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Decision-making modelling: application to autonomous Air to Air Refuelling

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Abstract

This document describes the application of a decision-making model to the separation phase within the scope of Automatic Air to Air Refuelling. Proper needs and reactions have been design to ensure a safe operation minimizing boom displacements. The system has been assessed by boom operator in a real simulator demonstrating good results. This application is considered as the first step to have a real autonomous air to air refuelling.

1. Introduction

A330 MRTT is a new generation certified tanker-transport in service and combat proven that can be customized with a combination of refuelling devices (underwing pod with/without under fuselage FRU or Boom). Installed in the MRTT the Advanced Refuelling Boom System (ARBS) is currently the most advanced and sophisticated digital Fly By Wire (FBW) boom in the market allowing up to 1200 gal/min fuel transfer. ARBS Full authority control system provides stability augmentation and the desired handling qualities for the Aerial Refuelling Operator (ARO). ARO manually flies the boom by means of a flight control stick that demands a boom position in pitch and roll, and a telescopic control stick that demands a telescopic speed extension.

Automation of the ARBS operation has been identified as one of the main enabler technologies in the frame of the Automatic Air to Air Refuelling (A3R) operation between manned or unmanned assets. In order to achieve the required automatization level the system must take control of all phases of Air to Air Refuelling (AAR) in failure free and handle failure cases (safe recovery is always ensured but ARO monitoring of the automatic operation is still needed). To achieve this level of automatization a real time decision-making module to determine how and when actuate to properly operate the boom, similar to what the operator does, is required.

Automobile industry has presented multiple autonomous car driver solutions in the last decade. Some of them have been analysed in order to assess suitability in decision-making application during automatic Air to Air refuelling (A3R). One of them, based on Maslow's hierarchy of needs has been selected to apply in ARBS operator decision-making modelling.

2. Objective

The aim is to apply this decision-making model in the separation phase within A3R operation. After the contact (between boom nozzle and receiver) and fuel transfer, there is a physical disconnection and separation between the boom and the receiver. Boom shall perform a safe separation from the receiver through its three degrees of freedom: pitch, roll and telescopic. The solution performed shall ensure safety but also minimize boom displacement (an operator does not separate the boom more than necessary).

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3. ARBS operation phases brief description

- Receiver in astern: receiver aircraft stabilizes in astern position ready to approach to contact uncoupled position when it is requested by the boom operator.
- Approach: Receiver moves from astern to contact uncoupled position and tries to stabilize. During the approach, boom must be controlled in order to avoid receiver (boom movement will depend on receiver geometry) and ensure a safe approximation.
- Contact: Once receiver is stabilized in contact uncoupled position, boom is flown in order to align the boom nozzle with the receiver receptacle. Receiver must be stabilized inside the contact envelope and, when this condition is satisfied, the boom operator will extend the probe to make the contact. After the contact, the boom moves with the receptacle and the flight control system moves boom ruddervators to ensure zero forces in the boom nozzle. During the contact phase the operator does not introduce any input to the flight/telescopic control stick. The fuel is transferred during this phase.
- Disconnection and separation: After fuel transference the operators request a disconnection (ARO or receiver pilot). Automatic disconnections are commanded by the system if the receiver receptacle move out of the disconnect envelope. In the disconnection, the boom physically separates from the receiver and the operator must take the control of the boom flying away the boom from the receiver in order to ensure a safe separation.
- During the automatic boom operation (boom A3R) boom attitude and telescopic length shall be automatically controlled through boom operational phases as a function of receiver position, system status and ARO commands. In particular after fuel transfer an automatic disconnection will be commanded and the boom shall be automatically controlled to ensure a safe separation from the receiver independently of receiver movement after disconnection. Decision-making approach has been developed to ensure a safe separation during boom A3R operation.

4. Decision making model based on needs fulfilment: key concepts extracted

A wide variety of projects developing the concept of modelling vehicle drivers can be found. Design methods are commonly based on artificial intelligence, such as fuzzy systems, neural networks, evolutionary algorithms or rule-based methods. The role of a decision system is to decide what reaction the system should perform. In this section, concepts extracted from the bibliography are summarized.

An ISD (intelligent system of decision-making) model based on human psychology has been selected [1]. The design of this system is a result of a thorough modelling of human psychology based on an extensive literature study. The application of this concept in autonomous car driver has proven that a computational management system based on a model of human psychology is able to operate in a satisfactory manner in concrete critical conditions with numerous restrictions imposed on it ([2]).

This decision-making algorithm is based on the design and definition of a set of needs (H) and proper reactions which must satisfy the needs. The system also allows certain emotions (ξ), which influence the process of recoding the need membership parameters, providing the system with a higher level of autonomy.

Each need is quantified by its degree of unfulfilment (η_i, which is measured from the state of the system and the environment). This is an abstract fuzzy value and takes one or two of three states: satisfaction prealarm and alarm: μ_s, μ_p, and μ_a respectively. Need weighting function ω_i is also dependant of η_i. Next figure represents evolution of these fuzzy values with respect to need unfulfilment: the bold dashed line denotes the weighting function ω_i, the back-slashed area describes the satisfaction state, the crossed area portrays the alarm state, and the slashed area means the prealarm state. The thick vertical line marks an actual value of the unfulfilment degree η_i, as an example.

