Creating Visualisations of - and simulations from - Formal Models of Interactive Medical Devices

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Background

• Formal models of interactive systems
  – Interface
  – Interaction
  – Functionality
Background
The Models

• Presentation models
  – Describe the interface at the level of the widgets, and behaviours in different modes

• Presentation interaction models
  – A state transition diagram showing how the user can navigate to the various modes of the device

• Z specification
  – Describes the functionality of the device

• Presentation model relation
  – Relates the operations of the Z specification to the behaviours of the presentation model
Background

• Safety-critical interactive systems
  – Medical devices – infusion pumps, syringe pumps, pain-management pumps

• Models of devices used to:
  – Check correctness and consistency of interface, interactions and behaviour
  – Check consistency of user manuals and devices
  – Model safety-properties
Background

• Originally models of interface and interaction were designed to be easily understood by designers who were used to designing artefacts such as prototypes, scenarios etc.

• Modelling safety critical devices introduced two new factors
  – Different end users
  – Model-checking of entire device (Z)
End Users

• Medical decision makers and biotechnicians
• Device manufacturers
• Neither ‘speak the language’ of our model checking tools
  – We can’t use the language of the models to explain potential problems, conflicts etc.
End Users

• Medical decision makers and biotechnicians
• Device manufacturers
• Neither ‘speak the language’ of our model checking tools
  – We can’t speak at the language of the models to explain potential problems, conflicts etc.
• We don’t always have access to the devices we are studying
Proposed Solutions

• Different ways of visualising the models and the model checking process which supports communicating with our audience

• Using the models to derive these visualisations – and then create simulations
T34 Syringe Pump
Model Checking

- The presentation interaction model can be described using μcharts which have their semantics in Z
- We can, therefore use model checking on both the functionality and interaction of the device
ProB

- We use ProZ – a subset of the ProB tool – for model checking
- Our first attempt at providing a more informative visualisation built on the ability to link images to operations in ProB
\begin{schema}{Dec decreasesDuration}
\Delta T34State\n\where
systemReady \equiv \text{no}\\
% Looking at the manual, no idea what the increments are, so assuming 1 minute
(minutesduration = 0 \land hoursduration = 0) \implies (minutesduration' = 0 \land hoursduration' = 0)\\
minutesduration \geq 1 \implies (minutesduration' = minutesduration - 1 \land hoursduration' = hoursduration)\\
minutesduration = 0 \implies t2\\
(minutesduration' = 59 \land (hoursduration \geq 1 \implies hoursduration' = hoursduration - 1) \land \ldots t4\\
(hoursduration = 0 \implies hoursduration' = 0))\\
secondsduration = secondsduration'\\
\Xi BatteryState\\
\Xi Syringe\\
\Xi KeyPad\\
\Xi TechMenu\\
\Xi Program\\
\Xi VTBI\\
\Xi InfusionRate\\
\Xi Flag\\
systemReady' \equiv \text{no}\\
\end{schema}

\begin{schema}{ConfirmsDuration}
\Delta T34State
\end{schema}

Ln 383, Col 12

**State Properties**

- invariant_ok
- PerCent \(= (0 .. 100)\)
- hours \(= \{0,1,2,3,4,5,6,7,8,9,10,11,12,13\}\)
- minutes \(= \{0,1,2,3,4,5,6,7,8,9,10,11,12,13\}\)
- seconds \(= \{0,1,2,3,4,5,6,7,8,9,10,11,12,13\}\)
- tenthmillilitres \(= (0 .. 100000)\)
- tenthmillilitresperhour \(= (0 .. 10000)\)
- tenthmillimeters \(= (0 .. 1000)\)
- tensvtbi(0) = 0
- tensvtbi(1) = 0
- tensvtbi(2) = 0
- tensvtbi(3) = 0

**Enabled Operations**

- BatteryTest --> 90
- ProgramLock
- KeyPadLock
- TechMenuLock
- SelfTest
- PlungerBack
- PlungerForward
- SyringeDisplay --> (BDPlastipak) --> 100
- SyringeScrollUp
- SyringeScrollDown
- Resume
- SyringeConfirmation(BDPlastipak, yes)
- SyringeConfirmation(BDPlastipak, no)

