Intelligent control engineering and AI in education and research at the Department of ICT and Natural Sciences at NTNU

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8 November 2018

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1 Background

In October 2018 I was asked by the head of the department to create an overview of AI research activities and courses taught at the department. Having joined the department in 2008, I have limited insight details predating this time. Nevertheless, to the best of my knowledge, I have attempted to provide an overview of the history, as well as current research and education activities and topics in AI being explored by staff at IIR, from my point of view as the head of the Cyber-Physical Systems Laboratory (CPS Lab).

The following is my personal account and there may well be information and activities of which I am not familiar with, or that I have portrayed slightly inaccurately, for which I apologise in advance. My fellow colleagues are invited to provide comments and suggestions for changes to this document.

2 The history of AI

The application of AI amongst staff at the IIR department has its roots almost 20 years back in time. In the early 2000s, the scientific fields of cybernetics and AI were typically quite separate fields, with researchers having limited knowledge about methods and theory outside their own field. Nevertheless, at the IIR department, good colleagues Webjørn Rekdalsbakken og Ottar L. Osen had started to investigate the possibility of applying AI in combination with control theory for solving cybernetical problems, an approach we might call *intelligent control engineering* (ICE). Through their own research and bachelor projects, they explored how methods from AI such as fuzzy logic, expert

systems, machine learning (ML) and artificial neural networks (ANNs), and evolutionary algorithms (EAs) such as genetic algorithms (GAs) could be used for controlling an inverted pendulum, motion platforms with 3 and 6 DOFs, and a ship autopilot, all of which are well-known and challenging problems in control theory. This work led to the creation of a new course, *Intelligent Systems*, which became a compulsory course for the bachelor degree in automation engineering and an elective course for the bachelor degree in computer engineering.

In the aftermath of this pioneering work, a sequence of scientific papers followed that concerned the use of AI in cybernetics and for solving practical real-world problems:

- *Design and Application of a Motion Platform in Three Degrees of Freedom* [1]

- *Feedback Control of an Inverted Pendulum with the use of Artificial Intelligence* [2]

- *The Use of Artificial Intelligence in Controlling a 6DOF Motion Platform* [3]

- *Feedback Control of an Inverted Pendulum by Use of Artificial Intelligence* [4]

- *Simulation of Intelligent Ship Autopilots* [5]

- *Intelligent Control of an Inverted Pendulum* [6]

In addition, Harald Yndestad was working on agent-based modelling and simulation (ABMS), which also became a central theme in the strategical university college project (SHP) *Virtuelle Møre*, financed by the Research Council of Norway (NFR). Yndestad also headed the development of a new master degree programme in simulation and visualisation, of which AI was going to play an integral part. The master programme was approved by the Norwegian Agency for Quality Assurance in Education (NOKUT) in 2012, with the first enrolment of students autumn 2014.

2014 was also the year when the Software and Intelligent Control Engineering Laboratory (SoftICE Lab) was established, with Hans Georg Schaathun as the head. The SoftICE Lab changed its name to the CPS Lab in spring 2018 to reflect the rapid changes in modern technology revolving around the Internet of Things (IoT), Industrial IoT (IIoT), and Industry 4.0, all of which have cyber-physical systems at its heart, and in which AI and cybernetics play a key role.

Since then, the department has experienced a formidable growth in AI-related education and research activities, with the creation three new courses at the master level and a long list of scientific publications as a result.

3   AI in education

As of today, the department offers four courses within the field of AI:

- IE303312 Intelligent Systems (BSc in Automation Engineering)
  - Teacher: Ibrahim A. Hameed
  - Former teachers: Robin T. Bye, Saleh Alaliyat, Ottar L. Osen, Harald Yndestad
  - Topics: Can be modified each semester; common topics include fuzzy logic, ekspert systems, ANN, ABMS, EAs and optimization,, etc.

