5

Detecting connected objects[1]

Informally, experts often indicate that bombs usually consist of a battery, a timing mechanism, a detonator, explosives and wires connecting those parts. Therefore, detecting a wire connecting objects is expected to be a task relevant for a baggage inspector. This chapter describes three experiments in which participants have to detect wires and connections. The first experiment tests the trade-off between the spatial resolution and the number of grey levels of the images, and the number of available views. The second experiment tests whether manual viewpoint selection can replace viewpoint selection via the eye position that was used in the first experiment. The last experiment tests whether, for this task, the total number of views over a given camera range affects observer performance.

To limit the x-ray dose to which the baggage is exposed, the number of available views will be limited in the same way as described in Chapter 4. Again, the observer has just one degree of freedom: the left-right movement (Figure 4.2). Only N images are available, with a constant angle $\Delta\varphi$ between two images. As with the experiment described in Chapter 4, I expect observer performance to increase with increasing camera range, up to 180˚. The camera movement was scaled to a maximum comfortable head movement of ±22.5˚, giving a scale factor $\varphi_{cam} / \varphi_{obs} = N.\Delta\varphi / 45$. But if the angle $\Delta\varphi$ gets too large, observer performance may decline.

In line with results from other experiments (Ranadivé, 1979; Swartz, Wallace and Tkacz, 1992; Snyder, 1973; Uttal, Baruch and Allen, 1995; Braunstein, Hoffman, Shapiro, Andersen and Bennett, 1987), the hypotheses are that the resolution R, the number of grey levels G and the number of views N will improve the performance of the observer from a threshold up to a saturation level. When the value for a variable falls below its threshold, the task cannot be done, regardless of the levels of the other variables. For example in the task used in this experiment, the resolution threshold is about 256x128. At lower resolutions it is impossible to see the wire to be detected, even when multiple views are available. There is also a saturation level for the resolution, at which increasing the resolution brings no improvement in task performance. For most tasks, this saturation level will be well below the visual acuity. Furthermore, the threshold and saturation levels will depend on the levels of the other variables (Smets and Overbeeke, 1995). For example, for a high resolution R the threshold of the number of grey levels G will be lower, and increasing the available views will lower the resolution threshold.

Finally, it is interesting to compare the performance of an observer using eye position to select the desired viewing angle with an observer using a knob to do so. The pictures that are presented are the same in these cases, but the way they 'feel' is different: in the first case, the observer gets the impression that he is moving around a box, in the second case he gets the impression that he is turning the box indirectly. The first case seems more 'natural', and I expect participants to perform better than in the second case. If they

[1] This chapter is based on Pasman, Smets and Stappers (1997).

perform the same, it may be unnecessary to use expensive eye position trackers for the X-ray inspection apparatus.

Experiment 1- view selection with eye position

This experiment tests the effects of image resolution, number of grey levels, number of available views, and the angle between the views on the ability of the participants to detect a wire, their ability to judge whether the wire connects two objects, and their response time.

Method

Stimuli

The stimuli are very similar to those of the first experiment in Chapter 4, but now some boxes also contain a wire. Figure 5.1 shows two examples of the actual stimuli. In each box, two objects were present. Some boxes also contained a wire. In some of the boxes, the wire connected both objects. This configuration was derived from the usual construction of a bomb: a wire between a battery and a detonator. The wires used had a diameter of 0.3 mm. For recording the stimuli, the same setup as described in Chapter 4 was used.

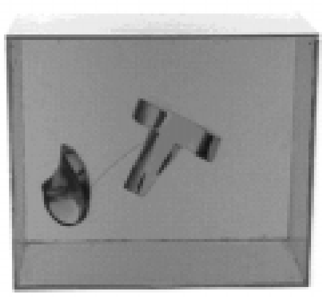

Figure 5.1a. Impression of stimuli: Two objects and a wire in a box.

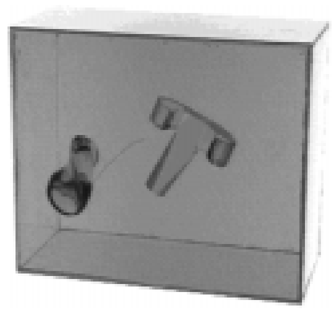

Figure 5.1b. Viewed from the right, the objects appear unconnected.

To model the possible situations in x-ray baggage inspection, I classified the contents of the boxes into three types *T*: no wire, connected and trick. Boxes of type 'no wire' did not contain any wire, only two objects. Boxes of the type 'connected' contained a wire that clearly connected both objects: in the front view the wire crossed both objects. Boxes of type 'trick' tried to fool the observer. An example 'trick' is when the second object was placed behind the first, disturbing the front view of a wire connecting the objects. Another 'trick' was to place the wire in such a way that the objects seemed to be connected in front view (Figure 5.1a), but not in side view (Figure 5.1b).

Preceding each trial, the required views of the box were read from hard disc, reduced in number of grey levels and resolution if necessary, and stored in working memory. This caused a pause of about 10 s between trials. During the trial, the appropriate images were shown from working memory on the screen. For a reduction of the number of grey levels, the original 16 grey levels were divided into 4 or 8 groups, and for each group the brightest value was taken. Informal evaluation by the experimenter indicated that this reduction had little effect on image contrast. To reduce resolution, the image pixels were grouped in 2 x 2 pixels whose intensity was averaged.

Apparatus

In Figure 5.2, an overview of the experimental setup is shown. The room was illuminated at 150 Lux by fluorescent lighting. The turn knob at the right on the table was present only in Experiment 2. The computer, display, reduction screen and viewpoint tracker were the same as in the first experiment of Chapter 4.

