NASA/TM–20240011332

Optimizing Air Traffic

Integrating Artificial Intelligence and Machine Learning in Flight Path Planning and 3D Airspace Visualization for Air Traffic Control

** All authors contributed equally to this memo. The names are listed alphabetically by surname.*

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August 2024

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Acknowledgments

This technical memorandum was made possible by the NASA Internship Program. The authors would like to thank Hanbong Lee and Eric Wang for their invaluable guidance and continuous support throughout this project. They also thank Alyssa Li and the Digital Information Platform researchers William Jeremy Coupe, Pallavi Hegde, and Sarah Youlton for their input and advice. Finally, the authors thank everyone at Ames Research Center who contributed to making this experience possible, especially Shannon Zelinski for coordinating this internship.

This report is available in electronic form at

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Abstract

Air Traffic Control (ATC) systems are vital components of the National Airspace System (NAS). ATC, Airport Traffic Control Towers (ATCT), and Terminal Radar Approach Control (TRACON) are responsible for directing all flights departing from and arriving at airports, managing our nation's airspace, preventing potential accidents, and ensuring that every flight is accounted for. However, these systems often face challenges in effectively monitoring the skies. Issues such as poor communication between operators, difficulty in performing operations, and the constant need for vigilance frequently burden ATC operators. Additionally, the projected increase in air traffic in the coming years will only exacerbate the stress associated with this role.

To address these issues, we propose a system that assists ATC operators in situations such as handovers, emergencies, and routing aircraft to avoid weather hazards. Our solution includes an Artificial Intelligence (AI) and Machine Learning (ML)-based Flight Pathways Planning System (FPPS) designed to find the fastest and most optimal routes for aircraft, taking into account weather conditions, restricted terrain, and Extended-Range Twin-Engine Operational Performance Standards (ETOPS) ratings. The proposed Predictive Weather Planning Model, included in FPPS, adjusts routes based on real-time and forecasted weather conditions. Additionally, our NVIDIA Omniverse 3D Visualization System offers a highly interactive environment for better visualization and a clear view of the airspace.

By incorporating these systems, the roles of ATC, ATCT, and TRACON operators will become more manageable and less stressful, equipping them to efficiently handle the growing density of airspace.

Introduction

Problem Statement

The current system that ATC uses for air traffic management leaves much to be desired. One of the most significant issues lies in the strain that operators experience when performing their duties, compounded by the fact that most airports' ATC centers are understaffed and increasingly rely on overtime work from their operators to function. This leads to delays and cancellations and an increase in ever-dangerous near misses that risk the lives of thousands aboard aircraft [1]. Additionally, the equipment available to ATC and TRACON operators is severely outdated. Although the Federal Aviation Administration (FAA) has attempted to remedy this with the introduction of NextGen, it has already reportedly failed to meet expectations for efficiency gains [2]. Advances directly improving the interface of ATC operators such as Standard Terminal Automation Replacement (STARS) and Integrated Display System Replacement (IDSR) exist, but there is no guarantee that these will alleviate the problems operators face. Air transport will continue to expand in the future, and is expected to reach a 44% increase by 2050 from 2019 despite dampening from the COVID-19 pandemic [3]. Systems involving the communication of operators are also not effective. Voice communication is heavily relied upon, but it often leads to miscommunication arising from poor signal quality, background noise, language barriers, varying accents (especially in international airspace), and human error in interpreting messages. As such, there is a great need for a system that effectively addresses all of these issues and equips ATC to handle the projected increase in air traffic volume, while minimizing incidents and delays.

Background

Overview

Individual ATC towers take on numerous responsibilities both in the air and on the ground. ATC operators constantly face the pressure of making decisions, responding to requests, and ensuring that they remain accurate when conducting procedures. In the United States, approximately 44,000 flights are operated daily. The ATC must guarantee the safety of the departure and arrival of every aircraft, monitor flight paths to prevent interference, avert accidents, and scan the skies for unaccounted aircraft. Unfortunately, many ATC towers still use outdated technology such as voice communication, 2D visualization, and paper strips for tracking flights. Such equipment is inadequate for keeping up with the increasing volume of work that ATC operators must perform. Using techniques such as paper strips to track flights is slow and tedious, and 2D visualization is limited in the amount of data it can present. Voice communication is prone to inconsistencies, creating potential misunderstandings and problems both in the air and on the ground [4]. Outdated technology is a large factor contributing to these accidents and issues; the various systems used for visual awareness are outdated, limiting the information they can convey. Additionally, limited technology and understaffing in ATC continue to cause problems within ATC, causing stress and reducing efficiency for operators [5].

Issues in ATC Operation

The shortage of ATC operators is a large reason behind the major issues within ATC towers. Difficulty and stress associated with the position are the defining factors behind this shortage. The role of ATC operators involves monitoring aircraft movements, providing instructions to pilots, coordinating with other controllers, and responding to emergencies. The high volume of flights demands constant vigilance and quick decision-making skills. As a result, ATC operators often experience mental and physical fatigue due to the intense nature of their work. A study found that ATC work requires a stress tolerance of 96.2, comparable to that of a surgeon, and has a significantly higher risk factor than police, fire, and ambulance dispatchers [6]. It follows that the entry requirements to such a role are very high, but this in itself poses an issue. ATC workers can study for up to 4 years just to not pass, as only about 1% of workers pass the exam to become fully licensed ATC workers [7]. The responsibilities of an ATC operator are often simply too complex for the average person. The FAA has expanded hiring operations to remedy understaffing, going so far as off-the-street hiring and removing academy requirements [1]. However, this could reduce the average quality of ATC operators, which is unacceptable for a role that is responsible for the lives of thousands. The ATC operators that do manage to become certified are not perfect, either, creating delays, cancellations, and near misses.

