# PTZ Control Methods - Meta Analysis and Novel Design Concept

Christian Thurow
chris@searidgetech.com
Searidge Technologies

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## Abstract

In the realm of air traffic management, the prevalence of digital towers is steadily increasing. Air traffic controllers (ATCOs) are embracing pan-tilt-zoom cameras (PTZ) as a viable alternative to binoculars. These advanced camera systems not only enhance situational awareness but also allow for focused observations of specific areas within an airport scene, particularly during anomalous situations. For instance, an ATCO can employ a PTZ camera to scrutinize the trajectory of a non-cooperative vehicle on the airfield or verify the landing gear status of an approaching aircraft. However, the introduction of this technology brings forth a set of challenges pertaining to implementation and ergonomic considerations. One of the obstacles lies in the initial learning curve and usability of certain PTZ human-machine interfaces, which can prove to be demanding. Over the years, we have diligently collected valuable feedback from our esteemed customers regarding the utilization of video cameras, with specific emphasis on PTZ systems. Our main contribution is the categorization of PTZ control methods into directional and absolute positioning. In this study, we compare these invaluable insights with the findings of other esteemed institutions and companies from within the industry. Through this comprehensive analysis, we have devised eight key findings. Finally, we used those findings to build the next generation of PTZ control systems, addressing the limitations identified by previous research endeavors.

## 1 Introduction

Modern digital towers need to consider the use of PTZ cameras, international standards such as ED-240A[1]. go into some aspects of this technology. When considering PTZ cameras, it is crucial to recognize that the primary parameters, including sensor resolution, zoom capabilities, and movement accuracy, hold significant importance. However, particularly with commercially available off-the-shelf models, the presentation of controls to the air traffic controller (ATCO) plays a crucial role also. The selection of an appropriate control model for a specific PTZ camera can be a challenging task, heavily influenced by the desired input device.

It is important to note that this document specifically addresses the use case of controlling a single PTZ camera manually. It is worth mentioning that a distinct area of research focuses on automatically curating PTZ cameras for a given scene, wherein multiple PTZ cameras observe the scene, and the "best" camera is selected at any given time [11]. However, since the prevalent scenario typically involves one camera per user at a time, our emphasis lies on the manual control of such cameras.

The subsequent section provides a comprehensive overview of various input devices available for controlling PTZ cameras. It delves into the advantages and disadvantages associated with each device type, allowing for a thorough examination of their respective merits and drawbacks.

## 2 Input Devices

When designing control concepts, user input devices play a pivotal role. While some inputs may share conceptual similarities, such as touch screen inputs and mouse inputs, others like gestures, voice control, and head-mounted devices require a distinctive approach. The following list outlines the range of input devices relevant to the use of PTZ cameras. It is important to note that this list is not exhaustive, as novel input methods may emerge in the future. Additionally, certain input methods, not readily accessible to the general public, have been omitted from this compilation.

1. Mouse
2. Touchscreen
3. Space Mouse
4. Joystick
5. Trackball
6. Touch-Pen
7. Keyboard-"Buttons"
8. Tracked VR-Headset
9. Gesture
10. Voice Control

Having an awareness of the available input devices represents the initial step towards selecting the most suitable input device and control concept combination for a given use case.

## 2.1 Mouse

Computer mice are the predominant means of interacting with human-machine interfaces (HMIs) at present. They are widely regarded as an intuitive method of machine interaction, as users are generally familiar with their operation. Mice offer high accuracy and ease of learning. However, there are notable considerations to bear in mind. Prolonged mouse usage can potentially strain the hands and arms of users. Additionally, when using a mouse with numerous monitors and windows, cursor movement to the desired position may be slow and occasionally cumbersome, as discussed in [16]

## 2.2 Touchscreen

Touchscreens represent the second most prevalent method of interacting with electronic devices today. Users encounter touchscreens commonly through professional monitors or personal devices such as smartphones and tablets. They address a key limitation of mice, enabling rapid cursor positioning directly on multiple or large screens. Unlike a mouse, touchscreens allow for direct positioning of the cursor without the need to locate the current cursor position and perform dragging motions to reach the desired location. This distinction between "direct positioning" and "drag positioning" will also factor into the control concepts explored in subsequent chapters. Touchscreens offer an unobtrusive input method for workstations, as the controls are integrated directly into the monitors without requiring additional space. In contrast, a mouse necessitates a dedicated flat surface on the workstation. However, touchscreens have several disadvantages compared to mice. Large touchscreens require more extensive arm movements, potentially posing greater health risks with prolonged use compared to mice, while also inducing more fatigue. Touch controls typically exhibit lower accuracy than mice. One significant drawback is the possibility of unintentional inputs, which can occur when resting a finger on the screen device. In the context of high-impact safety operations like ATC, this becomes highly relevant. Furthermore, the heat radiated from touchscreen devices can lead to discomfort for users' fingers. However, in certain scenarios, physical mice can be combined with touchscreen controls to leverage the benefits of both technologies while mitigating their respective drawbacks

## 2.3 Space Mouse

A space mouse is a specialized type of mouse originally developed for 3D manipulation of scenes, primarily intended for use with CAD software. However, given the 3D nature of PTZ cameras, space mice can also be valuable in this context. Due to their relative unfamiliarity, users typically require a learning period to become proficient in operating space mice. These devices are a specific type of joystick.

