Systematic reviews of evaluations of a Robotic Arm

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This paper provides full data on the systematic of a robotic arm using eight analytical evaluation techniques, and comparing those with video evidence of the arm in use. These reviews were all conducted by one author and independently checked by the other.
Note that issues 2 and 5 arose early on in analysis, were rapidly corrected by the developer, and therefore did not arise in the video evidence. The review consider whether or not these issues should have been identified by the methods, rather than whether they were, given the interface changes. The review also considers the task that was the subject of the video data, rather than the slightly different task for which the initial analyses were undertaken. There is no significance to the order of items.

1 CLARIFICATION OF MEANINGS OF USABILITY ISSUES

1. Long sequence of (mental) operators to move arm
The number of decision and action steps needed by the user to get the arm going is greater than necessary (does not apply to pre-taught positions). This is particularly so if the user wishes to move an individual joint, or to change the speed of arm movement.
2. Inability to backtrack.
In the first version of the system analysed, there was no 'undo' option. This omission was soon corrected.
3. Difficulty of choosing between Move Arm or Move
The user's first decision is between MoveArm (which moves the whole arm) and Move, which then allows the user to select an individual joint to move. The semantics of this choice may be difficult for novice users to grasp.
4. Lack of short cuts
There is no quick way to return to the direction menu, which might be required if the arm overshoots or if the whole arm is being moved and needs a change of direction.
5. Continue serves same function as Go, and is redundant
There was originally an option called 'continue', which served exactly the same function as 'go' and was therefore eliminated in an early redesign of the interface.
6. Confusion over joint called Arm
The term 'Arm' is used to refer to both the whole arm and an individual joint called 'arm'.
7. Gesture input with twice as many operations as voice because dependent on cursor movement
This refers to mental operations, not physical ones. The number of physical operations is the same in both cases, but it takes more mental effort to spot the gesture option and maintain attention on it until the cursor is in the correct place to select that option.
8. Problem if head moved to look at arm while gesture system operational: may be interpreted as a command
Since gestures may be part of user's normal repertoire of head movements, it is possible that the user might move their head in a way that is interpreted by the system as a gesture when it was not intended as such.
9. If user pauses in middle of saying "Move arm"...
Because "move arm" is made up of "move" and "arm, and "move" and "arm" are also valid commands, a pause in the middle could cause misinterpretation by the system.
10. If user engaged in conversation...
If the user of the speech controlled system is also engaged in another conversation, it is possible that some conversational words might be interpreted as commands by the system.
11. Lack of feedback about selection
This arose in the CW analysis specifically in relation to MoveArm. This reflects a broad concern that the system as analysed did not give feedback on selections at the time of analysis, although the gestural and voice input mechanisms did request user confirmation of choice.
12. Problems of determining left and right, especially when arm contorted
If the arm is contorted then "its" right and left may be different from right and left (or indeed up and down or in and out) as perceived by the user.

13. User cannot check direction choice until arm starts to move
This is really a combination of 11 and 12: that the user neither gets feedback on what they have selected nor can anticipate which actual direction corresponds to the command for a contorted arm until the arm starts to move.

14. Time taken to interact with system to stop arm
The user has to anticipate how long it will take the system to respond to 'stop' and issue the command at the right time.

15. Similarity between moving joint and moving whole arm
Both moving the joint and moving the arm follow a similar pattern of states and transitions. The interaction could be made more efficient and maybe clearer by combining these options into a single menu.

16. Illegal options
When the arm has reached its limit of movement, it is possible to issue command that would, in principle, send it beyond its limit. The only feedback to the user is that the arm does not move.

17. Mismatch between way that arm works and way that user would move arm
The way the user conceptualises what they are doing 'in the world' does not map readily on to the way the user has to program the arm to work.

18. Not clear that End returns user to main menu
This is about labelling: firstly, 'end' is semantically confusable with 'stop'; secondly, 'end' does not mean 'return to initial menu', although that is the effect of this action.

19. End having two meanings
Under all circumstances, 'end' returns the user to the initial menu. Other than at the end of the overall interaction, the user has a motivation to complete this step; right at the end of the interaction the user has no reason to restore the interface to its initial state, and may therefore omit the 'end'. This is unlikely to cause substantive user difficulties in the circumstances.

20. Lighting conditions
If lighting is poor, the user may have difficulty seeing options or seeing the arm's current position.

21. Difficulty for user to move field of vision
Disabled users may have difficulty shifting their visual attention from the display to the arm and vice versa.

22. User looking one way, menu options in other direction
The user has to divide their visual attention between the arm position or movements and the display that controls the arm.

23. Difficulty of judging arm movements
For novice users, it is likely to be difficult to judge exactly how the arm is moving and where it currently is. This issue is expanded below as more detailed issues.

24. Difficulty in judging speed and direction as getting close to target
As the gripper gets close to the target, it needs to reach it without overshooting or colliding. Depending on the direction of approach, the user may find this very difficult to judge.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target
Similarly, the position of the gripper may be difficult to ascertain.

26. Position and movement of most joints is of limited interest to the user
Since the user's main concern is with the position of objects in the world, which can only be manipulated by the gripper, the main concern is about getting the gripper in the right place, i.e. by moving the whole arm. Exceptions might be when fine-tuning the angle of the gripper on approach, and if avoiding other obstacles in the room.

27. Possible difficulty of timing gesture accurately as cursor moves between options
The user of the gestural interface has to time their gesture to select the correct option. This timing may be difficult for novices.

28. Voice recognition problems
If the user does not speak clearly, their words may not be interpreted correctly by the voice recognition system.

29. Speaking with mouth full…
If the user of a voice recognition system tries speaking while eating, there are likely to be voice recognition problems.

30. No display of speed
There is no feedback (other than the perceived speed of the arm while actually moving) of the current speed setting.

31. Arm obscuring user's view
The arm itself may get in the way of the user's view of the target object in the world.

32. No arm reversing.
It is not possible to reverse direction of the arm without going all the way through the set-up procedure again. This matters in cases where the user overshoots.
33. Difficult to match names to joints
For the novice user, it may take a while to learn the names of all the joints.
34. Long sequence of operators to recover from directional error
This is a combination of issues 1 & 32 plus an extra consideration, which is that if the user selects any wrong parameter (joint, direction, speed), it takes many steps to recover from that error.

2 VIDEO EVIDENCE

Video evidence was found to corroborate eight of the usability issues identified, although in some cases the same behavioural phenomenon can be attributed to multiple usability problems, and it is not possible to disambiguate the attribution.

- Issues 12 (Problems of determining left and right, especially when arm contorted) and 13 (User cannot check direction choice until arm starts to move) could only be assessed through excerpt 6, since the other excerpts used pre-taught positions. The video data shows four instances where all or part of the arm started to move in one direction, only for it to be stopped and moved in the opposite direction. This also illustrates the importance of addressing issue 32.
- Issues concerned with difficulty in positioning the arm (14, 17, 23, 24, 25) were again only applicable to excerpt 6. Video evidence shows various under- and over-shoots where the user had to subsequently correct the position of the arm, implying that an error had occurred. This is at least indicative of user difficulties in judging arm movements and position. On one occasion in excerpt 6, the gripper was poorly oriented for the task, and the user had difficulty seeing it (issue 25).