Issues in ATC Technology

The technology currently available to ATC operators fails to meet their needs, exacerbating the issue. Out of a mix of legacy systems and modern components, many of these technologies cannot keep up with the future demand for air travel. Numerous solutions have been proposed to help operators manage air traffic and to minimize delays and accidents. However, each solution is plagued with issues and setbacks. NextGen promised to bring greater efficiency to ATC operations and alleviate these issues. Despite this, the FAA did not accurately assess the schedule and costs of NextGen. As a result, many systems have been delayed and will not be operable by the original 2030 deadline, with costs running millions of dollars over budget [8]. Other systems, such as the IDSR and STARS that interact directly with ATC operators, are in the process of or are planned to be integrated with operator displays. However, it remains to be seen whether these will have a significant impact on operations. With an expected increase of 44% in air traffic from 2019 to 2050, further technology is likely necessary to ensure the efficiency and sustainability of operations.

Current ATC operator systems compromise an operator's ability to perform their roles effectively. When multiple interfaces are used, eye tracking and gaze duration become compromised, causing an operator to have reduced cognitive concentration. Studies have shown that a significant number of operators turn their heads to look at other displays, are forced to view displays peripherally and perform physical actions away from the STARS interface, all of which can lead to missing important information [9]. In addition, digitized communication is not yet a major feature in most STARS-equipped systems. Working with radars in ATC facilities has also been shown to induce eye fatigue, as the contrast between the dark screen and the luminous flight markers, as well as between the dark room and the bright surroundings outside the facility tends to strain the eyes [10]. These issues have to be addressed to ensure operators function at full capacity.

Another concern in ATC is voice communication. This system, heavily relied upon in all sectors of ATC, is notoriously unreliable. Poor signal quality, background noise, language barriers and varying accents, and the potential for human error in interpreting messages, all result from the use of voice communication [11]. These all lead to delays, misinterpreted instructions, safety hazards, and most importantly, affect an ATC operator's capacity for organized decision-making. For instance, the infamous Avianca Flight 052 incident, which left 65 passengers dead and 8 out of the 9 crew killed, was caused by a miscommunication between ATC operators [12]. The issue was quickly identified to be a failure of regional ATC controllers to notify local ATC controllers that Avianca Flight 052 was experiencing a fuel emergency. The ATC controllers issued a holding pattern that caused the flight to run out of fuel and crash. The Garuda Flight 152 incident, which resulted in the death of all 254 passengers aboard, was caused in part by another aircraft that was assigned the same flight number. The list of similar accidents goes on, including the Tenerife airport disaster, Flight EF306 Accident, and more [13][14]. Communication is a large aspect of ATC, without proper technology and further improvements being created, the safety of flights cannot be guaranteed.

Proposed Solution

Overview

To address the aforementioned issues, we propose a visualization system that aims to connect ATC, TRACON, and Air Route Traffic Control Center (ARTCC) operators across the nation together, allowing instant communication between operators and the FAA. This system aims to make operations such as flight coordination, rerouting, and accident avoidance more efficient using ML and smart notifications while providing a more informative overview of United States airspace.

ATC operators must reroute aircraft when their planned routes encounter hazards, such as dangerous weather conditions, either in the air or on the ground [15]. NASA's research development of the Digital Information Platform (DIP) handles reroutes for aircraft on the ground using the Collaborative Digital Departure Rerouting (CDDR) service. However, there is currently no system that allows operators to efficiently reroute aircraft while they are airborne. We propose that FPPS utilizes Dijkstra's Algorithm to enable operators to create effective reroutes for airborne aircraft efficiently and quickly.

Visualization becomes faster, more comprehensive, and easier to understand with new technology like NVIDIA Omniverse, which uses 3D modeling and real-time simulation to create these advantages [16] Unlike traditional 2D displays which can become cluttered and very difficult to understand and interpret, NVIDIA Omniverse provides a 3D environment where a controller can view airspace from multiple angles. This will enhance situational awareness by offering a more comprehensive understanding of aircraft positioning and movements. Moreover, the platform's advanced computational power ensures that data is processed and displayed quickly, therefore reducing latency and improving the overall responsiveness of the ATC system. Smart operations and automated processes, such as automated handovers and local ATC reroutes, can allow controllers to spend less time micromanaging and more time surveying the airspace, while also reducing the technical expertise required to operate the system. Assigned and automatically updated information allows every operator to be informed about every aircraft's situation at all times.

In the event of failure of one or more components of the system, every operator using the system is notified of the error. The system then continues to operate at reduced capacity. For example, if the internet connection between operators fails, the system reverts to using local data from radar equipment, notifies the operator of the outage, and disables any functions involving the use of an internet connection. In this scenario, operators must revert to using older equipment, such as voice communication, to continue performing their roles. These redundant systems are designed to keep ATC operational in the case of an emergency, which is essential for such an important part of maintaining United States airspace. When the downed equipment goes online again, the system can be restored to full capacity manually.

These implementations aim to reduce human errors, increase operational efficiency, enable operators to manage busy airspaces more easily, streamline the rerouting process, and increase awareness of airspace. This will allow controllers to make more informed decisions, which may result in safer and more efficient air traffic management.

Flight Pathways Planning System

System Details and Function

The FPPS is designed to find the fastest and most efficient route an aircraft can take between two points, taking into account certain factors such as weather, no-fly zones, and ETOPS ratings, without the involvement of a human operator in the flight pathway creation. This system will be used to rapidly issue reroutes for airborne aircraft that have a route that intersects with hazards such as weather, restricted airspace, or the routes of other aircraft. To create a reroute, a weather prediction model and algorithm will be created, utilizing data input from sources such as ERA5, NASA Fuser, airspace data provided by the FAA, and airspace data provided by local ATC centers. The flight plan will then be given to ATC for final approval and forwarded to the pilot's console, once approved.

