavelength is the distance between two consecutive wave crests. In the figure, the wavelength can be estimated to be about 50 μm. The maximum amplitude of the wave is about 0.8. the intensity of the wave varies along its length. The maximum intensity of the wave is about 0.8.

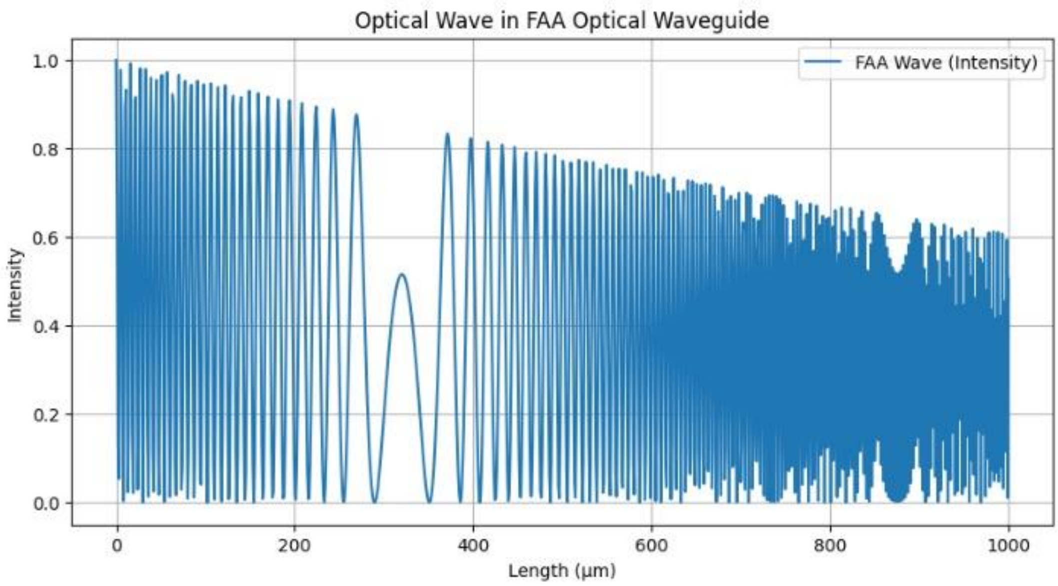

Figure 4. Optical Wave in FAA Optical Waveguide

The figure shows a graph of an optical wave using the FAA method. The wavelength can be estimated to be about 400 µm. The maximum amplitude of the wave is about 1.0.