- IE501614 Machine Learning (MSc in Simulation and Visualization)
  - Teacher: Ibrahim A. Hameed
  - Former teachers: Robin T. Bye, Hans Georg Schaathun (in an earlier version called IE501614 Functional Programming and Intelligent Algorithms)
  - Topics: supervised/unsupervised learning, support vector machines (SVM), ANNs (classical, deep, convolutional, recurrent)

- IE502014 Artificial Intelligence (MSc in Simulation and Visualization)

  – Teacher: Robin T. Bye

  – Former teachers: Ibrahim A. Hameed

  – Topics: introduction to AI and intelligent agents, uninformed/informed search algorithms, local search, adversarial search, constraint satisfaction problems (CSPs), GAs and optimization

- IE501714 Swarm intelligence (MSc in Simulation and Visualization)

  – Teacher: Saleh Alaliyat

  – Former teachers: Ibrahim A. Hameed

  – Topics: ABMS, social agents and boids, particle swarm optimisation (PSO), ant colony optimisation (ACO), bees colony optimisation, evolutionary agents, multirobot path planning and task allocation

Moreover, elements from AI are in use both in the bachelor course *IE303412 Cybernetics* (optimisation and tuning of a controller using a GA) and the master course *IE502114 Virtual Worlds* (intelligent agents), and the creation of a new course called *Agent-based Modelling and Simulation* is under consideration.

Finally, many students employ AI both in smaller course projects and during their bachelor thesis, even if they have not chosen the elective course Intelligent Systems. Supervisors then contribute with knowledge, references, and material related AI that the students can make use of.

4 AI in research

The last few years, several research projects at the department have involved members from the CPS Lab (formerly SoftICE Lab) and the Digital Transformation Lab, who have employed AI for applied research and development (only publications related to AI are shown):

- (2008–12) *Virtuelle Møre*

  – Financing: SHP (NFR)

  – Participants from IIR: Harald Yndestad (project leader), Robin T. Bye, Siebe van Albada

  – Topics: Virtual worlds, intelligent agents, ABMS, dynamic resource allocation, EAs, bio-inspired algorithms

  – Selected publications: [7–14]

- (2012–13) *A Flexible and Common Control Architecture for Rolls-Royce Marine Cranes and Robotic Arms*

  – Financing: MAROFF BIP (NFR)

  – Partners: Rolls-Royce Marine, Offshore Simulator Centre

  – Participants from IIR: Robin T. Bye, Siebe van Albada, Hans Georg Schaathun

  – Topics: virtual prototyping, crane design, GAs, ML, ANNs

  – Selected publication: [15]

- (2013–14) *Dynamic Resource Allocation with Maritime Application (DRAMA)*

  – Financing: RFF (NFR)

  – Partners: Molde University College, Naval Postgraduate School (Monterey, USA)

