Crib for 4C4 Design Methods 2021

Version: JMC/9

Question 1

a)

The overall function is `Predict Word` and its system boundary includes software concerns relating to receiving keystrokes, managing a list of words that can be predicted and receiving context information. It excludes everything else, including hardware concerns.

b)

The overall function can be decomposed into function structures in several ways and individual solutions are judged on whether they correctly model the flow of signals between necessary sub-functions to carry out the overall function. One method to arrive at a set of function structures is as follows. The overall function receives at least two signals: 1) a *Keystroke* signal; and 2) a *Context* signal. The overall function outputs at least a *Word Prediction* signal. The overall function can be decomposed into the following sub-functions: `Receive Context`, `Buffer Keystrokes`, `Access Word List` and `Rank Words`.

The sub-function `Receive Context` receives a *Context* signal relayed via the overall function and transmits it to `Rank Words`. Similarly, `Buffer Keystrokes` receives a *Keystroke* signal and transmits it to `Rank Words`. In addition, `Rank Words` will need a *Word* signal from a function accessing the word list (in this case, `Access Word List`. `Rank Words` ranks all, or a subset, of the words in the word list and outputs a *Word Prediction* signal which is relayed via the overall function to the main system.

Several solutions are possible. Solutions are expected to be drawn as function structures with arrows clearly indicating signal flows.

c)

The design sketched in the answer to (b) will need to be augmented to include a sub-function `Add Word`. In the function structures above, having a modular architecture would be preferable if the word list is mutable and thus one option is to move the word list out of the overall function `Predict Word`. This can be achieved by connecting a new input signal *Word* to the overall function `Predict Word` which is relayed to `Access Word List`. `Add Word` can then either be outside or inside the overall function depending on the definition of system boundary. Several solutions are possible and are judged on ability to model all the functionality in terms of completeness and simplicity, and by the strength of the motivation of the design and its coherence to the actual function structures.

d)

Critical controllable parameters are: the number of word predictions shown to the user; the number of words the system can predict, if fixed; and the word prediction method, such as for instance a prefix tree vs. a long-span language model.

Critical uncontrollable parameters are: the accuracy of the user's typing; the number of words the system can predict, if allowed to be manipulated by the user; the accuracy of word prediction; and how easy it is to predict the text the user is typing (i.e. its perplexity).

e)

The controllable parameters describe design parameters that can be set by the designer, understanding these parameters allow optimisation towards design objectives, such as maximising the probability to predict the user's intended word. Uncontrollable parameters describe how sensitive the system is to the environment. Simulating the effect of such parameters allow for sensitivity analysis of the system.

Comments

The majority of candidates attempted this question. Most candidates defined a sensible system boundary, but some made no mention of the context or explained their reasoning for the boundary. The function structures were generally very good, but many candidates neglected to explain the role of these diagrams. The additional functionality required to update the dictionary was generally well explained. Finally, the identification and demonstration of an understanding of the value of the controllable and uncontrollable parameters was well executed, with some excellent ideas for the final part of the question.

Question 2

a)

A solution-neutral problem statement derivation can, for example, be of the form: "Design a system that allows cyclists to navigate" → "Design a system that allows cyclists to navigate using egocentric instructions" → "Design a system that allows cyclists to navigate" → 'Design a system that allows cyclists to navigate using egocentric instructions provided by the bicycle."

b)

Key functions include:

1. `Provide Route` is a necessary function for the navigation system to be able to know the route to be navigated.
2. `Locate Current Location` is necessary for the system to be able to understand which direction to communicate to the user.
3. `Provide Direction` is necessary for the system to be able to communicate directions to the user.
4. `Cancel` is necessary in case the user changes their mind.

