The KOMPAÏ Challenge

Implementing Asimov's Laws

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***Abstract*—This document describes work done by our team during the last 12 months. We went deeper into motion anticipation and started intentions anticipation, based on linguistic intelligence. We provide the results, and explain the next step which will include a campaign of data acquisition in several nursing homes. We also update the team description, with 2 newcomers, including an academic partner.**

Keywords: motion anticipation, behavior anticipation, ethical robots, service robots

I. Problem Statement

Our main idea is to develop Artificial Intelligence (AI) tools and solutions to guarantee the ethical behavior of robots. We want to focus first on frail and isolated individuals, the most vulnerable population.

As demonstrators, we suggest using Asimov's laws as basic ethical behaviors :

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws

We are developing robots to help frail people and their caregivers, but we consider that robots in themselves, and AI in particular, are not meant to replace humans, though demographics could easily help argue to the need of supplementing a quantitative lack of caregivers. That is why our robots aims to facilitate social links rather than destroy them.

Since making ethical robots is a huge challenge, we decided during Year 2 to focus on Law 2 with motion anticipation, and start dealing with Laws 1 and 2 by understanding intentions of users, which is the core problem. Thanks to anticipation, our solution will reduce the two main risks for frail people: injuries and human isolation.

II. Developing Technologies

We already developed the motion anticipation module, started in year 1.

A. Motion anticipation

We have built hierarchical estimators using machine learning and neural network techniques to predict the robot's positions. Lower layer algorithms detect short-term patterns in collected data and past motions to estimate positions at different times in the future. Higher layer algorithms use larger memory states (older values) to classify the robot's behavior, select the adequate prediction time-span.

AI algorithms look to learn the position at several seconds by relying on past data considered "normal" and without any situation incompatible with the risks (related to Asimov's laws) we want to reduce.

We also worked on training a model to directly detect non-compatible situations, by adding a set marked as incompatible to the database and that presents a risk for human beings or the robot itself. Since it is less general, it can contribute to increased robustness of algorithms in situations where the model has been trained.

B. User's intentions

We are developing a specific chatbot for elderly people in nursing homes, from which we plan to extract unethical or risky intentions of users, for both patients and caregivers.

The concept of linguistic intelligence is based on the scientific understanding of the functioning of language (theoretical research) and the automatic understanding of texts (practical research). See references [14] to [16].

The automatic understanding of texts involves an analysis of the information, which proceeds in three steps:

1. Extraction of the data (identify information in a text in a linguistic form)
2. Qualification of the data (associate an information recognized with a meta-information)
3. Interpretation of the data.

This analysis of the information is performed by a semantic analysis machine that simulates three human linguistic capacities:

- The first capacity is lexical capacity, the memorization of the words. Digital tools reproduce this capacity by exploiting large electronic dictionaries.
- The second capacity is structural capacity. For the automatic analysis of texts, three levels are fundamental: a) the morphological level; b) the syntactic level: c) the semantic level. Formalized descriptions of the morphological, syntactic and semantic structures of languages allow a semantic analysis engine to reproduce this capacity.
- The third capacity is combinatorial capacity: express the same concept in all kinds of ways. This capacity is reproduced through a conceptual classification of utterances from the calculation of the relevant word combinations that built on the two previous capacities.

Through the simulation of these three capabilities, information is identified and semantically qualified by inserting tags. Meta-information added to the texts is then exploited by a base of rules to interpret it.

C. *Behavior management*

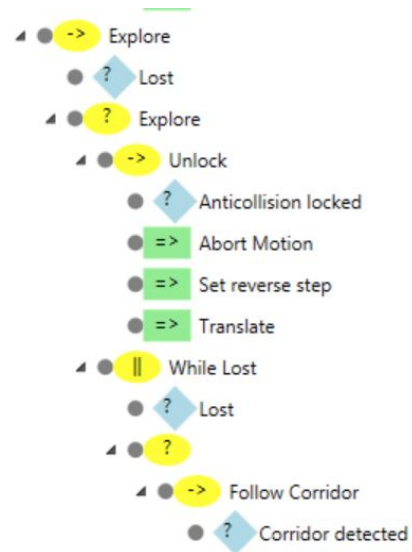
We are developing our own implementation of behavior trees on the top of the Artificial Neural Network described in section B to manage risks, see references [17] to [21].

