Assisting Persons With Dementia During Handwashing Using a Partially Observable Markov Decision Process

Jesse Hoey

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School of Computing
UNIVERSITY OF DUNDEE
System Overview

An intelligent cognitive device that tracks a user through handwashing, providing cues when necessary.
System Features

- **Monitors** a user with dementia during handwashing,
- **Prompts** a user only when necessary,
- **Calls** for human assistance if needed,
- **Vision based**: only video inputs,
- **Robust**: able to recover from tracker failures,
- **Real-Time**: $320 \times 240 @ 40$fps,
- **Probabilistic**: Explicit modeling of uncertainty,
- **Partially observable**: estimates user internal states,
Integrated System

- Camera
  - Video
  - Grab frame
  - Update tracker

- Tracking
  - Hand positions
  - Discretise observations
  - Check belief change
  - New, stable belief detected?

- Belief monitor
  - Summon human caregiver
  - Action
  - Policy
Tracking

Tracking through occlusions and changes in shape

- Objects modeled as *flocks of features*
- Simple *color features*, Gaussian distributions
- *Bayesian sequential* estimation
- Monte Carlo approximation (*particle filter*)
- *Three interacting* filters: 2 hands + towel
- Dynamics: *Constant mean velocity*
- *Mixed-state dynamics*
- *Data-driven proposal* (e.g. ICondensation)
Data Driven Proposal

new image

(t)

color segmentation

draw samples

data-driven

color
samples

task

data-driven
samples from
(1-\alpha)

prior distribution

(t-1)

draw samples

1-\alpha

proposal

samples from
prior
A POMDP is a probabilistic temporal model of an agent interacting with its environment: a tuple \( \langle S, A, T, R, O, B \rangle \)

- \( S \): finite set of unobservable states
- \( O \): set of observations
- \( B : S \times A \rightarrow O \) observation function
- \( A \): finite set of agent actions
- \( T : S \times A \rightarrow S \) transition function
- \( R : S \times A \rightarrow \mathcal{R} \) reward function
What can you do with a POMDP?

**Everything** you can do with a dynamic Bayes net (DBN)...

- monitor belief(s)
- compute data likelihood given model
What can you do with a POMDP?

Everything you can do with a dynamic Bayes net (DBN)...

- monitor belief(s)
- compute data likelihood given model

... plus! compute a policy of action, $\pi$

- $\pi(b(s))$: belief states $\rightarrow$ actions
- policy actions maximise long-term reward
- tradeoff multiple, competing objectives

get hands clean $\quad$ user independence $\quad$ caregiver burden

- Policy does not imitate a human - optimises for system
Handwashing POMDP

\[
\begin{align*}
S & \quad \text{PROMPT} \\
\text{HANDS LOCATION} & \quad \text{time t} \\
\text{HANDS LOCATION} & \quad \text{time t+1}
\end{align*}
\]
Handwashing POMDP

- PROMPT
- HANDS LOCATION
- PLAN STEP
- ATTITUDE
- BEHAVIOR

(time t)  (time t+1)
Handwashing POMDP: Actions

- **do nothing**: system waits
- **call caregiver**: system calls for **single step** assistance
- **prompts**:
  - audio/video
  - male voice
  - preceded with reminder: “you’re washing your hands”
  - 3 levels of specificity:
    - **low**: basic prompt with few details
      - “Use the soap”
    - **medium**: include person’s name, more details
      - “John, use the soap in the pink bottle”
    - **high**: medium prompt with video demonstration
Handwashing POMDP: Plansteps
Handwashing POMDP: Plansteps

![Diagram showing the steps of handwashing with labels a, b, d, g, j, k, h, e, and transitions indicating water on and off.]
Handwashing POMDP: Plan steps
Handwashing POMDP: Plansteps
Handwashing POMDP: Plansteps

- dirty
- clean
- soapy
- water off
- dirty, dry
- clean
- soapy
- water off
Handwashing POMDP: Plansteps

