Multi-Agent Based Military Health System for the Future Battlefield

Master Thesis Defence

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Overview

Research Goal and Questions

Research Goal:

Modelling and developing a distributed medical triage system with weighted diagnosed conditions and a costs model in a military setting for *remote sensor based rescue initiation counsel.*

Main Research Questions:

How can a military health system be modelled with Agent Based Modelling for distributed diagnose and triage in a military setting for rescue initiation?
How can this automated military health system include contemporary advancements in diagnosis capabilities, algorithms, a medical ontology, feasible sensor equipment, and creating methods for handling uncertainties in compliance with military requirements?

Research Goals and Questions *(Continued....)*

Sub-Questions:

How could applicable diagnosable conditions be modelled in a declarative programming language?
How could this modelled system be simulated in an automated demonstrable graphical environment for system evaluation purposes, including multiple sensor configurations and scenarios presenting the weighted diagnosed conditions and a costs model?

Modelling Requirements

Requirements:
- Pragmatic appliance in a military setting.
- *Belief, Desire and Intention* paradigm modelled Multi-Agent System.
- Non-obtrusive in physical and mental job performance.
- Low-power, fault-sensitive mobile devices.
- Robust fault tolerant design.
- *Institutional* disagreement in medical ontology definition.
- Multi-tier hierarchical MAS architecture.
- Automated sensor-only remote medical triage capabilities.

Towards a Modelled Medical Ontology

Selection of diagnosable medical conditions and values:
- Human incapacitating or high-risk medical conditions.
- Commonly applied triage methods.
- Non-human intervention methods for medical symptom diagnosis.
- Sensor and algorithm limited, distinguishable medical conditions.
- Hypotheses set modelled with *high level BDI Agent* reasoning concepts.

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Towards a Modelled Medical Ontology *(Continued....)*

Resulted in a diagnosable medical condition set with:
- *Chosen* threshold values because of *institutional* disagreement.
- Aggregated symptom diagnosis:
  - *Concurrent* diagnosable symptoms. *(hypotheses set)*
  - *Compounded* medical conditions. *(sensor capability limited)*
- Colour-coded triage method.
- Sensor-only confirmable hypotheses.

Resulting Modelled Medical Ontology

	Risk Zones:				
Sensor Types:	*L HighRisk {3}*	*L Risk {2}*	*Normal-Deviant {1}*	*H Risk {2}*	*H HighRisk {3}*
Systolic Blood Pressure (SBP) in mmHg	$\leq$60	61 - 80	81 - 160	161 - 180	$\geq$181
Pulse Oxygenation (SpO_2) in %	$\leq$80	81 - 92	93 - 100		
Heart Rate (HR) in beats/minute	$\leq$45	46 - 50	51 - 120	121 - 180	$\geq$181
Respiratory Rate (RR) in breaths/minute	$\leq$10		11 - 28		$\geq$29
Temperature in °C	$\leq$35		35.1 - 38.2	38.3 - 39.9	$\geq$40.0

Triage Colour Flags: Red {3}, Orange {2}, Green {1}

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Resulting Modelled Medical Ontology *(Continued....)*

Diagnosable Symptoms	Triage Colour Levels **Red {3}**	**Orange {2}**
Likely Dead:	*Likely Dead: (and Acceleration $\leq$ 0.4m/s, if available)* HR ≤ 0 & RR ≤ 1 HR ≤ 0 & RR ≤ 1 & SBP ≤ 1 HR ≤ 0 & RR ≤ 1 & Temp ≤ 28 HR ≤ 0 & RR ≤ 1 & SBP ≤ 1 & Temp ≤ 28	*Still Moving - Quite Abnormal:* Acc: $>$ 0.4 m/s *(if available,* *and confirmed hypothesis* *of Likely Dead)*
Shot	*Likely Shot:* SBP ≤ 50 SBP Drop≥ 0 & SBP Drop $\geq$ (2.0*standard deviation) SBP ≤ 50 & SBP drop≥ 0 & SBP Drop $\geq$ (2.0*std.dev.) *(SBP Drop = oldest measured value - most recent value)*	
Shock	*In Shock:* HR / SBP $\geq$ 0.9	
Undercooled	*Hypothermia:* Temp ≤ 35	
Heat Illness	*Hyperpyrexia:* Temp ≥ 40.0	*Hyperthermia:* Temp 38.8 - 40.0
Respiratory Issues	*Apnea:* RR ≤ 0 *Bradypnea:* RR ≤ 12 *Tachypnea or Hyperventilation:* RR ≥ 29	
Oxygenation related	*Impaired Mental Functions:* $SpO_2 \leq 65$ *Unconsciousness:* $SpO_2 \leq 55$	

Only available sensor measurements are used in hypothesis evaluation,
one line per hypothesis sensor combination, reported threshold values are adjustable

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Resulting Modelled Medical Ontology *(Continued....)*

General hypothesis confirmation principle:
- Valid sensor measurement availability

Multiple scenarios for single hypothesis confirmation can include:
- Non-rejecting conditions.