System Inputs

The FPPS will take into account airborne aircraft, off-limit zones, predictive weather, and congestion within airspaces.

Information regarding aircraft that require a flight plan can be taken from NASA Fuser. Fuser is a technology that NASA has produced to process and synthesize information from different sources, including different FAA sources, multiple third-party sources, as well as airline data [17]. This information, included in the aircraft's dossier, includes ETOPS rating, top speed, and flight characteristics in and out of wind. Prohibited and restricted flight zones, namely zones such as Temporary Flight Restrictions (TFRs) and Airspace Flow Programs (AFPs), provided by the FAA [18], are also taken into consideration by the algorithm. Finally, information about the flight routes and trajectories of other aircraft in the area is inputted. This is included to ensure that the generated route does not interfere with the routes of other aircraft.

Predictive Weather Planning Model

The Predictive Weather Planning Model uses historical weather data to produce predictive weather patterns for consideration in future flight plans. Predictive elements include wind patterns and dangerous weather, such as storms, fog, extreme temperatures, and turbulence. To do this, weather data must be used to make predictions for when the flight is to occur. The proposed system is similar to NVIDIA's CorrDiff model, which is used to predict meteorological weather patterns [19].

Weather data can be obtained through ERA5 reanalysis. ERA5 provides past weather data with a resolution of $25km^2$, which can be increased to 4 km^2 resolution using data interpolation and mapped onto a curvirectangular grid for viewing. From this weather data, geopotential height, 2m temperature, 100m *u* and *v* wind components, altitude levels at 300 hectopascals (hPa), 250 hPa, and 225hPa, and relative humidity will be taken as inputs for use in the model. Data from the years of January 2019 to December 2022 will be taken as training data, with data from January 2023 to June 2024 being used as testing data to prevent overfitting. Using inputs from ERA5, the model will produce outputs in the form of future wind speed and any obstructions with regard to weather [20].

System Outputs

The outputs of the predictive weather model will be used as inputs in the FPPS, along with other potential obstructions such as no-fly zones, areas outside the ETOPS clearance, and information about the aircraft.

This information will be used to weight and remove nodes in Dijkstra's Algorithm. Dijkstra's Algorithm is commonly used to find the shortest path from a given node to a target node. Wind data taken from the generative weather algorithm will be mapped as vectors on a grid representing the different areas where the individual vectors will be found. Next, these vectors will be split into *u/v* vectors, converting them to component form. Certain edges will be weighted to take different inputs, such as wind speed, into account. This will represent the cost in time for an aircraft to move from one node to another. Nodes with dangerous weather conditions, nodes within no-fly zones, nodes that intersect the flight path of other aircraft, and nodes outside the aircraft's ETOPS clearance will be removed from consideration, as aircraft cannot fly there. Because more favorable routes will be weighted less, Dijkstra's Algorithm will create the most fuel-efficient and fastest route, given the aforementioned restrictions (Fig. 1) [21].

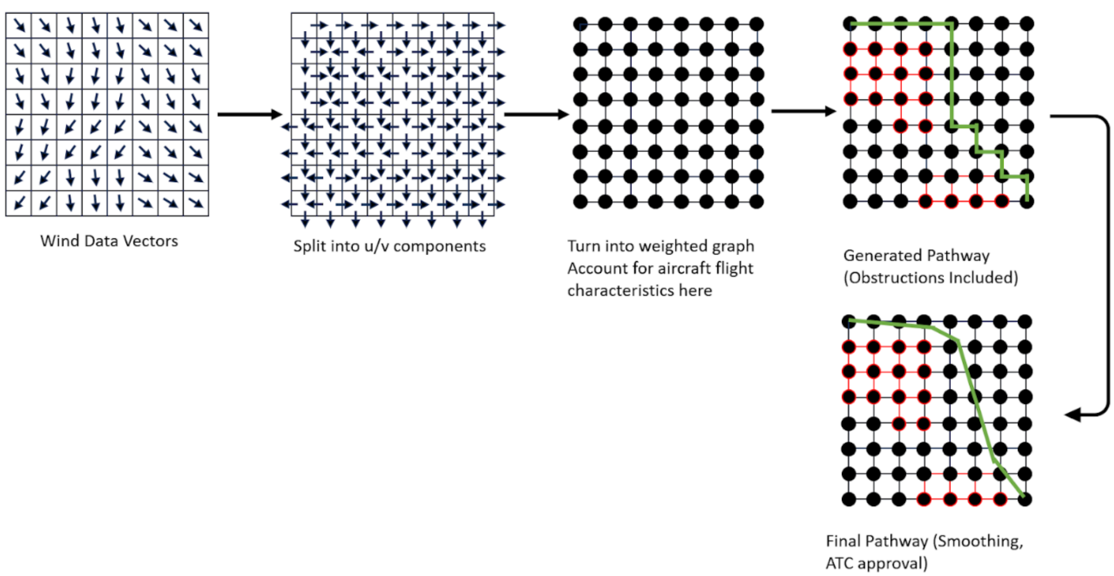

Fig. 1. Proposed implementation of Dijkstra's Algorithm

The path in Dijkstra's algorithm is made from scratch instead of using predefined routes, allowing it to have greater freedom compared to current systems that select paths between predefined routes. The high resolution of one node every 4 km^2 within the algorithm is used to ensure that flight paths for different aircraft do not collide. Any points that come into contact with another flight are removed from consideration, allowing for the algorithm to reroute the flight onto a safer path away from the potential collision site. Due to the use of GPU technology compatible with Omniverse, although this complex system of dynamic path-finding may use more computing power in the short term, it will have a reasonable processing time.