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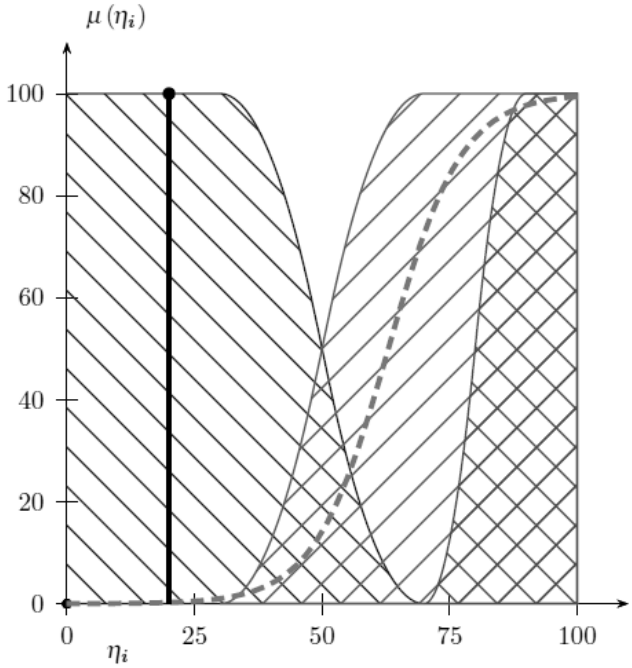

Figure 1: fuzzy logic states and weighting function

The needs are grouped according to their importance in a Maslow pyramid of classes, modelling the priority system of human needs in human psychology, represented in the next figure:

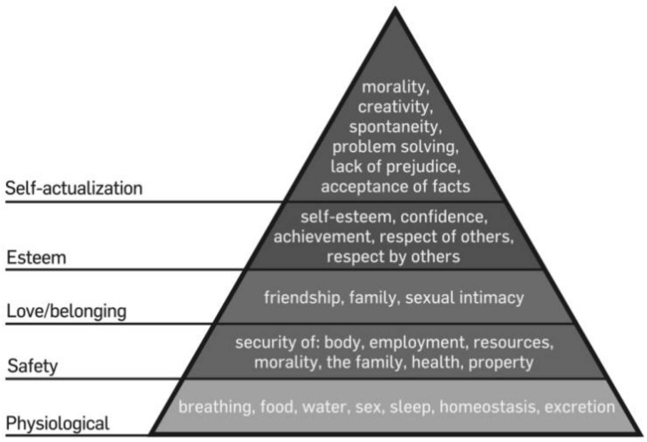

Figure 2: Maslow's Pyramid of needs

Each need of the same pyramid level/class has its individual importance, which changes according to its current weight. This importance is described by the weighting function $\omega_i(\eta_i)$ (see Figure 1).

The mechanism of selecting reactions models the thinking process once all the information is available. To accomplish this selection, as in human psychology, it is needed an "a priori" information about the incremental effects on the needs for each feasible reaction. Thus, the reactions impact on the needs should be estimated in order to select the proper reaction. The current values of the needs unfulfilment (η_i) and the incremental needs unfulfilment estimation ($\delta\eta_{i\ est}$) (for each reaction) are used to calculate the estimated states (through membership functions, Figure 1) of each need for each reaction.

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Managing these estimations is where the system allows learning procedures. Once a reaction is applied, the actual incremental unfulfilment value of this reaction (and regarding the current environment) can be computed and then a "reactions estimation database" can be properly adjusted.

The estimated states of one specific reaction are the inputs to the fuzzy neural network shown in Figure 3.

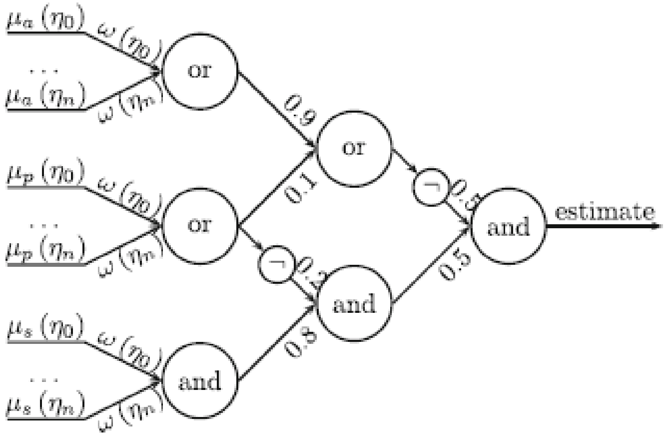

Figure 3: fuzzy neural network to estimate the suitability of one reaction

Figure above shows the procedure to calculate an estimation of the impact factor of one particular reaction. The input estimated states μ_a, μ_p and μ_s (alarm, prealarm and satisfaction) are membership functions and so the logical operations are performed with fuzzy logic operators (T-norm, S-norm and negation in the Yager sense). First layer weights are calculated upon the current unfulfilment need value and hidden layers weights are selected experimentally [2]. Impact factor value will be 1 when all needs are satisfied and none of them is in the prealarm or alarm state after the considered reaction. It describes how much the needs would be satisfied after the execution of the reaction. Thus, it will be obtained one impact factor for each reaction and the system will select and apply the reaction whose impact factor on needs is the highest.

Figure 4 summarizes the whole process of intelligent decision-making system taking all the concepts presented:

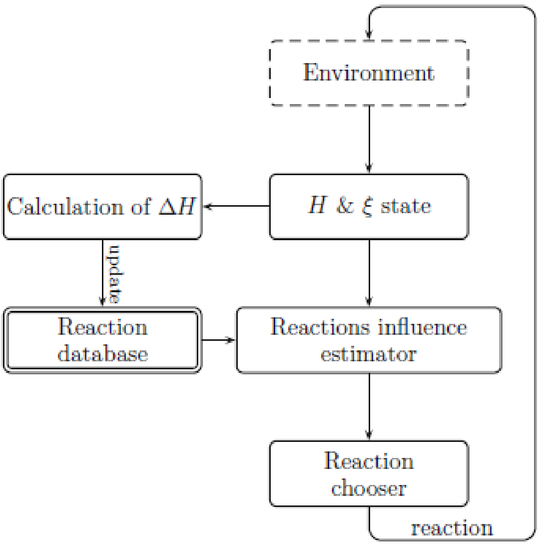

Figure 4: decision making system overview

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Changes in the environment have a determined impact on the system states of the needs. Increments of the states of needs (ΔH) from last decision are computed to feed the reaction database, which gives de information of the increments of the states for each reaction to the influence estimator. The influence estimator computes the suitability of each prospective reaction just adding to the actual states the increments from the database. The system will finally choose the best reaction and apply it.

