Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Assessment of visual cues by tower controllers, with implications for a Remote Tower Control Centre

Problem area
Remote control of airports implies application of cameras to replace direct visual observation from airport control towers by projection of the airport and its traffic in a remote control centre. Remote airport control is an emerging technique with benefits for smaller airports mainly, because it reduces the cost of personnel. Surprisingly, hardly any literature can be found to list the required visual objects and phenomena for tower control, i.e. the visual cues that need to be seen for tower control.

Description of work
The subject of this paper is to compose and validate a list of so-called 'visual cues' for tower control and to provide a guideline for the required pixel resolution of remote tower cameras and displays.

Results and conclusions
Our analysis leads to definition of a 'short-list' of important safety-related visual objects and phenomena for tower control. State of the art media are able to provide the required image resolution for visual *detection* of items from this list but not for *recognition*.

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Assessment of visual cues by tower controllers, with implications for a Remote Tower Control Centre

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Summary

Remote control of airports implies application of cameras to replace direct visual observation from airport control towers by projection of the airport and its traffic in a remote control centre. Remote airport control is an emerging technique with benefits for smaller airports mainly, because it reduces the cost of personnel. Surprisingly, hardly any literature can be found to list the required visual objects and phenomena for tower control, i.e. the visual cues that need to be seen for tower control. The composition and validation of the so-called visual cue list for tower control is the subject of this paper. Tower controller task analysis was used to compose a 'long-list' of visual features. The long-list has been presented to a group of operational air traffic controllers to test the need and the circumstances to observe these visual cues. Our analysis shows that most of the visual cues are useful for operational tower control but are not strictly mandatory for applying the rules of the International Civil Aviation Organization.. The requirement for visual image resolution of remote tower control is the second subject of the paper. Our analysis leads to definition of a 'short-list' of important safety-related visual objects and phenomena for tower control and the conclusion that state of the art media are just able to provide the required image resolution for visual *detection* but not for *recognition*.

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Abbreviations

ART	Advanced Remote Tower
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
ICAO	International Civil Aviation Organization
IEA	International Ergonomics Association
IFAC	International Federation of Automatic Control
IFIP	International Federation for Information Processing
IFORS	International Federation of Operational Research Societies
LFV	Luftfartsverket
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
TAR	Terminal Approach Radar
VHF	Very High Frequency

1 Introduction

In Europe, the first prototypes of remotely controlled airfields have emerged. The idea is to equip airfields with cameras, such that the air traffic controller (ATCO) can control the airfield from a virtual visual control room at a more convenient location. The view on the airfield is displayed in real-time on a display in this room. From here, the airfield can be surveyed and the traffic movements can be controlled. This concept is particularly suitable for a group of relatively quiet airports at geographically dispersed locations, such that the control of multiple airfields can be centralized, thus making efficient use of air traffic controller resources.
The topic of this paper focuses on two aspects:

1. The visual 'features' (objects, phenomena) that air traffic controllers should be able to see for safety reasons in a remote tower;
2. The minimum resolution requirements for remote tower control.

A list of visual features to be seen from the control tower is of interest because it strongly influences the requirements on the surveillance cameras, the data-communication links and the display system.. In this study, such a list of items, e.g. a flock of birds or debris on the runway, and the circumstances under which these items must be detected and recognized has been created. The basis for this list was established by considering the task-requirements of the air traffic tower controller.
Minimum required performance specifications are needed to determine the ability of camera surveillance and display systems to sufficiently display visual features. To see those features under widespread viewing conditions (day/night, sun/overcast, etc.) is key to the tower controllers' tasks and hence aviation safety. This means, that, in order to detect for example birds at the runway, parameters such as the visibility range from the tower, the resolution of the image, and the contrast between object and its background must exceed certain threshold values. This paper will discuss the establishment of the resolution threshold values.
This small study was made possible in the context of the Advanced Remote Tower (ART, 2006) project. ART is a 6th Framework Program project funded by the European Commission and run under project lead by Saab AB in Sweden and the Swedish Air Traffic Control organisation LFV.
The properties of Tower Control may not be well known to readers. Therefore, the next section is included to explain the procedures and systems used in state of the art Tower Control. The focus of this contribution, i.e. the analysis of tower control visual features and resolution requirements for remote projection is found in last sections.