Applications

The FPPS will be integrated into ATC, ARTCC, and TRACON operators' displays. In the case that flights are not projected to stay outside of the minimum separation enforced by the FAA, an operator can use the FPPS to generate an alternative course for the aircraft. This will make managing aircraft in high-congestion areas simpler and more manageable.

Airspace Visualization System

Overview

As airspace gets more crowded due to more air traffic, a better visualization system of the surrounding airspace would likely benefit TRACON, ATC, and ARTCC operators. The display ATC currently has access to features of a two-dimensional screen, a limited color display, and a decentralized platform that requires viewing multiple screens. This limits the airspace information accessible to the operator. This minimalistic style offers some beneficial advantages such as only displaying relevant information and reducing clutter for the operator. However, remaining within the confines of such a system may prove to be infeasible as air traffic increases, creating a need for a newer system that makes a high air traffic density more manageable.

3D Visualization

The Airspace Visualization System (AVS) will be rendered in NVIDIA Omniverse. Omniverse is used as a platform because of its ability to perform accelerated computing, which can perform real-time operations and has 42x energy efficiency compared to a CPU, both of which are ideal for a TRACON air traffic controller's display [22]. Omniverse also allows for 3D modeling, which is an integral part of AVS.

The AVS is designed to be used on a standard computer setup with a keyboard and mouse. The AVS will allow a TRACON operator to pan the viewpoint around to obtain a better understanding of the airspace. The system allows for a vertical traverse from 180 degrees above the horizon to 0 degrees below and a horizontal traverse of 360 degrees. A viewpoint is used to allow the operator to traverse the display. Moving the mouse while holding the right mouse button (RMB) rotates the viewpoint. Scrolling up and down on the scroll wheel zooms the viewpoint in and out, respectively. Moving the mouse while holding the middle mouse button (MMB) moves the viewpoint linearly (Fig. 2).

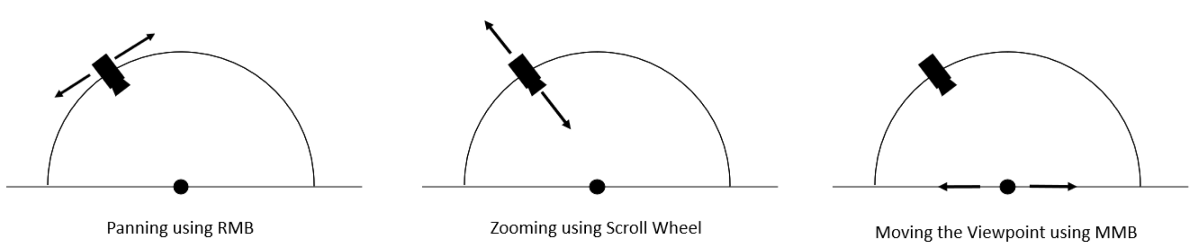

Fig. 2. Operator camera control system

In order to increase visual understanding of the airspace while also avoiding presenting unnecessary information and cluttering the display, a minimalistic approach has been taken for modeling the ground and surrounding landscape. Topography and basic terrain types are included in the model. To prevent clutter, objects such as buildings and trees are not modeled. The display has been changed from a dark background to a light one to reduce the luminosity contrast between the display information and the display background. A visual of what an operator sees compared to an ordinary display is provided (Fig. 3) [23]. The display remains as consistent as possible with the STARS display system to avoid confusion for those who previously worked with a 2D system (Fig. 4).