Likely Dead diagnosable symptom (Example)

- Includes the previous mentioned conditions.
- Severe *undercooling* requirement, because resuscitation is still an option with stopped heart and respiratory systems.
- Has the supposition of non-oxygen consuming tissue with a stopped blood flow, and renders the *pulse oxygenation* measurement unsuitable for this hypothesis.

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Resulting Modelled Medical Ontology *(Continued....)*

Compounded condition Tachypnea/Hyperventilation (Example)

- Differentiated by *shallow breathing*.
- *Shallow breathing* detection sensors, limit physical job performance.
- Resulting in compounded *high-risk* condition.

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Resulting Modelled Medical Ontology *(Continued....)*

Personalised Triage Risk-Zones and Hypothesised medical conditions

Inter-personal tolerances and differences in *normal-deviant* values exist.

Recommendation of *unadjustable high-risk zones*. *(human physical limitations)*

Recommendation of an *Institutional* authoritative policy for all adjustable values.

→ Flexible modelling requirement of all adjustable values. *(pragmatic appliance guideline)*

Modelling Sensor Fault Tolerance

Sensors:
- Produce *faulty* data.
- Can be *unreliable* in certain situations. *(inferior quality/body placement)*
- Have *inter-sensor* variances.
- Are prone to *sensor failure*. *(unknown MTBF/MTTF)*
- Redundant sensor configurations.
- Redundant sensors can measure deviating values during operation.
- Have *sensor-body compatibility* variances.
- Can be high-energy consuming devices.

→ Modelling Sensor Capability requirements.

Modelling Sensor Capabilities

Measured values have time-limited diagnostic value. → *(maximum sensor value lifetime)*
Valid sensor measurement evaluation mechanisms:
- Per sensor *dynamic threshold* calculation. *(faulty data/unreliable measurements)*
- Multi-measurement *outlier detection*. *(redundant sensors/deviating values/maximum sensor value lifetime)*
- *Majority voting* by statistical mean. *(redundant sensor configurations/maximum sensor value lifetime)*
- Sensor Online Status *(sensor failure/energy consumption/unreliable quality)*
- Sensor Health Status *(faulty data dynamic threshold evaluation/sensor failure)*
- *Active* sensor package response retrieval *(perceived and actual state of the world synchronisation)*

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Modelling Sensor Capabilities *(Continued....)*

Modelled sensor capability advantages:

The per sensor *dynamic threshold evaluated*, and per person aggregated, *outlier removed*, *maximum sensor value lifetime limited*, averaged sensor value results in a more gradually changing reported *sensor value*.

The *gradually changing* reported value results in less *false positives* or *incorrectly accepted* hypothesised diagnosable symptoms.

The modelled sensor capabilities do not rely on absolute statistical methods with a known or pre-defined:
- Chance of sensor failure. *(MBTF/MTTF)*
- Faulty measurement.
- Availability of *vital sign* change rates.
- Static evaluation thresholds for measured sensor values.

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Modelling Sensor Capabilities *(Continued....)*

Disadvantages of applied methods:

Slightly less absolute accurate representation of most recent measured values.

Slight delay in diagnosis of critical conditions.

Rapid value changes result in an *incorrect rejection* of a hypothesised diagnosable symptom.

Mitigation of *incorrectly rejected hypotheses*

Rejected hypotheses will become accepted *over time* when:
- Measured values have stabilised.
- Expired measured values have been removed.

Known modelling limitation:
- In case only two redundant sensors are available and produce significant different values, no value would be reported for diagnosis *(limitation can be mitigated in future efforts with minimum availability requirement of three redundant sensors.*

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Modelling Sensor Capabilities *(Continued....)*

Disadvantages of applied methods *(Continued....)*:

The *Likely Shot* hypothesis with *rapid SBP-drop* condition would render:

- The *outlier detection* methods not suitable, because this condition is based on an *outlier evaluation*.