[Diagram showing the plan steps]

1. a (dirty)
2. b
3. d (soapy)
4. e
5. g
6. h
7. j
8. k (clean, dry)
9. water off
10. clean, dry water off

[Legend: dirty, dirty, dry, soapy, water off, clean]
Handwashing POMDP: Plansteps
Handwashing POMDP: Plansteps

- **Behavior:**
  - Rinse
  - Dirty
  - Clean
  - Soapy
  - Soapy, dry
  - Water on
  - Clean, wet
  - Water on
  - Clean, dry
  - Water off
  - Dirty, dry

- **Diagram:**
  - Dirty
  - Soapy
  - Behavior: Rinse
  - Clean, dry
  - Water off
  - Clean, wet
  - Water on

- Nodes:
  - a
  - b
  - c
  - d
  - e
  - g
  - h
  - j
  - k

- Edges:
  - a → b
  - b → d
  - d → g
  - g → h
  - h → j
  - j → k
  - k → d
  - d → e
  - e → a
  - a → d
  - d → g
  - g → h
  - h → j
  - j → k
  - k → g
  - g → a
  - a → d

- Handwashing states:
  - Dirty
  - Soapy
  - Clean
  - Water on/off
Handwashing POMDP: Behaviors
# Handwashing POMDP: Attitude

<table>
<thead>
<tr>
<th>Factor:</th>
<th>Models:</th>
<th>Dynamics:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Awareness</strong></td>
<td>need for assistance</td>
<td>changes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>quickly</td>
</tr>
<tr>
<td><strong>Responsiveness</strong></td>
<td>response to assistance</td>
<td>changes from</td>
</tr>
<tr>
<td></td>
<td></td>
<td>day to day</td>
</tr>
<tr>
<td><strong>Dementia Level</strong></td>
<td>likelihood user will be aware</td>
<td>does not change</td>
</tr>
<tr>
<td></td>
<td>and responsive</td>
<td>change</td>
</tr>
</tbody>
</table>
Handwashing POMDP
Handwashing POMDP

Dementia Level
Awareness
Responsiveness

PROMPT

time t

ATTITUDE

PLAN STEP

BEHAVIOR

HANDS LOCATION

time t+1

ATTITUDE

PLAN STEP
Rewards and Solutions

Rewards and Costs:
- Task completion: large reward
- Prompts: costly
- Cost for prompting twice in a row (pestering)

Solution:
- 200K states $\times$ 198 observations $\times$ 26 actions
- Optimal solution \textit{intractable}
- \textbf{Approximations} used:
  - Point-based (\textbf{Perseus} - Vlassis & Spaan, 2005)
  - Structured solution (\textbf{SPUDD} - Hoey & St. Aubin, 1999)
  - Restrict size of solution (Poupart, 2005)
  - Disregard observations (Hoey & Poupart, 2005)
  - Merge states (St. Aubin & Hoey, 2000)
Overall System

- Runs on a single laptop Intel core 2 duo 2Gb Ram
- LCD screen for prompts
- Point Grey Research Dragonfly II
- 320x240 at 40Hz
- Modular processes
- UDP IPC communication through central broker
Simulation Results

Average over

- 20 simulation trials (50 steps each)
- 10 experiments
- all true user types (attitudes)
Simulation Results

Learning the user's dementia level over a clinical trial (20 handwashing simulations)
Actor Trials

Scenario 3:

Scenario 4:
Current System - Clinical Trials

- Full system to be deployed in clinical trials spring 2007
- Long-term care facility in Toronto, Canada
- 8 week trial (A-B-A-B baseline/system alternating 2 weeks)
- 10 participants moderate to severe dementia
- Measure: reduction in caregiver burden
Future Work

- Hierarchical modeling for full integration of tracking with POMDP
- Apply to other activities
- Learn POMDP parameters
- Bayesian Reinforcement Learning (online)
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