2 Tower Control

2.1 Basic duties

The ICAO task definition for air traffic controllers is (ICAO, 2005a) to:

- Prevent collisions between aircraft, and on the manoeuvring area between aircraft and obstructions. The manoeuvring area is the section of the airport to be used for take off, landing and taxiing excluding aprons;
- Favour an expedite flow of traffic.

These tasks have to be performed by visual observation. The procedures change when visibility conditions change. Definition of visibility conditions can be found in ICAO (2005b). If the tower controller cannot exercise visual control over all traffic, e.g. because of fog, a special procedure called Procedural Control is applied. It means that an aircraft is cleared via radio telephony to a point at the airport, where the pilot has to report when reaching that point. Procedural Control and its safety depend largely on the quality of the VHF communication channel and the situational awareness in the cockpit. Procedural Control implies much lower throughput capacity for the airport (often only one aircraft can be moved at the time). ICAO does not specify how visual surveillance from Control Towers shall be implemented in detail. ICAO does not specify what objects or visual cues have to be seen.

2.2 Airport Radar and Surveillance Systems

Air Traffic Control in the towers of airports is thus based on visual surveillance tasks. However, for low-visibility conditions, Airport Surface Detection Equipment (ASDE) with radar screens and information from the Terminal Approach Radar (TAR) are available at the larger airports. This kind of equipment serves the tower controllers, but controllers are not allowed to take decisions based on the ASDE and TAR only, although stakeholders are working hard to develop and improve this situation.

3 Analysis of Visual Features

3.1 Analysis of tower tasks and visual needs

We identified visual needs of the tower controller from our task analysis of tower operations (ART, 2008a), based on expert elicitation and task observation. The tower tasks were structured according to the time phases in ATC-handling of arriving and departing aircraft. Also general tasks (such as collecting weather information) and abnormal events (e.g. crash, bird strike, over-run of the runway) were taken into account. Our interest concerns the visual features at and around the airport which have to be surveyed as part of the task, such as specific features of aircraft (e.g. its apparent ability to land during final approach, flocks of birds, etc.). To make a more fine-grained assessment of the quality with which visual features can be viewed, different visual tasks can be distinguished:

- visual detection (you may or may not detect that an object is at a certain location);
- visual recognition (once you have detected the object, you may be able to recognise it, e.g. that an object is indeed an aircraft);
- visual identification (verify observed information, such as an aircraft at a particular position with other information, such as a flight-plan);
- visual judgment (concerns a more abstract relationship, e.g. a potential conflict between aircraft, or the descent rate of aircraft).

These different visual tasks put different requirements on human visual characteristics (e.g. visual acuity see e.g. Stamford-Krause, 1997) and therefore lead to different system requirements when displaying these features in a remote tower. Moreover, visibility conditions, such as fog, may affect these visual tasks differently.

3.2 List of visual features

The list of visual features that was derived from the task analysis includes the following items:

1 Large-size bird (e.g. goose) on the manoeuvring area or vicinity of the runway
2 One smaller bird (like a sea-gull) on the manoeuvring area or vicinity of the runway
3 Flock of smaller-size birds (e.g. small type sea-gull) on the manoeuvring area or vicinity of the runway
4 Animal, like a deer or a dog, on the manoeuvring area/ runway
5 Vehicle on the manoeuvring area
6 Aircraft entering the Control Zone of the tower
7 Stationary obstacles on the manoeuvring area
8 Aircraft in the circuit
9 Descent rate of aircraft
10 Aircraft undercarriage (main gear and nose wheel)
11 Aircraft position on final
12 Airspace for missed-approach/ go-around
13 Foreign objects on the runway (e.g. plastic bag, pieces of metal, pieces of exploded tire)
14 Aircraft flare at landing (judgement)
15 Aircraft touch-down inside touch-down zone
16 Detect smoke or water spray from tires when touching down
17 Aircraft slowing down on runway (judgement)