5. Decision making modelling - application in air to air refuelling separation phase

Previous section system concept will be applied in the separation phase within automatic air to air refuelling operation. The inputs required in this phase are not very complex in terms of precision as the aim is safe avoidance from the receiver without regarding the final position of the boom. But, on the other hand, there is a wide set (unlimited, indeed) of possible movements that can fully accomplish the safe separation requirements. Thus, after the disconnection, the operator will decide to fly the boom to where he considers a safe (subjective) position regarding boom/receiver proximity, spatial clearance criteria and considering his operational experience, fatigue and stress. This concludes in an (apparently) no complex manoeuvre but which is never repetitive and strongly dependant to many variables as the operator, turbulence, flight condition and receiver pilot.

The application of an intelligent system of decision-making tries to reproduce the boom operator decision process in this phase, regarding his perception of the environment, the needs he must satisfy and which actions he can perform to satisfy those needs.

In this application, the idea of emotions is not taken into account. Concept is mentioned in reference [1] only as an integral part of an intelligent decision-making system. The whole idea of the higher-level control system (including emotions) is coherent and ready for implementation in future work [2].

5.1 Fuzzy logic states

Calculation of the states and weight of each need has not been considered particularly different in this application as the system concept states of alarm, prealarm and satisfaction are universal and present a common dependency with a specific unfulfilment of a need. Data from reference [2] have been used, resulting in the below figure weight and membership functions:

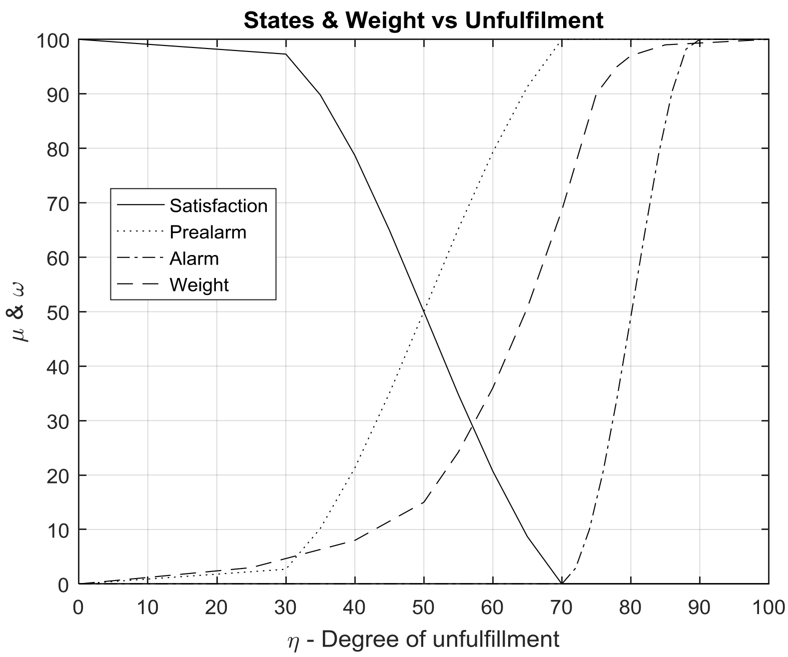

Figure 5: States membership functions and weighting function

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5.2 Needs identification and definition in ARBS separation phase

The next step following concepts from previous section 4 is to define a set of needs and how they can be measured from an operator point of view in terms of unfulfilment. It means modelling his perception of reality and how he feels that there is task that must be solved. But here there is an important restriction: only existing sensors and technology already installed in the ARBS can be used to do the measurements. Design and definition of the needs have been carried out with the help of an experienced AAR boom operator.

Thus, three needs are proposed: impact and elevation clearance regarding safety and energy optimization in order to avoid applying stick inputs larger than necessary. Both safety needs will take part of the bottom level of the Maslow's pyramid, the most essential. In the next level, on the top of the pyramid will be the energy optimization need which will be taken into account in the process of selecting a proper reaction. These results in the pyramid of Maslow depicted in Figure 6.

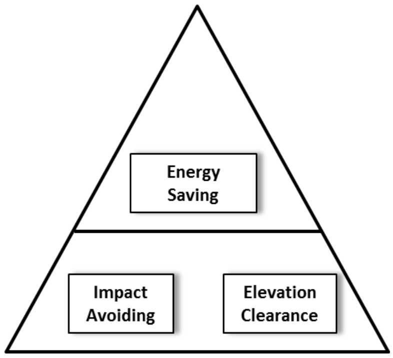

Figure 6: Maslow's pyramid applied to separation phase

5.2.1 Impact avoiding

This represents the most explicit need. The first aspect that an operator should be measuring to ensure a safe operation is the relative distance from the boom to the obstacle, which is the receiver in this case. A reduction of this distance will increase the risk and so this need unfulfilment. The opposite effect is expected if this distance increases. In addition, in order to predict a potential unsafe situation, a real operator also takes into account how this distance change, so relative distance variation between the boom and the receiver will be also measured. Negative relative speeds will result in an augmentation of the unfulfilment and vice versa. So impact avoiding unfulfilment will depend on both boom nozzle to receiver receptacle distance and tanker to receiver relative speed, being this unfulfilment represented in Figure 7.

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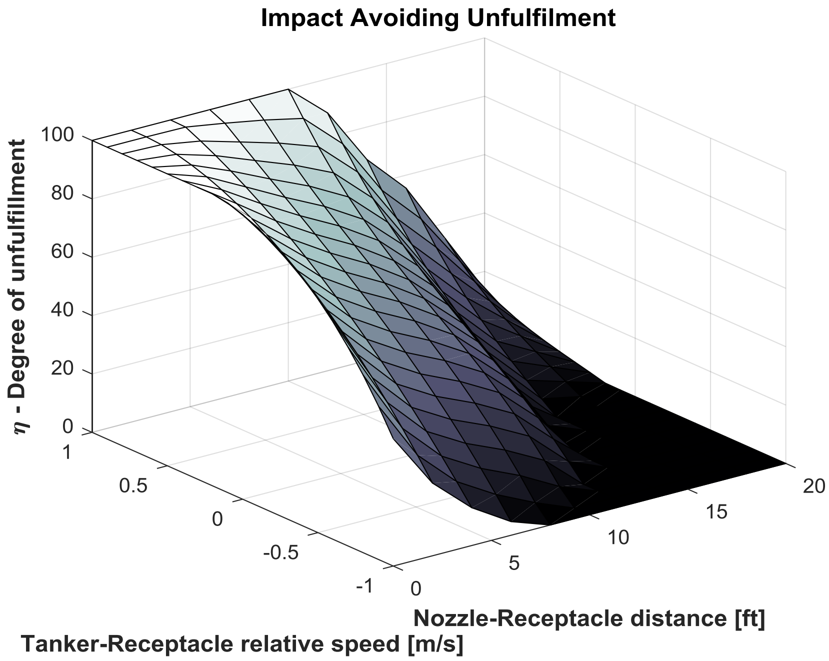