Likely Shot – SBP-drop-condition mitigation options

The *dynamic threshold* and *multi-measurement* outlier detection methods could be *disabled* for this sensor type,

or the sensor evaluation and condition algorithms could be expanded to include this exception,

or the outlier detections could be adjusted by:

- Enlarging the *minimum threshold* of the algorithms for the SBP measurement.
- Rapid sensor measurements to allow the linear regression algorithm to adjust.
- Shortening the maximum lifetime of SBP for *outlier detection* improvement.

Agent Modelled Military Health System

Hierarchically modelled Multi-Agent architecture:

- Command Centre related Agents:
  - Command Centre Agent. (aggregate, store, relay and display *diagnosed conditions, calculated rescue counsel*)
  - Database Analysis Agent. (display historic diagnosed conditions)
  - Rescue Counsel Simulation Agent. (display relayed set of *diagnosed conditions* with re-calculated *rescue counsel*)
- Team Agents (aggregate, temporary store, relay, and display *diagnosed conditions*).
- Body Agents (aggregate & evaluate sensor values, diagnose & triage-code *diagnosed conditions*, distribute *triage-colour-coded diagnosed conditions*).
- Sensor Agents (evaluate individual sensor measurements of multiple sensor types).
- Simulation Agents:
  - Staged Scenario Simulation Agent. (team specific)
  - Symptom Simulation Agent. (body agent specific)

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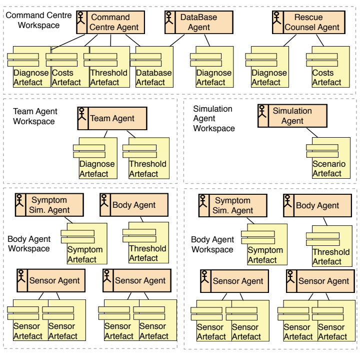
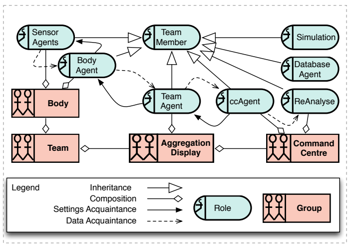
Agent Modelled Military Health System





Agent Modelled Military Health System *(Continued....)*

Have per team and mission specified, *in-mission* adjustable, *institutionally dependent*, thresholds for:

- The rescue counsel costs model.
- Per symptom weighted triage scores.
- Per triage category aggregated scores. (sensor typed risk-zones and diagnosable symptoms)
- Per value of each diagnosable symptom.
- Per value of all sensor typed risk-zones.
- Per Body Agent, sensor typed, maximum sensor value lifetime.
- Per initialised sensor, a *sensor calibration* value. (sensor-body compatibility/inter-sensor variability)
- Personalised threshold values for all risk-zones and diagnosable conditions. (inter-personal differences & tolerances)

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Agent Modelled Military Health System *(Continued....)*

Analysis capabilities:

- Team Agent aggregated diagnosed conditions.
- Command Centre Agent:
  - Aggregated real-time diagnosed conditions with rescue counsel.
  - Weighted diagnosed condition and costs model simulation based on *snapshot* dataset.
  - Real-time historic analysis of every recorded diagnosed condition of every Body Agent in any mission.

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Agent Modelled Military Health System *(Continued....)*

Further military specific capabilities:

- Radio Silence functionality.
- In-mission adjustable thresholds specifiable per team and mission.
- Rescue counsel *simulated-adjustment* environment for more desirable *counsel* results.
- Little overhead from *communication protocols* and *organisational Speech Acts* by not fully implementing the modelling concepts of *Organisation and Interaction*.

Demonstration of developed Military Health System

Demonstration ....

Conclusion

The advantages of this modelled distributed medical triage system:

- Can handle *institutional* disagreements.
- Can reason about multiple uncertain situational factors.
- Can be adjusted to personal and *institutional* preferences.
- Can perform automated remote triage without human intervention.
- Can be extended by non-programming experts, in the medical or military profession.
- Clear diagnosable symptom set and hypothesis confirmation conditions.
- Provides counsel with historic insight capabilities.

The developed Multi-Agent Military Health System provides an automated demonstrable environment for remote distributed medical triage with sensor based *rescue initiation counsel* according to presented specifications and in compliance with military requirements.

Questions

Master Thesis Defence Scheduled Questions ....