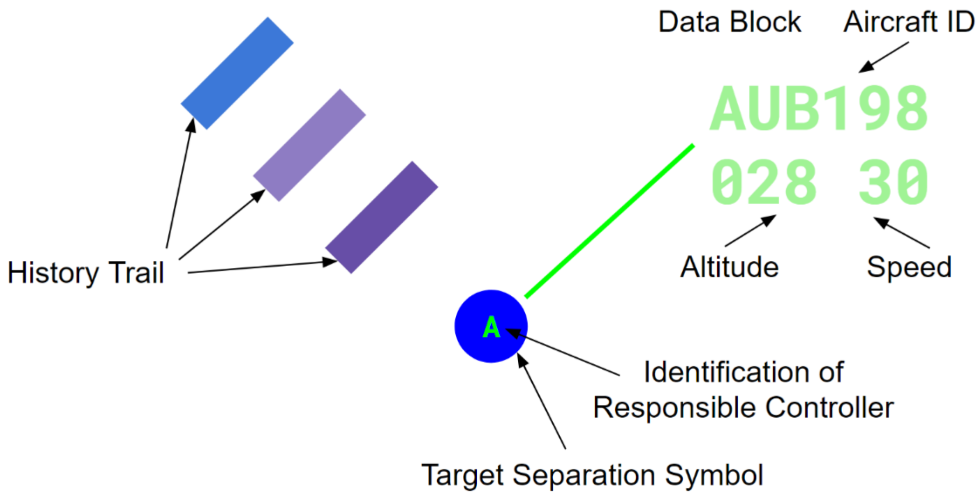

Fig. 3. Template for STARS capable system

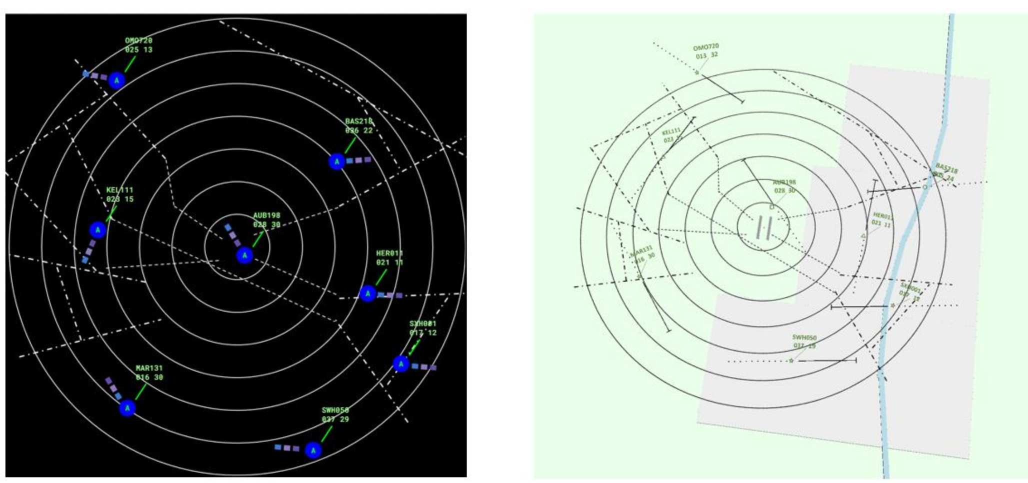

Fig. 4. A comparison of a STARS viewing screen (left) with the proposed implementation (right) under normal flight conditions

Color Coding and Coordination

Aircraft are identified by different icons. The current system that ATC uses to classify aircraft is to split them into Super, Heavy, Large, and Small, which are represented by a star, a diamond, a triangle, and a circle, respectively [24]. All aircraft operating normally appear bright green on the display. Aircraft that are not operating according to guidelines, such as the entry of an aircraft without a transponder into the airport’s vicinity, will be highlighted yellow instead. Aircraft in an emergency under Squawk Codes 7500, 7600, and 7700 will be highlighted orange, bright pink, and red, respectively, to differentiate them from the rest of the aircraft. The regular STARS display information is also presented on the screen [25]. An example is shown below. A red arrow has been provided for the STARS viewing screen image to better see the endangered aircraft (Fig. 5).

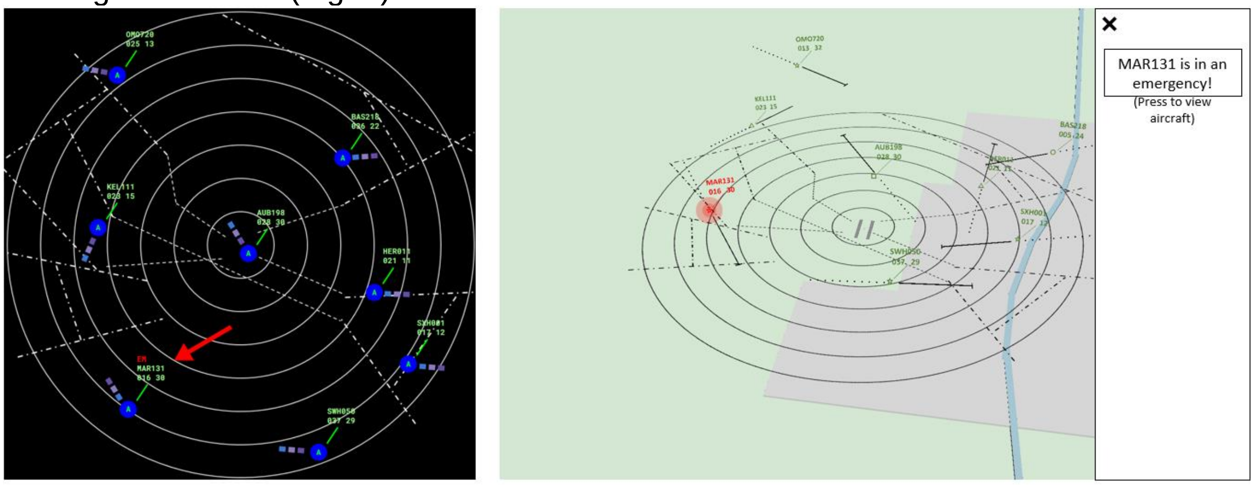

Fig. 5. A comparison of a STARS viewing screen (left) with the proposed implementation (right) under emergency conditions

Interactive Display

Not all the information associated with a particular aircraft is necessary to view at any given moment. Automatically updated electronic flight strips, similar to ones already in use, have been provided to store this excess information, along with other information such as heading, GPS location, and designated ATC operator. To allow for a more complete understanding of the aircraft's route, information such as estimated times over significant points have been replaced with the full projected flight route. This information can be taken from the FAA's Trajectory Based Operations (TBO) system. The strips will be colored on the screen based on certain discrete Secondary Surveillance Radar (SSR) codes, the presence of duplicated SSR codes, and non-Reduced Vertical Separation Minimum (RVSM) aircraft. More variables can be added as the system develops and controller feedback arrives. To communicate with another aircraft, the flight operator can press on the aircraft's icon and click a prompt to begin communication. The flight number of the aircraft will be used to automatically establish a connection between ATC and the aircraft. An example view of what an operator might see is shown below (Fig. 6).

A major goal of this system is to consolidate all of the necessary information onto a single display to allow operators to perform their duties without distraction or performing unnecessary actions that divide the operator's attention. As such, all of the information provided is accessible through buttons on the operator's Graphical User Interface (GUI). Any additional improvements to the system should be incorporated similarly.