See also Figure I for an example of implementation, the situation of "LOST" robot.

If a situation occurs where the algorithms predict a risky situation, then two possibilities emerge: a) the prediction is wrong and it is a false alert and probably an unnecessary correction, b) the prediction is correct and then there is a correction to be made. In this scenario, there is a predictor, a module that indicates if the prediction is problematic and a correction to be created. We are working on algorithms that aims to give weights to predictions at Nx1 seconds by combining several predictors.

Depending on predictions, the behavior tree will decide what to do to reduce risks and respect Asimov's law as well as possible.

Figure I. Excerpt of our behavior tree in "LOST ROBOT" situation



D. *Available data*

The robot we are developing is for cognitive and physical assistance, able to collect the following data :

- Position of the robot in a map
- Speed of the robot
- Laser scans
- Video images
- Conversations between users and robots
- Position of the user relative to the robot
- …

Data is used as input for the various AI modules described above.

As needed, we can validate that we are able to complete the robot's information with environmental data: switches on doors and windows, temperature, humidity, light, motion, UV, vibrations …

III. Technology Impact

We shall improve the everyday life of a worldwide ageing population. In 2015, 900 million of persons were aged 60 or over, representing 12.3% of the population while they will number 1.4 billion in 2030 (16.5% of the whole population) and 2.1 billion in 2050 (21.6% of the population). By 2030, the age 60 or older population will rapidly grow all around the world: 71% in Latin America and the Caribbean, 66% in Asia, 64% in Africa, 47% in Oceania, 41% in North America, and 23% in Europe. Projections indicate that in 2050 the 80 &

older population will number 434 million, having more than tripled in number since 2015, when there were 125 million.

Human assistance is the best answer to the needs of frail persons because it provides physical and cognitive assistance. However, the proportion between older persons and others (being able to provide support) will worsen: in 2015, one in eight[1] people worldwide was aged 60 years or over. By 2030, they are expected to account for one in six[1] and one in five[1] by 2050. The workforce will not grow fast enough to face the growing number of elderly (+56% by 2030). The OCDE[1] expects that the typical caregiver profile (women between 23 years old and 44 years old) will only grow by 7%. Thus, solutions have to be found to anticipate this trend.

For these reasons, robots will soon accompany a lot of elderly and frail people in their everyday life. One of the main identified ethical risk mentioned by Serge Tisseron is on the affective side : there is no way to avoid people loving their robots, as people can love other objects, but manufacturers can develop robots which fulfil users' wishes, leading them to consider that their robot loves them too. The direct consequence will be that users may start preferring spending time with robots rather than with unpredictable human beings. At that stage, robots will start replace people.

We believe that our work in this endeavor may pave the way towards robots able to increase social links between people rather than increasing isolation : we consider that isolation is harmful, and that according to Asimov's laws, a robot must avoid human beings come to harm.

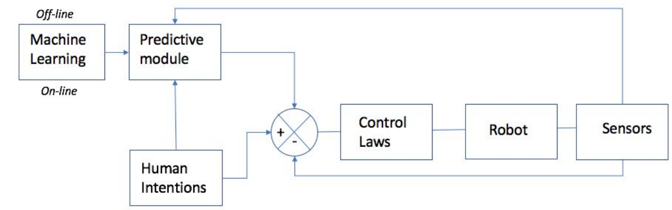
IV. Technical evaluation

Our basic idea is to develop an operational "predictive module" that is generic. Indeed, the prediction of the intentions of a user or the movements of a robot under the influence of external actions is one of the keys to the robotics of tomorrow: it means to anticipate behaviors, to avoid being reactive when it is often too late. The best illustration remains the dilemma of the autonomous vehicle that must choose the least worst of solutions in case of an impending accident. Being able to anticipate and therefore avoid these situations would provide some answers. More generally, giving robots an ethical dimension, for example, by allowing them to respect Asimov's laws, is one of the other big issues.