There are many more issues for which there is inadequate or no video evidence. Of course, the impoverished nature of the available video data makes this somewhat inevitable…

- Even for pre-taught positions (e.g. excerpt 1, mouse-controlled), the data shows that there are 4-5 mouse-clicks between every arm movement. Excerpts featuring voice activation show smaller numbers of commands (typically two between arm movements). There is therefore some evidence to corroborate problems 1 and 4, but it is poor and applies more to mouse control than other input mechanisms.
- Issues 2, 16, 18, 19, 33 were only applicable to excerpt 6, and the data does not definitively support any of these issues.
- Issues 3, 6, 11, 15 and 26 concern movement of individual joints vs whole arm. Only excerpt 6 would address this. There is no evidence to suggest confusion on the video tape.
- No relevant data was found to assess issues 5 and 9. 5 would not appear in a behavioural analysis; 9 might, but did not.
- Issue 7 concerns voice vs gesture. The video evidence was inconclusive on this, though it is an analytical observation. However, voice was seen to be more error-prone, and therefore more time-consuming.
- Looking at display: everyone did it even when (in principle) not necessary. This lengthened time for some activities.
- Issue 8 could not be examined because a wrist gesture system was used instead of a head one. However, there was no evidence of inappropriate wrist movements being interpreted as input.
- Issue 10 could only arise in excerpt 5. However, this did not show any supporting evidence as the conversation did not include key words. The user was observed to use a different tone of voice when communicating with the system from that used on normal conversation, so this might not be a problem. The use did note that using voice recognition while eating or drinking would be difficult (issue 29); this had not been considered due to the nature of the light-switch task.
- Issue 20 (lighting conditions) was not relevant because the study room was well lit.
- Issue 21 did not arise because both subjects had good head movement. However, they did need to move their heads, indicating that this would be a problem for users who had limited movement.
- Issue 22 (user looking in the 'wrong' direction) has some support. All users were observed to shift attention rapidly between the arm and the display. While there was no instance where the user was looking at the display and failed to see the arm move beyond the intended range, the user was clearly having to work hard to correlate different information sources.

Additional usability issues were uncovered in the video data:

- It was found that the arm itself obscured the user's view at times. Twice in excerpt 6, the user had to move his head substantially to see around the arm. This is issue 31.
- One of the users was heard to comment in excerpt 4: "I think it's on slow, innit?", indicating lack of display information about the current speed setting. This is issue 30.

3 INITIAL ANALYSIS FINDINGS

Key:
issue identified

CMN-GOMS and CPM-GOMS are included under the heading of GOMS

	PROBLEM	STN	CW	GOMS	PUM	Z	EMU	CASSM	HE	video
1	Long sequence of operators to move arm									poor
2	Inability to backtrack									n/a
3	Difficulty of choosing between Move Arm or Move									none
4	Lack of short cuts									poor
5	Continue redundant									n/a
6	Confusion over joint called Arm									none
7	Gesture input with twice as many operations as voice									poor
8	Head moved to look at arm while gesture system operational may be interpreted as a command									n/a
9	If user pauses in middle of saying "Move arm"...									none
10	If user engaged in conversation...									none
11	Lack of feedback about selection									none
12	Problems of determining left and right, especially when arm contorted									yes
13	User cannot check direction choice until arm starts to move									yes
14	Time taken to interact with system to stop arm									yes
15	Similarity between moving joint and moving whole arm									none
16	Illegal options									none
17	Mismatch between way that arm works and way that user would move arm									yes
18	Not clear that End returns user to main menu									none
19	End having two meanings									none
20	Lighting conditions									n/a
21	Difficulty for user to move field of vision									n/a
22	User looking one way, menu options in other direction									yes
23	Difficulty of judging arm movements									yes
24	Difficulty in judging speed and direction as getting close to target									yes
25	Difficulty in judging position, orientation and aperture of gripper as approaching target									yes
26	Position and movement of most joints is of limited interest to the user									none
27	Possible difficulty of timing gesture accurately as cursor moves between options									none
28	Voice recognition problems									yes
29	Speaking with mouth full…									yes
30	No display of speed									yes

31	Arm obscuring user's view									Yes
32	No arm reversing									Yes
33	Difficult to match names to joints									n/a
34	It takes a long time to recover from a directional error									None

Table 1: summary table of usability problems (stages 1 and 2 of analysis)

4 STN REVIEWED

1. Long sequence of operators to move arm

Since the STN shows the number of states that the user has to navigate through before the robotic arm can be moved, this issue should have been identified in the original analysis. However, STN deals with only physical state changes, and does not consider mental operations, so the effect is less marked for STN than it was for GOMS. That it was not identified shows the extent to which the analysis was dependent on the craft skill (or lack thereof) of the analyst.

2. Inability to backtrack [STN]

This issue is apparent from the STN, and was identified as a problem. However, the identification of this issue was possibly influenced by the explicit mention of this kind of problem in a discussion on "undo" in the source materials (Dix et al, 1993, p.291). This shows the effect that the source materials of a technique has on the application of a technique.

3. Difficulty of choosing between Move Arm or Move

The STN concentrates on the actual choice between the system states, rather than on the difficulties the user has in choosing between them. It is therefore not an issue that the STN on its own would be expected to identify, but might have been identified through craft skill.

4. Lack of short cuts

Since the STN explicitly shows the possible path of the interaction through the various states, the lack of short-cuts was an issue that might have become apparent if the analyst had been looking for it. This is therefore an issue that is a combination of craft skill and representation. That it was not noticed was possibly because the analyst's attention was more on obtaining the correct representation of the system states.

5. Continue versus Go: Continue seen as redundant

This was an issue found through drawing the STN, since the use of Continue creates more states for a user to navigate through, and adds little to the functionality of the interface. This is the kind of issue that the use of the STN should make apparent, and did.

6. Confusion over joint called Arm

The STN did not go into the detail of the individual options, so this issue did not arise. If the STN had been done at a different level of abstraction, this issue might have been identified through the craft skill of the analyst. It is not something that the STN would identify however, since it is concerned more with the user understanding of what a particular option choice means rather than with the option choice itself. Thus this issue highlights questions associated with both craft skill and appropriate levels of abstraction.

7. Gesture input with twice as many operations as voice

The STN was not written at the level of abstraction which would identify this issue. If it had been, this issue would probably have been identified, since it would be concerned with the number of states and transitions. For the gesture input, there are a series of states and transitions between them as opposed to the voice input which has one state with multiple transitions coming from it. This raises questions concerning the appropriate level of abstraction of an analysis.

8. Head moved to look at arm while gesture system operational may be interpreted as a command

This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice.