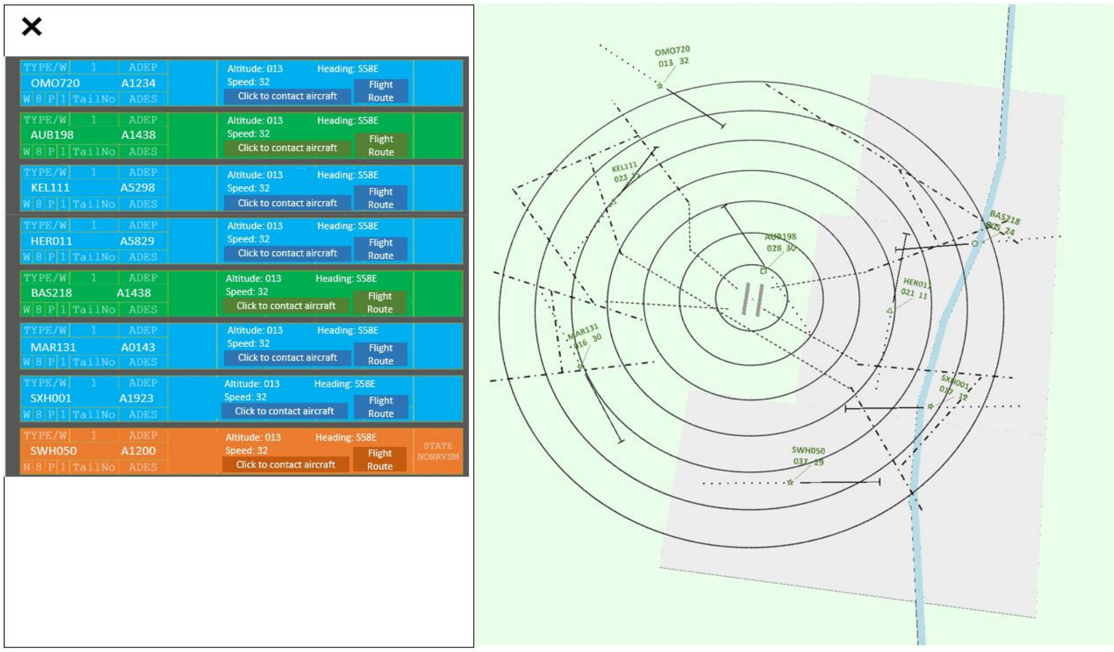

Fig. 6. Proposed flight strip-based communication system

A log of all important events is available to the operator. When an aircraft gives an emergency SQUAWK code, two aircraft remain on a collision course for an extended period, an aircraft requires a handover, or an unauthorized aircraft appears within the ATC controller's airspace, the AVS detects this and records it in the log. The operator can then act upon these warnings and mark them as resolved when the problem is over (Fig. 7).

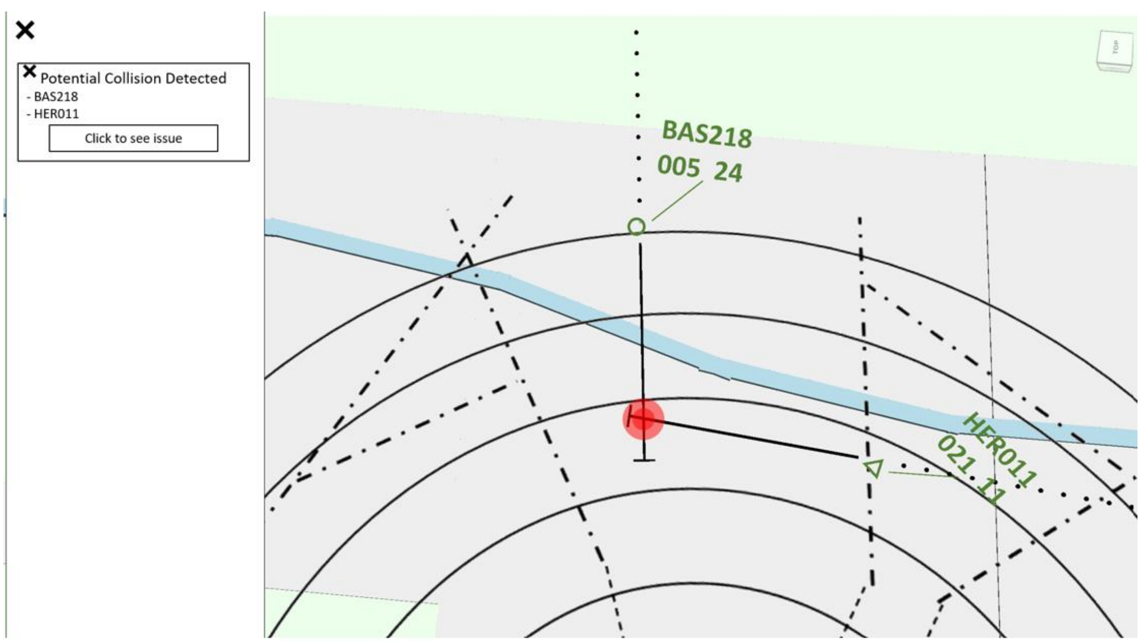

Fig. 7. Proposed notification system

Weather Data

Weather data is already implemented in most ATC display systems. However, the output from the FPPS can be used to further augment the system. Utilizing the real-time predictive data that the FPPS provides, operators would be able to have access to weather predictions in the future. These can be used to notify the operator if any aircraft are on a route that brings them into contact with potentially hazardous weather. The FPPS can then be used to reroute the aircraft to avoid a collision.

Unified Airspace

To promote a cohesive and collaborative environment between the numerous elements of the NAS, the AVS utilizes a shared environment between all ATC, ARTCC, TRACON, and FAA operators, using the multi-user capability that Omniverse provides. This allows all members to work together to handle operations such as handovers, establishment of restricted airspace, Traffic Management Initiatives (TMIs), and accidents that involve more than one ATC operator.

Included in the system is the ability to click on the icon of an ATC or TRACON station to begin communications with them. However, since the use of voice communication in airspace management is not ideal, certain operations are given a digital tab that both operators can see and modify in order to make events such as handovers more efficient and to reduce reliance on voice communication.