Our idea is therefore to have a module capable of processing a large number of heterogeneous input data, to select and train neural networks that give prediction information to the control laws, then to make a real-time implementation of this module on a Raspberry type card. Such a module can be used on-board in most service robotics applications, and operate in real-time.

[1] Help Wanted ? Providing and Paying for Long Term Care OECD Health Policy Studies, OECD Publishing, 2011

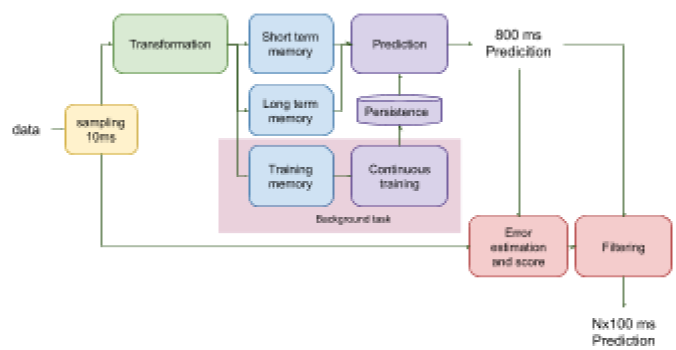
Figure II. Generic Predictive Module



We put in place a modular software development environment that allowed us to test different types of neural networks from the data that was provided, and to obtain the results described below.

The following figure shows the architecture chosen as a solution for the prediction. It consists of four main functions: a) transformation function, b) prediction function, c) continuous learning function and d) filtering function or selection of the prediction period.

Figure III. Architecture of the predictive model



Among the many solutions developed and tested, here are those that have been specifically studied in simulation and used in the first implementation

- **First order estimator**: estimate based on an angular velocity calculated on the last N available samples provided by the transform functions.
- **Linear regression**: linear regression with presence or absence of one or two order regularization function. Non-linearity introduced by the choice of transformations carried out downstream.
- **Polynomial interpolation**: performed by a two-function pipeline
  - calculation of "features" of degrees 2 or 3 (including cross products)
  - linear regression on the basis of the new "features" with presence of a degree 1 or 2 regularization function.
- **Simple neural network**: simple network of "Multi-layer Perceptron" type up to 8 layers and several types of activation function

- **Deep neural network**: More complex neural network with many types of combinations of activation and generalization functions (drop) using Tensorflow libraries via Keras. Integration into the scikit-learn API for compatibility with the rest of the environment.
- **Network type LSTM**: recurrent network with LSTM cell in the dual idea of being able to detect behaviors corresponding to long sequences and without having to increase the size of the layers of the multi-layer perceptron style.
- **Extreme machine learning**: Simple neural network with fast learning of extreme machine learning type. Hoping to accelerate continuous learning.

V. Problem Impact Evaluation

Our approach is to anticipate motions of robots and intentions of users, and apply rules to decide whether the forthcoming situation is in line with Asimov's Laws. But the practical measurement of ethical behaviors is not easy, the first approaches being in the business area [13]. Such methods are based on direct and indirect questionnaires, text analysis ... which cannot be used in real-time.

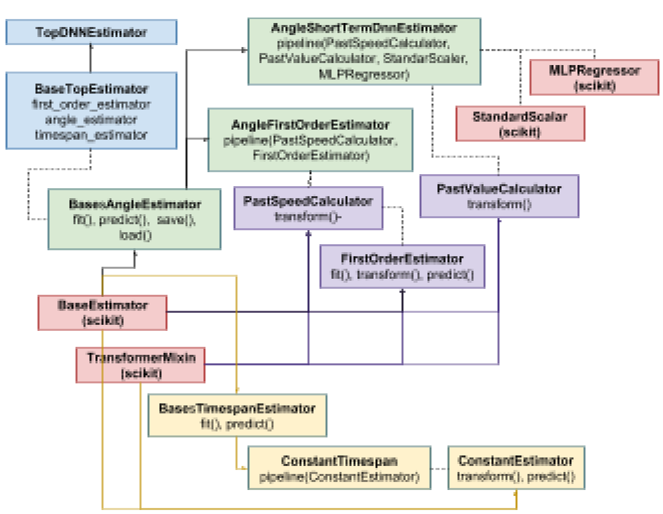
Our contribution is not the definition of rules, but a module being able to anticipate a forthcoming situation based on motion and speech analysis. To have the opportunity to avoid unethical situations before they occur, by using more classical measurement methods as mentioned in [13]. This part is still at the definition stage.