Figure 7: Impact avoiding need unfulfilment

5.2.2 Elevation Clearance

The second need consist in an elevation clearance between the boom and the receiver so that the first should be above the second. Besides safety reasons, an operator would never be comfortable (unless the receiver is considerably far away from the tanker) with a visual perception of the receiver close to the boom (receiver movement can lead to operational situations in which there is no possibility to escape from the receiver). Thus, the unfulfilment of this need will be dependent on the clearance itself and the distance between boom nozzle and receiver, resulting in a dependency as represented in the next Figure 8:

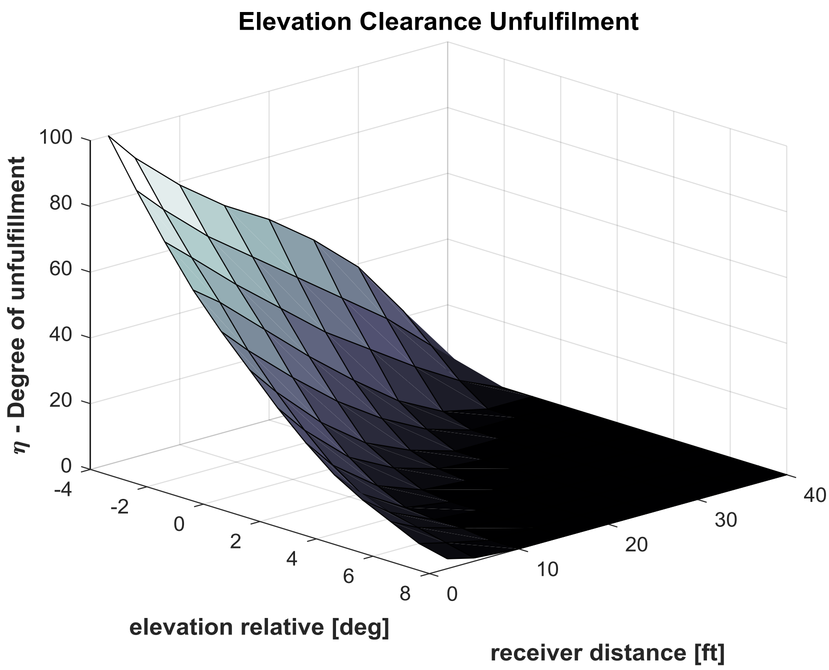

Figure 8: Elevation clearance need unfulfilment

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5.2.3 Energy saving

The last need has the purpose of modelling the energy of the operator when he takes the decision to perform a separation from the receiver after disconnection, trying to minimize the stick inputs (workload) so they are not larger than necessary. This need unfulfilment only has one dependency, which is the mean absolute value of boom flight control stick inputs (pitch and roll) introduced in the last 4 seconds, represented in Figure 9.

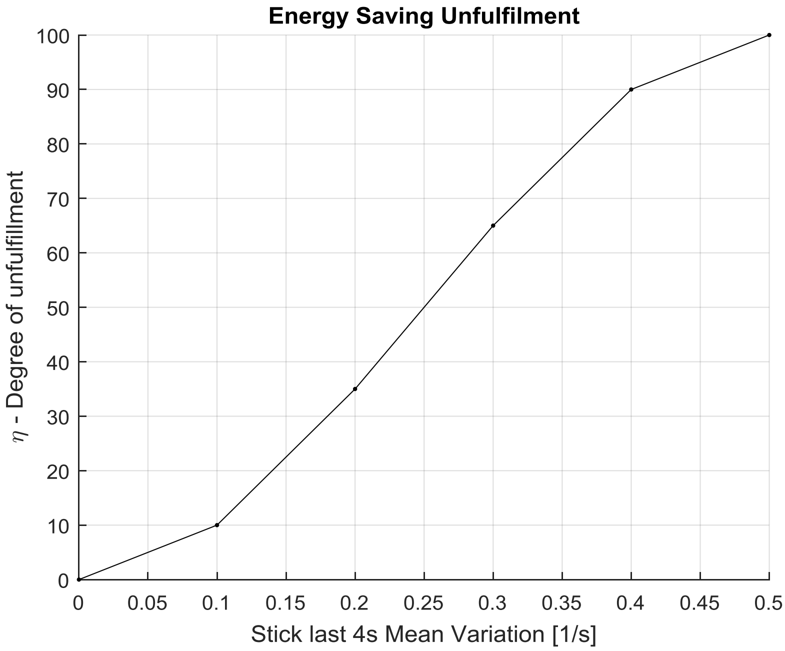

Figure 9: Energy saving need unfulfilment

4 seconds value has been selected both according to operator experience and experimentally, and it represents the "memory" of the operator in terms of energy/workload. Stick inputs before the last 4 seconds will not be taken into account to measure this unfulfilment need.

5.3 ARBS separation reactions

Reactions have been initially designed to satisfy a specific need but, at the same time, they can have positive, negative or neutral impact on the other needs. This has been taken into account as in a real life an operator has in mind a set of reactions which can fulfil just one or several requirements at the same time. The mechanism of selecting the reaction will choose the best reaction depending on the current needs unfulfilment.

However, there has not been designed any specific reaction to fulfil energy saving need. This is somehow different from the concept in reference [1], where each need has its particular set of reactions.

When the system detects that there is a need that must be satisfied, it will select and apply a reaction until one of these three events occurs, in decreasing priority order: any other more weighted need is detected (switching to a specific reaction of that need), any other reaction in the current need reactions set has a larger impact factor (switching to this reaction) or all needs are satisfied (stop applying any input).