18 Taxiing aircraft follows designated route
19 Water, snow or slush on runway
20 Aircraft acceleration during take-off run (judgement)
21 Aircraft lift-off (judgement)
22 Aircraft climb (judgment)
23 Cloud base
24 Clouds (type and coverage)
25 Visibility range (as judged from visibility of objects with known distance)
26 Aircraft lining up on the runway
27 Number or logo on skin of aircraft
28 Aircraft starts to move
29 Aircraft starts to turn
30 Aircraft landing lights
31 Precipitation (type) (judgement)

4 Method and Results

A questionnaire was presented to a group of seven controllers. This questionnaire referred to the visual features listed above. The controllers were asked to give their safety related experience about the maximum viewing range (detection range) for each of the features. Subsequently, they were asked to state the importance for safety reason to detect or judge a feature on a scale from 0 (not important for safe control) to 6 (very important for safe control). If it was not required to see the feature, the controller should indicate “0”.

The controllers had to indicate at which distance they would detect a feature in good visibility and daylight. Figure 1 summarizes the estimates of the seven controllers. With these distances, it should be considered that tower controllers often use binoculars to better see certain objects or phenomena, but this was not allowed for answering the questions. The middle section of the runway on the airport where the controllers are active is about 700 meters away from the tower with the runway thresholds located at about 1100 and 1400 meters from the tower. Note that the distances to the runway and to the runway thresholds lead to many responses close to these values. It is clearly important for safety that the runway is free of obstacles, wildlife and birds and that the monitoring of aircraft landing and take-off requires a visibility range of up to two kilometres from the tower. The “plateau” in figure 1 at approximately 3800 m distance is explained as a typical value for monitoring of the circuit.

It must be realised that these visual features are not equally important for the tasks of the tower controller. Therefore, it was attempted to impose an order on the list of features in accordance with the importance for the job. Figure 2 below depicts the importance to *detect* objects in order to do the job with emphasis on safety, on a scale from 0 to 6.

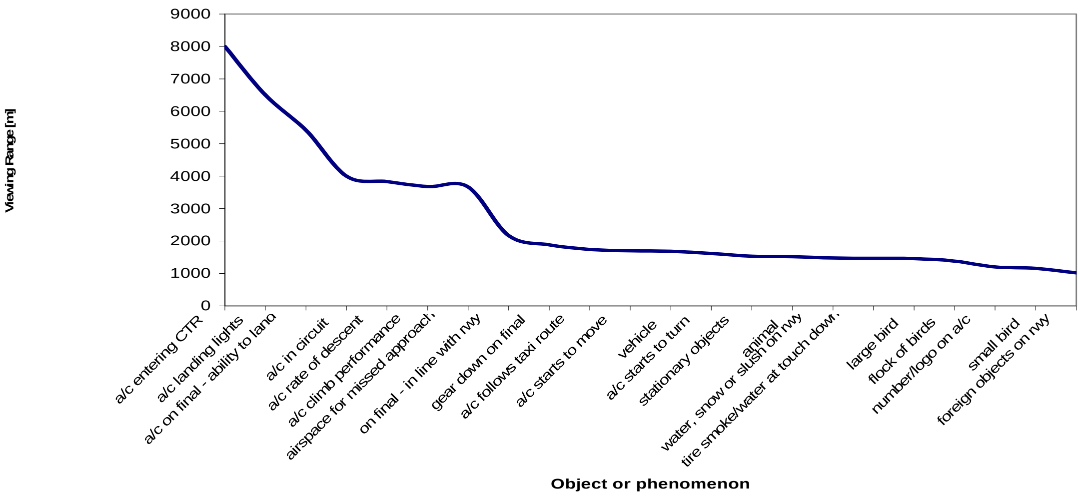

Figure 1: Viewing range for detection at which tower controllers see objects or phenomena in good visibility and daylight