We describe below the results we got for motion anticipation, and how we plan to do for intention anticipation.

VI. Results of motion anticipation

We built a complete framework written in Python for algorithm development and real time implementation of linux hardware (illustration on figure IV).

Figure IV. Development framework

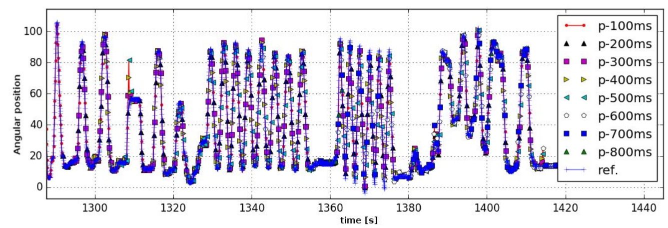


It is a very modular approach where all pieces of the motion anticipation solution are modules derived from base classes and therefore it is very easy to test or implement various types of machine learning algorithms.

Figure V illustrates prediction results of an angular position using an adaptive timespan between 100 ms and 800 ms.

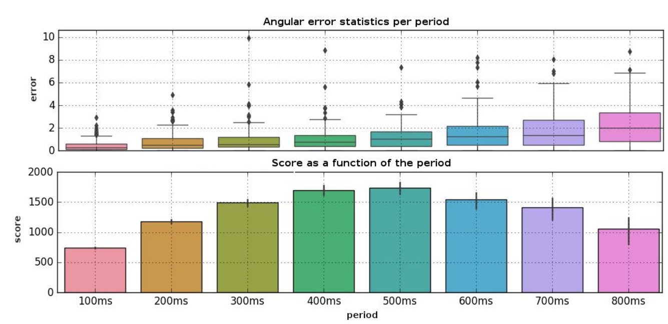
The model is able to cope with various types of movements and different speeds and can predict behaviour very close to or even beyond the "local period" of a displacement which is interesting because it proves that the solution is able to learn complex behaviors that goes far beyond simple linear regression.

Figure V. Angular position prediction



And indeed, we can observe the statistics of the prediction error (figure VI) and score that have a good distribution among the prediction period which means that the error remains small enough at a long prediction span in order to anticipate the motion of the robot.

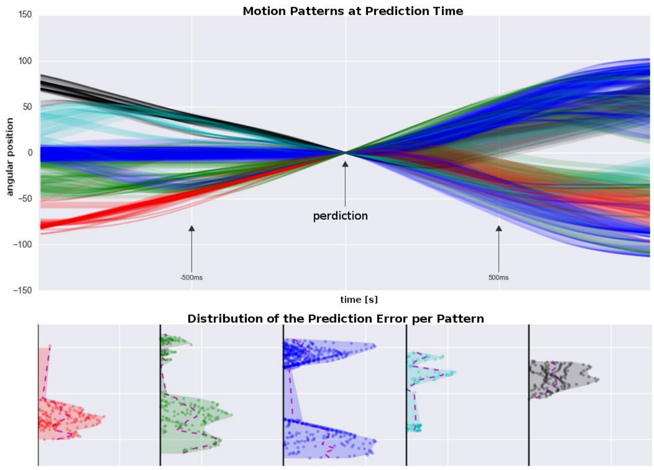
Figure VI. Prediction Statistics



The ability to learn in real time motion patterns is the key point towards longer timespan predictions. And at higher level it is necessary to include a new layer in the prediction like the intention anticipation because there are situations where it is more challenging to make predictions, for example when there is suddenly a major change in the motion.

In figure VII, motion patterns with different colors are shown at prediction time during challenging situations.