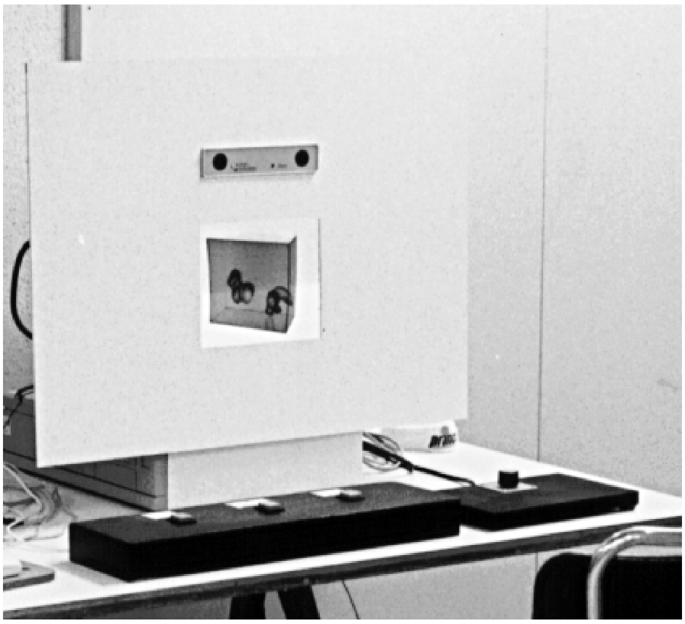

Figure 5.2. Overview of the experimental setup. Display with reduction screen in front, and the head tracker sensor on top of it. On the table on the left the button box and on the right the knob. The knob was present only in Experiment 2.

Independent variables, hypothesis

The hypotheses bear on the effects of the image resolution R, the number of grey levels G, the number of available views N, the angle between the views $\Delta\varphi$ and the type of the box contents T. Table 5.1 shows the independent variables and the tested levels. I estimated the threshold and saturation levels in some pilot sessions, and used these as lowest and highest level for the variables.

Table 5.1. The independent variables. $\theta = 22.5^\circ / 32$.

Name of variable	Description	Used values
R	Image resolution	256 x 128 pixels, 512 x 256 pixels
G	Number of grey levels	4 , 8 , 16
N	Number of available views	1 , 2 , 4 , 8 , 16 , 32
$\Delta\varphi$	Angle between the views	θ , 2 θ , 4 θ , 8 θ
T	Type of box contents	no wire, connected, trick

A higher ability of the participants to detect a connection and a lower response time were expected with increasing camera range, up to a camera range of 180˚. For this range, N = 32 views were expected to be near the saturation level. This gives an angle between the views $\Delta\varphi = 180^\circ / 32$ (In fact 33 frames are needed to reach the 180˚, so the range is slightly smaller). To simplify the notation, angles are expressed as multiples of $\theta = 22.5^\circ / 32$. Figure 5.3 gives an impression of the views for different resolutions *R* and numbers of grey levels *G*.

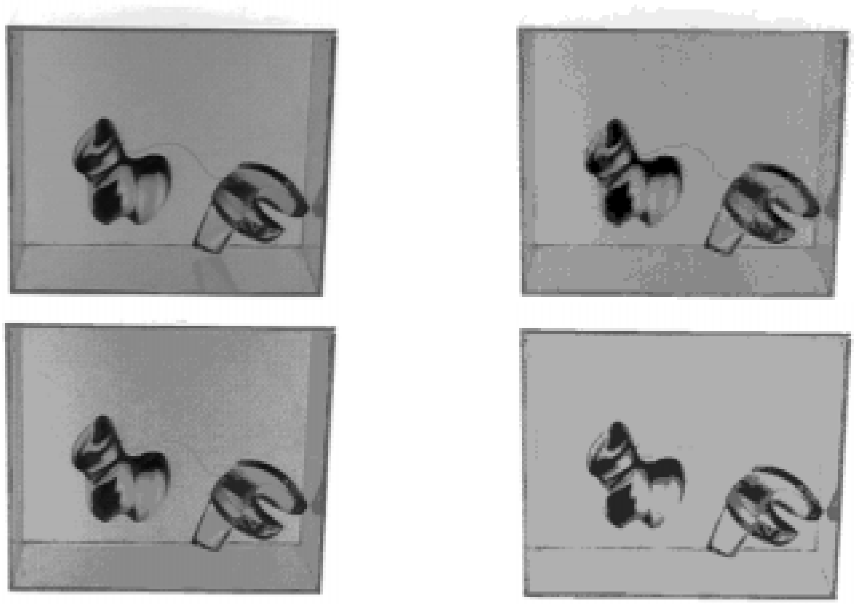

Figure 5.3. Screen impressions. Top left: *R*=512x256 and *G*=16. Top right: *R*=256x128 and number of grey levels *G*=16. Bottom left: *R*=512x256 and *G*=8. Bottom right: *R*=512x256 and *G*=4.

Dependent variables

Table 5.2 gives the measured dependent variables. The participant had to choose whether or not the two objects in the box were connected. A third choice 'wire, but not connected' was available. This was necessary to make a difference between seeing no wire at all and seeing a wire that does not connect the objects. Furthermore, the response time was measured and analysed to find uncertainty with difficult stimuli.

Table 5.2. Dependent variables.

Description	Possible values
chosen button	no wire, wire but not connected, connected
response time	> 0 s

Participants, Design

Each participant had to judge 30 boxes (10 of each type *T*). The order of presenting the boxes was the same for all participants, but randomized over all conditions. The 2(*R*) x 3(*G*) x 6(*N*) x 4($\Delta\varphi$)=144 conditions of each box type *T* were distributed randomly over 15 participants (150 judgements for each box type *T*). The remaining 6 judgements for each type were discarded. This way of defining the conditions for 15 participants was repeated 5 times to get 5 measurements for each condition, so 75 participants were tested.

The participants were 75 students from the Faculty of Industrial Design Engineering (25 women, 50 men). They were naive and paid volunteers. The first 15 participants received NLG 10 (USD 5) for taking part, the other 60 NLG 7.50 (a loaf of bread costs about NLG 2).