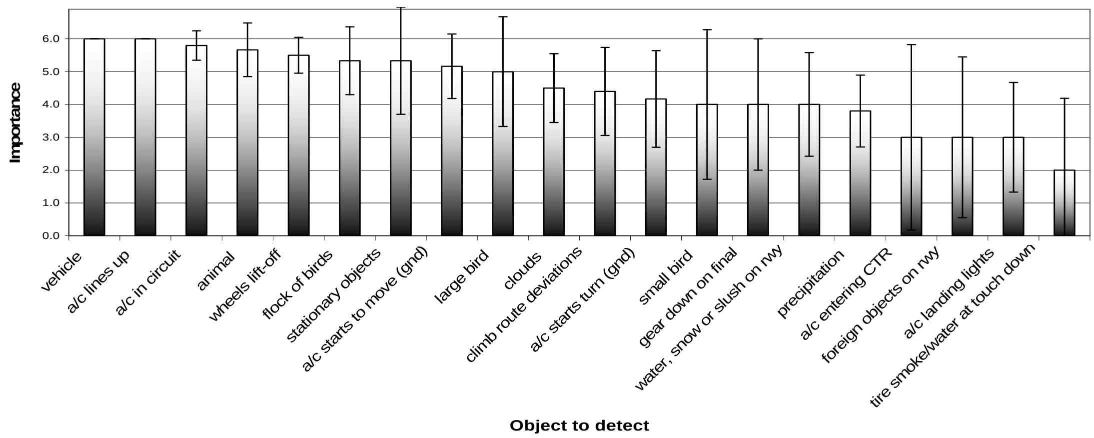

Figure 2: Rated importance to detect objects (6 is high importance). Standard deviations (n=7) in the rating are indicated.

There was a high level of agreement among the controllers about the most important objects to detect. It should be considered that there is considerable variance in the importance-ratings of objects that are on average considered less important, sometimes depending on the way controllers interpret their job. Some controllers indicated that detection of certain objects (such as foreign objects on the runway) is not part of the tower controllers' tasks, but rather that of other airfield personnel, such as those responsible for runway inspection between flights.

Figure 3 depicts the importance to *recognise* objects in order to do the job, on a scale from 0 to 6.

The five least important objects to detect are:

16. Tire smoke/water when touching down,
30. Aircraft landing lights,
13. Foreign objects on the runway,
6. Aircraft entering the Control Zone, and
31. Precipitation.

The five most important objects to detect are:

5. Vehicle on the manoeuvring area (1700 m),
26. Aircraft lining up (1400 m),
8. Aircraft in circuit (4000 m),
4. Animal on the manoeuvring area and runway (1500 m),
21. Aircraft lifts up, wheels from runway (1000 m).

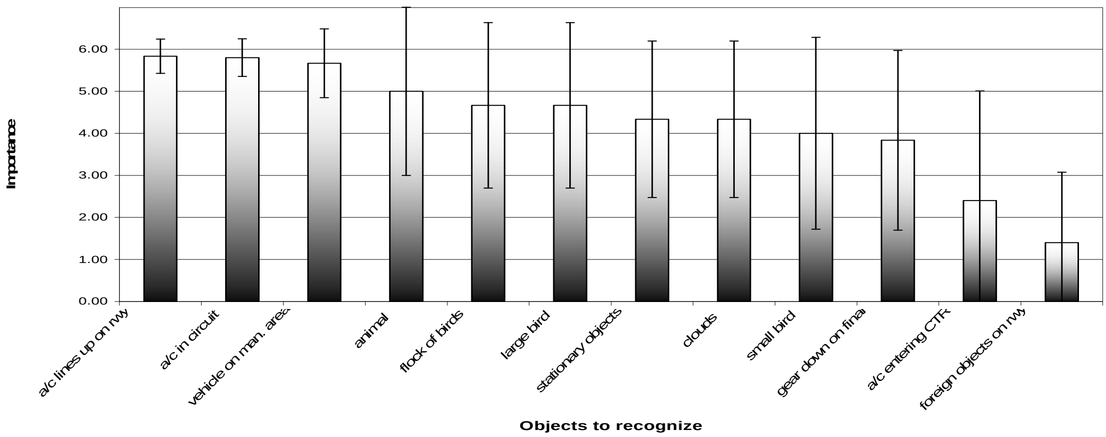

Figure 3: Rated importance to recognise objects. Standard deviations (n=6) in the rating are indicated.