Figure VII. Distribution of prediction



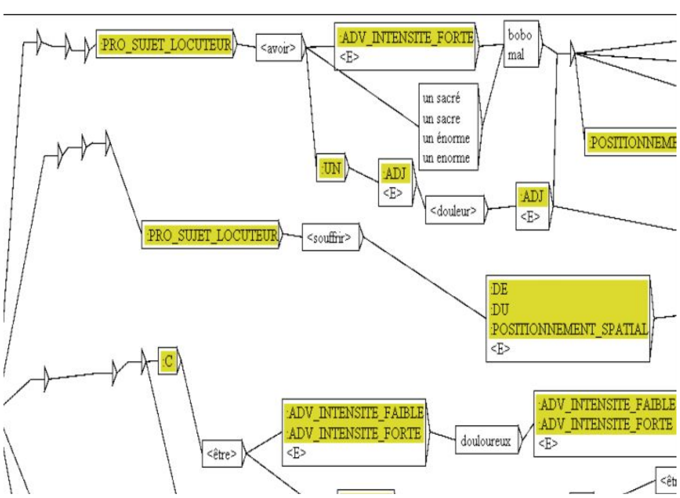
The distribution of the error shows that it is when there is suddenly a different pattern that the prediction is less accurate.

External information having information about the reason of the sudden changes can significantly improve the quality of the prediction, for example with contextual information from user's anticipation. The detection and classification of specific patterns is also the base of the scheme for the detection and marking of non-compatible situations where there is a risk for the human being or robot.

VII. Intentions anticipation

Regarding intentions anticipation, we have not yet completed development work, we have started developing local grammars (see figure VIII , an excerpt of "health issue"), and are preparing acquisition campaigns.

Figure VIII. Excerpt of local grammar (health issue)



The general context is that of personalized assistance to the elderly such as robots intervene in addition to caregivers. One of the objectives is to facilitate the dialogue between a user and a robot, but also between patients and caregivers.

The verbal interactions processing focuses on requests for information, such as obtaining visiting hours, and requests for action, such as calling a loved one on the phone. These requests are done by user either directly, in the form of an order, or after a solicitation of the robot. The robot must be able to understand them and respond by providing the desired information or by acting as specified. Other aspects of the dialogue are solicited. In particular, the information related to the state of health of the user; for example, an indication of particular or general suffering. From this point of view, the data processed by the robot are in accordance with the first Asimov's Law, because they enable it to alert the user's entourage in case of painful physiological or psychological feeling and, as a result, to obey the first Law, especially its second term: "through inaction, allow a human being to come to harm".

This approach is also in compliance with the second law since it obeys "the orders given to it by a human being" in the form of a request for information or action. The second part of the law "as long as such protection does not conflict with the First Law" implies associating, where appropriate, claims formulated by user with indications of dangerousness so that a danger is detected through a request. Not only, the robot must not obey the order but it must alert the user's entourage of the identified danger. This aspect of the second law is problematic from the point of view of the autonomy of the user and his freedom to decide. One solution would be to modulate the dangerousness according to the users. Asking to leave one's room has different consequences depending on whether the patient is suffering from senile degeneration or whether he has full possession of one's intellectual faculties.

The third law requires a comment. Its non-contradictory feature applies entirely to the first law but partially to the second. The latter has two parts: one concerns the need to obey to human being, the other the fact that given orders do not endanger any human being. It follows that the third law prohibits a robot from obeying orders that destroy it unless those orders save a human life. The short story "Closed Cycle" of Isaac Asimov (The cycle of robots volume 1) illustrates this problem inherent in the third law. As part of the project, this law is implemented by identifying requests from a user corresponding to orders that jeopardize the integrity of the robot, and by not responding to these demands.

As far as verbal interactions are concerned, our research aims to integrate the three laws of robotics into their language interpretation module. It involves identifying information and associating it with meta-informations related to these three laws and their internal coherence.

VIII. Next Steps

Our next step is a project of massive real world data acquisition. The project should take at least 6 months, followed by analysis and processing work.

With the European leader of nursing homes onboard, KORIAN Group, (almost 750 facilities), we have much more locations and persons (both residents and caregivers) than needed to carry out the acquisition campaign.