An operator performs the control of the boom through both the flight control stick (FCS) and telescopic control stick (TCS). FCS is an attitude demand stick and makes it possible to fly the boom inside the pitch/roll boom control attitude envelope. TCS is a speed demand stick with which the extension/retraction of the boom is controlled. As it is explained above, while a reaction is being applied, the system is able to switch to other reaction. Therefore, reaction stick boom attitude demands will be built thorough a final demand and a rate demand, not being necessary to reach the final reaction demand.

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5.3.1 Impact avoiding reactions

When an operator feels that there is some risk of impact between boom and receiver, he will apply any input to clear the boom from the receiver in a safe way, using both the flight control stick and the telescopic control stick. As this risk comes from receiver movement uncertainties and/or instabilities, it is expected that the reaction input will be according to the receiver movement. So, there is a set of reactions whose inputs depend on where the receiver is, how fast and where is it moving. These are reactions: r4, r5, r7 and r8 whose final demand point in terms of pitch and roll are depicted in Figure 10:

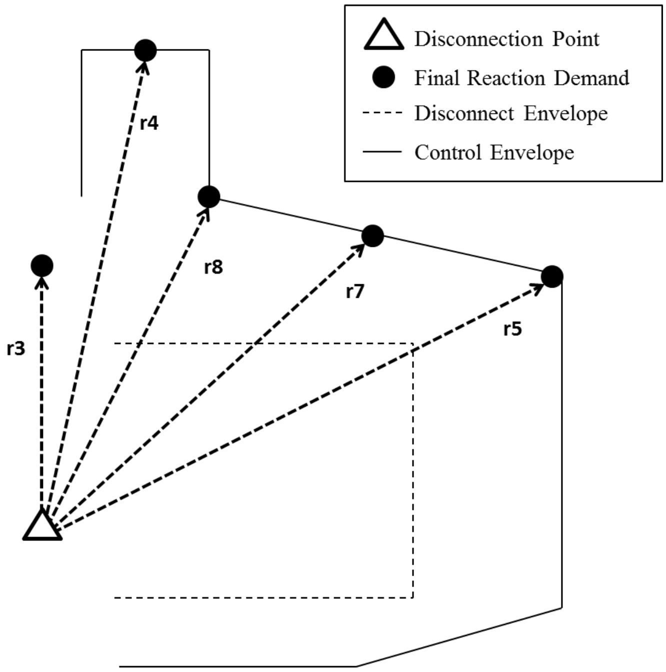

Figure 10: Impact avoiding reactions scheme

Reactions attitude demands are represented as arrows that start in a disconnection attitude point (represented as an example). Only mid side of the attitude envelope has shown, this is because the system will select a safe side of the attitude control envelope depending relative nozzle-receptacle positions at the disconnection. Because of aerodynamics, nozzle will not remain stable aligned to receptacle after disconnection, presenting some relative pitch/roll distance to the receptacle. Reactions roll demand will not overtake receptacle roll at the disconnection so roll attitudes to the opposite side will be demanded. As it is explained before, these reactions rate demand will be proportional to receiver attitude rate. These proportionality constants will be a different parameter for each reaction, in order to assess them in simulator. Final values of these constants are in Table 1.

In addition, all these reactions demand a constant speed retraction, -1,2m/s. This speed demand value has also been agreed with experimented operator as a normal operation reference value.

These reactions are designed to fulfil impact avoiding need and, depending on initial boom and receiver positions, some of them can also satisfy elevation clearance need. So the system is expected to choose the best one regarding elevation clearance need (if it is enough weighted). Regarding energy saving, and also depending on initial point and receiver attitude rate, this set of reactions will be quite different in terms of energy so the system will have different alternatives to decide.

Frequently, after a disconnection, the receiver moves back and downwards to come back to astern position so elevation clearance and boom-receiver distance values are soon large enough to fulfil its corresponding needs. In these cases, operator barely feels any risk and only applies a telescopic retraction. So, it is proposed a reaction consisting only in a telescopic retraction at the same speed demand that previous ones, reaction r6. The idea is not only to apply this reaction after the disconnection scenario before mentioned, but also when needs are close to be

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fulfilled, minimizing flight control stick inputs. This reaction is not represented in Figure 10 as boom attitude demand does not change.

Reaction r3, whose demands are regardless receiver rate, have been defined (will demand 10degrees pitch up from receiver at 6deg/s, with no inputs in roll and telescopic retraction at -1.2m/sec) to cope together with r6 (telescopic retraction) with most of the normal disconnection operational conditions (receiver stable) in which the impact avoidance need id fulfil with a small pitch up and simultaneous telescopic retraction. Furthermore, this reaction will be useful when the system is satisfying impact avoiding need and elevation clearance need un-fulfilment is high.

Next Table 1 summarizes impact avoiding specific reactions demands:

Reaction	Pitch Dmd	Roll Dmd	Rate Dmd [deg/s]	TCS Speed Dmd [m/s]
r3	RCVR pitch -10	Min (current roll, max roll at pitch Dmd)	6	-1.2
r4	Min pitch	0	2*RCVR_Rate	-1.2
r5	Min at current roll	Max	5*RCVR_Rate	-1.2
r6	Current pitch	Current roll	0	-1.2
r7	(r5+r8)/2	(r5+r8)/2	5*RCVR_Rate	-1.2
r8	Stovepipe corner	Stovepipe corner	5*RCVR_Rate	-1.2

Table 1: Impact avoiding reactions demands

Not being strictly faithful to the application in reference [2], the system designed here allows switching from one reaction to another without waiting for the final effects. The idea of this modification is the possibility of adding alternative reactions according to the operator impressions in simulator and so making the response of the system more continuous, instead of demanding only corner points.