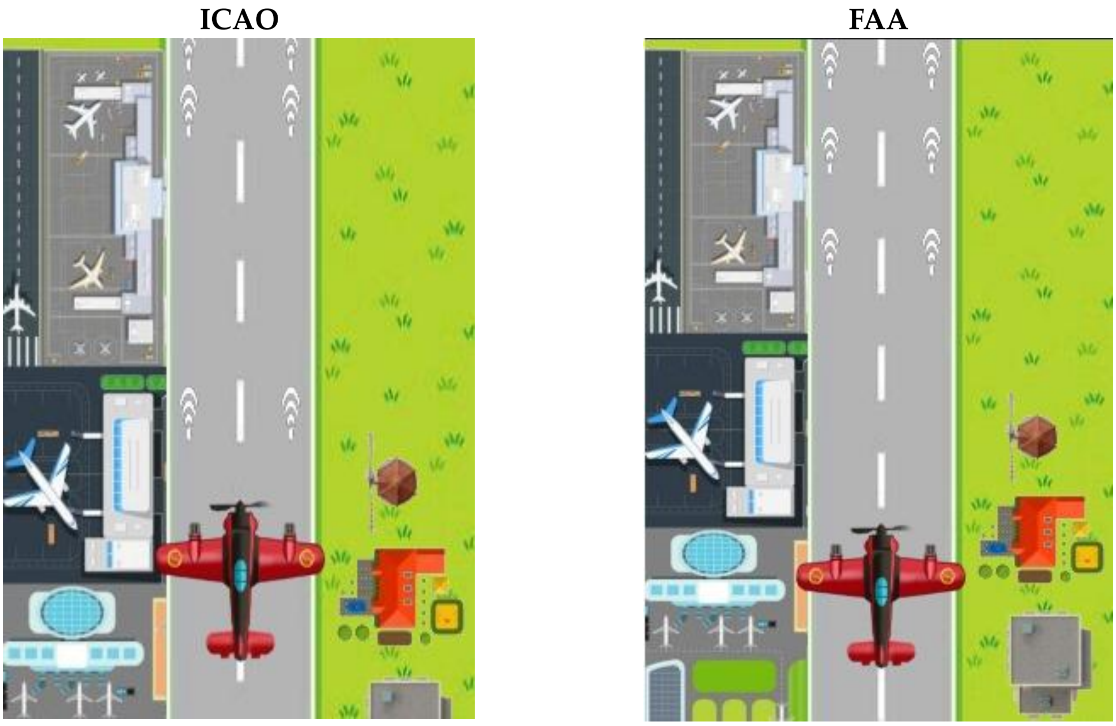

Figure 5. Simulation Result

The picture above is a visualization of the signal waveform that has been created, where the signal sent by the FAA aircraft is faster to send signals and more effective than the ICAO aircraft.

Since the value of v for both methods is v = 3 x 108, the result of the calculation for the FAA method is 3 x 10-6seconds or 3 microseconds for a distance of 10 km. While for the ICAO method the calculation result is 2,6 x 10-6 seconds or 2.6 microseconds for a distance of 8 km. From both methods, it can be concluded that the FAA is faster.

ALGORITHM

Variable Initialization

SCREEN, WIDTH, HEIGHT	: Screen size set to 288x512 pixels.
Info, width, height	: Current screen resolution information.
Win	: Pygame window object prepared based on the screen resolution.
Clock	: Clock object to set the game speed.
FPS	: The frames per second rate is set to 24.
WHITE	: White color in RGB format.
'bg'	: The `Background` object represents the game's background.
'p'	: The `Player` object representing the game's player.
player_bullet_group	: A sprite group to manage the bullets fired by the player.

moving_left, moving_right, moving_up, moving_down: Boolean flags to track the player's movement to the left, right, up, and down.

- **Main Algorithm**
  1. It uses `pygame.image.load` to load the image from the given path.
  2. Uses `pygame.transform.smoothscale` to resize the image.
  3. Gets the rectangle of the image using `get_rect` for easy positioning and movement.
  4. Move the background vertically.
  5. Move the player based on the direction input.
  6. Replace the player image for animation.
  7. Use `win.Blit` to draw background, player, and bullet images on the game screen.

- **Background Class**
  1. Load and resize background images using `pygame.image.load` and `pygame.transform.smoothscale`.
  2. Get the rectangle for each background image using `get_rect`.
  3. Set the initial position of the background image. The image is placed on top of the screen with a height of 512 pixels to move down gradually.
  4. Moves the background down at a certain speed.
  5. If the image goes beyond the bottom border of the screen, its position is reset to the top of the screen.
  6. Display the background image on the game screen (`self.win.blit`).

- **Class Player**
  1. Loads two player images for animation.
  2. Resizes the player image using `pygame.transform.smoothscale`.
  3. Stores the images in a list (`self.image_list`).
  4. Set the starting position and other attributes.
  5. Move the player to the input direction (left, right, up, down).
  6. Change the player image to give an animation effect.
  7. Restrict the player's movement from going outside the game screen boundary.
  8. Display the player image on the game screen (`win.blit`).

- **Bullet Class**
  1. Load and resize bullet images based on bullet type (`type_`).
  2. Set the position and speed of the bullet.
  3. Moves the bullet according to its speed.
  4. Removes the bullet if it goes out of the screen boundary.
  5. Display the bullet image on the game screen (`win.blit`).