The five least important objects to recognise are:

13. Foreign objects on the runway,
6. Aircraft entering the Control Zone,
10. Gear down on final,
2. Small bird, and
24. Type of clouds.

The three most important features to recognise are:

26 Aircraft lines up on runway (1400 m),
8. Aircraft in circuit (4000 m),
5. Vehicle in the manoeuvring area (1700 m).

Again, there was a high level of agreement among the controllers about the three most important objects to recognise. It should be noted that recognition of objects requires a higher visual acuity (and imposes higher system requirements for displaying these objects) than detection.
Subsequently, controllers were asked to rate the importance to judge phenomena. The ratings are depicted in figure 4.
There is a moderate to good level of agreement among controllers about the importance of phenomena to be judged. The controllers are unanimous in the rating of importance that they must be able to visually judge the availability of (conflict free) airspace in case an aircraft has a missed approach and must make a go-around.

Finally, the controllers were asked to rate the importance of making an identification of an aircraft on the basis of logo or number visible on the skin of the aircraft. This importance was however rated as low.

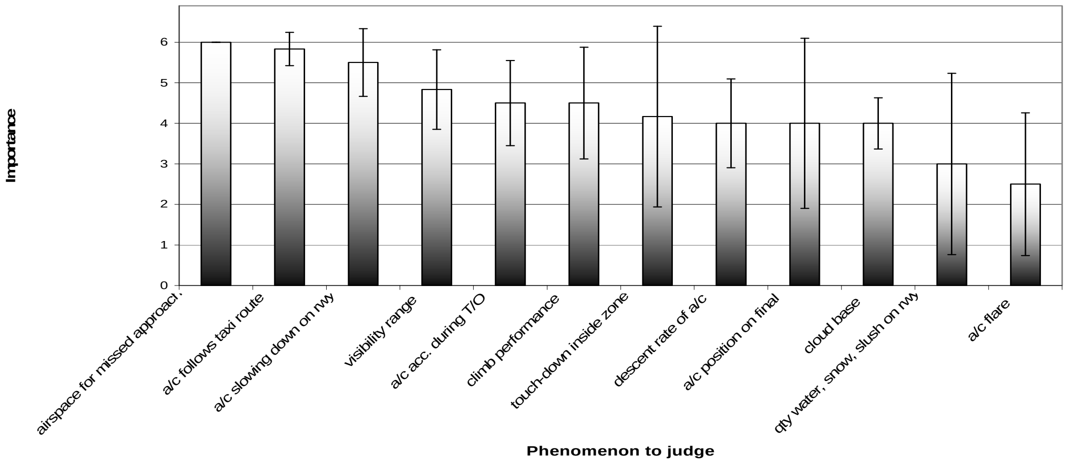

Figure 4: Rated importance to judge phenomena (6 is high). Standard deviations (n=7) in the rating are indicated.

Controllers were asked how they would rank the safety related importance of being able to see the features during night. Their answer was unanimous: no feature can be surveyed by visual observation in the dark unless it carries lights. Lights provide a high contrast and resolution against a dark background, making visual observation during night different from daylight conditions. Therefore night operations have not been further analysed in this paper.

The five least important phenomena to *judge* visually are:

26. Aircraft flare,
19. Water, snow or slush on the runway,
23. Cloud base,
11. Aircraft position on final, and
9. Descent rate of aircraft.

The five most important phenomena to *judge* visually are:

12. Conflict free airspace that must be available for approaching aircraft in case such an aircraft has a missed approach and must make a go-around (at approx. 3700 m maximum),
18. Whether aircraft follow or deviate from a designated taxi route (at approx. 2300 m),
17. Whether aircraft slow-down sufficiently after touch-down (at approx. 1500 m),
25. The visibility (range) from the tower, and
20. Aircraft acceleration during take-off (at approx. 1000-1500 m).