5.3.2 Elevation clearance reactions

The range of feasible reactions to fulfil the elevation clearance need is not as large as in impact avoiding need. Previous reactions telescopic retraction will be also demanded: this retraction will not augment the elevation clearance itself but will increase boom-receiver and distance so reduce elevation clearance unfulfilment. To increase elevation clearance, boom pure pitch up manoeuvres will be demanded, being these reactions equivalent to r3. Indeed, reaction r1 will be equal to r3 and r2 will consist in the same 10degrees pure pitch up but at higher pitch rate (12deg/s). Next table collects these reactions data:

Reaction	Pitch Dmd	Roll Dmd	Rate Dmd [deg/s]	TCS Speed Dmd [m/s]
r1	RCVR pitch -10	Min (current roll, max roll at pitch Dmd)	6	-1.2
r2	RCVR pitch -10	Min (current roll, max roll at pitch Dmd)	12	-1.2

Table 2: Impact avoiding reactions demands

5.3.3 Energy saving reactions

As it has been mentioned before, a different way from original concept has taken in this need. Maybe a reaction consisting in limiting the amount or rate of stick input that is being introduced can satisfy this need, but this is considered out of the system concept (the system does not allow taking more than one need at the same time) and

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unnecessary, as without any specific reaction the aim of this need is considered accomplished as it is explained afterwards.

Once it is identified the need that must be satisfied, reaction chooser mechanism will predict the impact of each available reaction in each of the needs, weighting these needs depending on the current value of each need unfulfilment. By this way, the system will choose the reaction which best satisfies the overall requirements:

- If there have not been inputs in the last instances (so energy saving unfulfilment will be zero), the system will not penalize the reactions with aggressive inputs.
- However, if the system comes from a period with aggressive stick inputs, energy saving need will penalize the impact factor of aggressive inputs selecting a less aggressive manoeuvre. Of course, the need is going to be satisfied in any case.

5.4 ARBS states estimation

From original concept (see section 4) reactions states increments that are to be estimated are the differences between the states of the needs before making the decision and after the selected reaction implementation. Once estimated states increments are known, they are added to current system states values, resulting in one overall system needs states estimation for each reaction. However, in this application, no states but boom attitude is going to be estimated. States increments in original concept are thought to include the effects of applying a reaction in the environment. Furthermore in many systems there are a considerably high number of uncertainties. The system in which this decision-making concept is being applied has a characteristic non-linear plant (complex aerodynamics) but, with more or less precision, it is known how it will respond to an input and the final position in the steady state, being possible with this information to estimate the final states after applying an input (taking also into account that there will not be future effects in the environment because of taking a reaction). The issues here appear when it is needed to either estimate a position during a dynamic movement or an accurate steady-state attitude, and this is the reason why several estimators will be tested.

As it has been explained in previous section, the system here differs from original in the way of reaction implementation. Once applied the best reaction, it is not waited for it to finish: if at any moment any other reaction is considered better, the system will switch to this reaction. This implies that the estimator will not wait until the reaction is finished; it will be estimating the system every time. The time when the system is going to be estimated is not trivial and it is also difficult to select the best option for the designer. Large values of this time means that the system will be estimating the effects of each reaction after some time, maybe when the reaction is finished (similar to original concept), not taking into account intermediate positions. Furthermore, each reaction needs a different time to be applied and finished, but estimation time needs to be the same for every reaction so they can be comparable in terms of impact factor on the system. Small estimation time vales will not be a solution as each reaction has a different rate demand so in small periods of time it is even possible to find no effects of the reactions in the system. Thus this time estimation value is a trade-off that must be found experimentally. Several time estimating values have been tested in simulator and finally one second has been set as an optimum trade-off solution.

Regarding energy saving, the system will be estimating energy from current moment to one second after, adding this estimation to the energy computed in the last three seconds, resulting in a total four last seconds energy that is required to calculate this need unfulfilment (see section Energy saving).

As explained before, several estimator have been tested, three in particular. Further details of each estimator model are presented below, in increasing order of complexity.

First and simplest estimator model tested is based on reaction attitude demand. ARBS system internally transforms flight control stick input demand to boom attitude demand. As each reaction is built through attitude and rate demands, it is possible to use them to estimate boom attitude in the steady state. Thus, this estimator will not take

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into account boom dynamics and system non-linearities. Results are acceptable in most of the times except in some cases: if there is a considerable difference between the reaction final demand and steady state boom attitude (frozen reaction demand) decision-making behaviour is not as expected, as there are better reactions that the system does not detect because of this estimation error. To solve this problem in these specific cases, a correction is implemented so that the estimation is updated to boom attitude current value when reaction demand is frozen. This correction will be available as long as the system does not take any other reaction. It must be remarked that this correction is not memorized anywhere. The correction does not depend only in current attitude demand, but also in boom attitude, boom telescopic extension and flight condition. Because of this, memorizing these corrections will result in a more complex model, similar to the second model tested. This estimator has been designed as the simplest option in terms of computation and implementation so memorizing these corrections is discarded.

As first model, second tested estimator model does not take into account any boom dynamics. A steady-state (trimmed conditions) model is developed through a deep knowledge of aerodynamic boom model. Boom attitude is then tabulated in stabilized conditions for each attitude demand, telescopic extension and flight condition (fuel, aircraft tanker weight and attitude, receiver…). This boom attitude in steady-state conditions is used as the boom attitude estimation. Results are also acceptable, not being qualitatively different to those with previous estimator model, so the increase in implementation complexity and computation resources requirements does not seem to justify the complexity increase of this model.

Third and last model seeks to consider boom dynamics. Besides complexity, boom non-linear models will penalize too much the estimator in terms of real time computation, so non-linear real time simulations to estimate boom for each reaction are not considered. Though precision will not be the same, linearized boom simulator model is able to take dynamics into account without so much computation penalization, so is the solution selected for this estimator. Boom simulator is linearized for one specific flight condition, attitude and telescopic extension to do the testing, but it must be remarked that this linearization work must be done at all conditions to completely implement this model. Estimator will use these plants to simulate the system response to reaction stick inputs. Results with this estimator are good, but it cannot be affirmed that the system presents a better behaviour regarding decision-making objective. So, as in second model case, the non apparent improvement makes difficult to justify the drawbacks that this estimator present.

As a result, there have not been found evidences that justify a more precise and complex estimator model so first estimator has been chosen as the best option.

5.5 Reaction Chooser

An estimation of the impact factor for each feasible reaction is carried out as in Figure 3, taking into account states estimation of each reaction computed as explained in section 5.4. Best reaction in terms of impact factor will be selected and applied until any of the three events described in section 5.3 is triggered.