Procedure

For instruction, the participant was told that boxes would be shown on the screen, with two objects in each box. His task would be to decide whether there was a thin wire in the box and, if so, whether it connected both objects. He had to choose between 'no wire', 'wire but not connected' and 'connected' by pressing one of three buttons labelled with these words.

A participant could view the box from different sides by moving his head to the left or to the right. He was instructed to inspect the box from all sides before making a judgement, and to base his choice on the things he could see (and not the things he could imagine). During the training, the participant got a warning from the experimenter if he did not do so. He was warned that he had just 10 seconds to look at the box, but he was instructed to try to make the right choice, and that a quick response was less important.

To get used to the range and speed of the Dynasight tracker, the participant was trained without views being displayed on the monitor. The tracker provided feedback by a control light which was green if the reflector was in track, and red if it was not. At this stage one participant was found to be colour blind, but this did not pose problems.

For the training, the participant was shown 10 different boxes. One box was shown twice under different movement conditions. After the participant had made his choice, the screen showed the right choice, whether he had made the right choice, his response time and the range of his eye positions.

During the experiment, the participant was shown 30 boxes. All these boxes contained different objects and wire configurations. After the experiment, the participant was told how many stimuli were recognised correctly.

Overall, each experiment took about 25 minutes.

Results

The participants had to make two choices: 1 'is there a wire?' and 2 'if so, does it connect the objects?'. Therefore, the judgements can be split into two categories: 1 when is it possible to see a wire? and 2 when is it possible to see whether or not the wire connects both objects? Furthermore, the response time will be analysed. The results are evaluated in this order, with an analysis of variance to find the significant effects and by a graphical representation to explain the effects. An alpha level of 0.05 was used to test the significance of all effects.

From analysis of the eye movements of the first 15 participants, their average viewing distance showed 45 cm, with a standard deviation of 9 cm. Thus, the average viewing distance matched the camera distance used for recording.

Visibility of the wire

The judgement 'wire but not connected' and 'connected' both indicate that the participant saw a wire. For this analysis, only boxes of type *T* = 'connected' are used because for this box type the wire can be seen in the front view, and other views may be unavailable in some conditions. Table 5.3 shows the significant main effects and interactions.

Table 5.3. Significant interactions for the visibility of a wire

Interaction	*F*	*p*
G	$F(2,576)=177.38$	<0.001
N	$F(5,576)=6.59$	<0.001
R	$F(1,576)=288.72$	<0.001
$G \times R$	$F(2,576)=72.39$	<0.001
$N \times \Delta\varphi$	$F(15,576)=2.13$	<0.01
$N \times R$	$F(5,576)=4.22$	<0.001

For all independent variables except for the angle between the views, the performance increases with increasing value of that variable, as was expected. The non-significance of the angle between the views $\Delta\varphi$ is unexpected. An explanation may be that I analysed only the measurements from the *T*='connected' case, and that the effect would have been significant if more measurements had been done for this condition.

In Figure 5.4 - 5.6, the vertical axis shows ratios from 0 (no participant saw a wire) to 1 (all participants saw a wire). The middle point of each marker shows the average value, and the upper and lower points show the limits of the 95% confidence interval (Loosen, 1994). The shapes of the markers indicate different conditions.

Figure 5.4 shows the interaction between *G* and *R*. For 16 grey levels, the score is nearly perfect (>94% for low resolution). For fewer than 16 grey levels, the resolution has much more effect on the visibility of a wire.

Figure 5.5 shows the interaction between *N* and $\Delta\varphi$. Only a combination of an angle between the views larger than 4θ and a large number of views larger than 16 has a clearly positive effect on performance. This indicates that a wider range of inspection angles leads to increased visibility of the wire.

Figure 5.6 shows the interaction between *N* and *R*. At high resolution, performance is so good that a larger number of views produces no further increase.

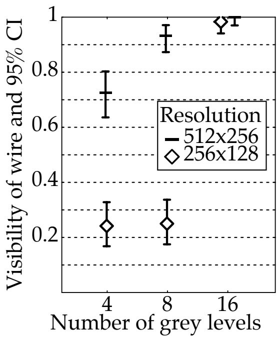

Figure 5.4. Effect of the number of grey levels and resolution on the visibility of a wire.

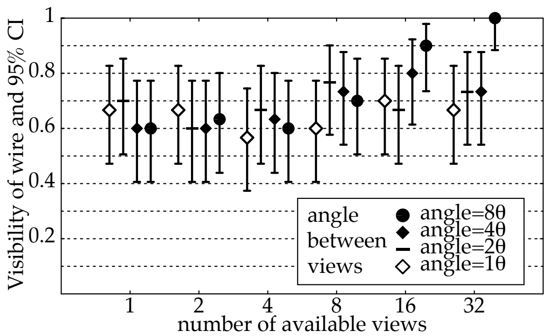

Figure 5.5. Effect of the number of views and the angle between the views on the visibility of a wire.

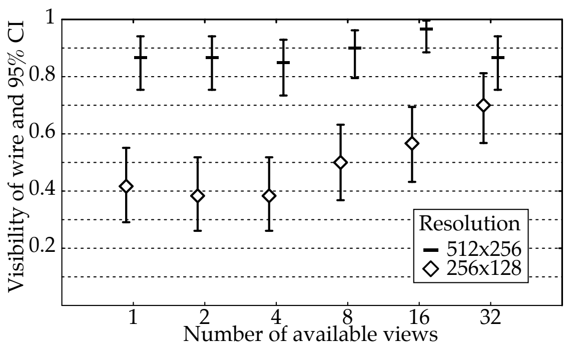

Figure 5.6. Effect of the number of views and the resolution on the visibility of a wire

Correct-ratio

Correct judgements are those judgements of the observers that match the actual situation in the box. The correct-ratio is the ratio of the correct answers to the total number of answers. In Table 5.4 the values for the main and interaction effects are shown. All main effects are significant.

