# White Paper

## Operational Applications

of Fuzzy Mathematics

Author: Prof. Dr. Zyed ZALILA
zyed.zalila@intellitech.fr

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**Zalila, Z.** (2009-2023) *Operational Applications of Fuzzy Mathematics,* White Paper, December 2023, v.4.1, INTELLITECH [intelligent technologies], Compiègne, France, 11p.

# Contents

This document lists several examples of operational applications of Fuzzy Mathematics at the global level. A large number of them were carried out thanks to the XTRACTIS® Trusted General Reasoning AI.

# 1. MISCELLANEOUS

- Prediction of the level of well-being of a city, a country, a company, a university (welfare economics).
- XTRACTIS® the General Reasoning AI for trusted decisions: the world's first AI to discover, from a structured dataset, transparent predictive models composed of IF…THEN rules (with continuous logics) that have at least the predictive and real performances of opaque models produced by the best open source AI techniques (random forest, boosted trees, neural network). Invented and designed by Z. Zalila in 2003, co-developed with INTELLITECH, v1 published by INTELLITECH in 2003.
- Characterization of blind people exploratory trajectories to discover their environment, thanks to the use of XTRACTIS®.
- Prediction of the hourly learning volume required to complete a task, thanks to the use of XTRACTIS®.
- Prediction of the frequency of contribution to Wikipedia, thanks to the use of XTRACTIS®.
- Reverse engineering from opaque models to transparent models, thanks to the use of XTRACTIS®:
  - Old models audit and Redesign/Maintenance (models which have become difficult to maintain, following the departure / death of field experts for example)
  - Deciphering the hidden behavior of opaque models (neural networks, random forests, boosted trees, KSVM…) into robust and intelligible IF…THEN rule-based systems with continuous logics
  - Deciphering the hidden behavior of enemy / competing systems into robust and intelligible IF…THEN rule-based systems with continuous logics
  - Detection of discriminatory biases of opaque systems, by analysis of the IF…THEN rules induced by XTRACTIS®. The discriminatory biases here are due to the modeled human decision strategy.
  - Audit and certification of opaque models.
- Detection of noise or discriminatory biases in the reference data, thanks to the use of a robust XTRACTIS® model.
- Improvement and increase of business knowledge, training and coaching of novice experts, thanks to the use of the IF…THEN rules induced by XTRACTIS® explaining the studied complex process / phenomenon.
- Improvement and increase of scientific knowledge, training and coaching of students, thanks to the use of the IF…THEN rules induced by XTRACTIS® explaining the studied complex process / phenomenon.

## 2.   AUTOMOTIVE INDUSTRY

-   ABS wheel anti-lock system during emergency braking.
-   ACC: Control of the speed of a vehicle and the safety distance from the front vehicle with automatic acceleration and braking (on motorways and in traffic jams). Invention by Z. Zalila in 1990, in partnership with Renault.
-   Automatic gearbox, adaptive to the driver's driving style and to the driving environment (slope, descent, turn, emergency situation). Invention by Z. Zalila & al marketed by Renault.
-   Emergency braking assistance, adaptive to the driver's braking style.  Invention by Z. Zalila & al marketed by Renault.
-   Automatic guidance of a bus, using a ground marking; Diagnosis of the driver's wish to take back control; Automatic docking of the bus on a raised platform so that passengers enter the bus on the same level as in a metro train. Invention by Z. Zalila & al marketed by Renault Vehicules Industriels, then by Irisbus.
-   Automatic steering of a vehicle: it is no longer necessary to control the steering wheel. Invention by Z. Zalila & al.
-   XPARK!® Automatic Parking: the world's first system operational in the most demanding road situations. Invention by Z. Zalila and INTELLITECH in 2000.
-   Intelligent traffic management: lighting of traffic lights taking into account the flow of vehicles and the priority of traffic lanes.
-   Assessment of car driving risks (hypovigilance, dangerousness), thanks to the use of XTRACTIS®.
-   Assessment of customers' liking for automotive materials, thanks to the use of XTRACTIS®.
-   Expert sensory evaluation of automotive materials, thanks to the use of XTRACTIS®.
-   Lateral and longitudinal automatic piloting of a vehicle on a closed circuit, thanks to the use of XTRACTIS®.
-   Prediction of gas consumption on open roads, thanks to the use of XTRACTIS®.
-   Prediction of engine tests (consumption, $CO_2$ and fine particles emission...), thanks to the use of XTRACTIS®.
-   Emergency detection for an automatic braking assist, thanks to the use of XTRACTIS®.
-   Identification of the longitudinal action required when approaching traffic lights, thanks to the use of XTRACTIS®.