9. If user pauses in middle of saying "Move arm"...

This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice.

10. If user engaged in conversation...

This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice.

11. Lack of feedback about selection
The feedback for the interface had not been implemented at this stage, so could not have been represented. Even if the feedback had been implemented this was not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than in providing confirmation that a particular choice has been made.
12. Problems of determining left and right, especially when arm contorted
This is not an issue that could be identified from the STN, since it relates to how the user views the arm rather than the states and transitions of the arm.
13. User cannot check direction choice until arm starts to move
This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than in providing confirmation that a particular choice has been made.
14. Time taken to interact with system to stop arm
This was not a problem identified by the STN, since this is a problem related to the user making the choice rather than the actual choice. Vocalising the word or making the gesture may take too long for the arm to stop in exactly the correct place. This is therefore a matter of user judgement rather than states and transitions, and as such the STN would not be applicable.
15. Similarity between moving joint and moving whole arm
This was an issue found through drawing the STN, since both moving the joint and moving the arm follow similar pattern of states and transitions. This is the kind of issue that the use of the STN should make apparent and did.
16. Illegal options
This issue was not represented on the STN. There was no state showing that the arm had reached its limit of movement, nor was there an end option leading from the travel until stop state which might also represent it. This shows how difficult it is to draw STNs correctly, and relates to the level of skill of the analyst in determining how the system states should be represented. If the STN diagram had been correctly drawn, it is still unlikely that this issue would have been identified without explicitly checking for illegal options. This is similar to issues discussed in the action properties section of the source materials (Dix et al, 1993, p.288) which acknowledge how difficult it is to identify these issues. On this occasion, although the STN allowed for this issue to be identified, the ease of identifying this issue was dependent upon the craft skill of the analyst.
17. Mismatch between way that arm works and way that user would move arm
This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice. However, the difference between state and transitions represented by the STN and how a user might naturally go about moving an arm might have been identified through the craft skill of an analyst.
18. Not clear that End returns user to main menu
This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice. In the STN it is clear that End returns the user to the main menu.
19. End having two meanings
This is not an issue that could be identified from the STN since the STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice. From the STN it is clear that End returns the user to the main menu.
20. Lighting conditions
This is an issue relating to the robotic arm's environment rather than the states and transitions of the system, and would therefore not have been identified by the STN analysis. It is unlikely that the craft skill of the analysis would have identified this.
21. Difficulty for user to move field of vision
This is a user concern, therefore the STN analysis, which concentrates on the system functionality, would not be able to identify this issue.
22. User looking one way, menu options in other direction
The STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice, so this is not an issue that could be identified.
23. Difficulty of judging arm movements

The STN is concerned with the choices available for the user in moving from one state to another, rather than how that choice is made or the problems the user might have with that choice, so this is not an issue that could be identified. However, the difference between the states and transitions represented by the STN, compared with how a user might go about moving an arm, might have been identified by the craft skill of an analyst.

24. Difficulty in judging speed and direction as getting close to target

STN is not concerned with user perceptions or understanding, and therefore would not consider this issue.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target

Again, this is about user perceptions, and is therefore outside the scope of STN.

26. Position and movement of most joints is of limited interest to the user

This is again a user issue; the way the user chooses options is outside the scope of STN.

27. Possible difficulty of timing gesture accurately as cursor moves between options

STN does not explicitly consider timing. With a more detailed STN (level of abstraction), this issue might have been spotted through craft skill. In the event, it was not.

28. Voice recognition problems

This issue is outside the scope of STN.

29. Speaking with mouth full…

This issue is outside the scope of STN.

30. No display of speed

The STN description did not include an explicit representation of what information is displayed, so this issue is outside the scope of the approach.

31. Arm obscuring user's view

This issue is outside the scope of STN.

32. No arm reversing.

Because the STN focuses on the device states, and the direction of motion is simply a parameter on that state, the domain requirement to make it easy to reverse does not appear through the STN. It would have required a very different kind of STN to allow this issue to emerge.

33. Difficult to match names to joints

This issue is outside the scope of STN.

34. Long sequence of operators to recover from directional error

STN has no notion of error, and hence none of error recovery, so this issue is outside the scope of the method.

5 CW REVIEWED

1. Long sequence of operators to move arm

This is something that would not be found strictly by the method, but by using craft skill on the material gathered.

2. Inability to backtrack

CW does not deal with error in terms of its implications, therefore would not find this issue, although it might come out from the craft skill of the analyst through thinking about rectifying errors.

3. Difficulty of choosing between Move Arm or Move

This is the kind of issue of misleading option labels that CW is designed to uncover, and did so.

4. Lack of short cuts

This is something that would not be found strictly by the method, but by using craft skill on the material gathered.

5. Continue versus Go: Continue seen as redundant

This would not be uncovered by the method, since it has no adverse effects on the use of the robotic arm. It might come out through craft skill.

6. Confusion over joint called Arm

This is the kind of issue of misleading option labels that CW is designed to uncover, and did so.

7. Gesture input with twice as many operations as voice because dependent on cursor movement

The CW does not examine the interface at this level of detail, and would not uncover this issue because it is not an issue that can be identified from the questions.

8. Problem if head moved to look at arm while gesture system operational may be interpreted as a command

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

9. If user pauses in middle of saying "Move arm"...

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

10. If user engaged in conversation...

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

11. Lack of feedback about selection

For the purposes of the original analysis, this was not relevant, since the feedback had not been implemented, but it was an important issue raised by the method that would have to be addressed once feedback had been implemented.

12. Problems of determining left and right, especially when arm contorted

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

13. User cannot check direction choice until arm starts to move

This issue is one that could not be derived from the failure stories, unless the analyst was very insightful, and would therefore depend upon craft skill for identification.

14. Time taken to interact with system to stop arm

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

15. Similarity between moving joint and moving whole arm

This is not the kind of issue that CW looks for, so would not have been addressed. It might have come up through craft skill recognition of the similarities of the action sequences.

16. Illegal options

CW would not have uncovered this issue since the task did not call for any of these illegal states to be explored. It would depend on the task as to whether this issue would be uncovered by CW.

17. Mismatch between way that arm works and way that user would move arm

One of the aims of the method is to uncover this kind of issue, however there is not much support within the questions for this to be identified at a high level, because of the method's concentration on the step-by-step nature of the task. This is more likely to be uncovered by craft skill therefore.

18. Not clear that End returns user to main menu

This is the kind of issue of misleading option labels that CW is designed to uncover, and did so.

19. End having two meanings

This is the kind of issue of misleading option labels that CW is designed to uncover, and did so.

20. Lighting conditions

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

21. Difficulty for user to move field of vision

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

22. User looking one way, menu options in other direction

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

23. Difficulty of judging arm movements

This issue is one that could not be derived from the failure stories, and would depend on the skill of the analyst, therefore dependent upon craft skill for identification.