## 2.4 Joystick

Joysticks, once commonplace in PC input devices, now have limited usage in niche applications. They are commonly employed for manipulating objects in 3D space, such as robot arms or airplanes, and are also well-suited for PTZ camera control. Due to their unfamiliarity, most users will require a learning period to maximize their effectiveness. They also take up valuable desk space.

## 2.5 Trackball

The trackball, an older concept, can also be used for manual PTZ control. Conceptually similar to a mouse, trackballs offer some differences, such as the absence of the need to move the arm during operation. Additionally, trackballs can be spun freely to accelerate movement, while a mouse's speed is constrained by the user's arm movements. Trackballs, however, have a relatively steep learning curve and require maintenance, as they tend to accumulate dirt over time, degrading their sensitivity until cleaned.

## 2.6 Touch-Pen

The touch-pen is used either with a specialized trackpad or directly on a screen. Compared to finger-touch input, touch-pens provide reduced heat radiation from the screen device and significantly improved accuracy. Unintentional inputs are also greatly minimized. However, touch-pens have a higher learning curve compared to conventional touchscreens.

To summarize the list of input devices thus far, all the aforementioned input device categories belong to cursor-based methods, or they can be used in conjunction with cursors. The cursors may always be visible but can be conceptualized as being at the center of the screen, as is the case with most joystick applications. These methods employ relative positioning techniques, such as dragging in a specific direction. Touch inputs, on the other hand, can utilize direct positioning but require a fixed reference surface and cannot extend beyond it, whereas a joystick or mouse can move outside the reference area. All of the above devices enable analog manipulation of the cursor or objects in the 3D space of interest. Here, the term "analog" refers solely to the perception of continuous movement, without quantizing the step width, as would be the case with directional keys (discussed in the next subsection).

## 2.7 Keyboard - "Buttons"

Keyboards, specifically keys that can function as shortcuts for presets or directional keys (typically arrow keys), remain prevalent in HMIs. Since text input is often necessary for many use cases, keyboards are commonly present in most HMIs. It is important to note that keyboards can also be simulated in software and projected onto screens, in which case the keyboard becomes a set of simple buttons without haptic feedback. Both software and hardware keys are conceptually equivalent. Keys or buttons can serve as shortcuts, allowing for the positioning of a PTZ to a previously configured spot, known as a preset. Keys and buttons can also provide directional commands for incremental PTZ movement. Based on our experience, preset buttons are among the most frequently used methods for positioning a PTZ, necessitating the presence of some form of keyboard or buttons, either virtual or physical. Additionally, buttons can be part of certain joystick devices.

## 2.8 Tracked VR-Headset

Head tracking, with or without a head-mounted display (HMD), is a control concept where the PTZ follows the user's head movements. A motion sensor captures head movements (optionally including eye movements), which a software program then translates into Pan, Tilt, and Zoom motions sent to the PTZ camera. The effectiveness of this method depends on the latency of PTZ cameras, as any delay, even in the order of milliseconds, can be noticeable. If used with an HMD, it can also induce simulator sickness and disorientation, as demonstrated by [14]. It should be noted that their work includes two different approaches to displaying PTZ video data to the user's HMD, as shown in figure 1.

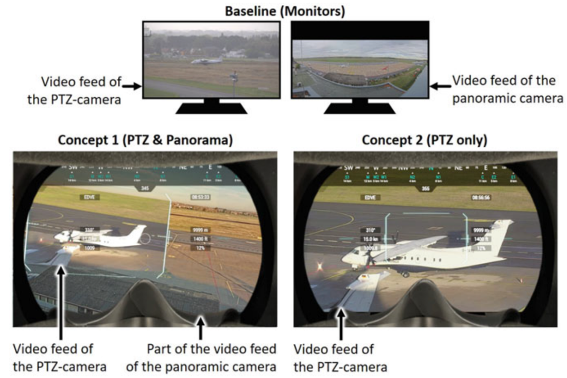


Figure 1: Virtual Reality Display Concepts from [14]

This control method should be regarded as a research tool rather than a practical consideration for operational use. Additional disadvantages include increased wear on PTZ motors due to constant minor adjustments, limited usability of HMDs for extended periods due to fatigue, and restricted field of view for users in most HMD models. At present, mixed reality devices are not yet suitable for this purpose.