First layer weights are the weights of each need calculated as explained in section 4. Regarding second and third layer, different and constant weights have been tested, starting from close values to those proposed in [2]. This analysis concluded in an almost negligible effect for values close to reference [2], not presenting any improvements with respect to reference values. Adaptive learning procedures have not been considered here as this is still not acceptable from on-board software certification point of view.

6. Results and conclusions

Next figures correspond to a separation simulation with the decision-system designed. Figures show system evolution from physical separation instant.

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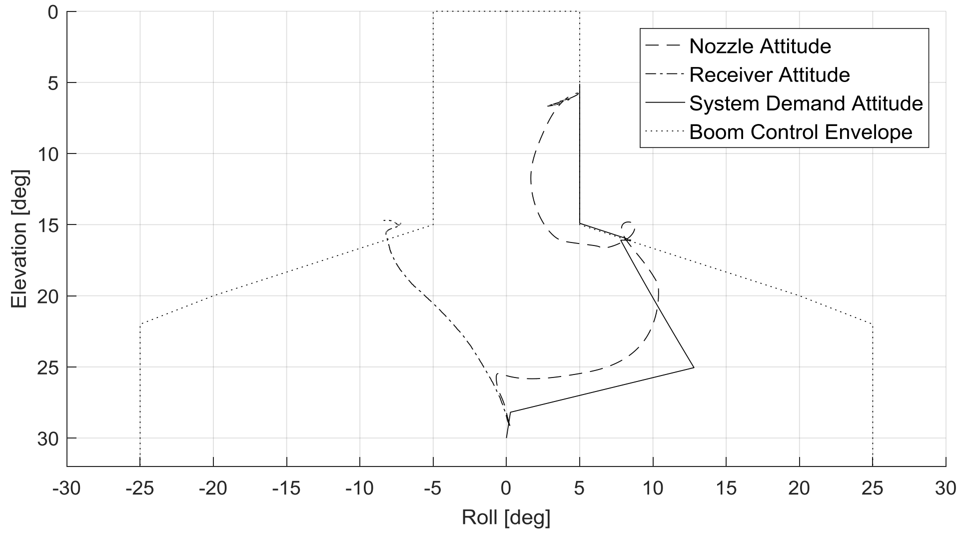