24. Difficulty in judging speed and direction as getting close to target

This is outside the scope of CW because CW does not address monitoring actions.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target

Again, this is about monitoring, and is therefore outside the scope of CW.

26. Position and movement of most joints is of limited interest to the user

This is set in the task definition, so might emerge through craft skill in creating that definition, but is not within the scope of the approach.

27. Possible difficulty of timing gesture accurately as cursor moves between options

CW does not deal with timing issues. This might emerge through craft skill, but did not.

28. Voice recognition problems

This issue is outside the scope of CW.

29. Speaking with mouth full…

This issue is outside the scope of CW. Unless speaking while eating were a part of the task definition, which is somewhat implausible.

30. No display of speed
Because the display of speed (or the lack of it) is outside the essential task definition (unless the task were to be to move the arm at a particular speed, which would involve craft skill in perceiving the need for such a task), this would not naturally emerge from a CW analysis.
31. Arm obscuring user's view
This issue is outside the scope of CW.
32. No arm reversing.
Because CW does not naturally consider error states (such as overshooting), this issue would not naturally emerge from a CW analysis.
33. Difficult to match names to joints
This issue concerns labelling, and therefore should be within the scope of CW. This was an omission from the analysis.
34. Long sequence of operators to recover from directional error
CW doesn't consider error recovery, so this issue is outside the scope of the method.

6 CMN AND CPM GOMS REVIEWED

The CPM GOMS analysis was unable to identify many issues over and above those identified by CMN GOMS, other than the difference between the use of voice and gesture operators. This re-analysis focused on the use of CMN GOMS. A CPM GOMS analysis that indicated where the user would want to look at the arm to check its position or movement would have raised more issues. These possibilities are highlighted in *italics*.
1. Long sequence of operators to move arm
By writing out the methods, even though the operators were not examined, the long sequence showed that this would take a long time. This is something that the CMN GOMS should explicitly identify, and did.
2. Inability to backtrack
This was an issue that was identified using craft skill from the CMN GOMS sequence of goals and methods.
3. Difficulty of choosing between Move Arm or Move
CMN GOMS does not support the identification of issues relating to problems choosing between commands. This is therefore an issue identified by craft skill.
4. Lack of short cuts
By writing out the methods, the long sequence showed that this would take a long time and that there were no short cuts. Whether this emerges from the analysis or is derived through craft skill is a moot point.
5. Continue versus Go: Continue seen as redundant
The use of CMN GOMS in writing the goals and the sequence of methods and operators allowed this issue to become apparent. Therefore this issue was identified by the method.
6. Confusion over joint called Arm
CMN GOMS does not support issues relating to the correct identification of options. This issue was therefore identified through craft skill.
7. Gesture input with twice as many operations as voice
CMN-GOMS was able to identify the individual operations. This issue was therefore identified through the use of the method.
CPM GOMS was also able to identify this issue, which was within the scope of the technique.
8. Problem if head moved to look at arm while gesture system operational may be interpreted as a command
This issue is outside the scope of cmn goms and was not identified.
9. If user pauses in middle of saying "move arm"...
This issue is outside the scope of cmn goms and was not identified.
10. If user engaged in conversation...
This issue is outside the scope of CMN GOMS and was not identified.
If the task description included reference to another conversation, this issue should be identified through CPM GOMS; however, this depends on analyst insight in specifying such a task.
11. Lack of feedback about selection
CMN GOMS would not identify this issue since it assumes correct user action.
12. Problems of determining left and right, especially when arm contorted
This issue is outside the scope of CMN GOMS and was not identified.
13. User cannot check direction choice until arm starts to move
This issue is outside the scope of cmn goms and was not identified.

14. Time taken to interact with system to stop arm
This issue was clearly identified by cmn goms which identified the number of operators for both voice and gesture, and found that gesture had twice as many as voice for this.
15. Similarity between moving joint and moving whole arm
The use of cmn goms in writing the goals and the sequence of methods and operators allowed this issue to become apparent. Therefore this issue was identified by the method.
16. Illegal options
Cmn goms was unable to identify this issue because it is a procedural and task-based technique, and the task as given did not explore those states.
17. Mismatch between way that arm works and way that user would move arm
This issue is outside the scope of cmn goms and was not identified.
18. Not clear that end returns user to main menu
This issue is outside the scope of cmn goms and was not identified.
19. End having two meanings
This issue is outside the scope of cmn goms and was not identified.
20. Lighting conditions
This issue is outside the scope of cmn goms and was not identified.
21. Difficulty for user to move field of vision
This issue is outside the scope of cmn goms and was not identified.
22. User looking one way, menu options in other direction
This issue is outside the scope of cmn goms and was not identified.
23. Difficulty of judging arm movements
This issue is outside the scope of CMN GOMS and was not identified.
24. Difficulty in judging speed and direction as getting close to target
This issue is outside the scope of CMN GOMS and was not identified.
25. Difficulty in judging position, orientation and aperture of gripper as approaching target
This issue is outside the scope of CMN GOMS and was not identified.
26. Position and movement of most joints is of limited interest to the user
This issue did not emerge. Indeed, a task definition would include a specification of which joints to move, so this issue is more strongly excluded from the set of possible issues than most.
27. Possible difficulty of timing gesture accurately as cursor moves between options
CMN GOMS does not consider timing issues such as this.
CPM GOMS should have spotted this issue, had the interface been described at the appropriate level of abstraction.
28. Voice recognition problems
This issue is outside the scope of CMN GOMS and was not identified.
29. Speaking with mouth full…
This issue is outside the scope of CMN GOMS and was not identified.
It would only be identified by CPM GOMS with a very inspired choice of tasks, which is not included in the simple feeding task.
30. No display of speed
This issue is outside the scope of CMN GOMS and was not identified.
31. Arm obscuring user's view
This issue is outside the scope of CMN GOMS and was not identified.
32. No arm reversing.
Because GOMS focuses on correct performance, the idea that the arm might overshoot and need to be returned to the correct position is outside the scope of the approach.
33. Difficult to match names to joints
This issue is outside the scope of CMN GOMS and was not identified.
34. Long sequence of operators to recover from directional error
GOMS assumes expert behaviour, and hence not error recovery, so this issue is outside the scope of the method.

7 PUM REVIEWED

1. Long sequence of operators to move arm
This issue was mentioned in the original analysis, but not in a strong enough way for it to be apparent as an issue of consequence. It was identified from looking at the heavy ordering identified by the analysis, and was therefore dependent upon the craft skill of the analyst.

2. Inability to backtrack
The original analysis found a heavy ordering, which is within the bounds of the pum technique. However, from this was derived the lack of backtracking provision, which is therefore identified by the craft skill of the analyst, based on the representation provided by the method.

3. Difficulty of choosing between move arm or move
This was identified by the original analysis from modelling the user knowledge required.

4. Lack of short cuts
This is not an issue that PUM would identify, however it is one that might be expected to be identified through craft skill, since it is closely connected to the heavy ordering of the task, and the lack of mapping between the device and the domain.