## 3.   AEROSPACE

-   Diagnosis of cracks in the wing of a fighter aircraft.
-   Automatic docking of the space shuttle on the international space station.
-   Automatic piloting of a fighter aircraft (on a simulator), developed by the University of Cincinnati and its spin-off Psybernetix, with the support of the US Air Force Research Laboratory.
-   Automatic detection of crop types in satellite images, thanks to the use of XTRACTIS®.
-   Automatic detection of object classes in satellite images, thanks to the use of XTRACTIS®.
-   Quality control of integrated circuits for satellites, thanks to the use of XTRACTIS®.
-   Prediction of the noise level on an aircraft wing, thanks to the use of XTRACTIS®.

- Predictive maintenance of aircraft turbines, thanks to the use of XTRACTIS®.
- Predictive maintenance of satellites, thanks to the use of XTRACTIS®.
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# 4. RAILWAY

- Sendai automatic metro (since 1987 in Japan). The driving is very soft without any jerk (a milk bowl placed in the train does not overflow during the whole trip); economy and extreme accuracy of stops on the docks.
- Diagnosis of cracks in the composite structure of the trains and high speed trains by acoustic analysis, thanks to the use of XTRACTIS®.

# 5. MARITIME

- Automatic harbor crane for containers unloading: the fuzzy system counters the dangerous pendulum effect induced by bad weather (wind gusts in ports).
- Predictive Maintenance of frigate turbines and engines, thanks to the use of XTRACTIS®.
- Prediction of the congestion of secure communication networks between military naval units, thanks to the use of XTRACTIS®.
- Prediction of the rupture of a flexible underwater pipe, thanks to the use of XTRACTIS®.

# 6. COMPUTER / VIDEO GAMES

- Automatic setting of a microprocessor clock frequency.
- Characters' intelligence in a video game: the human player interacts with virtual characters (3D synthetic images) having an intelligent behavior. The "Lord of the Rings" battle scenes used such a fuzzy-based artificial intelligence engine to control the behavior of hundreds of thousands of virtual actors (Orcs...).
- Characters' intelligence in combat simulators used by armies (Serious Games).
- Virtual poker player.
- Automatic recognition of handwritten characters for smartphones.
- Detection of faults in critical software, thanks to the use of XTRACTIS®.

# 7. HOME APPLIANCES

- Most washing machines with automated settings (amount of powder, amount of water, speed and movement of the drum, stirring frequency, washing temperature and time, rinsing time, spin time) having at least the rating "A+" in energy savings: the fuzzy system computes the optimal settings according to the sensors data, to the laundry mass, its soiling degree, the water hardness, the delicacy of the clothes…
- Most tumble dryers with automated settings having at least an "A+" energy saving rating.
- Most dishwashers with automated settings (amount of cleaning product and rinsing salts, washing time) having at least an "A+" energy saving rating: the fuzzy system computes the optimal settings based on the sensors data, the water lime content and the soiling degree of the dishes.

- Microwave oven with automated settings (operating time, power level) according to the food temperature and mass, the air humidity in the appliance, etc.
- Rice cooker with automated settings.
- Extractor hood with automated settings: automatically sets the optimum motor rotation speed and the air extraction time, depending on the humidity level of the air drawn in and on the ambient temperature; hence less noise and more energy savings.
- Autonomous vacuum cleaner (obstacle avoidance, return to the charging station) adjusting the suction power according to the floor type (carpet, hard floor, parquet) and its soiling degree.

# 8.   HOME AUTOMATION / BUILDING

- Tatami temperature control.
- Air conditioning control in buildings (hot / cold): energy savings and better thermal comfort.
- Air conditioning control in tunnels.
- Intelligent fire detector to avoid false alarms.
- Automatic temperature control of a shower / bath.
- Water quality analysis.

# 9.   AUDIO / PHOTO / VIDEO

- Image stabilizer in camcorders, in smartphone cameras.
- Automatic settings of cameras.
- Quality of color printed images.
- Software for recognition of radio broadcasted music, to help collect copyrights.
- Detection of objects in images / videos, thanks to the use of XTRACTIS®.

# 10.   HEALTH

- Most blood pressure monitors.
- Artificial respirator with adaptive pressure control for sleep apnea.
- Automatic insulin dosage for diabetics.
- Automatic dosage of anesthetic during surgery.
- Diagnosis of an individual's health condition: integrated into the toilet, the system analyzes feces and urine.
- Diagnosis of thyroid cancer (ultrasound scan).
- Early diagnosis of geriatric diseases.
- Diagnosis of breast cancer from the anatomopathological analysis of breast cells images, thanks to the use of XTRACTIS®.
- Early diagnosis of breast cancer from the analysis of gene expression intensity, thanks to the use of XTRACTIS®.