For all variables except box type *T*, the correct-ratio increases with increasing value of that variable, as was expected. The angle between the views $\Delta\varphi$ has a very small effect (Figure 5.7). This may explain why the angle between the views had no significant effect on the visibility of the wire.

Table 5.4. Significant interactions for the correct-ratio.

Interaction	*F*	*p*
G	*F*(2,1728)=53.91	<0.001
N	*F*(5,1728)=16.88	<0.001
$\Delta\varphi$	*F*(3,1728)=4.02	<0.01
R	*F*(1,1728)=121.13	<0.001
T	*F*(2,1728)=587.34	<0.001
G x *R*	*F*(2,1728)=22.66	<0.001
G x *T*	*F*(4,1728)=73.92	<0.001
N x $\Delta\varphi$	*F*(15,1728)=2.88	<0.001
N x *T*	*F*(10,1728)=3.63	<0.001
R x *T*	*F*(2,1728)=53.91	<0.001
G x *N* x $\Delta\varphi$	*F*(30,1728)=1.70	<0.01
G x *R* x *T*	*F*(4,1728)=12.54	<0.001

The three-way interaction between number of grey levels *G*, resolution *R* and box type *T* (Figure 5.8) fully explains the interactions between *G* and *R*, between *G* and *T* and between *R* and *T*. Boxes without a wire are nearly always judged correctly, maybe because a low image quality hides wires, causing a bias towards a 'no wire' judgement. For boxes of the type 'connected', the correct-ratio depends largely on the visibility of the wire: compare Figure 5.4. For boxes of type 'trick', resolution *R* and number of grey levels *G* are less effective.

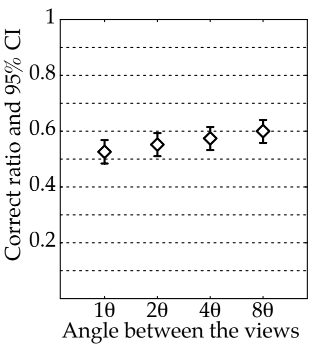

Figure 5.7. Effect of the angle between views on the correct-ratio

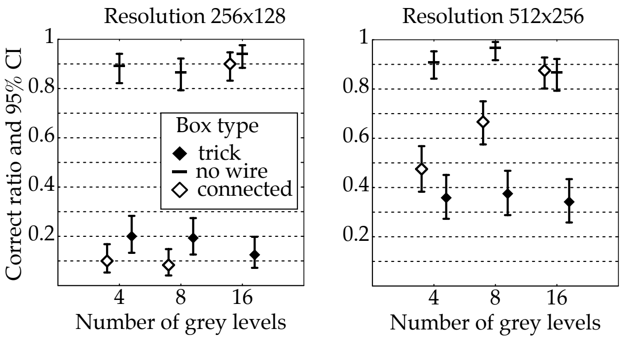

Figure 5.8. Effect of number of grey levels, resolution and box type on the correct-ratio

The interaction between the number of available views *N* and the box type *T* (Figure 5.9) shows that *N* has a positive effect mainly in the case of the boxes of type 'trick'. *N* has less effect on the correct-ratio for boxes of type 'connected', and has no effect in the case of boxes with 'no wire'.

The interaction between the number of available views *N* and the angle between the views $\Delta\varphi$ (Figure 5.10) shows that only a combination of a large number of views and a large angle between the views improves the correct-ratio. Only the combination of 16 or more views and an angle of at least 4θ is really effective.

I did not recognize clear patterns in the three-way interaction between *G*, *N* and Δφ: there are a large number of cells, and they have large confidence intervals.

Both Figure 5.9 and Figure 5.10 show an increase of the correct-ratio from up to 8 available views. This seems to indicate a threshold level for the number of views. However, in the case of trick boxes only, the task becomes impossible when the number of available views falls below its threshold level.

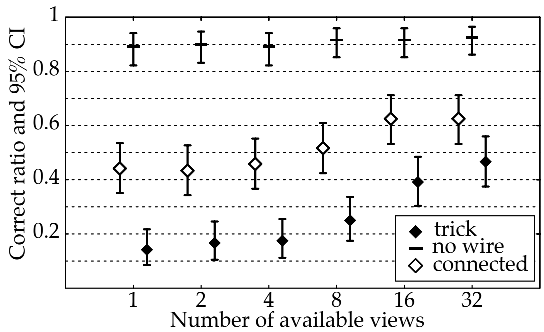

Figure 5.9. Effect of number of views and box type on the correct-ratio

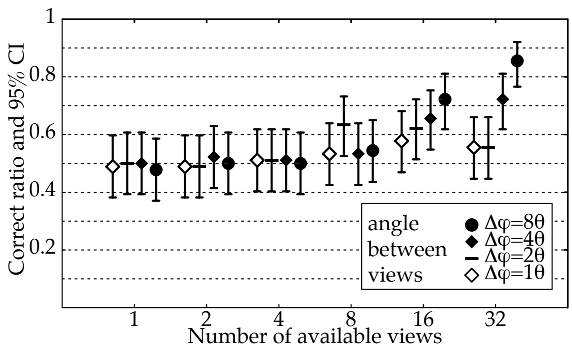

Figure 5.10. Effect of number of views and angle between views on the correct-ratio

Post-hoc analysis of camera-range

Possibly the ability for the observer to choose the view from a large range is more important than the number of views in that range and the impression of rigidity. A first indication for this hypothesis is that the angle between the views Δφ is a measure for the jerkiness in the spatial impression when moving. It has a very small influence on the correct-ratio (Figure 5.7). This suggestion is strengthened by Figure 5.10, showing that a small angle between views Δφ and a small number of views *N* has no effect, and that the situation with $N = 16$ and $\Delta\varphi = 8\theta$ has both the same correct-ratio and the same camera range as the situation with $N = 32$ and $\Delta\varphi = 4\theta$.