We are preparing two complementary data acquisition campaigns but in a single session, one for the motion anticipation of the robot and the other one for users' spoken intentions.

In these two campaigns, we plan to tag ALL encountered situations as Asimov's Laws compliant or not. We shall also try to tag ethical/unethical situations. We expect this work will contribute to better define when Asimov's laws are respected or not from real situations. The same for the meaning of ethical/unethical behaviors of robot.

In terms of developments, we also shall do the following during the next year :

- Apply tools of motion prediction to emotion prediction, to get real-time processing of both
- Develop relevant behavior trees using our proprietary technology, in a few identified situations, to prevent infringement of Asimov's laws
- Prepare a full demonstrator, a complete robot with AI anticipation functions
- Define metrics to demonstrate our system capabilities. We will focus on measuring reduction of injuries for residents, and increase of social ties between residents and caregivers, which is a good illustration of isolation reduction.

A. Data campaign for motion anticipation

Our latest robot, Kompaï-3, is still under development but first prototypes should be available before the end of the year.

Kompaï-3 is the result of Kompaï-1 and 2 findings, enriched by a unique validated mechanism for mobility assistance. It can provide the same support as a robust caregiver for mobility assistance. It has been fully designed for frail people and caregivers, it is not a general purpose robot developed for healthy people. It is also smaller than previous versions (providing more visibility when walking), no bigger than a standard chair, a better ergonomy (more space for feet), 360° vision with the bottom laser (better localization in the building), sensors for patient's legs movement detection to control speed and direction, RFID antenna in the head.

Three robots, equipped with a data acquisition module (see section "Data Available" above), will be used for six months in at least three differents facilities to collect enough data. This data, totally anonymous, will be stored in the cloud to be processed.

B. Data campaign for user's intentions

We have scheduled a campaign to acquire spoken data in the next months, in KORIAN's facilities.

We will record conversations between residents, caregivers and the robot. From these conversations, we will recover as sound files, a set of records that will serve as a corpus of work. The topics of conversation of users are of all kinds. Several potential topics have been identified, but many more remain to be discovered, this is one of the objectives of the campaign. For instance :

Requests for information:

- Request for information on TV programs
- Request time information
- Request for information on meal menus
- Request information on activity schedules
- Request information on visiting schedules
- Request for information on activities
- Request for information on weather
- Request for information on the date
- Request information about the time of day
- Request for information on visits
- ...

Requests for action:

- Request for action related to a health problem
- Action request about a drug intake
- Request for action relating to listening to a radio
- Action request for a television program
- Action request for reading an audiobook
- ...

The parameters to be taken into account in the profiling of the users are :

- Sex: man / woman
- Age: a) under 80 years of age; (b) between ages 80 and 90; (c) between 91 and 100; d) older than 100
- Level of dependence: a) independent; b) dependent; c) very dependent
- Cognitive state: a) very alert; b) alert; c) not very alert

For each profile, we must select 3 candidates. If possible, the social level of the 3 candidates should be different. What is done by 3 levels of language: 1) sustained; 2) normal; 3) familiar.

Thus, while we theoretically need 216 candidates (which may be difficult, because, for example, finding 3 men over 100 years old, independent and very alert is unlikely), we must try to to have a minimum number that corresponds to the 72 profiles to have a wide variety of informants.

IX. IRB Review Status

In our projects, we solicit a dedicated ethics committee before undertaking experimentation, within the PPC (Patient Protection Committee) procedure. We are required to present the details of the experiment and how we will protect the privacy of the participants: the committee then makes a decision. This process is experiment-specific, and must be conducted for each campaign. This campaign being similar in ethics as to those we have already conducted, we are confident in the Ethics Committee's approval. The PPC requires the informed consent of patients/residents, or of their family when they are under guardianship. Also, all data acquired and transmitted during the campaign will be anonymized.

In any case, we plan for the commercial version to apply a general ethical code, preferably an international standard that applies to service robots. Work of this type is currently applied in the UK; the BSI (British Standard Institution) published early 2016 a proposal entitled "Guide to the Ethical Design and Application of Robots and Robotic Systems" ref 8611:2016.