Other functions are arguably also necessary, such as `Transform Route to Directions`. In general, several variants are possible and acceptable as long as they are motivated and form the critical functions for addressing the solution-neutral problem statement in (a). The solution above can be thought of as the minimal acceptable solution.

c)

Function/Solution	Solution 1	Solution 2	Solution 3
Provide Route	Mobile Phone	Screen at Steering Wheel	Speech
Locate Current Location	GPS	Linear Accelerometer	Computer Vision
Provide Direction	Visual LCD on Handlebars	Stereo Audio by Earphones	Haptic Actuation on Handlebars
Cancel	Physical Button Press on Handlebars	Dial	Voice

Preferred conceptual design: One choice is having the route provided by a mobile phone app paired by, for example, Bluetooth to a system mounted on the handlebar. This reduces cost on the unit. Voice require more processing or demands a high-speed wireless connection, which may not always be available. Voice is also problematic if background noise is substantial. This is an uncontrollable parameter in the design and therefore it is undesired to expose the design to it if it can be avoided. Location can be provided by GPS as GPS works well for outdoor navigation and integrated chipsets with GPS are easy and inexpensive to procure. Directions can be provided by haptic actuation in the handlebars to avoid cognitive and sensory overload on the visual and auditory channels, which are important to avoid overloading due to safety reasons. A secondary concern is also that stereo audio feedback would conflict with some users' desire to listen to music or radio while cycling. A cancel action can be handled by a physical button press on handlebar. A long-press is desired to avoid false activation.

Several other preferred conceptual designs can be created and are valid as long as they are motivated. For example, the conceptual design sketched above relies on substantial integration with the handlebars which brings other weaknesses, such as installation on existing bike, threat of theft, and also raises additional design questions, such as the possibility of selling the device as a complete replacement of handlebars. It is important, however, that all key functions are translated to viable function carriers and that the motivated design provides a narrative for why it is preferred. Numerical scoring can optionally be used to assist the selection of a single preferred conceptual design.

d)

Requirements must be testable and traceable. There are many possible solutions and many sources are possible. The requirements should follow-on from the conceptual design in (c). It is also possible to include priorities but not necessary as the question asks about key requirements. Examples of requirements include:

1. Mobile phone app must connect to the system in less than five seconds from initiating a connection from the app. Source: User research.
2. Mobile phone app must work on Apple and Android devices. Source: Market research.
3. Battery life must exceed 30 hours of use. Source: User reserach.
4. Handlebar actuation must have a just-noticeable difference (JND) threshold of 10% or less compared to normal operation. Source: Haptic design guidelines.
5. Unit must be integrated into handlebars. Source: User and market research.
6. There must be a mechanism for signalling to the user that the navigation system lost the GPS signal. Source: Safety guidelines.
7. There must be a mechanism for signalling to the user that the system has successfully mapped out a route. Source: Usability guidelines.

8. It must take a typical user less than 5 minutes to replace the battery. Source: Market research.

e)

A cross-verification matrix consists of a row for each requirements and each row has the following columns:

- Requirement ID (matching the requirements specification)
- Requirement (matching the requirements specification)
- Verification method (without precise method)
- Allocation (indicating the subset of components and modules affected)
- Success criteria

A verification method will refer to an inspection, demonstration, test or analysis protocol.

Referring to the requirements in (b) above (VM = Verification Method; A = Allocation; SC = Success Criteria), an example cross-reference verification matrix is provided below. Other solutions are possible as long as they relate to the requirements and provide sensible verification methods, allocations and success criteria.

1. VM: Demonstration; A: System; SC: Connection established within threshold.
2. VM: Demonstration; A: Mobile Phone App; SC: Successful operation on both platforms.
3. VM: Test; A: System; SC: Successful operation exceeding the threshold.
4. VM: Test; A: Handlebar actuation; SC: JND staircasing experiment with 24 representative users demonstrating an acceptable JND threshold.
5. VM: Inspection; A: System; SC: Evidence of unit integration with handlebars.
6. VM: Demonstration; A: System; SC: Successful signal communicated to the user when the GPS signal is lost.
7. VM: Demonstration; A: System; SC: Successful signal communicated to the user when a route has been successfully mapped out.
8. VM: Test; A: System; SC: An opportunity sampled set of 8 users can reliably swap out the battery in less than five minutes without assistance.