❖ **Airplane Algorithm**

- **Main Algorithm**

1. Initialize Pygame and screen settings.
2. Creates game objects (background, player, and bullet group).
3. Handles input from the user to move the player and shoot bullets.
4. Updates the position and state of the game objects.
5. Draws game objects on the screen.
6. Set the frame rate and update the screen display.
7. It exits Pygame when the game is stopped.

Functions for Managing Input

- **handle_keydown(event):**
  1. Handles input when a key is pressed.
  2. Sets the movement variable according to the key pressed.
  3. If the space key is pressed, it creates two bullets fired from the player's left and right positions.
  4. If the Escape key or 'q' is pressed, stops the game.
- **handle_keyup(event):**
  1. Sets the movement variable to False when the button is released.

Initialization and Initial Setup

1. Calls pygame.init() to initialize all necessary Pygame modules.
2. If the screen width exceeds or exceeds the screen height, set the borderless display mode (pygame.NOFRAME).
3. Otherwise, set frameless, scaled, and full-screen display modes.
4. Creates a clock object to set the frame rate using pygame.time.Clock().
5. Specifies frames per second (FPS) as 24.
6. Defines white with RGB values (255, 255, 255).

- **Game Objects**
  1. Initializes the background object (bg) with the win parameter (game screen).
  2. Initializes the player object (p) with the starting position (144, 432).
  3. Creates a sprite group for the bullets fired by the player (player_bullet_group).
  4. Defines the movement variables (moving_left, moving_right, moving_up, moving_down) and sets their values to False.

- **Game Main Loop**
  1. Handles events such as exiting the game, button pressed, and button released.
  2. Updates the background position (bg.update(3)).
  3. Updates the player's position and image (p.update(moving_left, moving_right, moving_down, moving_up)).
  4. Update bullet positions and check collision detection (player_bullet_group.update()).

5. They are clearing the screen by filling it with black (win.fill((0, 0, 0))).
6. Draw the background (bg.update(3)).
7. Draw the player (p.draw(win)).
8. Draw bullets (player_bullet_group.draw(win)).
9. Set the frame rate using clock.tick(FPS).
10. Update the screen display with pygame.display.update().
11. Exit Pygame when the game is stopped (pygame.quit()).

RESULTS AND DISCUSSION

We explored the performance of optical wireless technology to ensure audio communication inside an aircraft cockpit. One advantage is that, unlike radio frequency, opaque objects block optical signals so they cannot penetrate walls. This can reduce the security risk against eavesdropping and physical layer hacking, which is one of the main concerns in the aviation environment. However, optical wireless technology faces several problems, including range limitations and sensitivity to obstruction. We created a simulation with a single aircraft sending signals to a tower to study the achievable performance. In this case, the average speed of the signal is $v = 3 x 10^8$, and it can be seen that the FAA aviation method $3 x 10^{-6}$ seconds or 3 microseconds for a distance of 10 km. As for the ICAO method, the calculation result is 2,6 x 10^{-6} seconds or 2.6 microseconds for a distance of 8 km. So, from both methods, it can be concluded that the FAA is faster. From this, it can be said that companies that want to expand must consider several factors such as market, competitors, risks, and achievements with adjustments made according to the destination country and can work by existing regulations in the country.

The above parameters show a difference between the optical wave technologies used by FAA (Federal Aviation Administration) and ICAO (International Civil Aviation Organization). However, this difference is not directly related to the speed of FSO signal transmission but to the characteristics and performance of each technology. The following is an explanation of the above parameters:

Maximum Transmission Distance:

FAA Optical Waveguide: 5 - 10 km
ICAO Optical Waveguide: 3 - 8 km
Conclusion: FAA has a longer maximum transmission distance.

Signal Loss:

FAA Optical Waveguide: 0.5 - 1 dB/km
ICAO Optical Waveguide: 1 - 1.5 dB/km
Conclusion: FAA has lower signal loss, making it more efficient in maintaining signal strength during transmission.