- Early diagnosis of colon cancer from the analysis of gene expression intensity, thanks to the use of XTRACTIS®.
- Early diagnosis of ovarian cancer from spectral analysis of serum, thanks to the use of XTRACTIS®.
- Diagnosis of prostate cancer from the analysis of gene expression intensity, thanks to the use of XTRACTIS®.
- Identification of lung cancer from the analysis of gene expression intensity, thanks to the use of XTRACTIS®.
- Diagnosis of the Parkinson's disease from voice analysis, thanks to the use of XTRACTIS®.
- Diagnosis of chemotherapy receptivity, thanks to the use of XTRACTIS®: prediction of long survival in patients with metastasized lung cancer; lifespan estimation.
- Homology of protein sequences, thanks to the use of XTRACTIS®. Application to the detection of mutant viruses.
- Early diagnosis of cardiovascular dysfunctions of astronauts on long-term missions (orthostatic tolerance), thanks to the use of XTRACTIS®.
- Prediction of the opening of a general medicine practice place after medical residency, thanks to the use of XTRACTIS®.
- Prediction of postoperative thoracic complications, thanks to the use of XTRACTIS®.
- Cardiotocographic identification of fetal heart conditions, thanks to the use of XTRACTIS®.
- Serological diagnosis of chronic kidney disease, thanks to the use of XTRACTIS®.
- Drug Discovery, thanks to the use of XTRACTIS® :
    - Assessment of a molecule / formulation toxicity risk in the treatment of a pathology
    - Prediction of the therapeutic efficiency of a molecule / formulation in the treatment of a pathology, in the eradication of germs
    - Discovery of optimal molecular profiles / optimal formulations.

## 11. ROBOTICS

- Obstacle avoidance and guidance systems for autonomous robots that have explored Martian soil since 1997.
- Sony's Aibo robot dog: adapts to the behavior of its owners and eventually develops its own behavior.
- Helicopter drone with civilian applications (surveillance of crowds, construction sites, forests, engineering structures, etc.) or military (surveillance of enemy units, borders; troop transportation, wounded soldiers).
- Diagnosis of robot mission failures, thanks to the use of XTRACTIS®.

## 12. INDUSTRY

- Automatic control of cement kilns (since 1979): control of the coal quantity, the kiln rotation speed, the quantity of introduced air, the quantity of introduced cement.
- Automatic control of steel rolling mills.
- Control of the steel homogeneity during the molding processes.

- Temperature and humidity control in sanitized rooms.
- Injection of solidifying substances in a wastewater treatment plant.
- Waste combustion control.
- Automatic control of paint quality on car body. Invention by Z. Zalila exploited by Renault.
- Color mixer / detector: recognizes shades such as "a little darker", "reddish"…
- Supervision of a nuclear power plant.
- Quality control of nuclear fuel, thanks to the use of XTRACTIS®.
- Classification of defects in steel tubes / plates, thanks to the use of XTRACTIS®.
- Prediction of the defects appearance in cast steel parts, thanks to the use of XTRACTIS®.
- Quality control of welds, thanks to the use of XTRACTIS®.
- Detection of damage in a material, thanks to the use of XTRACTIS®.
- Prediction of the bursting pressure of a steel and composite tube, thanks to the use of XTRACTIS®.
- Assessment of an underground pipe rupture risk, thanks to the use of XTRACTIS®.
- Prediction of materials and formulations properties, thanks to the use of XTRACTIS®.
- Discovery of optimal formulations or the optimal specifications of a product (agri-food, hygiene & wiping products, optics, sports & leisure, automotive, cosmetics, etc.), thanks to the use of XTRACTIS®.
- Detection of counterfeit products, thanks to the use of XTRACTIS®.

# 13. MARKETING

- Prediction of expert sensory evaluation, consumer liking and preference for products, thanks to the use of XTRACTIS®: cheese, tomatoes, pet-food, soda, energy drink, cake, wine, chocolate, chewing gum, optical glasses, cosmetics, rusks, bread dough, vehicle interior materials, vehicle interior acoustics, thermal comfort of a vehicle, hygiene and wiping papers, sports products, leisure products, video games…
- Prediction of clients' palatability for financial products, thanks to the use of XTRACTIS®.
- Optimization of a marketing mix, thanks to the use of XTRACTIS®.
- Detection of the emotions of a consumer / viewer, thanks to the use of XTRACTIS®.

# 14. MANAGEMENT / CRM

- Assessment of the customer insolvency risk (unpaid debts), attrition (cancellation, return, subscription termination), thanks to the use of XTRACTIS®.
- Forecast of sales, number of customers, thanks to the use of XTRACTIS®.
- Efficiency of commercial promotions, thanks to the use of XTRACTIS®.