**Increase Duration**
- IncreaseVTBI
- INITIALISATION(yes, 90, BDPlastipak, yes, v1)
- SETUP_CONSTANTS((0 .. 100), (0, 1, 2, 3, 4))
Volume 0 0 ml

Press YES
ProB Visualisation

• Advantages
  – Provides a display similar to that of the device itself
  – Allows a user to see the effect of operations in the specification at the display level

• Disadvantages
  – Very basic
  – Requires manual production of images and linking of these to results of operations in the specification
  – Requires a large set of images to be meaningful
Simulating Devices

• Using the models to derive interactive simulations of the device they describe
  – Requires an image of the device
  – If we are deriving the simulation from designs we need to create a prototype image

• Can be used as a visualisation of a device

• Can be used as a design tool
  – Experiment with layouts and interface choices
Online Visualisation

• Web-based tool which takes as input
  – Image of the device
  – Set of models of the device
• Regions of the image are then selected and defined as widgets
• Behaviours of the models are then linked to the widgets
• Simulate mode allows a user to interact and see results in real time
# Medical Device Simulator

## Devices

<table>
<thead>
<tr>
<th>Device Number</th>
<th>Device Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0001</td>
<td>Medical Device 0001</td>
</tr>
<tr>
<td>0002</td>
<td>Medical Device 0002</td>
</tr>
<tr>
<td>0003</td>
<td>Medical Device 0003</td>
</tr>
<tr>
<td>0004</td>
<td>Medical Device 0004</td>
</tr>
</tbody>
</table>

### New Device

Please enter the name of the medical device:

- **Niki T34 Syringe**

Select an image to upload:

- ![Niki T34 Syringe.png](c:/somedirectory/NikiT34Syringe.png)

Select a PIM file to import:

- ![Niki T34 Syringe.xml](c:/somedirectory/NikiT34Syringe.xml)

[Create] [Cancel]
Medical Device Simulator

**Niki T3 Syringe**

![Image of T34 Syringe Pump](image_url)

1. Press and Hold key until SELF TEST appears.
2. Wait until Pre-Loading has finished (actuator stops moving).
3. Load Syringe—position correctly so all sensors stop flashing.
4. Confirm syringe size & brand.
5. Press for New Patient or to Resume current regime.
6. Confirm volume to be infused or Change.
7. Confirm infusion duration or Change.
8. Confirm calculated rate or Change.
9. ALWAYS check data on the summary screen matches prescription before pressing key to confirm acceptance.
10. Press key to start infusion.

**NOTE:** Steps 6-8 are skipped if a pre-set duration is selected. Whilst delivering shows infusion data & battery life.
Medical Device Simulator

Niki T3 Syringe

New Widget

Name: MainDisplay

Behaviours:
- showInfusionTime
- showBatteryLevel
- other
- other

PM Category: ActionControl, Responder

Actions:
- Press and release
- Press and hold
- No Action

Create
Cancel
Medical Device Simulator

Niki T3 Syringe

MainDisplay

InfoButton

OnOffButton
Medical Device Simulator

Niki T3 Syringe

![Image of Niki T3 Syringe Pump](image-url)
Android Devices

• Generating Android simulations from models and images
  – Based on earlier work on automatically generating Android applications from models
  – Models are fed into a parser, a skeleton Android app is generated and a UI allows the developer to select interface options (widget selection, layout etc.)
Current Limitations

• At the moment we are using the interface and interaction models just to derive the simulations
  – The functional specification is not used
• The next part of our work involves creating a plug-in for ProB to allow us to interact remotely with the model checker to access the relevant information
Pro B

Plug-in

Web simulation

Android simulation

Other....
Next Steps

• One of our aims is to be able to incorporate our models into the CHI+Med simulation tool

• We also want to further develop the Android and web simulations so that they can be used as a design aid
  – Allow the designer to make changes to the interface
  – Feed back the new information to the interface and interaction models
Final Goals

• To be able to present the models and model checking in different ways to support different activities
  – Discussions with end users
  – Experimentation with interfaces
  – Generate simulations which can be used for training