The data of aircraft routes from each control tower is combined to make a complete dataset of each aircraft's routes. This can be used by tower control to plan ahead to ensure that the air traffic density within certain sectors remains low and makes it easier to spot conflicts in flight pathways. In addition, TRACON can also utilize this system. Each operator has access to a list detailing the aircraft that will cross the operator's designated zone, the route the aircraft will take, and the estimated time of arrival. This will allow operators to make informed decisions and plan for their actions.

When the FAA needs to enforce a TMI or restrict airspace, an FAA operator can create the restriction within the AVS system, which will send a notification to every affected ATC and TRACON operator. If any reroutes are necessary due to these restrictions, the FPPS can be used to reroute the affected aircraft.

ML Integration in ATC Operation

To make the job of an ATC or TRACON operator more manageable and efficient, an AI will assist the operator using an ML algorithm. The ML algorithm will utilize a neural network and observe the information that the operators see and the actions that they take in response. When enough sample data has been amassed, the ML algorithm can make suggestions for actions that the operator may wish to take and provide the option for it to be performed automatically, if applicable.

In addition, TRACON operators occasionally encounter false targets, caused by radar signals that resemble aircraft being projected on the operator's screen. Sources range from clutter from other flying objects such as birds, multipath propagation, and faulty radar signals. These targets are uncontactable (due to not actually existing) and often cause unnecessary stress for operators. However, false targets usually have a unique radar signal, such as an arc or circle [26]**.** An ML algorithm could mark targets as potential phantoms by analyzing radar data. This would help operators work more efficiently and reduce panic caused by false targets.

Documentation

Documentation is an important part of the FAA's policy in ATC. As such, all information provided in the system will be recorded into the airport's database and uploaded to a proper database platform for data sharing like NASA's DIP. Since the information provided using this system is far more complicated and broad than the information provided on most operator displays, provisions need to be made to store all of the data.

Integration with DIP and ATC Management

The Digital Information Platform (DIP) is a subproject in the ATM-X Air-Traffic Management eXploration (ATM-X) project that NASA has been researching and planning to integrate into airports in the coming years. DIP is a database system that utilizes ML and AI to create an efficient system that can aid in advancing cybersecurity, performing automated operations, integrating information, and collaborating with other service providers [27]. The DIP utilizes NASA Fuser, which takes in input data from various sources including the FAA, airlines, vehicles, and weather, and makes it into a format that is consistent and easy to use. This allows for DIP to be used in widespread applications, and be adapted to the needs of each individual airport making it scalable. It also allows for new services to be added and registered, and uses DIP's architecture.

The CDDR platform uses machine learning to perform on-the-ground reroutes, facilitating air traffic within the airport space, predicting arrivals, and providing re-route suggestions to ATC controllers who would then accept these suggestions [28].

The Omniverse visualization model would be used in addition to the CDDR platform as a service available for airports and flight providers in the API Gateway. It would be registered on the DIP platform as a service available. The collaborative nature of the NVIDIA Omniverse Cloud visualization platform would allow for the information available to be stored and backed up, as the rest of the DIP is, which would allow for easy handovers to be done between TRACON, ARTCC, and ATC operators.

Additional Services to DIP

Based on the technology provided in this paper, additional services can be added to the DIP. The DIP allows for programs such as the airspace visualization system and the FPPS to be available on a platform that is used commonly by many airport authorities.

The diagram below outlines how the Airspace Visualization System (AVS) and the Flight Pathways Planning System (FPPS) would be integrated with DIP through four different services that would be used by ATC, ARTCC, TRACON, and FAA operators (Fig. 8).

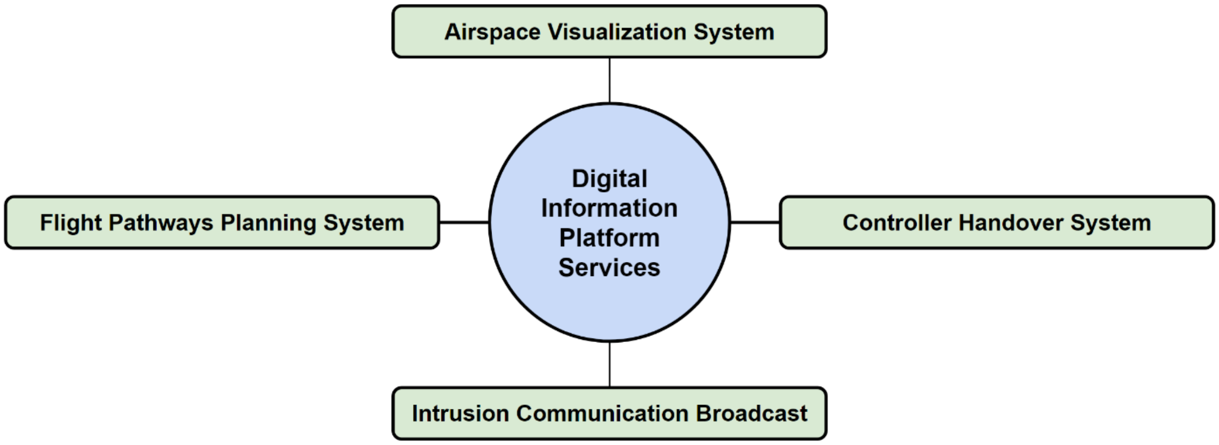

Fig. 8. A diagram of additional services to the DIP

The AVS, the FPPS, the Controller Handover System, and the Intrusion Communication Broadcast are the proposed services that would be added to the DIP. The 3D visualization would benefit from having access to NASA Fuser, which would provide it with the flight information it requires. It would be tailored to contain the airspace surrounding the airport and would be adaptable for various airports. It would additionally allow for the widespread use of the visualization system.