Comments

All of the candidates attempted this question. The majority of the solution neutral problem statements were very good, but a number lacked essential details, such as mention of a route. The identification and reasoning about the key functions was done well. There were some excellent morphological charts, but a significant number of the candidates presented concept evaluation tables rather than the required charts. The requirements specifications were universally very good, including reference to measurable outcomes. There were some good attempts at describing the verification requirements, but some candidates struggled with this final part of the question.

Question 3

The main underlying thread for this question, is that all design and risk requirements need to be considered in the context of a community village in the Himalayan mountains, where per capita income levels are likely to be low, and the ability to support advanced technology difficult.

a)

Key requirements should be traceable (where do they come from? e.g. scoping survey, literature review) and testable (how?), and are likely to include:

- a device (or devices) to measure rain fall or water levels in streams, in the mountains above the village
- a method to send measurement data, at near real-time, from these devices to the village
- a centralised system to receive, collect and store the data, at the village
- a means to alert the community of a potential flash flood
- a means to identify and alert when devices are failing to transmit data
- a record of alarms, and false alarms, to verify the successful operation of the system
- security measures to ensure devices and equipment remains in operation

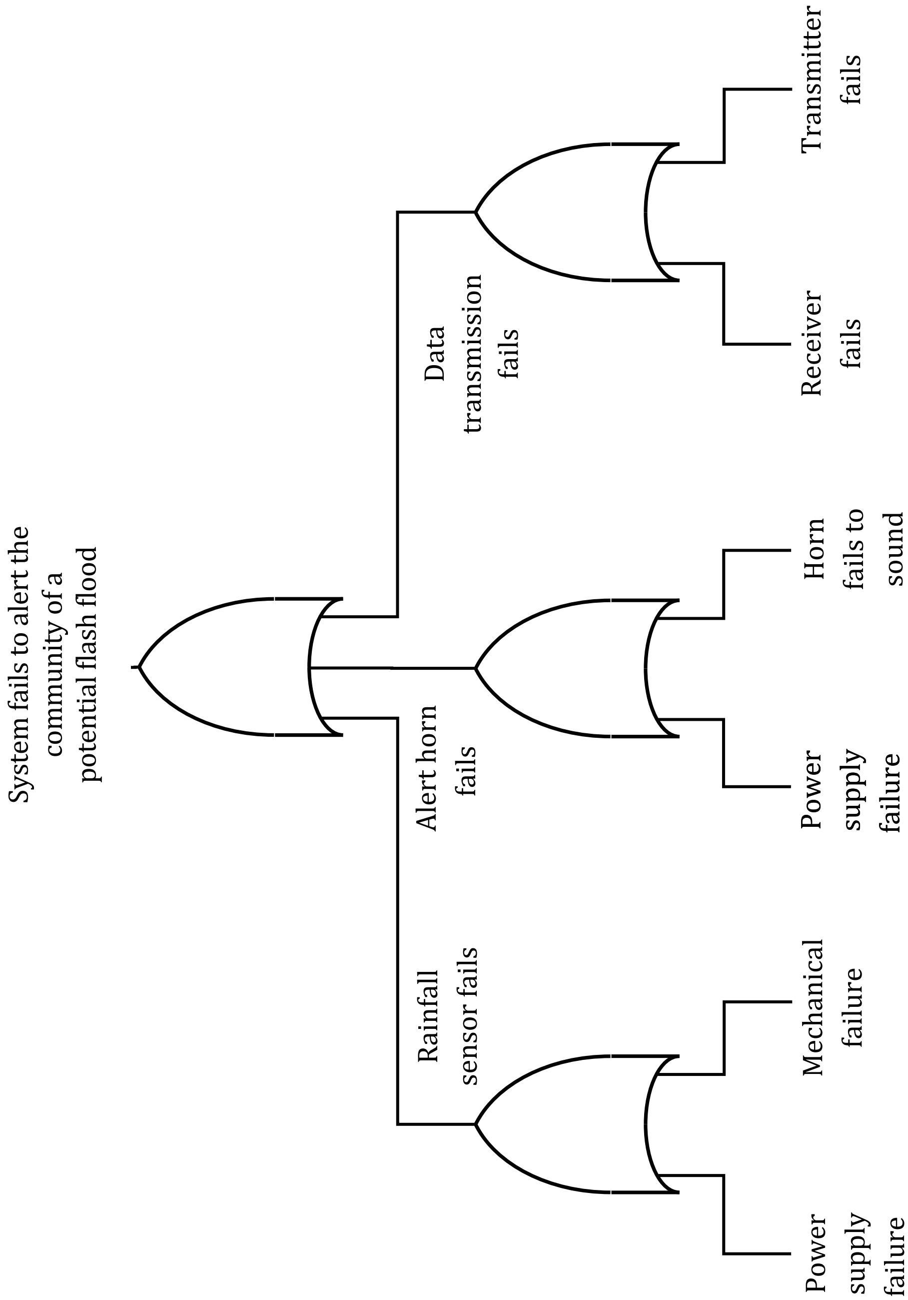
b)