5. Continue versus Go: Continue seen as redundant
This is an issue that should have been identified through a thorough PUM analysis as the analyst defines the actions that correspond to each goal. There should have been two almost identical operations, differing only in their filtering pre-conditions, to achieve getting the arm moving. This was overlooked in the analysis.

6. Confusion over joint called Arm
This was identified by the original analysis from modelling the user knowledge required.

7. Gesture input with twice as many operations as voice because dependent on cursor movement
This did not come out in the original PUM analysis, because the analysis was not written at a low enough level of abstraction for this to be apparent. If the precondition of the cursor under the correct option had been written then the differing number of preconditions for the two input devices should have been recognised, and this issue identified. This is therefore a matter concerning the appropriate level of abstraction of analysis.

8. Head moved to look at arm while gesture system operational may be interpreted as a command
PUM does not consider the misinterpretation of user actions by the system, since it concentrates more on user interpretation of the system. Therefore, PUM was unable to identify this issue.

9. If user pauses in middle of saying "Move arm"...
PUM does not consider the misinterpretation of user actions by the system, since it concentrates more on user interpretation of the system. Therefore, PUM was unable to identify this issue.

10. If user engaged in conversation...
PUM does not consider the misinterpretation of user actions by the system, since it concentrates more on user interpretation of the system. Therefore, PUM was unable to identify this issue.

11. Lack of feedback about selection
The output was not included in the original analysis. If it had been then the PUM analysis might have picked up on this issue, in the modelling of the user knowledge, because the user would not know that the option had been selected. As it was, PUM could not identify this issue because of the boundaries of the original analysis.

12. Problems of determining left and right, especially when arm contorted
PUM assumes that the user has certain knowledge, and is therefore unlikely to make this issue explicit from the analysis. However, the craft-skill of the analyst might identify this issue.

13. User cannot check direction choice until arm starts to move
The output was not included in the original analysis. If it had been then the PUM analysis might have identified this issue through the modelling of the user knowledge, because the user would not know that the option had been selected. But unlikely.

14. Time taken to interact with system to stop arm
This was identified in the initial PUM analysis through craft skill, thought thinking about actions and effects.

15. Similarity between moving joint and moving whole arm
The way that the PUM analysis was conducted meant that this issue was not identified, although it would probably have been recognised if the analyst was looking for it. Therefore, although the PUM analysis represented the operations, it would take the craft skill of the analyst to identify their similarity.

16. Illegal options
The PUM analysis did not find this issue since it was concerned with the user performing a correct task, rather than all possible states and choices.

17. Mismatch between way that arm works and way that user would move arm

This was an issue that was identified by the PUM analysis, and is the kind of issue that the technique should identify, because of PUM's consideration of the device and domain issues.

18. Not clear that End returns user to main menu

This was identified by the original analysis from modelling the user knowledge required.

19. End having two meanings

This was identified by the original analysis from modelling the user knowledge required.

20. Lighting conditions

PUM can not identify issues related to the environmental context of use.

21. Difficulty for user to move field of vision

PUM does not consider user physical constraints, and therefore would be unable to identify this issue.

22. User looking one way, menu options in other direction

PUM does not consider user physical constraints, and therefore would be unable to identify this issue.

23. Difficulty of judging arm movements

PUM does not consider tactical goal choice, and therefore would be unlikely to identify this issue.

24. Difficulty in judging speed and direction as getting close to target

If a much more detailed PUM model had been constructed, it is possible that this issue might have been identified, through the process of describing a 'monitoring' activity more detailed than the 'wait and then stop' implemented in the current model. This is therefore both a level of abstraction and a craft skill issue.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target

It is unlikely that this would be spotted by a PUM analysis, although it is in principle possible.

26. Position and movement of most joints is of limited interest to the user

Because PUM doesn't encourage the analyst to 'step back' in this way, it is unlikely that this issue would fall inside the scope of a PUM analysis.

27. Possible difficulty of timing gesture accurately as cursor moves between options

It would be necessary to construct a PUM model at a much finer grain of detail for this issue to emerge. This is not a level at which PUM naturally works, so it is unlikely that this issue would be spotted.

28. Voice recognition problems

This is outside the scope of PUM.

29. Speaking with mouth full…

This is outside the scope of PUM.

30. No display of speed

This issue was in fact identified within the PUM analysis, in the context that the user needs to know the current speed in order to decide whether to set it faster or slower.

31. Arm obscuring user's view

This kind of contextual information is outside the scope of a PUM analysis.

32. No arm reversing.

This was identified in the initial PUM analysis through thinking about actions and effects – in particular, through considering the task of restoring the arm to its intended position after overshooting. This reflects a high degree of craft skill.

33. Difficult to match names to joints

In relating domain to device knowledge, the PUM analysis made this issue emerge.

34. Long sequence of operators to recover from directional error

PUM would only identify this issue if it started from the erroneous state, and it is very unlikely that an analyst would consider that. Hence this issue is outside the scope of the method.

8 Z REVIEWED

1. Long sequence of operators to move arm

This issue was not apparent because of the way that the specification was constructed, although the specification did represent it. This issue therefore highlights the important difference between an issue being represented and identified. It would take a certain amount of craft skill on the part of the analyst to identify this issue.

2. Inability to backtrack

This was an issue identifed by the z analysis, and one that would be expected to be identified due to the strongly ordered nature of z specifications.

3. Difficulty of choosing between move arm or move

The z specification was concerned more with representing the choice than with how the user would make that choice, so this is not an issue that the z analysis would be expected to uncover. It would take a certain amount of craft skill for this issue to be identified.

4. Lack of short cuts

The z specification represented the lack of backtracking opportunities, due to its concentration on the ordering of the interaction. The lack of short-cuts was therefore also represented. However, the issue, although represented, was not identified, which again illustrates the difference between an issue being represented and identified, and the importance of the craft skill of the analyst in identifying significant issues.

5. Continue versus go: continue seen as redundant

This issue was identified by the z specification since both options share the same functionality, and were represented by different schemas with identical contents.

6. Confusion over joint called arm

This issue should have been identified when the type armpart was declared, since the whole arm had to be called "wholearm" rather than "arm", due to there already being a joint called arm. Therefore, although this issue was represented by the specification it was not identified by the analyst, which indicates the amount of craft skill necessary to identify important issues.

7. Gesture input with twice as many operations as voice because dependent on cursor movement

This issue was not identified by the z specification because the specification was not written at a low enough level of detail to represent the cursor movement. This illustrates the need for the appropriate level of abstraction of the representation.

8. Problem if head moved to look at arm while gesture system operational may be interpreted as a command

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

9. If user pauses in middle of saying "move arm"...

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

10. If user engaged in conversation...

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

11. Lack of feedback about selection

This z specification did not cover the interface output other than the motion of the robotic arm, since this was not implemented at the time of the analysis, and therefore did not identify this issue.