We want to contribute to the emergence of international ethical rules for such robots (in touch with frail people) design, which will help facilitate industrial deployment by helping to shape the rules governing the fundamental ethics of robotics.

X. About the team

KOMPAÏ robotics started alone, and ADITEM joined us in the first year, as the specialist in "real-time" AI. They work on the motion anticipation problem.

In year 2, we completed the team with Teamnet, a software development company, having human resources available for developments and experimentations, and Laboratoire TTN in Paris, experts in "linguistic intelligence" to work on users' intentions extracted from spoken exchanges with the Chatbot.

KORIAN Group, the European leader of private nursing homes, (almost 750 facilities, 250 000 patients/residents and almost 50 000 employees) is an historic partner of KOMPAÏ robotics. They allow us to experiment with their staff and residents. They also manage all legal and ethical issues related to these experimentations.

References

A. Motion anticipation

The references below (from [1] to [12]) deal with prediction using Artificial Intelligence which is a topic that has been addressed by several researchers in different fields.

<u>In robotic applications</u>, Abdul M. K. et al. [1], for a robotic rehabilitation application, used a method based on the Extreme Learning Machine (ELM) to predict the intent of the human movement. ELM stands out from other learning methods with unique features such as extremely fast training, good generalization and universal approximation ability [2] [3]. Moreover, this methodology teaches the function with a minimum of neurons and therefore involves a minimum calculation cost. The developed algorithm was implemented on a 2-axis exoskeleton to predict arm movements based on information such as position, force exerted and velocity. The results show that this ELM method can successfully learn the human movement model and can predict future motion based on its sensor inputs. However, in the article he does not give the prediction periods.

[1] Abdul Manan Khan, Fatima Khan, and Changsoo Han, "Estimation of Desired Motion Intention using Extreme Learning Machine for Upper Limb Assist Exoskeleton", IEEE International Conference on Advanced Intelligent Mechatronics (AIM) Banff, Alberta, Canada, July 12–15, 2016

[2] G. Huang, G.-B. Huang, S. Song, and K. You, "Trends in extreme learning machines: A review," Neural Networks, vol. 61, pp. 32–48, 2015.

[3] C. Deng, G. Huang, J. Xu, and J. Tang, "Extreme learning machines: new trends and applications," Science China Information Sciences, vol. 58, no. 2, pp. 1–16, 2015.

A. Siswoyo, Z. Arief [4] implemented an artificial neural network for predicting the direction of the electric wheelchair using the input of the brain signal through an electroencephalogram (EEG). Good results obtained on the control of the wheelchair. However, this work remain specific to the use of this type of sensors. D. Varshneya, G. Srinivasaraghavan [5], and A. Bera [6] worked on methods of predicting trajectories of people in overcrowded scenes using deep learning coupled with a soft focus mechanism and algorithms of Bayesian learning. The results have been validated by simulation but must be evaluated in the real world (for example to predict the trajectory of an autonomous vehicle in an overcrowded area).

[4] [Agus Siswoyo, Zainal Arief, Indra Adji Sulistijono, Politeknik Elektronika Negeri Surabaya "Application of Artificial Neural Networks in Modeling Direction Wheelchairs Using Neurosky Mindset Mobile (EEG) Device" International Journal of Engineering Technology Vol. 5, No. 1, June 2017

[5] D. Varshneya et G. Srinivasaraghavan "Human Trajectory Prediction

using Spatially aware Deep Attention Models" International Institute of Information Technology Bangalore May 2017
[6] A. Bera, T. Randhavane, R. Prinja and D. Manocha, "SocioSense: Robot Navigation Amongst Pedestrians with Social and Psychological Constraints", University of North Carolina at Chapel Hill, USA 2017

In the industry to predict the wear of machining tools: Bukkapatnam et al. [7-9] have developed effective tool wear monitoring techniques using Artificial Neural Network (ANN) based on characteristics extracted from the principles of nonlinear dynamics. Ozel and Karpat [10] presented a predictive modeling approach to surface roughness and tool wear for hard turning processes using ANN. The inputs of the ANN model include the hardness of the workpiece, the cutting speed, the feed rate, the axial cutting length, and the average values of three force components. Experimental results have shown that the driven model provides accurate predictions of surface roughness and tool sidewall wear