'Gates' in the fault tree are likely to be OR gates. The fault tree can take a number of different forms, but should address issues across the entire system, and relate to the key requirements identified in (a).

c)

The six principles for creating systems that work, in integrated system design, are:

1. Pursue the purpose: the system will alert the community to the potential of a flash flood. Cost, performance, timescale and risk are the key requirements to be defined. "Requirements determine how the system will impact on its environment and how the environment will impact on the system".
2. Think holistic: an integrated system needs to consider the system as a whole. Students should describe the components of the system (sensors, transmitters, receivers, alarms), the environment in which it operates (mountains, developing country, low-technology capacity) and the tools/procedures to build it (training, commissioning, maintenance). "Like a chain, a system is only as good as its weakest link".
3. Follow a disciplined procedure: "Systems that work do not just happen ? they have to be planned, designed and built". The V-diagram as a methodology for partitioning (breaking the problem down into manageable parts) and integrating (bring the parts back together), would be an appropriate method to follow.
4. Be creative: in this context, the design would need to made from readily available components and simple technologies to delivery the early warning system. For example, several off the shelf rain fall measurement device (many for redundancy), linked to a mobile phone, RF or text protocol for communication, and a car horn for an alarm. "Think creatively, laterally and logically ? remember the aim is to deliver capability, not technology".


System fails to alert the community of a potential flash flood
Rainfall sensor fails
Alert horn fails
Data transmission fails
Power supply failure
Mechanical failure
Power supply failure
Horn fails to sound
Receiver fails
Transmitter fails

5. Take account of the people: People are part of the system, and need to build, install, operate, test, maintain and decommission the system. Therefore designers need to take account of the human aspects of the system. People will also be required to defend, challenge or tolerate the system. In this context, the designer should co-create the design with the community stakeholders, drawing on their flexibility, inventiveness and intelligence to avoid unanticipated system failure. "People are at the heart of most systems; they may be both its weakest and strongest link".

6. Manage the project and relationships: Large systems require many people to specify, design, build, operate, maintain and dispose, therefore it is critical to design the project, not just the system. The system for one community is relatively small, but will still have complex interactions to manage (i.e. between suppliers, designers, the community, emergency services, government officials, NGOs, etc). The specific system architecture for the early warning system will require, for example, testing procedures, training, monitoring, maintenance, and supply of spare parts.

d)

Key factors of good risk management might include, but are not limited to:

- careful assessment of the requirements for the new early flood warning system;
- consideration of the appropriate costs and technology level for a Himalayan village
- testing to ensure the early warning system delivers improved flood warning times;
- assessing and mitigating the risks of false alarms;
- consideration of the reliability and security of the system in the local environment;
- training provision for the community to operate and maintain the system;
- clear definition of the system performance requirements, and how these can be regularly tested;
- communication of the system changes to the community, and relevant safety bodies;
- communication with those at risk about what actions to take in the event of a potential flood.