12. Problems of determining left and right, especially when arm contorted

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

13. User cannot check direction choice until arm starts to move

This z specification did not cover the interface output other than the motion of the robotic arm, since this was not implemented at the time of the analysis, and therefore did not identify this issue.

14. Time taken to interact with system to stop arm

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user would interact with the robotic arm, and therefore did not identify this issue.

15. Similarity between moving joint and moving whole arm

This issue was identified by the z specification because of the similar functionality, and represented in almost exactly the same manner, except that the choice of directions available changed.

16. Illegal options

This issue was identified since the z specification involves examining in detail each operation and what is allowable for any given state of the interface. The interface offers options to the user that cannot in fact be carried out. When the arm reaches its limit of movement, the interface displays the options **continue**, **speed level**, **end**. However, **continue** and **speed level** are irrelevant: **continue** because the arm cannot move any further; and **speed level** because any speed selected now will not be kept when **end** is chosen and the interface returns to the initial menu.

17. Mismatch between way that arm works and way that user would move arm

The z specification concentrates on representing the states of the robotic arm, and is less concerned with problems that the user has in interacting with the robotic arm. Therefore the specification would not identify this issue as such. However, by writing the specification, the difference between the way that the robotic arm works and how a user would move their arm would be apparent. Identifying this issue, although represented, would take a certain amount of craft skill.

18. Not clear that end returns user to main menu

The z specification was concerned with the states of the arm, rather than the user interpretation of available options, and therefore was not able to identify this issue.

19. End having two meanings

The z specification was concerned with the states of the arm, rather than the user interpretation of available options, and therefore was not able to identify this issue.

20. Lighting conditions

The z specification was concerned only with the states of the robotic arm and movement between those states, and therefore could not identify this issue.

21. Difficulty for user to move field of vision

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

22. User looking one way, menu options in other direction

The z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

23. Difficulty of judging arm movements

The Z specification was concerned with the possible states of the robotic arm and movement between them rather than the specifics of how the user interacted with the robotic arm, and therefore was unable to identify this issue.

24. Difficulty in judging speed and direction as getting close to target

The Z specification does not include any consideration of user perceptions, so would not identify this issue.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target

Again, this is about user perceptions, and is therefore outside the scope of Z.

26. Position and movement of most joints is of limited interest to the user

This is again a user issue; the way the user chooses options is outside the scope of Z.

27. Possible difficulty of timing gesture accurately as cursor moves between options

Z does not deal with such issues.

28. Voice recognition problems

This issue is outside the scope of Z.

29. Speaking with mouth full…

This issue is outside the scope of Z.

30. No display of speed

The Z description did not include an explicit representation of what information is displayed, so this issue is outside the scope of the approach.

31. Arm obscuring user's view

This issue is outside the scope of Z.

32. No arm reversing.

Because the possibility of overshooting is not considered, this issue is outside the scope of the Z analysis.

33. Difficult to match names to joints

This issue is outside the scope of Z.

34. Long sequence of operators to recover from directional error

It is highly unlikely that this issue would emerge from a Z specification because there is no explicit representation of error.

9 EMU REVIEWED

1. Long sequence of operators to move arm

This issue was identified from the interaction sequence using craft skill.

2. Inability to backtrack

Emu does not look at the implications of error and therefore cannot identify this kind of issue. The representation of the interaction does not allow for the identification of this issue.

3. Difficulty of choosing between move arm or move
This is a potential semantic clash, and is the kind of issue that emu can identify, and did.
4. Lack of short cuts
The notation used by emu does not allow for the identification of this issue. It is not an issue that would be identified by either the method, or craft skill based on the materials provided as a result of following the method.
5. Continue versus go: continue seen as redundant
This particular task did not involve the use of the continue option, and was therefore not identified as an issue.
6. Confusion over joint called arm
This is a potential semantic clash, and is the kind of issue that emu can identify, and did.
7. Gesture input with twice as many operations as voice because dependent on cursor movement
The interaction sequence of the modalities represented the cursor, but the extra modalities relating to the cursor were not identified as significant. This kind of issue could not be identified by emu.
8. Problem if head moved to look at arm while gesture system operational may be interpreted as a command
The comparison of the system profile with the user modalities raised this issue. The method therefore supports the identification of this kind of issue.
9. If user pauses in middle of saying "move arm"...
This was not an issue identified by the method because emu does not consider timings and the start and finish of modalities.
10. If user engaged in conversation...
This was not an issue identified by the method since it was not indicated in the initial scenario that the user would be engaged in conversation. If that information had been included in the environment profile, then this issue would have been identified by emu.
11. Lack of feedback about selection
Feedback was not considered due to it not being implemented.
12. Problems of determining left and right, especially when arm contorted
Emu is not able to identify issues of this nature, except possibly in terms of clash unless expert, which would take a large amount of craft skill to identify.
13. User cannot check direction choice until arm starts to move
This issue relates to the feedback available. Since the feedback was not implemented at the time of this analysis, this issue was not identified.
14. Time taken to interact with system to stop arm
The interaction sequence was able to represent the modalities used for this command in detail, and was therefore able to show that both the gesture and voice commands would only use the same number of modalities. Although emu does not represent time as such, it is able to examine sequences of modalities, whose timing properties can then be investigated. This issue was identified through craft skill using the representation from the emu analysis.
15. Similarity between moving joint and moving whole arm
This issue was not identified by emu since emu does not require this to be examined.
16. Illegal options
This was not an issue which emu could identify since the analysis was task-based, and the task as given did not explore those options.
17. Mismatch between way that arm works and way that user would move arm
Stage one of emu concentrates attention on the task, so at this point this kind of issue would be expected to be noted, through the craft skill of the analyst.
18. Not clear that end returns user to main menu
This issue was not identified in the original analysis and should have been, since it is a potential mismatch. This demonstrates how the identification of any issue is dependent upon the analyst, and that mistakes and omissions can occur.
19. End having two meanings
This issue was not identified in the original analysis and should have been, since it is a potential mismatch. This demonstrates how the identification of any issue is dependent upon the analyst, and that mistakes and omissions can occur.
20. Lighting conditions
Emu calls for the explicit examination of the environment, and comparison with the modalities used. Therefore, the identification of this issue is supported by the method.
21. Difficulty for user to move field of vision

The method in stage four compared the user profile with the system modalities and was able to identify this issue.

22. User looking one way, menu options in other direction

This is the kind of issue that is explicitly found by the method with regards to the field of vision of the user and the resulting potential physical clash.

23. Difficulty of judging arm movements

This is a clash unless expert issue, and the method instructs the analyst to look for these clashes.

24. Difficulty in judging speed and direction as getting close to target

The EMU analysis, maybe paradoxically, focuses attention on the user of the control system, and not on the real-world aspects of the task, so this is outside the scope of EMU.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target

Again, this is outside the scope of EMU.

26. Position and movement of most joints is of limited interest to the user

Because the EMU analysis works through pre-defined tasks, this issue does not emerge through the analysis.