## 2.9 Gestures

Gesture control offers the advantage of not requiring physical contact with a device. However, extended usage can lead to fatigue, and gesture-based controls are generally less accurate than their physically-based counterparts.

## 2.10 Voice Control

Voice-controlled actions can be employed in the context of PTZs for executing presets, such as saying "Move PTZ to Apron 3" or "fully zoom out." However, it is difficult to envision using this input method for directional controls. Voice control may become more relevant when applied alongside higher levels of automation. For instance, saying

"Follow AC3971" can be less labor-intensive than locating a target on a flight strip or map and commanding the PTZ to follow it.

In conclusion, this section has provided an overview of various input devices commonly used for human-machine interaction in the context of PTZ camera control. We have explored the strengths, limitations, and considerations associated with each device, ranging from traditional methods such as mice and keyboards to newer technologies like touchscreens, space mice, and VR headsets. We have also established that there are cursor based and non-cursor based input methods. Noteworthy is also the introduction of the terms "relative positioning" and "direct positioning". The next section, "Control Concepts," will delve deeper into the different approaches and strategies for effectively controlling PTZ cameras, taking into account the capabilities and characteristics of the input devices discussed here.

# 3 Control Concepts

Control concepts provide a framework for users to effectively control PTZ cameras using the available input devices. These concepts dictate how user inputs are translated into physical movements of the camera and how feedback is provided to the user. There are two fundamental categories of control concepts: directional positioning and absolute positioning. In directional positioning, users can move the PTZ camera in a specific direction and at a specific speed. Feedback in the form of video images helps users stop the movement once the desired position is reached. On the other hand, absolute positioning relies on a frame of reference, such as a map or reference panorama, to allow users to set a movement goal directly and wait for the PTZ to reach it. The choice between these concepts depends on factors like latency, with absolute positioning being preferable in high-latency systems. Due to delays in image capture, image decoding, transmission and especially mechanical limitations of movement speed and positioning of open loop stepper motors. Based on our experience, there are no commercial grade PTZ models available today that do not exhibit high latency. If there was a low latency PTZ, then directional positioning could give finer control options in practice. Today, these are constrained to military grade PTZ cameras though.

I. Directional Positioning
   A. Incremental Steps
   B. Vector Control
   C. Drag and Spin
II. Absolute Positioning
   A. Presets
   B. Click to Image Section
   C. Reference Viewport
   D. Cardinal Controls
   E. Map
   F. 3D Manipulation
   G. Automatic
      1. Image Based
      2. Knowledge Based

The following subsections will provide concise descriptions of each of these control concepts, highlighting their features and benefits in PTZ camera control.

## 3.1 I,A - Directional, Steps

The directional steps control concept is the most common approach, used by many PTZ manufacturers, where users can move the PTZ camera in incremental steps by pressing software buttons or virtual keys on the image edges or corners. It can also be implemented using hardware keys. While this method is easy to implement, it is often considered cumbersome to use.

## 3.2 I,B - Directional, Vector Control

Vector control allows users to control the direction (pan and tilt) and speed of PTZ movement simultaneously. Users draw a virtual line from the center of the PTZ image or a chosen point on the UI to indicate the desired movement direction, and the length of the line determines the speed. Releasing the cursor or tracing the line backward stops the movement. A "drag circle" and the current vector can be displayed on the UI to assist users in controlling the PTZ. For instance on the PTZ image directly or a control panel elsewhere on the UI.

## 3.3 I,C - Directional, Drag and Spin

Drag and Spin is a variation of the vector control method. Similarly, the user would place the cursor at any starting point and move into a direction. However, where the vector control method would continue to move the PTZ into that direction, until the cursor is released, the Drag and Spin method would move the PTZ as quickly as possible by the distance the user instructed by moving the cursor away from the starting position. This results in fast, but limited distance movements. The advantage of this method is that it may work well even if latency is high, because the user can more easily wait until the PTZ reaches a certain movement distance and then make adjustments from there.

## 3.4 II,A - Absolute, Presets

In the category of absolute positioning, it is the most obvious approach. The advantage of this method is that it is the fastest way of positioning a PTZ. Presets may be defined beforehand and then recalled at any point during runtime of the application using only a single click or button press. They are static and not ideal for moving a PTZ manually, except as a starting point.

## 3.5 II,B - Absolute, Click to Image Section

Click to image section on a PTZ image is a common way of navigating images on touch input devices. The user may click on any part of the PTZ image currently in view. Once the PTZ moved, the clicked point will now have become the new center of the scene. While this is very easy to use, it has one big limitation, which is that the PTZ can only be commanded to move as far as one image width at a time at the most. Realistically, only half the image width for panning and half the image height for tilting. Although this could be improved by selecting a different zoom level, it is not a desired way of navigating with real PTZ cameras as it proved too cumbersome in real applications. One factor here is the relatively slow zoom speed of most PTZ camera models and the need for re-focussing afterwards.