Comments

Most of the candidates attempted this question. Students were able to list key requirements of the system, but some failed to related these to the flood warning system, and many forgot to mention testing and maintenance measures. Many students lost marks for focusing the fault tree on ?flood occurs? or ?village fails to evacuate? rather than the ?unsuccessful operation of the flood warning system?, and in general more detail could have been given. Most student could describe the six principles of integrated system design, but some did not apply these in the Himalayan context. Students could describe key factors for risk assessment, but again did not always apply these in context, e.g. listing rework as an issue, and in general overlooked testing and reliability aspect of risk.

Question 4

The calculation details for a), b), and c) are shown below.

a) Shaft and bush	symbol	units	mean	+/−	min	max	range	no. dev	dev	dev^2
From BS4500 H7 - h6										
Bush diameter (inside)	φ_h	mm	50.015	0.015	50.000	50.030	0.030	6	0.00500	0.000025
Shaft diameter	φ_s	mm	49.9905	0.009	49.981	50.000	0.019	6	0.00317	0.000010
Using c = φ_h - φ_c and y = a1x1 + a2x2										
Clearance	c	mm	0.0245						0.00592	0.000035
Probability	z = (x-μ) / σ		-4.14							
	P(z)		1.000	*Is well above chart max of 3.4, 0.9998*						
	1 - P(z)		0.002%	*The probability of not obtaining a clearance fit.*						

b) Bearing housing and bush	symbol	units	mean	+/−	min	max	range	no. dev	dev	dev^2
From BS4500 H7 - n6										
Hole diameter (bush housing)	φ_{bh}	mm	66.0150	0.015	66.000	66.030	0.030	6	0.00500	0.000025
Bush diameter (outside)	φ_b	mm	66.0295	0.010	66.020	66.039	0.019	6	0.00317	0.000010
Using c = φ_{bh} - φ_b and y = a1x1 + a2x2										
Clearance	c	mm	-0.0145						0.00592	0.000035
Probability	z = (x-μ) / σ		-2.45							
	P(z)		0.993							
	1 - P(z)		0.714%	*The probability of not obtaining an interference fit.*						

c) Bush, sheet thickness	symbol	units	mean	+/−	min	max	range	no. dev	dev	dev^2
	1 - P(z)		20.0%	*The probability of not obtaining an interference fit.*						
	P(z)		0.800							
Probability	z		0.842							
From above, with +/- 15mm each side of sheet										
Bush diameter (inside)	φ_h	mm	50.015	0.015	50.000	50.030	0.030	6	0.0050	0.000025
Hole diameter (bush housing)	φ_{bh}	mm	66.0150	0.015	66.000	66.030	0.030	6	0.0050	0.000025
Calcualte clearance for new bush diameter (outside)										
Using H7 -n6 fit		mm		0.015			0.030	6	0.0050	0.000025
									0.00707	0.000050
Clearance, using z = (x-μ) / σ	c	mm	-0.00595							
Using c = φ_{bh} - φ_b and y = a1x1 + a2x2										
Bush diameter (outside)	φ_b	mm	66.0210	0.015	66.0060	66.0360	0.030	6	0.00500	
Difference in daimater	φ_b - φ_h		16.0060						0.00707	
Sheet thickness	t	mm	8.0030						0.00354	

d)

Candidates should note that the interference fit between the bush and the bearing house will require the bearing housing to be heated for assembly. In operation, changes in temperature of the bearing will cause expansion of the housing and bush, and may lead to variability in the probability of an interference fit. A grub screw, fitted radially, can be used to prevent the bush from rotating with in bearing housing, if the interference fit is not maintained.

Comments

Few students attempted this question but those that did scored well. Many students struggled to interpret the British Standard tolerance table, despite there being an example in the lecture notes. Parts a) and b) of the questions were answered accurately, with many students achieving full marks. Part c) was more difficult and required the students to work back from the 20% probability given, to find the difference in diameters, and hence the sheet thickness. To achieve full marks in part d) students needed to realise that the tolerance fit requires the differential heating of the parts to assemble, and that key slots or grub screws can be used if a clearance fit is used.