To test this hypothesis, a new variable expressing the camera range $(N - 1) \cdot \Delta\varphi$ is introduced. Figure 5.11 shows the camera range as a function of the angle between views and the number of views. These camera ranges were grouped into eight classes of similar value, with the range roughly doubled in each subsequent class.

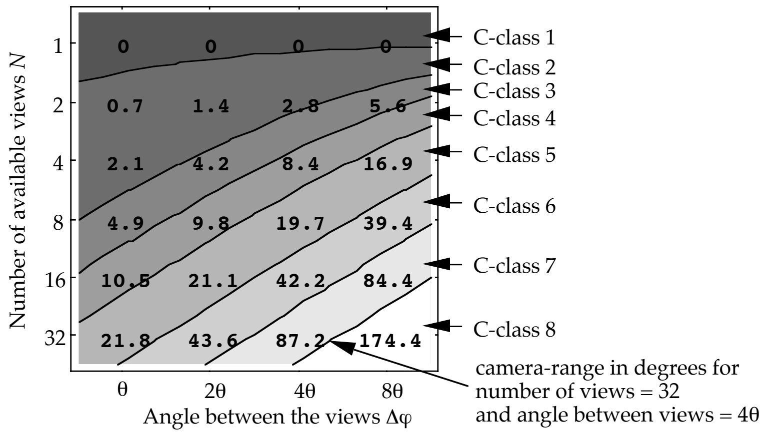

Figure 5.11. Camera range for all combinations of the number of views and the angle between views. These combinations are grouped into eight C-classes of similar range.

The independent variables are now resolution *R*, number of grey levels *G*, and camera range class (C-class) *C*. Because the C-classes comprise between 1 and 4 Δφ-*N* pairs, the number of measurements from the experiment is not the same for each C-class. C-class 8 is the smallest, and it contains only 5 measurements per condition. Therefore, from the other C-classes only the first 5 (random, since the conditions were in random order) measurements are taken for further analysis.

Table 5.5 shows the significant main and interaction effects according to analysis of variance. The main effect of *T*, *G* and *R*, and the interactions between *T* and *G*, between *T* and *R*, between *G* and *R* and between *T*, *G* and *R* were discussed under 'Correct-ratio'.

Table 5.5. Significant interactions for the correct-ratio using the C-class.

Interaction	*F*	*p*
T	*F*(2,576)=168.11	<0.001
C	*F*(7,576)=13.43	<0.001
G	*F*(2,576)=10.72	<0.001
R	*F*(1,576)=35.26	<0.001
T x *C*	*F*(14,576)=3.07	<0.001
T x *G*	*F*(4,576)=15.21	<0.001
T x *R*	*F*(2,576)=6.48	<0.01
G x *R*	*F*(2,576)=6.77	<0.01
T x *G* x *R*	*F*(4,576)=4.75	<0.001
C x *G* x *R*	*F*(14,576)=2.15	<0.01

The effect of the interaction between *C* and *T* is shown in Figure 5.12. If we compare the effect of *N* (Figure 5.9) with the effect of *C* (Figure 5.12) on the correct-ratio, the C-class has a much stronger effect, even with box type 'connected' for which I did not expect positive effect from a bigger camera range when compared with the number of views. There seems to be a jump upwards in the correct-ratio from C-class 6 to 7 (camera range of 45° and 90°). Thus, the threshold noticed at 8 available views (Figure 5.10), actually seems to be a threshold at a camera range of 45°.

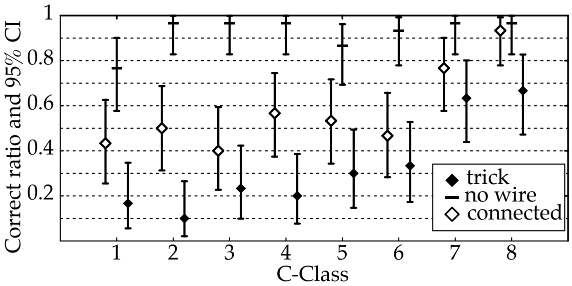

Figure 5.12. Effect of C-class and box type on the correct-ratio

The interaction between C-class, number of grey levels and resolution (Figure 5.13) shows that C-class has little effect when 16 grey levels and low resolution are used. For the other conditions, a bigger camera range improves the correct-ratio. Furthermore, at low resolution the threshold seems to lie at about C-class 6, while this is not the case for the high resolution conditions.

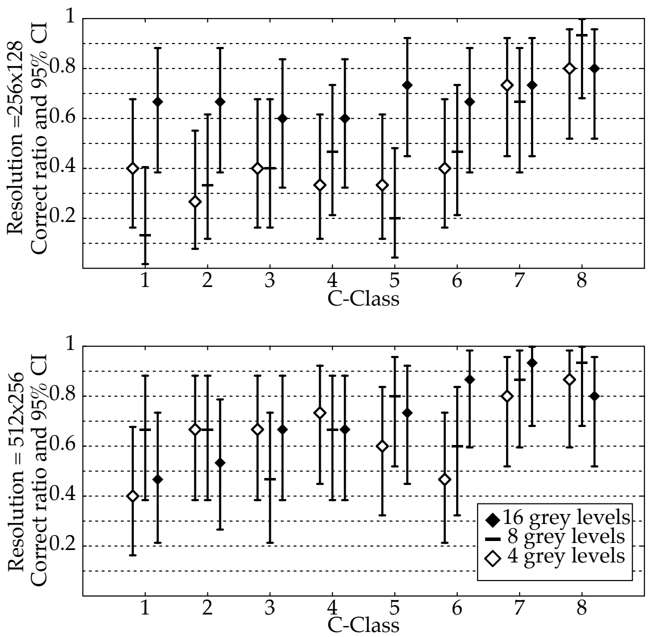

Figure 5.13. Effect of C-class, resolution and number of grey levels on the correct-ratio.