27. Possible difficulty of timing gesture accurately as cursor moves between options

EMU does not explicitly consider timing. This issue was not identified, and is outside the scope of EMU.

28. Voice recognition problems

EMU assumes that the system performs as intended, so would not identify this issue.

29. Speaking with mouth full…

This issue should have been identified by EMU with the feeding task.

30. No display of speed

EMU takes a fairly localised view of the interaction, so does not consider broader user knowledge such as this.

31. Arm obscuring user's view

Paradoxically, this issue is outside the scope of EMU, unless it were identified through craft skill, because the bulk of the rest of the arm (other than the gripper) is not represented.

32. No arm reversing.

The requirement for arm reversing did not emerge in the analysis because this kind of domain error was not considered. It would not naturally emerge from an EMU analysis.

33. Difficult to match names to joints

This labelling issue is outside the scope of EMU.

34. Long sequence of operators to recover from directional error

EMU has no notion of error, and hence none of error recovery, so this issue is outside the scope of the method.

10 CASSM REVIEWED

1. Long sequence of operators to move arm

Cassm is not procedural, so would not identify this issue.

2. Inability to backtrack

Cassm is not procedural, so would not identify this issue.

3. Difficulty of choosing between move arm or move

This is a decision issue, and is outside the scope of cassm.

4. Lack of short cuts

Cassm is not procedural, so would not identify this issue.

5. Continue versus go: continue seen as redundant

Because cassm doesn't consider the details of user commands (or actions), this issue is outside the scope of the approach.

6. Confusion over joint called arm

With a slightly expanded cassm description that includes the concept of the whole arm as being made up of joints, this issue should have emerged. This issue *should* have been identified.

7. Gesture input with twice as many operations as voice because dependent on cursor movement

Cassm is not procedural, so would not identify this issue.

8. Problem if head moved to look at arm while gesture system operational may be interpreted as a command

This is concerned with user actions, and is therefore outside the scope of cassm.

9. If user pauses in middle of saying "move arm"...

Cassm is not procedural, so would not identify this issue.

10. If user engaged in conversation...
Cassm is not procedural, so would not identify this issue. Unless the details of voice input were unpacked further, in which case the action might be assessed as 'hard', in which case this might reasonably emerge. But i think not very straightforwardly.
11. Lack of feedback about selection
Cassm does not explicitly consider feedback of this kind.
12. Problems of determining left and right, especially when arm contorted
The issue of judging directions when the arm is contorted emerged (with some craft skill) from looking at joints and what the user knows about the directions in which joints can move. It does not emerge directly from the cassm representation.
13. User cannot check direction choice until arm starts to move
This is outside the scope of cassm, unless it were spotted by craft skill, which it wasn't.
14. Time taken to interact with system to stop arm
Cassm is not procedural, so would not identify this issue.
15. Similarity between moving joint and moving whole arm
Cassm is not procedural, so would not identify this issue.
16. Illegal options
Cassm is not concerned with system states at this level of detail, so would not identify this issue.
17. Mismatch between way that arm works and way that user would move arm
This emerged very clearly through the cassm analysis, due to the fact that this is the ultimate mismatch, and that's precisely what cassm's about.
18. Not clear that end returns user to main menu
Cassm is not procedural, so would not identify this issue.
19. End having two meanings
This is outside the scope of cassm because actions are of secondary consideration.
20. Lighting conditions
Cassm doesn't consider the environment in this way, so this issue is outside scope.
21. Difficulty for user to move field of vision
Cassm doesn't consider the context and details of user capability in this way, so this issue is outside scope.
22. User looking one way, menu options in other direction
This emerged in the initial analysis through craft skill, while considering the user's perspective on the gripper and the object-in-the-world.
23. Difficulty of judging arm movements
This emerged through the process of considering the mismatch between gripper and world.
24. Difficulty in judging speed and direction as getting close to target
This emerged through the process of considering the mismatch between gripper and world.
25. Difficulty in judging position, orientation and aperture of gripper as approaching target
This emerged through the process of considering the mismatch between gripper and world.
26. Position and movement of most joints is of limited interest to the user
This emerged through the process of considering what's actually of significance to the user.
27. Possible difficulty of timing gesture accurately as cursor moves between options
This emerged through the process of considering menu items (as a concept) and how they were selected.
28. Voice recognition problems
This emerged through the process of considering menu items (as a concept) and how they were selected.
29. Speaking with mouth full…
Cassm doesn't consider the context and details of other user activity in this way, so this issue is outside scope.
30. No display of speed
This probably should have emerged through the consideration that there is a difference (misfit?) between the perceived speed of the arm as moving and the speed setting as determined (but not displayed) through the interface. This one's a bit marginal…
31. Arm obscuring user's view
CASSM doesn't consider the context and details of system behaviour in this way, so this issue is outside scope.
32. No arm reversing.
Because CASSM doesn't consider procedures or overshooting kinds of errors, this is outside the scope.
33. Difficult to match names to joints
CASSM should have facilitated the spotting of this, but it would still be a bit crafty, in my opinion.

34. Long sequence of operators to recover from directional error
CASSM is not procedural, so this issue is outside the scope of the method.

11 HEURISTIC EVALUATION REVIEWED

1. Long sequence of operators to move arm
HE does not consider task structure, so this issue is outside scope.
2. Inability to backtrack
This issue was identified through the 3rd heuristic ("user control and freedom") which includes the consideration of undo and redo.
3. Difficulty of choosing between move arm or move
This issue arose through craft skill while considering the names of joints, because the similar names match different real-world terms (heuristic 2).
4. Lack of short cuts
This might have emerged under 'efficiency of use' (heuristic 7).
5. Continue versus go: continue seen as redundant
This emerges through considering "consistency and standards" (heuristic 4).
6. Confusion over joint called arm
This might have been discovered by considering match between system and real world, but would have relied on substantial craft skill.
7. Gesture input with twice as many operations as voice because dependent on cursor movement
HE is not procedural, so would not identify this issue.
8. Problem if head moved to look at arm while gesture system operational may be interpreted as a command
If the analyst were very familiar with gesture systems, this might be identified under heuristic 5 (error prevention).
9. If user pauses in middle of saying "move arm"...
If the analyst were very familiar with voice input systems, this might be identified under heuristic 5 (error prevention).
10. If user engaged in conversation...
If the analyst were very familiar with voice input systems, this might be identified under heuristic 5 (error prevention).
11. Lack of feedback about selection
This emerges directly from heuristic 1.
12. Problems of determining left and right, especially when arm contorted
While heuristic 2 concerns the match between the system and the real world, there are no cues to make this kind of high level match, so this is outside the scope of HE.
13. User cannot check direction choice until arm starts to move
This might be spotted through craft skill if the analyst is familiar with this kind of system (visibility of system status).
14. Time taken to interact with system to stop arm
HE is not procedural, so would not identify this issue.
15. Similarity between moving joint and moving whole arm
HE is not procedural, so would not identify this issue.
16. Illegal options
HE is not concerned with system states at this level of detail, so would not identify this issue.
17. Mismatch between way that arm works and way that user would move arm
This kind of high level mismatch between the system and the real world would be unlikely to emerge from a HE unless the analyst were looking out for it specifically (under heuristic 2).
18. Not clear that end returns user to main menu
This should have emerged from heuristic 2: that 'end' is the wrong term for this meaning.
19. End having two meanings
This is outside the scope of HE.
20. Lighting conditions
HE doesn't consider the environment in this way, so this issue is outside scope.
21. Difficulty for user to move field of vision
HE doesn't consider the context and details of user capability in this way, so this issue is outside scope.
22. User looking one way, menu options in other direction

HE doesn't consider user activities in this way, so this is outside the scope of the method.