[7] Bukkapatnam, S. T., Lakhtakia, A., and Kumara, S. R., 1995, "Analysis of Sensor Signals Shows Turning on a Lathe Exhibits Low-Dimensional Chaos," Phys. Rev. E, 52(3), p. 2375.
[8] Bukkapatnam, S. T., Kumara, S. R., and Lakhtakia, A., 2000, "Fractal Estimation of Flank Wear in Turning," ASME J. Dyn. Syst. Meas. Control, 122(1), pp. 89–94.
[9] Bukkapatnam, S., Kumara, S., and Lakhtakia, A., 1999, "Analysis of Acoustic Emission Signals in Machining," ASME J. Manuf. Sci. Eng., 121(4), pp. 568–576.
[10] Ozel, T., and Karpat, Y., 2005, "Predictive Modeling of Surface Roughness and Tool Wear in Hard Turning Using Regression and Neural Networks," Int. J. Mach. Tools Manuf., 45(4), pp. 467–479

In the health sector, Jing Ma and Jiong Yu [11] analyzed the relationship between triglycerides (TG) and cholesterol (TC) with liver and kidney function indices, to develop a TG, TC prediction model. in overweight people using ANNs. The ANN model of TG achieved its training goal at 59 iterations, while the TC model achieved high prediction accuracy after 1000 iteration training. Popular AI techniques include machine learning methods, neural network and modern deep learning are used in stroke in the three main stages: early detection and diagnosis, treatment, predicting outcomes and assessment of prognosis [12].

[11] Jing Ma, Jiong Yu, Guangshu Hao, Dan Wang, Yanni Sun, Jianxin Lu, Hongcui Cao and Feiyan Lin, "Assessment of triglyceride and cholesterol in overweight people based on multiple linear regression and artificial intelligence model", BioMed Central 2017
[12] Fei Jiang, Yong Jiang, Hui Zhi, Yi Dong, Hao Li, Sufeng Ma, Yilong Wang, Qiang Dong, Haipeng Shen, Yongjun Wang, "Artificial intelligence in healthcare: past, present and future", BMJ Publishing

B. *Ethical robots*

[13] Ethical Systems.org, Business Integrity through Research : Measuring Ethical Culture https://www.ethicalsystems.org/content/measuring-ethical-culture

C. *Linguistic Intelligence*

[14] Pierre-André Buvet, sous-presse "Linguistique et intelligence" in Linguistique et... (ed. Jan Goes, Salah Mejri et Olivier Soutet), Presses Universitaires d'Artois
[15] BUVET, P-A. 2009, "Quelles procédures d'étiquetage pour la gestion de l'information textuelle électronique ?", L'information grammaticale, 122, Peeters.
[16] Max Silberztein 2016: Formalizing Natural Languages: the NooJ approach. Wiley Eds.: Hoboken, USA. (329 pages).

D. *Behaviour trees*

The paper [17] focuses on dynamic retrieval of behaviours taking into account the world state and the underlying goals to select the most appropriate state machine to guide the Non-Player Characters behaviour in games. Reference [18] shows that behaviour trees are a good control architecture for swarm robotics, as they are comprehensible and promote modular reuse. Its implementation both in simulation and reality shows that the controller is compact and understandable. The basic elements of the behaviour tree (BT) used in decision making (DM) process of soccer robots are described in [19]. The integration of BT and fuzzy logic is proposed to increase the flexibility of the decision made by DM modules. Reference [20] shows how Genetic Design Methodology using BT can effectively model the security requirements of a sensor system, and be used to model and show the security of a complex sensor system. This model was tested in home health care system. Behaviour Trees has evolved in Grammatical Evolution in order to create controllers for the Mario AI competition [21]. The results obtained reinforce the applicability of evolutionary programming systems to the development of Artificial Intelligence in games, and in dynamic systems in general, illustrating their viability as an alternative to more standard AI techniques.

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