- – Participants from IIR: Robin T. Bye (project leader), Siebe van Albada, Mikael Tollefsen, Hans Georg Schaathun
  - – Topics: optimal dynamic positioning of ships, GAs, mixed integer programming (MIP), optimization
  - – Selected publications: [16–22]
- (2014–15) *AI for Crane Design (KIK)*
  - – Financing: VRI (NFR)
  - – Partners: IHB, ICD Software
  - – Participants from IIR: Robin T. Bye (project leader), Ottar L. Osen, Ibrahim A. Hameed, Hans Georg Schaathun
  - – Topics: virtual prototyping, EAs, bio-inspired algorithms, multiobjective optimisation (MOO)
  - – Selected publications: [23–27]
- (2015–present) *Design driven field studies for safer demanding marine operations (ONSITE)*
  - – Partners: The Oslo School of Architecture and Design, DNV GL, Ulstein Group, Pon Power AS
  - – Participants from IIR: Hans Georg Schaathun (project leader), Aya Saad, Mikael Tollefsen
  - – Topics: field studies, semantic web, ontologies, multimedia metadata, ML, ANNs
  - – Selected publication: [28]
- (2016–17) *An Approach toward Optimal Control of Ship Manoeuvring in Offshore Operations*
  - – Financing: RFF (NFR)
  - – Partners: IHB, Rolls-Royce Marine, Offshore Simulator Centre
  - – Participants from IIR: Hao Wang
  - – Topics: optimal ship control, ML, ANNs
  - – Selected publication: [29]
- (2016–17) *AI for Winch Design (KIV)*
  - – Financing: VRI (NFR)
  - – Partners: IHB, Seaonics
  - – Participants from IIR: Robin T. Bye, Ottar L. Osen, Ibrahim A. Hameed, Webjørn Rekdalsbakken
  - – Topics: virtual prototyping, EAs, MOO
  - – Selected publications: [30, 31]
- (2018–present) *CodinGame: Development of E-Learning Material for Programming*
  - – Financing: Excited (NTNU)
  - – Partner: Nord University
  - – Participants IIR: Robin T. Bye, Ottar L. Osen
  - – Topics: E-Learning, algorithms (search, optimisation, EAs, etc.) and data structures in AI
- (2018–present) *Social Robots*
  - – Financing: NTNU

- Partners: IHA, Haram municipality

- Participants from IIR: Ibrahim A. Hameed, Girt Strazdins

- Topics: social robots, health and welfare, ML, ANNs

- Selected publication: [32]

- (2018–present) *NTNU-Sparebanken Møre TEFT Lab*

  - Financing: Sparebanken Møre, NTNU

  - Partners: IIF, Sparebanken Møre

  - Participants from IIR: Ibrahim A. Hameed, Hao Wang, postdocs, PhD students

  - Topics: service innovation, entrepreneurship, finance and technology, ML, ANNs

- (2018–present) *Autonomous Ships*

  - Financing: NTNU, ERCIM

  - Partners: ITK

  - Participants from IIR: Robin T. Bye (project leader), Ottar L. Osen, Ibrahim A. Hameed, Anete Vagale, Elias Hasle, Rachid Oucheikh

  - Topics: path planning, collision avoidance, situational awareness, EAs, bio-inspired algorithms, ABMS, ML, ANNs, etc.

  - Selected publication: [33]

Several AI-related papers have also been published by department staff through work not necessarily related to the projects above [34–45].

5 Summary of current topics in AI and active researchers

The topics in AI listed previously in educational and research activities can be summarised as follows:

- ML/ANNs

- search and optimisation algorithms

  - EAs, bio-inspired algorithms, swarm algorithms (GA, PSO, ACO, Bees Colony Optimisation, Grey Wolf Optimization, etc.)

  - search algorithms for finding goals or path planning (DFS, BFS, Uniform Cost Search, Iterative Deepening, A*, GA, etc.)

- fuzzy logic, expert systems, adaptive neuro fuzzy inference systems (ANFIS), etc.

- intelligent agents and ABMS

- knowledge-based reasoning, semantics, ontologies

Based on *my subjective perception* and the educational and research activities presented above, the following permanent staff at the department can be defined as being active within the field of AI:

- Hans Georg Schaathun, professor

- Robin T. Bye, associate professor

- Ibrahim A. Hameed, associate professor

- Ottar L. Osen, associate professor

- Saleh Alaliyat, assistant professor

In addition, the following departmental postdocs and PhD students are active in AI:

- Rachid Oucheikh, postdoc, *Autonomous Ships*

- Anete Vagale, PhD student, *Autonomous Ships*

- Elias Hasle, PhD student, *Autonomous Ships*

- Aya Saad, postdoc, *ONSITE*

- 3–4 PhD students, *TEFT*

Finally, a number of staff have good knowledge of AI and/or have contributed to one or more research projects and published scientific articles where AI has been central. In *my personal opinion* these persons include Webjørn Rekdalsbakken, Siebe van Albada, Girt Strazdins, and Hao Wang.

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