Modal Dispersion:

FAA Optical Waveguide: Higher
ICAO Optical Waveguide: Lower
Conclusion: The lower dispersion modal in ICAO means that signals tend to be more stable and less distorted. However, this depends on the specific application, as a higher dispersion modal could be appropriate in some situations.

Coupling Efficiency:

FAA Optical Waveguide: Higher for large divergence angle sources
ICAO Optical Waveguide: Higher for small divergence angle sources
Conclusion: The higher coupling efficiency of the FAA for large divergence angle sources means that the FAA is more flexible in accepting different types of light sources.

Environmental Resistance:

FAA Optical Waveguide: More resistant to light leakage
ICAO Optical Waveguide: Less resistant to light leakage
Conclusion: FAA is more reliable in challenging environmental conditions as it is more resistant to light leakage.

From these parameters, the FAA Optical Waveguide performs slightly better regarding maximum transmission distance, lower signal losses, and reliability under certain environmental conditions, such as being resistant to light leakage. However, dispersion capital and coupling efficiency differences will probably affect other operational characteristics such as signal stability and transmission reliability. While these parameters give an idea of the relative characteristics of the two optical wave technologies, you may need to consider other factors, such as latency, the communication protocol used, and the capabilities of the sending and receiving devices, to assess more specific transmission speeds. So overall, for the fastest and most efficient transmission speeds in more challenging environmental conditions FAA Optical Waveguide is the superior choice.

It can be analyzed from the mathematical equations presented that the formulation of the velocity vector is known as the derivative or change of the position vector concerning time. It can be further investigated by integrating the derivative with a specific limit. Then, the final result of the decrease in the form of a change in position x (delta x) is the product of the velocity vector with a change in its time. In physics, Optical Waveguide Simulation is an essential tool to understand and model the optical communication path between aircraft and airports. This makes it easier for some companies to estimate if they want to expand to destination countries with different aviation methods by considering several factors such as market, competitors, risks, and achievements. Then, in its application, Optical Waveguide simulation has some vital meaning in sending communication wave signals between the airplane and the airport through the tower. By applying this simulation, engineers and technicians can design, plan, and maintain an optimal communication system to meet the growing needs of airborne communication. Therefore, the comparison of signal transmission between FAA and ICAO aircraft is superior and more efficient namely FAA aircraft signal transmission. Our consulting firm handles the case of an American airline company that manufactures aircraft and has its airline. The company uses an FAA (Federal Aviation Administrator) license only valid in the United States. Meanwhile, some countries use an ICAO (International Civil Aviation Organization) license. Using an FAA license limits the airline's range of operations in the United States. To operate in other countries.

CONCLUSION

1. The movement of the signal emitted by the aircraft at a certain distance and time is highly dependent on electromagnetic principles. By considering various factors such as signal, beam strength, and atmospheric conditions, measuring the signal at a certain distance and time is possible to determine the position and speed of the aircraft in real-time and the transmission quality for navigation and communication of the aircraft with the monitoring tower.
2. Optical waveguides enable data transmission with high speed and minimal loss through several processes, such as a light confinement mechanism in the waveguide core, dispersion processing, and minimization of intrinsic losses such as absorption and scattering. High-quality materials and advanced fabrication techniques are required to increase transmission efficiency.
3. When applied to problem-solving, signal movement can significantly reduce technical and operational issues, particularly in the context of aircraft operations. It is instrumental in determining navigation, communication signals, and flight monitoring. Furthermore, in the case of optical waveguide, signal movement plays a crucial role in optimizing design, reducing losses, and increasing data transmission capacity, thereby enhancing the efficiency of the system.
4. Our consulting firm was instrumental in assisting an American airline company that was limited to operating in the United States due to its FAA license. To expand its operations globally, the airline needed to obtain an ICAO license, a complex and time-consuming process. We identified an opportunity to help the airline by offering services such as license requirement gap analysis, documentation preparation, staff training, and ongoing support to ensure compliance with ICAO requirements. With our support, the airline successfully obtained an ICAO license, opening up new business opportunities in the international market.

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