Response time

The response times were analysed with an analysis of variance (Table 5.6). Three main effects were found to be significant: the number of available views, the resolution and the box type. Interactions were not found to be significant.

Table 5.6. Significant interactions for the response time.

Interaction	*F*	*p*
T	$F(2,1728)=15.073$	<0.001
R	$F(1,1728)=11.552$	<0.01
N	$F(5,1728)=10.963$	<0.001

Figure 5.14 shows the effect of box type on mean response time. The response time for boxes of the trick type is slightly longer than for the other types. Figure 5.15 shows that response time is slightly lower in the high resolution condition than in the low resolution condition. Figure 5.16 shows that up to 4 available views, response time increases slightly with the number of available views. More than 4 views do not affect the response time.

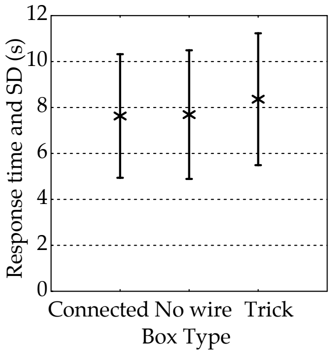

Figure 5.14. The effect of box type on mean response time.

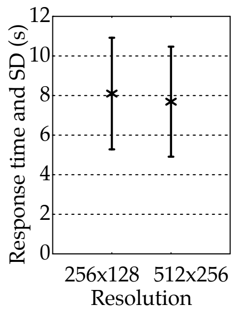

Figure 5.15. The effect of resolution on mean response time.

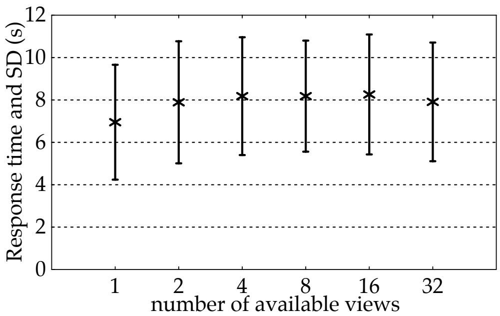

Figure 5.16. Effect of number of available views on mean response time.

As with the correct-ratio, the results for the response time might become clearer if the number of views and the angle between the views are replaced with the C-class grouping. For the C-class grouping, the effects of the variables on mean response times were tested with an analysis of variance (Table 5.7). Three main effects were found to be significant: resolution, C-Class and box type.

Table 5.7. Significant interactions for response time using C-class.

Interaction	F	p
T	$F(2,576)=5.188$	<0.01
R	$F(1,576)=8.809$	<0.01
C	$F(7,576)=4.521$	<0.001

The effects for resolution, number of available views and box type are similar to those of Figure 5.14 and Figure 5.15. The effects of C-class are shown in Figure 5.17. Up to C-class 3, that is a camera range of about 5°, response time seems to increase slightly with increasing C-class. Higher C-classes do not affect the response time.

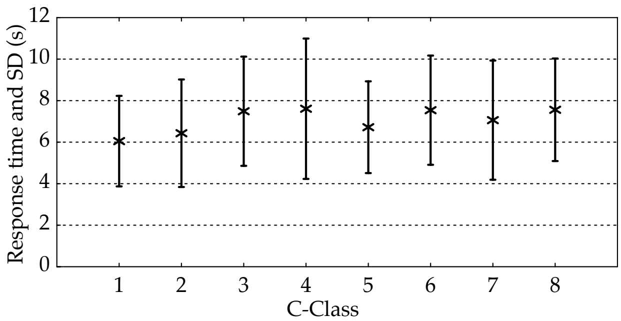

Figure 5.17. Effect of C-Class on mean response time.

The results indicated that camera range, and not the angle between views, is important for this task. This will be tested explicitly. However, the plan was to compare viewpoint selection by eye position with manual viewpoint selection, and the following experiment will test this first.

Experiment 2- knob movement

In this experiment, the viewpoint selection by eye position of experiment 1 is replaced by viewpoint selection by a knob. It was expected that selecting the view by eye position would work better than selecting it with a knob, since it seems more natural to look around a box than to turn a knob that indirectly causes a box to turn.

Method

Apparatus, Stimuli, Procedure

The same apparatus as in Experiment 1 was used. The eye position tracker was replaced by a turning knob. The turning knob was a wire-wound potentiometer with a mechanical turning angle of 270°. φ_{obs} now indicated the knob position. The camera movement was scaled to use the range of the potentiometer, giving $\varphi_{cam} / \varphi_{obs} = N.\Delta\varphi / 240°$. The turning knob was read out by an A/D converter. A millisecond timer was used to update the displayed view on the screen at 37 Hz, to match the update rate of Experiment 1.

The same stimuli were presented in the same order as in Experiment 1. The training and experiment ran as in Experiment 1, except that the training and explanation of the viewpoint tracker was replaced by an explanation about the turning knob.

Variables, Design, Participants

The dependent and independent variables and the design were the same as in Experiment 1. Each participant had to judge 30 boxes (10 of each type *T*). The order of presenting the boxes was the same for all participants, but randomized over all conditions. The 2(*R*) x 3(*G*) x 6(*N*) x 4($\Delta\varphi$)=144 conditions of each box type *T* were distributed randomly over 15 participants (150 judgements for each box type *T*). The remaining 6 judgements for each type were discarded.

The participants were 15 students from the Faculty of Industrial Design Engineering (4 women, 11 men). They were naive and paid volunteers, and were paid NLG 7.50 (USD 3.75) for their participation.