## 15. ECONOMY / FINANCE

- Purchase / sale of shares, thanks to the use of XTRACTIS®.
- Asset allocation, choice of investment strategy, wealth management, thanks to the use of XTRACTIS®.
- Assessment of the fair price of a real estate asset, thanks to the use of XTRACTIS®: predicting the price of real estate negotiation taking into account the specificities of the buyer, the seller, the property and the macro/micro economic situation.
- Prediction of the real estate price in a geographical area, thanks to the use of XTRACTIS®.
- Assessment of the financial investment risk, thanks to the use of XTRACTIS®.
- Scoring of the default risk of a consumer loan or a mortgage loan, thanks to the use of XTRACTIS®.
- One-year bankruptcy forecast of companies, thanks to the use of XTRACTIS®.

## 16. DEFENSE / SECURITY / MALICIOUS BEHAVIOR / CYBERSECURITY

- Optimal deployment of missiles to defend a strategic site, thanks to the use of XTRACTIS®.
- Acoustic detection of underwater mines, thanks to the use of XTRACTIS®.
- Prediction of rates of various types of crime in a city, thanks to the use of XTRACTIS®.
- Log-based detection of cyber intrusions, thanks to the use of XTRACTIS®.
- Log-based identification of cyber intrusions, thanks to the use of XTRACTIS®.
- Identification of objects in satellite images, thanks to the use of XTRACTIS®.
- Detection of fraudulent actions (taxes, insurance, social allowances, payment means, money laundering), thanks to the use of XTRACTIS®.
- Temporal identification of aircraft by trajectory analysis, thanks to the use of XTRACTIS®.
- Temporal identification of criminal profiles and action phases by metadata analysis of intercepted communications, thanks to the use of XTRACTIS®.
- Identification of UAV intrusion based on Wi-Fi analysis, thanks to the use of XTRACTIS®.
- Identification of land mines by passive magnetic analysis, thanks to the use of XTRACTIS®.

## 17. GEOMATICS

- Optimal location of wind turbines.
- Optimal location of self-service bicycle sites.
- Optimal layout of public transport lines and stops (tram, bus, metro).
- Optimal location of hospital sites, sales areas, thanks to the use of XTRACTIS®.
- Prediction of urban density, thanks to the use of XTRACTIS®.

## 18. STRUCTURE / SIMULATION

- Optimal mesh of a car body.
- Selection of a bridge curvature for the choice of pylons.
- Diagnosis of cracks in concrete.

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- Optimization of the parameters of a finite-element-modeled structure, thanks to the use of XTRACTIS®. Application to a skyscraper, a bridge.
- Prediction of concrete compressive strength, thanks to the use of XTRACTIS®.
- White-box reverse engineering of a complex digital model by finite elements, thanks to the use of XTRACTIS®. The model induced by XTRACTIS® makes it possible to carry out simulations in real time and at very high frequency (up to 70,000 Hz on an Intel i7 with 8 physical cores @2.5 GHz): it thus generates enormous savings in time and energy.

# 19. ENVIRONMENT / NATURAL SCIENCES

- Prediction of harvests.
- Management of forests and natural parks.
- Modeling of plant growth.
- Modeling of sedimentation at the bottom of the oceans.
- Forecast of earthquakes and their importance.
- Prediction of avalanches, floods, landslides, hurricanes.
- Prediction of the ozone level in the air based on weather conditions, thanks to the use of XTRACTIS®.
- Modeling of the intensity of a laser in a chaotic state, thanks to the use of XTRACTIS®.
- Detection of free electrons in the ionosphere, thanks to the use of XTRACTIS®.
- Automatic detection of crop types in satellite images, thanks to the use of XTRACTIS®.
- Seismic analysis, porosity prediction, oil / gas detection, thanks to the use of XTRACTIS®.
- Prediction of a chemical molecule biodegradability, thanks to the use of XTRACTIS®.
- Prediction of a chemical molecule ecotoxicity risk on different animal species, thanks to the use of XTRACTIS®.
- Discovery of new molecular profiles of non-toxic herbicides, thanks to the use of XTRACTIS®.

# 20. OPERATIONAL RESEARCH

- Optimization of the distribution of elevators in skyscrapers.
- Creation of timetables for buses.
- Nonlinear multi-objective optimization under flexible constraints, thanks to the use of XTRACTIS®.
- Nonlinear multi-objective optimization of a supply chain under flexible constraints, thanks to the use of XTRACTIS®: maximizing the overall profit by distributing the manufacture of different products to different production and storage sites and by transporting them to different sales areas, using different means of transport.