The Controller Handover System would be tailored to enable communications between ARTCC and ATC management at airports. Using the AVS, which is collaborative, controllers would be able to view aircraft as they traveled from one controller's airspace to the next, allowing for quick and visual transfers of a flight from one controller to the next. It would provide alerts to ensure that the controllers are aware of the transfer.

The Intrusion Communication Broadcast would deal with informing other ATC controllers and pilots (if pertinent) if foreign objects have entered the airspace. With the increase of alternate devices for flight, such as the increase in UAVs, sightings of such devices near airports have increased. The Intrusion Communication Broadcast allows for sightings of these UAVs to be documented and communicated so that appropriate actions can be taken to ensure that the UAV doesn't interrupt the airport's operations. It also intends to maintain an integrated airspace that is not only filled with commercial airplanes but also with UAVs and other means of flight.

As air traffic is increasing steadily, the path aircraft take relies more and more on the positions of other aircraft. Because the FAA has the most access to this type of information, the FPPS would be provided through DIP to allow easier access to airspace data.

Limitations

The Federal Aviation Administration (FAA) needs to ensure that flying is safe for everyone. The FAA sets the rules for how airplanes should be built, maintained, and operated. Most importantly for our case scenario, it manages ATC operations and defines how every process should be done. The FAA requires operator displays to meet certain parameters [29]. These are important for standardization, but the system we have proposed violates many of these rules. As such, in order for this technology to be implemented, the FAA must discuss changing the restrictions imposed upon operator display systems.

Implementation of the necessary technology into airports also poses a major issue. Many other projects that the FAA has planned have failed due to technical issues and a lack of talented workers available to install such a system. Fortunately, the system that we envision does not require a large amount of novel technology to work, except for the GPU technology. GPU systems can be very expensive, and great care must be taken to ensure that the project does not run over budget in a similar fashion to NextGen. However, most of the system involves software rather than hardware, which is less expensive and less likely to incur major technical issues. If integration of GPU systems remains infeasible, however, other data processing systems could be used, although the system may run at a reduced rate.

The system for Unified Airspace is also already proven to work. Connecting ATC and TRACON operators together on a national scale has at least been partially completed with the NextGen system, and many of the features outlined in this proposal are software elements, which are much easier to install. The integration with NASA's DIP makes the process even easier. Therefore, we envision that our proposal can be quickly and rapidly initiated across all major airports. If technical problems do occur, however, collaboration with the FAA and stakeholders will be necessary to ensure that the system functions as intended.

Color coding and coordination in ATC systems are very important for quickly detecting and managing aircraft, but they come with limitations. The current system uses different icons and colors to categorize aircraft based on their size and status: super heavy, heavy, large, and small aircraft are represented by distinct shapes, and their operational status is indicated by colors ranging from bright green for normal operation to red for emergencies [30].

While this system aims to provide clarity and immediate visual cues, there are several possible issues. One limitation is the overreliance on color, which can be problematic for controllers with color blindness. Distinguishing between different shades may prove challenging, leading to potential misidentification. While using bright colors for emergencies can be effective in many cases, it may cause a visual information overload, especially if several emergencies occur at the same time. In addition, the standardization of colors and symbols across different ATC systems is crucial but can be hard to achieve. Our proposed system also takes a radical step away from that standard, which could upset the uniformity of controller displays. This can lead to errors and confusion if it's not addressed properly.

Cognitive loading theory states that an individual can only receive as much information as they can effectively process [31]. Therefore, providing too much information has been a significant concern in the development of novel technologies for ATC operators. The design of the proposed system should go through tests to ensure that operators are not overloaded with information and that the most important information is also the most available.

Conclusion & Recommendations

ATC and airports are constantly striving to become safer for employees and customers alike. Tackling major issues such as poor communication, outdated visualization technology, and ATC operator stress is a high priority within this growing industry. Air traffic will only increase, as seen from the trends above, and it is important to catch up technology-wise. The system we propose aims to push ATC above and beyond. ML algorithms, the DIP, and Omniverse can make airport technology more advanced and capable than it has ever been. We hope to be able to revolutionize air travel for the future and make flying a safer and more enjoyable experience for everyone.

Future Applications

Conducting trials and tests will be critical to ensure the feasibility and practicality of the designed system. Prototypes and models will have to be constantly developed for full implementation in airports. Testing the proposed system in relatively small airports will allow for tests and trials without the risk of major accidents or incidents. Airports such as the Frederick Douglass Greater Rochester International Airport (ROC) in New York, with certain traits such as fair weather and sparse overhead traffic, would be ideal to begin testing and evaluation. These airports should have relatively little overhead traffic and have fair weather to make conducting tests safer. Data and results will then be taken in to improve the system. If issues are found within the system, researchers and engineers will have the opportunity to improve the program and refine it based on the gathered data. This process will repeat, slowly upscaling over time, until the program is ready for mass integration. With airspace safety and security being incredibly important to the lives of the passengers and aircrew, the extensive run review is a necessity to avoid and mitigate problems and major accidents.

After significant testing has been done in smaller airports such as the ROC, the system then can move on to larger international airports such as Hartsfield–Jackson Atlanta International Airport (ATL) in Georgia. These larger airports will push the boundaries of the system to further improve it. The program can then be fully integrated at major airports, similar to ATL, as a final design phase of the project. Once fully operational, the system would be able to connect all major airports in the US. Expansion to international communication could also be conducted depending on the success of the project.

Concluding Statements

In a world with an ever-increasing amount of air traffic, safety in the skies has never been a bigger priority. We hope to improve operational efficiency and accuracy using the FPPS and the AVS to never-before-seen levels. With the program being quite adaptable and flexible, these systems will continue to keep up with new technological developments and designs. While difficulties may arise from technical issues, further testing will hopefully remedy any difficulties encountered. Using these systems, we plan to ensure a safe and comfortable experience in the skies, for both operators and consumers.

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