## 3.6 II,C - Absolute, Reference Viewport

This method uses a reference image or viewport to position the PTZ field of view inside it. The user may draw a rectangle, representing the desired target field of view of the PTZ within a panorama image for instance. Or drag an existing fov-rectangle to the desired position. Note that this method requires either a set of panoramic cameras at the same mast as the PTZ camera mounting location or a generic (meaning not live) image as reference. Both must be very well calibrated beforehand, which can be challenging in practice. The payout for this method in terms of usability is big though. As has also been found by other researchers[8]. The representation methods here are numerous, the PTZ image could be displayed directly in the fov-rectangle on the reference image (aka. panorama) or kept separate. Both images could be combined to a more enhanced view and so on. The reference image may also be of more conceptual nature, for instance a rendering of the airport.

## 3.7 II, D - Absolute, Cardinal

The cardinal control method employs a separate UI window which includes cardinal directions in a circle around the PTZ. Clicking on any point of the cardinal circle directly moves the PTZ to the respective pan value. Likewise, a bar representing the available tilt values is shown next to it. This method allows for very quick and precise control. In conjunction with additional representations, such as a map for instance, it is a very useful option to users familiar with the airfield map and where targets may be with respect to cardinal directions. Which is usually the case with ATCOs.

## 3.8 II,E - Absolute, Map

Using a Map, or top down view of the airfield is strictly speaking a variation of the Reference Viewport described above. Because they are two 2D slices of different orientation of the same 3D volume that is the airfield. Depending on the preferences of the user, this method may be more intuitive for users with radar map background. A user would click anywhere on a map to have the PTZ camera move its field of view (FOV) to that location. Similarly, a representative view cone of a 2D map could be used to visualize where a PTZ is currently looking at. It is therefore imaginable to allow the user to also drag the view cone to a specific rotation (pan) and distance (tilt) on the map and change its view angle (zoom) accordingly.

## 3.9 II,F - Absolute, 3D-Manipulation

While all the previous methods could be seen as 2D manipulation methods, which operate in only one of two planes, either the X,Y(image plane)- or the X,Z(map)- plane, this method can be used to simultaneously operate in all planes. In this control method, the view frustum of the PTZ is represented in a 3D environment, see figure 2. The user may move the frustum to any view direction by moving it to any direction allowed. This method is sometimes used in games and when manipulating joints of a robot in software. In the context of PTZs, it has the advantage of being able to manipulate all 3 modes: pan, tilt and zoom in one go. Note though, that this method requires a lot of training and is not as intuitive for most users.

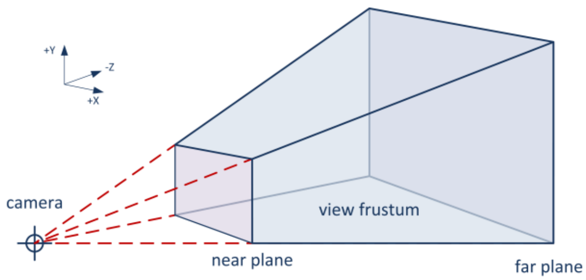


Figure 2: 3D view frustum concept [6]

### 3.10 II,G - Absolute, Automatic

Automatic PTZ positioning is a form of absolute positioning. Because in this method, a user would either give the system a command to follow a certain target or have it curated by an algorithm to pick the correct PTZ and follow relevant parts of the scene automatically.

This category can be divided into two different approaches, knowledge based and image based. The knowledge based approach uses outside data sources, such as radar, A-SMGCS, ADS-B or similar with absolute real world positions to move a camera to those positions directly. Whereas the image based methods include additional steps before estimating the real world positions of targets. Or operate purely on image data and translate pixel positions into pan, tilt and zoom values that way.

The image based methods rely on computer vision algorithms, of which there are many, however the most common approaches in the air traffic control domain are:

1. background estimation
2. optical flow
3. neural network

For detecting targets within images. Neural networks may also go further and allow for classification or even identification of targets. All these computer vision methods provide the added benefit of having bounding boxes around targets and some even pixels on targets resulting in exact outlines. Both could be reused on not just the PTZ images but also to position targets on a map or to highlight targets on panorama images.