5 Discussion and Effect on Resolution

This study was performed to investigate the features that benefit safety if observed under good visibility conditions during the day.. A long-list of features was extracted from a tower controller task analysis. This list was presented to operational controllers in a questionnaire about the importance of these features for safe tower control. The responses to the questionnaire were ordered with respect to importance for the tower controllers' job, distinguishing between features that are important to be detected, to be recognized, or to be judged with emphasis on safety. More expensive visual systems would be able to detect the smallest objects at the largest distances and even recognize and assist in judgment but it would not be cost beneficial. Therefore we removed the features from the list that are ranked the least important either for detection, recognition or judgment. For daylight these are: (2) Smaller birds, (6) Aircraft entering the Control Zone, (9) Descent rate of aircraft, (10) Aircraft gear down, (11) Aircraft position on final, (13) Foreign objects, (14) Aircraft flare, (16) Smoke or water spray, (19) Water, snow or slush, (23) Cloud base, (24) Type of clouds, (30) Aircraft landing lights and (31) Precipitation. The reasons for controllers to find these features less important are obvious: these features are too small, too remote or not very important at all for safe control of aircraft. Off course, aircraft and vehicle lights are very important for night operations, but this investigation focused on daylight operations in good visibility. The low importance rating for item 27: Number or logo, was not expected. This result might stem from the typical traffic at a small airport with well known users. This feature and result was therefore excluded from further analysis.

The results were translated to image resolution requirements. For the surveillance of objects at large distances, the capability of a display system to make small details visible (i.e. the resolution) is critical. The resolution depends on the camera, the addressable resolution of the graphics processor (expressed in pixels per degree visual angle in horizontal/vertical direction)

and the resolution of the display (which in turn depends on such factors as pixel-size and video-bandwidth).
The size and distance of small objects determine the required limiting resolution of the image system and display. Ideally the limiting resolution of the image system should at least be equivalent to the ATCO's ability to perceive detail. Perception of detail is expressed as visual acuity (i.e. the inverse of the smallest perceptible object angular detail) in $arcmin^{-1}$ (1 arcmin, or minute of arc, equals 1/60 deg). ATCOs might have a minimum separable acuity between 10 and 40 arcsec-1, when tested in the laboratory (e.g. Boff and Lincoln, 1988). However, to set a minimum requirement for the 'noisy' tower environment we shall assume that the ATCO has a visual acuity of only 1 arcmin-1, which is reached by 85% of the population. On this basis, we assume a limiting resolution of 60 lines per degree. This would ideally correspond to an 'addressable' resolution (that is, addressable pixels of the image generator) of 60 pixels per degree. However, to account for the loss of resolution in a system, we should divide the latter addressable resolution by 0.7 (the so called Kell-factor, Padmos and Milders, 1992). Hence, dividing the addressable resolution of 60 pixels per degree by 0.7 results in the *required* addressable resolution of 86 pixels per degree.
In this context only the visual features for detection and recognition are contributing to the requirements. Table 1 is an inventory of remaining visual features that play a role in safe conduct of tower operations. These features are ordered according to importance in figure 2 for detection and figure 3 for recognition. For each feature, cross section area and typical size were estimated. The distance at which the features are observed comes from the data in figure 1.
For features for which a visual judgment is required, the resolution requirements are not specified and would need further investigation. These features are: (12) Airspace for missed approach/go-around, (15) Aircraft touch down capability, (17) Aircraft slowing down on runway, (18) Taxiing aircraft follows designated route, (20) Aircraft acceleration during take-off, (22) Aircraft climb, and (25) Visibility range. Feature (29) Aircraft starts to turn will probably be preceded by (28) Aircraft starts to move and is thus expected to bring similar requirements.
For recognition of objects, we can use the criterion that at least eight image lines overlay a recognisable object. Under optimal conditions in the tower, ATCOs may be able to recognize high-contrast features subtending a visual angle of 2 arc-minutes. This would mean that we need a limiting resolution of 240 lines per degree (343 pixels per degree). However, taking into account more realistic conditions, Padmos and Milders (1992) propose a more relaxed guideline for the required addressable resolution (in pixels per degree):

0.14 x object distance / object size (expressed in the same unit of length).