23. Difficulty of judging arm movements

The heuristics are too general to focus on issues like this.

24. Difficulty in judging speed and direction as getting close to target

The heuristics are too general to focus on issues like this.

25. Difficulty in judging position, orientation and aperture of gripper as approaching target

The heuristics are too general to focus on issues like this.

26. Position and movement of most joints is of limited interest to the user

The heuristics are too general to focus on issues like this.

27. Possible difficulty of timing gesture accurately as cursor moves between options

This emerged by considering possible causes of user error (heuristic 5).

28. Voice recognition problems

This emerged by considering possible causes of user error (heuristic 5).

29. Speaking with mouth full…

If the analyst were very familiar with this kind of system this might emerge while considering heuristic 5.

30. No display of speed

This should have emerged through considering visibility of system status

31. Arm obscuring user's view

HE doesn't consider the context and details of system behaviour in this way, so this issue is outside scope.

32. No arm reversing.

This is part of error recovery, and is a specific example of issue 34, which emerged in this analysis, and so is covered as a special case of that.

33. Difficult to match names to joints

This emerged while considering match between the system and the real world.

34. Long sequence of operators to recover from directional error

This was identified through craft skill while considering error recovery (heuristic 9).

12 CLASSIFICATION OF ISSUES BY GROUPS

Five types of issues emerged. These can be grouped as follows:

12.1 System issues:

1. Long sequence of (mental) operators to move arm
2. Inability to backtrack.
4. Lack of short cuts
5. Continue serves same function as Go, and is redundant
7. Gesture input with twice as many operations as voice because dependent on cursor movement
15. Similarity between moving joint and moving whole arm
16. Illegal options
32. No arm reversing
34. Long sequence of operators to recover from error in direction

12.2 User knowledge issues:

3. Difficulty of choosing between Move Arm or Move
6. Confusion over joint called Arm
11. Lack of feedback about selection
13. User cannot check direction choice until arm starts to move
18. Not clear that End returns user to main menu
19. End having two meanings
30. No display of speed
33. Difficult to match names to joints

12.3 Conceptual fit issues:

17. Mismatch between way that arm works and way that user would move arm
23. Difficulty of judging arm movements

24. Difficulty in judging speed and direction as getting close to target
25. Difficulty in judging position, orientation and aperture of gripper as approaching target
26. Position and movement of most joints is of limited interest to the user

12.4 Physical issues:

8. Problem if head moved to look at arm while gesture system operational: may be interpreted as a command
9. If user pauses in middle of saying "Move arm"...
10. If user engaged in conversation...
12. Problems of determining left and right, especially when arm contorted
14. Time taken to interact with system to stop arm
22. User looking one way, menu options in other direction
27. Possible difficulty of timing gesture accurately as cursor moves between options
28. Voice recognition problems
29. Speaking with mouth full…

12.5 Contextual issues:

20. Lighting conditions
21. Difficulty for user to move field of vision
31. Arm obscuring user's view

13 SUMMARY OF ANALYSIS

Key: O=overlooked; should have found. M = found by method
C = found by craft skill C? = could have been found by craft skill
A = level of abstraction issue (a kind of craft)

CMN-GOMS and CPM-GOMS are included under the heading of GOMS

	PROBLEM	STN	CW	GOMS	PUM	Z	EMU	CASSM	HE	video
1	Long sequence of operators to move arm	O	**C**	**M**	**C**	C?	**C**			poor
2	Inability to backtrack	**M**	C?	**C**	**C**	**M**			**M**	n/a
3	Difficulty of choosing between Move Arm or Move		**M**	**C**	**M**	C?	**M**		**C**	none
4	Lack of short cuts	C?	C?	**C**	C?	C?			C?	poor
5	Continue redundant	**M**	C?	**M**	O	**M**			**M**	n/a
6	Confusion over joint called Arm		**M**	**C**	**M**	C?	**M**	O	C?	none
7	Gesture input with twice as many operations as voice	A		**M**	A	A				poor
8	Head moved to look at arm while gesture system operational may be interpreted as a command		**C**				**M**	C?	C?	n/a
9	If user pauses in middle of saying "Move arm"...		**C**						C?	none
10	If user engaged in conversation...		**C**				C?	C?	C?	none
11	Lack of feedback about selection		**M**		C?				**M**	none
12	Problems of determining left and right, especially when arm contorted		**C**		C?			C?		yes
13	User cannot check direction choice until arm starts to move		**C**						C?	yes
14	Time taken to interact with system to stop arm		**C**	**M**	**C**		**C**			yes
15	Similarity between moving joint and moving whole arm	**M**	C?	**M**	C?	**M**				none
16	Illegal options	C?	C?			**M**				none
17	Mismatch between way that arm works and way that user would move arm		C?		**M**	C?	**C**	**M**		yes
18	Not clear that End returns user to main menu		**M**		**M**		O		O	none
19	End having two meanings		**M**		**M**		O			none
20	Lighting conditions		C?				**M**			n/a
21	Difficulty for user to move field of vision		C?				**M**			n/a
22	User looking one way, menu options in other direction		C?				**M**	**C**		yes
23	Difficulty of judging arm movements		C?				**M**	**M**		yes
24	Difficulty in judging speed and direction as getting close to target				A			**M**		yes
25	Difficulty in judging position, orientation and aperture of gripper as approaching target							**M**		yes
26	Position and movement of most joints is of limited interest to the user		C?					**M**		none
27	Possible difficulty of timing gesture accurately as cursor moves between options		C?	A				**M**	**M**	none
28	Voice recognition problems							**M**	**M**	yes
29	Speaking with mouth full…						O		C?	yes
30	No display of speed				**M**			C?	O	yes

31	Arm obscuring user's view									yes
32	No arm reversing	C?			**C**				C?	yes
33	Difficult to match names to joints		O		**M**			O	**M**	n/a
34	It takes a long time to recover from a directional error								**C**	poor

Table 2: summary table of findings after reanalysis

14 REFERENCES

BLANDFORD, A., HYDE, J., CONNELL, I. & GREEN, T. (2004) *Scoping Analytical Usability Evaluation Methods: a Case Study*. Working paper available from http://www.uclic.ucl.ac.uk/annb/CASSMpapers.html

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