Automatic PTZ control, initialized by the user, should be seen as the main goal of a well rounded Digital- and Remote tower system. As automation greatly increases usability [5], and allows the users to focus on important tasks rather than spending mental capacity on manually controlling PTZs. That having said, such a system should always allow users to manually control PTZs if they so choose. A surveillance source could be degraded and thus blocking the use of automatic PTZ control, or the ATCO may choose to check on a specific part of the airfield where there is no preset defined for it. Therefore, manual control must be present as an option and preferably in an easy to use, intuitive way.

## 4 UX Design Principles

Apart from the control concept and input devices, it is crucial to adhere to standard UX guidelines to ensure optimal usability in PTZ control interfaces. This chapter provides a concise overview of these guidelines and principles. In his book, "The Design of Everyday Things," D. A. Norman[12] outlines several useful principles for designing user interfaces:

- **Visibility** "The more visible functions are, the more likely users will be able to know what to do next. In contrast, when functions are 'out of sight', it makes them more difficult to find and know how to use."
- **Feedback** "Feedback is about sending back information about what action has been done and what has been accomplished, allowing the person to continue with the activity. Various kinds of feedback are available for interaction design-audio, tactile, verbal, and combinations of these."[13]
- **Constraints** "The design concept of constraining refers to determining ways of restricting the kind of user interaction that can take place at a given moment. There are various ways this can be achieved."[13]
- **Mapping** "This refers to the relationship between controls and their effects in the world. Nearly all artifacts need some kind of mapping between controls and effects, whether it is a flashlight, car, power plant, or cockpit. An example of a good mapping between control and effect is the up and down arrows used to represent the up and down movement of the cursor, respectively, on a computer keyboard."[13]
- **Consistency** "This refers to designing interfaces to have similar operations and use similar elements for achieving similar tasks. In particular, a consistent interface is one that follows rules, such as using the same operation to select all objects. For example, a consistent operation is using the same

input action to highlight any graphical object at the interface, such as always clicking the left mouse button. Inconsistent interfaces, on the other hand, allow exceptions to a rule."[13]

- **Affordance** "Affordance is a term used to refer to an attribute of an object that allows people to know how to use it. For example, a mouse button invites pushing (in so doing acting clicking) by the way it is physically constrained in its plastic shell. At a very simple level, 'to afford' means 'to give a clue'. When the affordances of a physical object are perceptually obvious it is easy to know how to interact with it." [13]

In our work with digital and remote towers, we have found that following these guidelines had a great impact on user satisfaction levels. Although other works in the field of UX exist, we had great success in using these guidelines specifically. But we have no reason to doubt that other guidelines exist that may lead to comparable results. With that in mind, we can recommend from experience, to explore further works, such that of Ben Shneiderman's book Designing the User Interface: Strategies for Effective Human-Computer Interaction[17]. The eight rules described by this book can be seen as guidelines to a good interaction design and to improve the usability of an interface. We use them to supplement the UX design principles outlined above.

- Strive for consistency "Consistent sequences of actions should be required in similar situations; identical terminology should be used in prompts, menus, and help screens; and consistent commands should be employed throughout."[17]

- Enable frequent users to use shortcuts "As the frequency of use increases, so do the user's desires to reduce the number of interactions and to increase the pace of interaction. Abbreviations, function keys, hidden commands, and macro facilities are very helpful to an expert user." [17]

- Offer informative feedback "For every operator action, there should be some system feedback. For frequent and minor actions, the response can be modest, while for infrequent and major actions, the response should be more substantial." [17]

- Design dialog to yield closure "Sequences of actions should be organized into groups with a beginning, middle, and end. The informative feedback at the completion of a group of actions gives the operators the satisfaction of accomplishment, a sense of relief, the signal to drop contingency plans and options from their minds, and an indication that the way is clear to prepare for the next group of actions."[17]

- Offer simple error handling "As much as possible, design the system so the user cannot make a serious error. If an error is made, the system should be able to detect the error and offer simple, comprehensible mechanisms for handling the error."[17]

- Permit easy reversal of actions "This feature relieves anxiety, since the user knows that errors can be undone; it thus encourages exploration of unfamiliar options. The units of reversibility may be a single action, a data entry, or a complete group of actions." [17]

- Support internal locus of control "Experienced operators strongly desire the sense that they are in charge of the system and that the system responds to their actions. Design the system to make users the initiators of actions rather than the responders."[17]

- Reduce short-term memory load "The limitation of human information processing in short-term memory requires that displays be kept simple, multiple page displays be consolidated, window-motion frequency be reduced, and sufficient training time be allotted for codes, mnemonics, and sequences of actions."[17]

By following these principles, PTZ control interfaces can be designed to optimize usability, enhance user satisfaction, and improve the overall interaction experience.

# 5 Meta Analysis

In the rapidly evolving field of Digital and Remote Towers, various organizations and companies have implemented their own methods and approaches to enable users to interact with PTZ systems effectively. These control methods play a crucial role in facilitating smooth camera movements, precise targeting, and efficient surveillance operations.

