Summary

This thesis investigates the possibility of improving x-ray baggage inspection by presenting the inspector a spatial impression of the baggage. The Delft Virtual Window System (DVWS) is used to give the inspector such a spatial impression of the baggage on a normal monitor display. This spatial impression of the baggage is obtained by coupling the position of the x-ray camera to the viewing position of the observer. For example if the inspector moves to the right, an image is displayed that shows the suitcase more from the right.

Each image taken exposes the baggage to an x-ray dose, and the maximum allowable x-ray dose is reached after about 25 images. Therefore we have to be careful about which viewpoints the inspector can investigate. Furthermore, given the state of the art techniques of making sharp x-ray pictures with a low x-ray dose, the resulting pictures have unusual perspective properties: they contain convergent perspective in, e.g., the horizontal direction of the picture, but parallel perspective in the vertical direction. Considering the costs, we prefer to use the existing techniques. Therefore, the perspective properties of the views have to be chosen carefully in order to get views which are acceptable when presented interactively with the DVWS. Chapter 3 outlines the possibilities of shooting such multiple x-ray views efficiently, using the current technologies of baggage inspection.

Thus, the question about the usefulness of the DVWS in the context of baggage inspection expands to a number of questions:

1 What exactly does 'useful' mean for baggage inspection, and how do we test it?
2 What are the useful images (what image quality; what viewpoint; how many viewpoints)?
3 How should the inspector control the image he views?
4 How should the images be presented, for optimum inspector performance?

The first of these questions is difficult to answer. Applying the DVWS to an x-ray inspection system is useful if it enhances the ability of the inspectors to find suspicious items as compared to x-ray inspection systems without the DVWS. As a baggage scanner based on the DVWS was expected to be used essentially for hold baggage, where the threat of bombs is most serious, the 'suspicious items' were reduced to 'bombs'. Usually, a bomb consists of a battery, a detonator, a timing mechanism, a wire connecting these parts, and explosives, and it seems reasonable to assume that detecting such parts and connections is important for baggage inspection. Still, the replacement of the vague term 'suspicious' by 'bomb' does not help us much in analysing the baggage inspection task scientifically, as most bomb parts do not have fixed shapes and as some parts are not always present in a bomb. For example, explosives and batteries can be shaped in any form, and wires may be omitted. But the importance of these problems was not clear when starting this project. I started to investigate a number of tasks that seemed relevant for x-ray baggage inspection, using perception theories as a criterion.

To find out what sort of images would be useful and how the observer should control the image he views, I started with an experimental investigation of image quality, required number of viewpoints, and the way the observer selects the viewpoint.

Experiments 1 to 3 (Chapters 4-6) deal with these questions. Next I investigated a more difficult question, i.e. the best way to present the images (Chapter 3 and Chapter 7). The results of these experiments interested an airport and a manufacturer of x-ray scanners (Heimann GmbH). We cooperated on testing the effect of providing multiple viewpoints on real baggage inspection (Chapter 8).

In the first experiment (Chapter 4), I tried to show that the DVWS can improve the ability to see sharp edges. This task is more relevant for hand baggage than for hold baggage, but at that time I had not decided yet to concentrate on hold baggage. I found many unexpected results here: for example, response time increased and performance decreased with the available number of views.

In the second experiment I showed that, for detecting wires connecting two objects, performance increases with increasing *camera range* (the angular distance between the extreme available views). Furthermore, a reduced image quality (resolution and number of grey levels) can be offset by increasing the number of available views. It was shown that three extreme views are sufficient for this task, and that increasing the number of views within this range does not improve observer performance. I concluded that for x-ray baggage inspection it is necessary to provide extreme views to the inspector. Another welcome result was that, for this task, observers performed just as well when selecting the view manually instead of via their head movements. Selecting a view with the knob is less tiring than moving the head, and eliminates the need for expensive head position tracking. Although three views were found sufficient to detect wires connecting objects, I suspected that the availability of only three views would give a limited spatial impression and therefore might be insufficient for a task in a more complex scene.

In the third experiment it was shown that a large camera range is not sufficient for following a wire through a semi-transparent knot. Performance increased with the number of available views within a fixed horizontal range, up to continuous views. Providing both horizontal and vertical continuous views did not improve performance as compared with horizontal continuous views only. Here, response times decreased with the number of available views. Thus, the required image quality and number of available views seem to depend on the spatial complexity of the scene. For x-ray baggage inspection, the number of required views was expected to lie somewhere between that required for this task and the three views required for detecting a wire between two objects.

The best way to present the images – the optimum configuration of various perspective and display possibilities – was investigated in Chapter 3 and Chapter 7. In Chapter 3 a large range of perspective and display possibilities is explored, but this range was too large to investigate completely in an experiment.

The fourth experiment (Chapter 7) tested the effects on observer performance of a viewpoint measurement error and of the way the camera settings are coupled to the viewpoint of the observer. There are at least two ways to make an image given some viewpoint: one can keep the camera aimed at some point in the scene (*on-axis coupling*) or alternatively one can shift the camera to the new viewpoint without rotating the projection plane (*off-axis coupling*). The DVWS is an on-axis coupling. Geometrically, off-axis coupling seems the correct choice if the camera position is coupled to the eye position, because it is only with off-axis coupling that the objects represented subtend the same optical angles as objects in a real scene would subtend. Furthermore, measurement inaccuracies of the actual viewing position of the observer may cause the scene to appear different from a real scene (*distortion*). Both the coupling method and viewpoint measurement errors may decrease observer performance. It was shown that such distortions do occur as predicted by geometry, although usually observers do not notice them. However, human observers also use other than geometric cues for their task, and the distortions found seem less relevant for x-ray baggage inspection. For baggage inspection, on-axis coupling (i.e. the DVWS) seems the right choice, especially when the view is being selected via a knob.

The last experiment (Chapter 8) tested the effect of the number of available viewpoints on 'real' x-ray baggage inspection. An expert from an airport packed 68 suitcases, hiding complete bombs in 15 of them. The suitcases were scanned on an x-ray baggage scanner. The acquired views were presented with the DVWS to experienced baggage inspectors at the airport, and they were asked to detect bombs. The results showed no effect of the number of available views on the judgement of the inspectors, although the response time increased when two viewpoints were provided instead of one. These results suggest that the inspectors need a thorough training to interpret the spatial impression of the baggage. Probably, as happens frequently with new technology, it may even be necessary to use new inspectors with no experience of traditional x-ray inspection.

In conclusion, for baggage inspection and related tasks I found the following answers to the four questions posed at the start of this abstract:

1 In general, it is essential to clearly operationalize the task in perceptual terms.
2 Depending on the task, two views are sufficient or continuous views are required.
3 For some tasks, a knob is sufficient to select the required view, while for other tasks a coupling with the actual viewpoint of the observer can improve performance.
4 The perspective properties of the views can disturb the observer, depending on the choices made for (3).