Results

To test for a possible difference between experiment 1 and 2, the correct-ratio of the first 15 participants of Experiment 1 is taken and compared with the results of the participants of Experiment 2 with an analysis of variance. The viewpoint selection method was not found to be significant: $F(1,567)=0.467$, $p=0.495$. Interactions with the method of choosing this angle do not prove significant either. Therefore, the hypothesis that selecting the view by eye position gives a higher observer performance than selecting the view by a knob is not confirmed.

Similarly, response times were compared with the response times of the first 15 participants of Experiment 1 with an analysis of variance. Here, the viewpoint selection method was found to be significant: $F(1,876)=53.52$, $p<0.001$. Furthermore, the resolution was found to be significant: $F(1,876)=5.74$, $p<0.05$. Figure 5.18 shows both effects: participants selecting the viewpoint by eye position work significantly faster than those selecting the viewpoint manually.

The effect on response time is surprising: it is contrary to our hypothesis, and no effect was found on the correct-ratio. It seems that the average response time of the first 15 participants in the viewpoint selection by eye position condition is faster than the average as shown in Figure 5.15. In fact, average response times as found for the manual viewpoint selection are very close to those found in Figure 5.15 for viewpoint selection by eye position. Therefore this result for the response time seems dubious.

Concluding, the findings suggest that, for the discussed task, both methods of selecting the viewpoint work equally well.

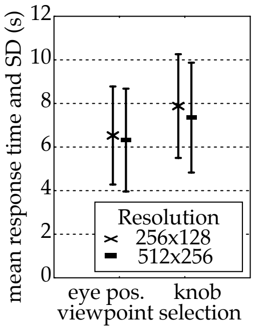

Figure 5.18. Effect of viewpoint selection method and resolution on mean response time.

Experiment 3-constant camera range

The results for the C-classes suggested that the total camera range, and not the angle between the views, is relevant for detecting connections. In the present experiment this will be tested explicitly, by manipulating the number of views over a fixed camera range of 180˚. Given the results of the previous experiments, it is expected that the angle between views will have no effect on the correct-ratio and response time of the participants.

Method

Apparatus, Stimuli, Procedure

The apparatus, stimuli and procedure were the same as in the first experiment.

Variables

The independent variables and their levels are shown in Table 5.8. The angular resolution $\Delta\varphi$ was manipulated, with possible values 8θ, 16θ, 32θ, 64θ and 128θ (θ = 22.5˚ / 32, as above). The number of available views was such that the total camera range was 180˚ (Figure 5.19) (i.e., 33,17,9,5 and 3 views). The three box types *T* were the same as in the previous experiment: Boxes of type 'no wire' did not contain any wire, only two objects. Boxes of the type 'connected' contained a wire that clearly connected both objects: in front view the wire crossed both objects. Boxes of type 'trick' tried to fool the observer. The first experiment showed the biggest effect of the number of viewing angles at an image quality of 512x256 pixels with 16 grey levels (see Figure 5.13), so I used only this image quality in the current experiment. The dependent variables were the same as in the previous experiments, response choice and response time (Table 5.2).

Table 5.8. The independent variables.

Name of variable	Description	Values used
$\Delta\varphi$	angle between the views	8θ, 16θ, 32θ, 64θ, 128θ
T	Type of box contents	no wire, connected, trick

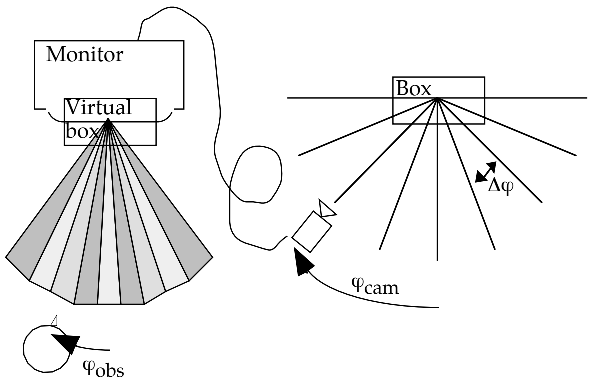

Figure 5.19. The total camera range is 180°. The angle Δφ between the available views is manipulated. The movements of the observer are magnified 4 times in the experiment.

Design, Participants

Each participant saw all 30 boxes once. The conditions were randomized over the participants in such a way that after five participants each box had been examined once in every condition, thus giving 10 measurements per condition. This procedure was repeated to obtain conditions for ten participants, of whom only the first eight were tested. To get an equal number of measurements per condition, the first 13 results for each condition were used for analysis.

The participants were 8 students from the Faculty of Industrial Design Engineering (4 women, 4 men). They were naive and paid volunteers. They were paid NLG 7.50 (USD 3.75) for their participation.

Results

An analysis of variance (Table 5.9) showed that there is no significant interaction between the correct-ratio and the angle between the views: $F(4,195)=0.690$, $p>0.5$.

Figure 5.20 shows the correct-ratio and 95% confidence interval (CI, Loosen, 1994) for each angle. The results confirm our expectations that the angle between the images has no effect on the correct-ratio.

The box type shows no significant interaction with the correct-ratio. This can be explained because the previous experiments suggested that high resolution combined with large camera range allowed high performance for all box types.

Table 5.9. Results of an analysis of variance of correct-ratio.

Interaction	F	p
$\Delta\varphi$	$F(4,180)=0.706$	0.589
T	$F(2,180)=1.412$	0.246
$\Delta\varphi \times T$	$F(8,180)=1.412$	0.190

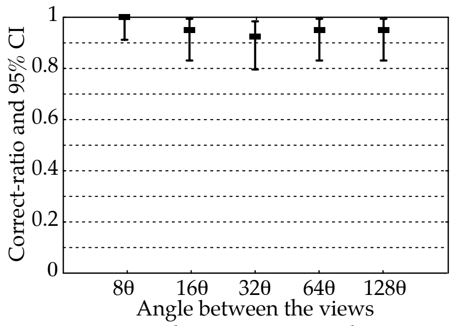

Figure 5.20. Effect of the angle between the available views on the correct-ratio.