Thus, to *recognise* an object with a characteristic size of 1 m at a distance of 600 m requires 84 pixels per degree visual angle. The required visual subtended angles from the controller responses have been translated in the last two columns of table 1 in to the calculated resolution for detection and recognition using our literature references given above. When traffic is labelled, such that detection and recognition of traffic is facilitated, the requirements listed in table 1 may be lowered.

Table 1: Selected important visual features for visual tower control with their typical dimensions, observing distance from the tower and the consequences for remote projection in pixels per degree both for detection and recognition (daylight conditions, good visibility)

	Important visual feature	**Cross section**	**Characteristic size**	**Range**	**Vis. angle**	**Res. for detection**	**Res. for recognition**
No.	(m	^{2}) (	m)	(m)	(arcmin.)	(pixels/deg.)	(pixels/deg.)
1.	Large-size bird	0.50	0.71	1500	1.7	51	289
3.	Flock of smaller-size birds	20.00	4.47	1400	11.1	8	43
4.	Animal 1.	00	1.00	1500	2.3	37	210
5.	Vehicle on the manoeuvring area	4.00	2.00	1700	4.1	21	118
7.	Stationary obstacles	1.00	1.00	1500	2.2	38	215
8.	Aircraft in the circuit	6.00	2.45	4000	2.1	41	229
12.	Airspace for missed-approach/ go-around	see text		3700	see text		
15.	Aircraft touch down inside touch-down zone	see text		1500	see text		
17.	Aircraft slowing down on runway	See text		1500	see text		
18.	Taxiing aircraft follows designated	See text		1700	see text		
20.	Aircraft acceleration during take-off	See text		1500	see text		
21.	Aircraft wheels lift-off	1.00	1.00	1000	3.4	25	140
22.	Aircraft climb	See text		3700	see text		
25.	Visibility range	see text					
26.	Aircraft lining up on the runway	6.00	2.45	1400	6.0	14	80
27.	Number or logo on skin of aircraft	See text		1200	see text		
28.	Aircraft starts to move	1.00	1.00	1700	2.3	37	210
29.	Aircraft starts to turn	See text		1700	see text		

The visually most demanding task is to recognise a large bird at 1500 meter, which is on the edge of what can be detected and recognised with unassisted eyesight. However, tower controllers will expectedly use binoculars if they detect distant objects or movements, for which an equivalent camera/display system, such a separate PTZ-camera may be used in remote tower operations.
Most of the other features will be viewed with a minimum subtended visual angle of 2 to 6 minutes. The resolution required for detection and recognition of a flock of smaller-size birds would need additional investigation, since it will obviously depend on the actual size of each bird, and the number and distribution of birds. Typical camera and projection systems provide about 30 to 40 pixels per degree viewing angle. From the table it can be concluded that that resolution is sufficient to provide *detection* of the most important features for visual tower control. For detection of small features, for example, when a steady aircraft start to move (nr. 28), binoculars (zoom camera) and (automatic) tracking would be required. If features have to be recognised, five to six times the number of pixels per degree that are needed for detection will be needed. Video image enhancement techniques may be required to achieve resolution and contrast for recognition, therewith providing cost beneficial solutions to the requirements.
This survey is our first attempt to derive optical requirements for remote tower operations. It is planned to include more air traffic controllers (including military air traffic controllers) in the survey in order to fine-tune the analysis. Further analysis will also address minimum contrast requirements for remote tower control. For the ability to detect objects in a complex scene, contrast sensitivity of the human and hence image contrast in the projected image is at least as important as visual acuity/ image resolution (e.g. Streid, 2007).

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