In this chapter, we will conduct a meta-analysis of PTZ control methods employed by several prominent organizations in the industry.

Through an examination of available resources, including marketing videos and research papers, we aim to provide an approximate overview of the control methods utilized by these organizations.

The table presented below presents an overview of the control methods used by organizations such as Frequentis, Kongsberg, Saab, AFIS, LFV, and DLR. While the available documentation is limited, for most organizations relying on marketing videos as the primary source of information, we have attempted to compile relevant details regarding their PTZ control approaches.

The information presented is based on the best available resources, and not all organizations may have showcased their most recent versions or provided extensive documentation. Nevertheless, the table provides valuable insights into the diverse range of control methods utilized in the industry.

To further explore and understand the PTZ control methods, we will delve into three organizations that have published research papers on their approaches: LFV, AFIS in Japan, and the DLR. These organizations offer more detailed descriptions of their PTZ control methods, shedding light on the underlying principles and technologies involved.

Through the analysis of these organizations' control methods, we aim to uncover innovative techniques, identify common patterns, and gain a deeper understanding of the factors influencing the design of effective PTZ control interfaces.

## 5.1 AFIS System

In this project[9], the researchers discuss the design of a user interface for a Remote Aerodrome Flight Information Service (AFIS) based on a User Experience (UX) approach. The AFIS provides essential information to pilots such as weather conditions, clearance for departure and approach, and more. The remote AFIS system allows operators to provide flight information remotely from a Flight Service Centre (FSC) using camera systems and sensor information. The paper[9] highlights the need to improve and expand the handling capacity of the remote AFIS system as air traffic is expected to increase in the future. User interface design is identified as a crucial factor in enhancing the performance of remote AFIS operations. The authors propose a practical design process based on the UX approach and present a prototype concept design based on their analysis. The current interface of remote AFIS systems in Japan is described, noting that it consists of multiple displays and panels with confusing and non-unified layouts. The future concept of remote AFIS systems includes a large panoramic view with high-quality picture resolution, seamless multi-display panels, and a moving target tracking system for increased safety and efficiency. The paper outlines the practical design process based on the UX approach, which involves user surveys, user modeling, storyboarding, prototype concept development, and user testing. The authors emphasize the importance of observation and task analysis in understanding the operator's workflow and identifying design problems. They also discuss the evaluation of the current user interface and the creation of concept design ideas for future remote AFIS systems. Overall, the paper focuses on the importance of user-centered design in improving the usability and effectiveness of remote AFIS systems. The proposed UX-based design process and prototype concept design aim to enhance the operator's working performance and optimize the remote AFIS interface. One particularly interesting finding is: *"As an example of our concept design, we noticed that operator couldn't know the direction of PTZ camera quickly from the result of analysis. Because, in the current system, the system doesn't show a direct position of PTZ camera. It means the system lacks information of situation awareness. Thus, we created a support interface which showed the camera direction on map based on analysis. Operators can know the PTZ camera direction intuitively by using the map interface"*[9]


Figure 3: The assisting functions of PTZ camera direction map [9]

## 5.2 LFV Research System

The research work focuses on the Advanced Remote Tower (ART) project, specifically on the validation results of the project. The ART project aims to enhance remote tower control by incorporating various technologies and functionalities. The validation was conducted at the Swedish Ängelholm airport with the participation of 15 air traffic controllers.

The validation program involved controllers spending time in the remote tower cabin, evaluating the ART functions and providing feedback. The results highlighted areas of improvement, such as the need for better depth perception

| Organization | PTZ Control Method | Notes |
|---|---|---|
| Frequentis | Vector Control | Rheinmetall Dual Sensor with Laser Range Finder, at DFS[2] |
| | Drag and Spin (non locational swiping) | in Brazil[3] |
| | Presets | at DFS[4] |
| Kongsberg | Vector Control (Joystick)[10] | |
| Saab | Auto Tracking | In a simulator only[15] |
| | Reference Viewport | in LCY[15] |
| AFIS, Japan | Directional Keys[7] | |
| | Automatic | image based aka. box and follow[7] |
| LFV | Presets[9] | |
| | Vector Control[9] | |
| DLR | Cardinal Control[18] | |
| | Automatic | Mode-S Transponder based[18] |

Table 1: High level overview of available systems and studies

Figure 4: PTZ control concepts as used by [18]

and improved visibility in certain lighting conditions. The overall findings from the validation program provided valuable information for further development and operational application of the ART system.

Overall, the research work emphasizes the use of PTZ cameras as part of the ART system for remote tower control. The PTZ camera allows controllers to remotely monitor and track aircraft and vehicles, enhancing their situational awareness in low visibility conditions.