Analysis of variance of response time (Table 5.10) showed that there is a significant interaction between response time and box type: $F(2,180)=17.176$, $p<0.001$. Figure 5.21 shows the mean response time and the standard deviations for each type. It might be expected that boxes of type 'connected' can be judged faster than boxes of type 'trick', because finding a trick-wire in a 'trick' box may imply a new search for another wire. But, surprisingly, the 'connected' type takes the longest response time.

Figure 5.22 shows the effect of the angle between the views on the mean response time. Although not significant, the tendency suggests that a smoother coupling improves observer performance. This hints that, in contrast with our expectations, observers are disturbed slightly by larger angles between the views.

Table 5.10. Results of an analysis of variance of response time.

Interaction	*F*	*p*
$\Delta\varphi$	$F(4,180)=1.227$	0.301
T	$F(2,180)=17.178$	<0.001
$\Delta\varphi \times T$	$F(8,180)=1.421$	0.190

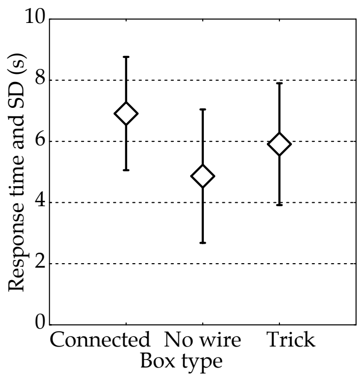

Figure 5.21. Effect of box type on response time.

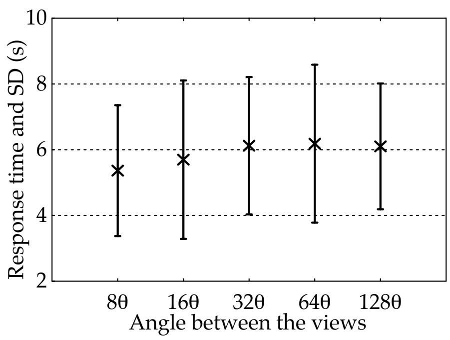

Figure 5.22. Effect of angle between views on response time.

Conclusions

As was already suggested by the results of the first experiment, a front view and two side views are sufficient to judge whether two objects are connected. A large angle between the views seems to interfere with the rigid 3D impression of the scene, and has a minor though insignificant effect on response time. However, large angles between views pose no problems in detecting connections between two objects.

General discussion and conclusions

Summarizing, the most important conclusions of the present experiments are:

1 Up to the tested range of 180˚, a larger camera range can compensate for a small number of grey levels and low image resolution.
2 Down to the tested number of 3 views over a range of 180˚, the number of views over a range is not important for detecting whether two objects are connected.
3 In order to reach a certain observer performance, a trade-off can be made between number of grey levels, resolution and camera range. This trade-off is different for a wire detection task and for judging whether objects are connected.
4 Selecting a view by eye position works just as well as selection with a turning knob.
5 For the detection of a wire, 16 grey levels is sufficient.

This experiment used mock-up baggage with simplified contents and a simplified inspection task. Nevertheless, it is expected that similar effects will occur when the DVWS is applied to baggage inspection. But it is premature to conclude that just three views (maybe even two as x-ray views have no diffraction as our transparent stimuli have) will be sufficient to do the baggage inspection task. The experiment in the next chapter investigates the effect of a small number of available views over a fixed camera range on the inspection of more complex scenes.

It is expected that it is important for a baggage inspector to be able to detect wires and to which objects these wires connect. Therefore, the present result suggest that providing 3 views over a range of 180˚ will be useful for baggage inspection. For wire detection, the usual number of grey levels in an x-ray scan (more than 256) would seem more than sufficient.

Another important result for x-ray baggage inspection via the DVWS is that viewpoint selection by eye position can be replaced with manual viewpoint selection. Viewpoint selection by eye position might tire the inspectors and thus make them less alert (McVey, 1970). Furthermore, viewpoint selection by eye position might be undesirable for aesthetic reasons: for example a number of inspectors indicated that they would not appreciate markers for a head tracker on their cap.

Finally, a lower resolution for each view may be used if multiple views are available. The recording of such images may reduce the x-ray dose required to take that image, and therefore making available N views does not necessarily imply an N-times as high exposure of the baggage to x-rays.

Need for geometric correctness of the display

Some virtual window systems, e.g. Ware, Arthur and Booth (1993), require the precise eye location of the observer to make the correct projection of the scene on the monitor screen. Deering (1992) even makes perspective corrections for the thickness of the glass of the monitor screen. Are such geometric corrections needed to do a task correctly?

The adapted Delft Virtual Window System used in the present experiment corrected the view only for the angular position of the observer, and not for his viewing distance. Furthermore, only horizontal observer movements were coupled. Because 100% correct scores are reached in the condition with 32 views and an angle between the views of 5.625°, it can be concluded that, for this task, neither correcting for viewing distance nor the ability to make vertical movements was essential for correct observer performance. Furthermore the highest correct-ratio was found at a scaling of movements camera:head=4:1, where 1:1 would match the principle of the DVWS. So this experiment does not support the necessity of geometric corrections.

It seems that providing appropriate views is more important than providing a geometrically correct presentation. Chiruvolu, Hwang and Sheridan (1991) discuss this issue and find that, for putting a peg in a hole on a moving object, a clear focus on the goal is needed. In a report from Martin Marietta Aerospace (1986) it was shown that two orthogonal views are sufficient for a module replacement task in space. To increase observer performance, making all information available that would be available in a natural situation will not always improve observer performance, but instead the display system should be optimized to the task demands.

The issue of the need for geometric correctness of the display system will be investigated in more detail in the experiment described in Chapter 7.