Among other results, they have found that a single representation of the PTZ position and likewise a single way of controlling the PTZ is not sufficient. *"Manual steering of the camera could be done by the mouse on either the PTZ monitor or the panorama screen. The actual heading direction and zoom factor of the camera was graphically indicated on a compass rose at the right top corner of the PTZ monitor (see Fig. below). The PTZ camera could be slaved to a track and its image was also displayed on the panorama screen as a Picture-in-Picture (PIP).."*[18]

Furthermore, it was found that: *"The controllers found the PTZ rather useful for searching and detecting aircraft and vehicles, for manual and automatic runway inspection and for inspection of aircraft and vehicles, most of all during daylight and good visibility. The PTZ Picture in Picture should be moveable to any position on the panorama screen. The response of the PTZ camera was considered good enough and residual time delays were acceptable. The automatic tracking capability of the PTZ depended on the choice made for central video tracking and thus its performance. Controllers did not expect to handle more traffic with PTZ. The availability of the PTZ picture-in-picture camera favoured to keep a better focus on the panoramic display, but there was a risk to stay too long with the PTZ. Controllers found the PTZ operating procedures easy to use and felt confident using the PTZ camera."*[18]

## 5.3 DLR Research System

The DLR is part of the most extensive research program in the remote tower domain. Their research system gives a good overview of what the limitations are and what the best way forward should be. Their system allows for automatic PTZ control, commanded via a click on flight strips and driven by Mode-S Transponder positions. They also employ manual PTZ control methods in multiple ways, firstly they allow to drag the FOV rectangle of the PTZ on a reference panorama (see II,C, Absolute Reference Viewport), but also drawing a FOV rectangle on the panorama. And secondly, they've implemented a cardinal control UI that shows a map of the airfield at the center. *"For manual control of the pan tilt zoom camera (PTZ) a specific display was developed that offers several possibilities to navigate the camera, based on pentouch input functionality. Figure [below] depicts a photo of this advanced HMI ver-*

*sion which represented an advanced version derived from the initial experimental one described in chapter "Remote Tower Experimental System with Augmented Vision Videopanorama". On the top right side a number of preset buttons and buttons for static commands like move, zoom or (window) clean is located. Below a kind of wind rose can be seen. The inner circle serves as "virtual joystick" where a seamless movement of the camera in a specified (tilt) direction is possible with specified speed. The outer ring serves for commanding the desired horizontal (pan) position. The actual position and field of view of the camera is highlighted there with yellow color. On the left side of the ring a corresponding vertical scale is integrated for setting the tilt position. Outside of the ring are the fields to control predefined zoom factors, Z = 2, 4, 8, 16. At the bottom left a reduced version of the video panorama can be seen. A click inside this sector moves the camera viewing direction to the corresponding pan-tilt angles. The position of the camera is shown in the video panorama by a yellowframe. Usability trials with operators showed that this feature supports the orientation when users manually control the camera."*[16]

Structured interviews of controllers during design workshops and RTO-simulator experiments (see Sect. 2 of the present chapter and chapter "Assessing Operational Validity of Remote Tower Control in High-Fidelity Simulation") as well as during the shadow mode validation experiments (chapters "Which Metrics Provide the Insight Needed? A Selection of Remote Tower Evaluation Metrics to Support a Remote Tower Operation Concept Validation" and "The Advanced Remote Tower System and Its Validation") showed that automated tracking of the pan tilt zoom camera would be very helpful.[16]

It was not intended to activate the automatic movement detection and tracking functions within the validation experiments due to limited reliability that was not sufficient for operational testing. The results of the validation experiment however show, that automation features of this kind are probably required in order to rise the RTO-system performance and usability to the operational level.[16]

### 5.4 Meta Analysis Conclusion

Our analysis has demonstrated the implementation of numerous PTZ control methods in various research and commercial applications. Many of these methods, compared to those discussed in the "Control Concepts" chapter, have been successfully integrated into production. As more research findings become available, it becomes apparent which methods prove most effective in terms of usability, user satisfaction, and performance. The key findings from the research literature and real-world installations emphasize the following aspects of PTZ control:

1. User-centered design and interface customization are crucial in PTZ control methods.
2. Absolute positioning methods, particularly for high-latency systems like remote towers, are widely applicable, while directional positioning is reserved for low-latency scenarios. Given the nature of mechanical PTZ cameras, latency plays an important role when selecting the right manual control concept. It is desirable to use the lowest latency PTZ camera possible, given a set budget. Even when using absolute positioning control methods.
3. Maintaining situational awareness is of utmost importance, achieved through clear and easily understandable direction indicators for the PTZ.
4. A single representation and control method for the PTZ camera are insufficient.
5. Manual steering options should be available, with graphical indicators for the camera's heading direction and zoom factor.
6. The availability of a picture-in-picture view enhances operators' focus on the panoramic display.
7. The inclusion of certain automated tracking features is necessary to improve the performance and usability of remote tower operations.
8. Presets should always be provided for any digital or remote tower system to at least supplement other control methods.

From our experience and knowledge provided by various research agencies, we can conclude that controlling PTZ cameras is a vital part of a remote and digital tower system, by following the findings as stated above, it is possible to create a new and improved control system (meaning HMI), which we will explore in the next section.

## 6 Designing a better Control System

This final section provides a design for the next generation of PTZ control for Digital and Remote

Figure 5: EAVD HMI, May 2023

Towers using the EAVD product by Searidge Technologies as an example. The EAVD (Enhanced Airport Vision Display) product is a digital tower system which provides a highly customizable HMI and follows a camera agnostic approach. Thus is an ideal candidate for implementing all findings of the meta analysis from the previous section.

We are proud to present the following HMI, as shown in 5. The HMI consists of a 360° stitched panoramic video representation with a cardinal direction indicator overlay. As a first PTZ representation, the PTZ content is overlaid on the panorama in the correct relative position. With this overlay being configurable in terms of opacity. At the same time, the user can interact with the overlay using the mouse to reposition the window anywhere on the panoramic screens. This is an absolute positioning method, whereas the panorama acts as a reference overview of possible PTZ positions. The calibration of the PTZ to the fixed panorama is made possible by co-locating the PTZ with the static panoramic cameras.

Figure 5 also shows another screen at the bottom. This touch-screen contains a larger view of the actual PTZ video, compared to the overlay on the panorama. As this touch-screen is a vital part of the system, we show the screen in more detail in the figure 6.

Figure 6: EAVD HMI, PTZ touch screen controls

The currently active PTZ is shown on the top left window of the screen. A secondary PTZ is also shown on the top right window. Note that in practice, a number of PTZ cameras may be present, depending on the size of the airfield and number of controllers needing simultaneous access to a PTZ. The active PTZ also contains a cardinal direction overlay, just as on the main panorama. At the bottom of the screen, we see an array of configurable preset buttons, which can be interacted with by using the touch input of the screen or the mouse, as well as predefined shortcuts on a keyboard, if

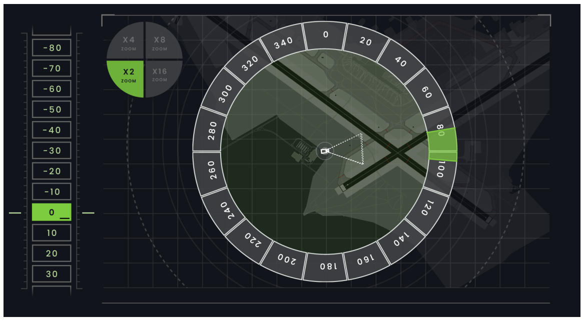


Figure 7: EAVD HMI, Cardinal Direction and Min-Map Panel

present. This is one of the most used ways to position PTZs in our experience. As well-customized preset locations can eliminate the need for manual control methods under normal circumstances.

Following the findings of the DLR, we have devised an improved version of the cardinal direction control panel using the map as base representation. The control panel is shown in the bottom right corner in figure 6 and shown in more detail in figure 7.

The user can activate the desired PTZ by selecting it on the mini-map. The camera view is represented using a camera cone, based on its current position and field of view. As the camera is zoomed in or out, the camera cone changes in shape accordingly. The current selected camera is placed at the center of a cardinal direction circle. This circle edge is interactable with, which allows the user to once again use an absolute positioning control method to place the camera accurately and quickly. This way, the ATCO uses their knowledge of the airfield to intuitively adjust the camera pan. The camera's tilt can be adjusted using the scale on the left side of the panel, which changes the "height" (up or down) directly in a similar fashion.

The final manual adjustment can be made to the zoom of the camera, both by using the mouse scroll wheel or by selecting one of the preconfigured zoom levels, as shown by the four buttons at the top left of the panel.

For automation, EAVD interfaces with a number of common electronic flight strip systems to allow the PTZ to follow aircrafts using their position as reported by surveillance data. For cases where such systems are not available, and for non-cooperative targets, EAVD implements a neural network (aka. AI) tracking system to automatically identify and follow targets within the PTZ video scene. This process is started by selecting the target either on a radar map, the flight strip system or by manually drawing a bounding box around the target of interest within the PTZ video or panoramic video.

## 7 Acknowledgement

We conclude our work by thanking the researchers and workers in our industry for their invaluable contributions. We aim to provide the highest standard, according to our long standing experience and state of the art research to our valued customers. We will continue to put forward improvements and innovation with the ultimate goal of highest possible safety and user satisfaction in air traffic management.[1]

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