Figure 11: Nozzle, demand and receiver attitude cross-plot

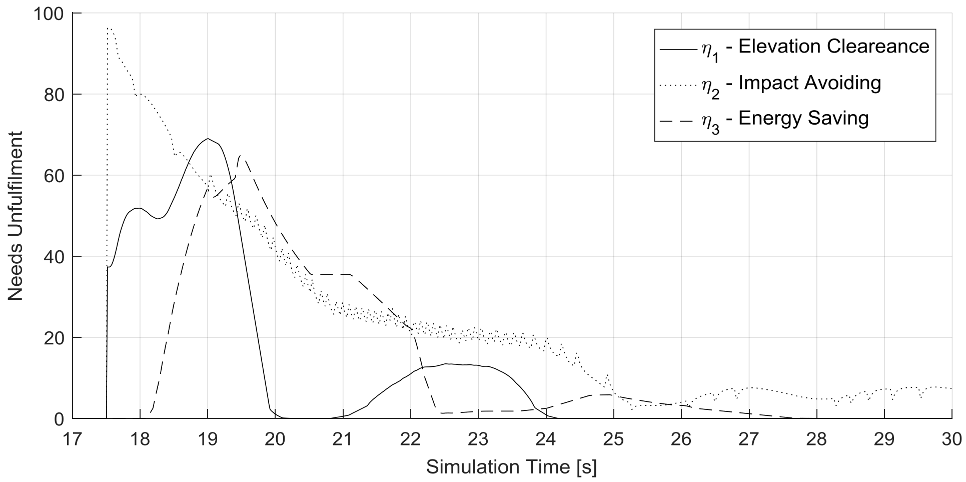

Figure 12: Needs unfulfilment

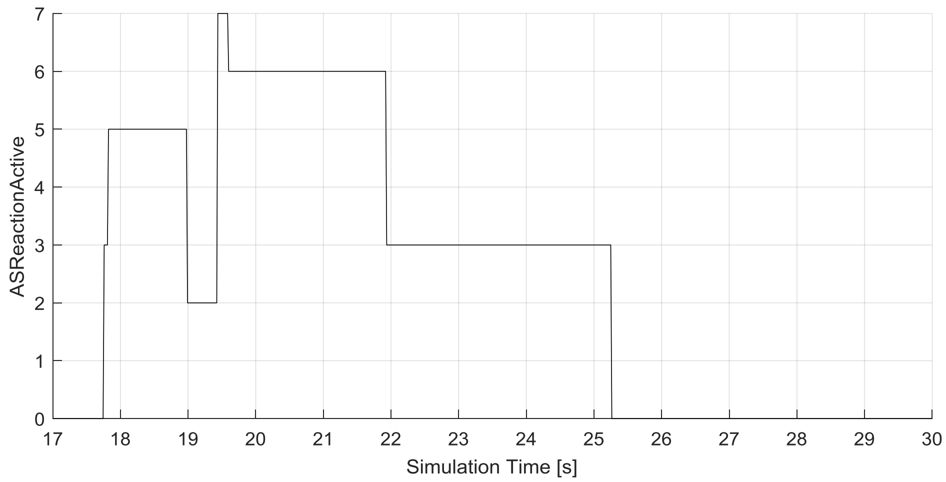

Figure 13: Reaction Active

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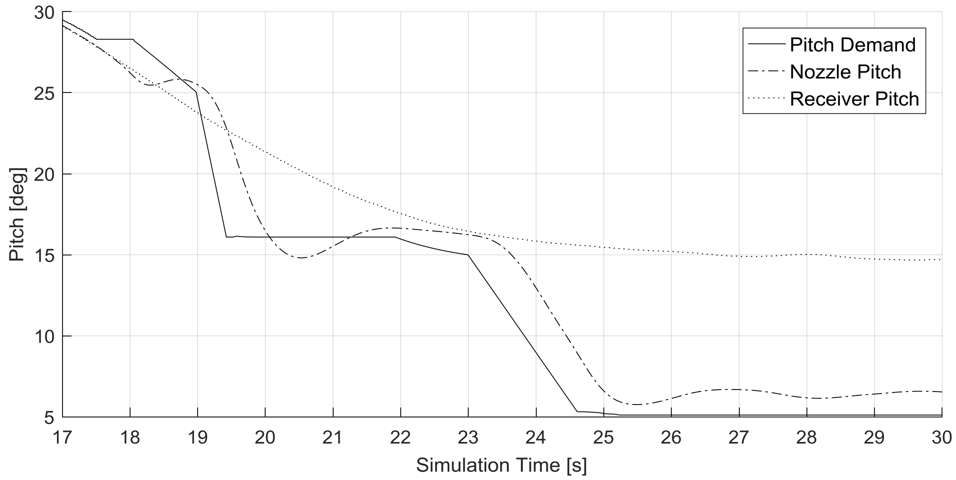

Figure 14: Nozzle, Demand and Receiver pitch

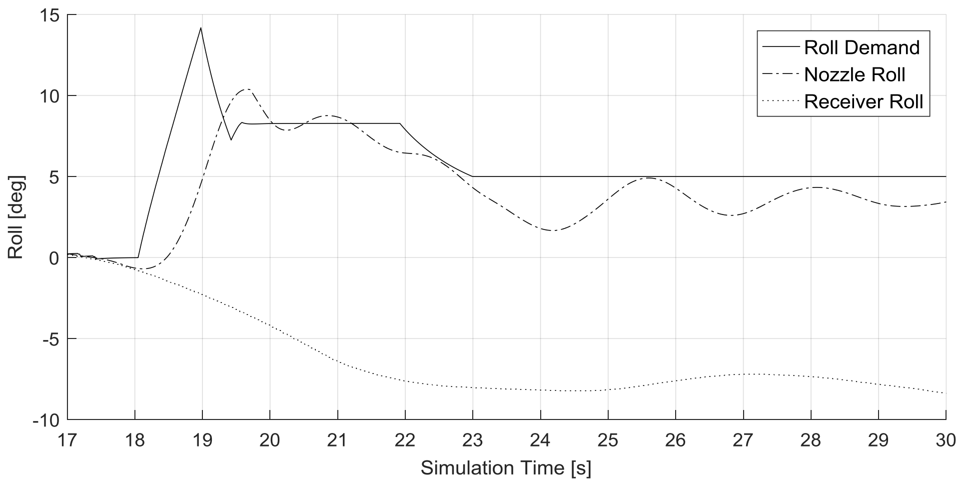

Figure 15: Nozzle, Demand and Receiver roll

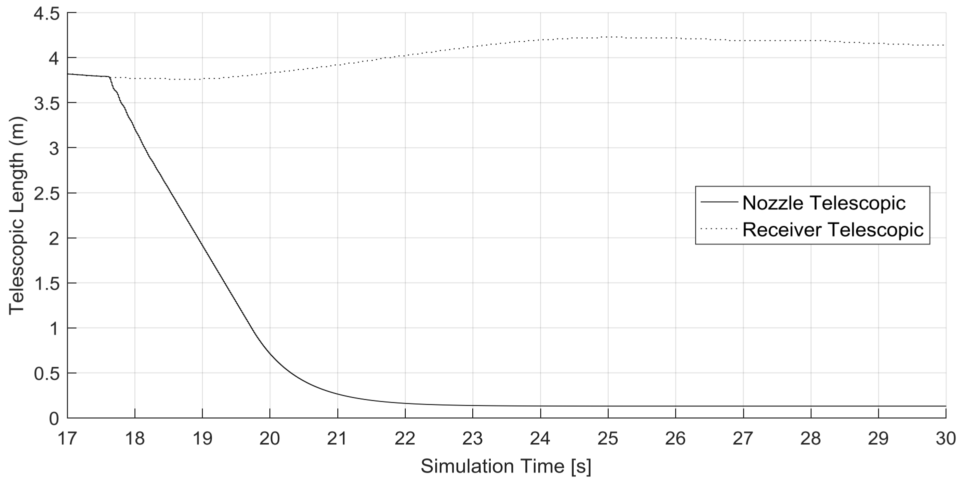

Figure 16: Boom and receiver telescopic

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Above figures prove that the system is working well: boom nozzle safely separates from the receiver even in a considerably risky scenario. After a normal operation disconnection, the receiver is expected to move back and downwards towards astern position. In this simulation, receiver maintains the relative distance between receptacle and boom nozzle and performs a 15deg pitch up after disconnection. It is shown how needs are progressive fulfilled through applying different reactions, being always a safe clearance from boom to receiver in terms of pitch, roll and telescopic. Boom displacements are smooth and not higher than necessary.

It is demonstrated that this decision-making model based on needs fulfilment is applicable to model an ARBS operator in the decision-making task. Regarding reactions management and estimator, small modifications have been introduced decision-making systems proposed in reference [1], but it is considered that overall original model concept idea has been retained.

Three needs have been designed in order to applicate original decision-system model in ARBS separation phase. To measure needs unfulfilment boom operator experience has been a key point. Also according to an experienced operator, a total of eight different reactions have been designed in two phases in order to give the system enough flexibility and reactions variety. Three estimator models have been tested and the simplest one has been selected due to simplicity and computation requirements reasons. Different values in reaction chooser input weight have been also tested.

Model has been proven and validated in simulator by experienced operator for different receivers and flight conditions. Simulation results show a safe separation between boom and receiver resembling manual AAR operation.

7. Future work

Boom attitude estimator is considered simple but good enough. This decision making model has been tested in many scenarios with good behaviour but it is not ensured that the absence of precision does not imply any issue to this system behaviour (a formal clearance considering different scenarios, flight conditions receiver types and movements will be performed to formally validate current boom attitude estimator). In any case, additional estimator precision enhancements without penalizing computation requirements will be study.

Impact avoiding unfulfilment is measured thorough boom nozzle to receiver receptacle distance from image processing. This makes this system somehow blind to the rest of the receiver geometry. It will be desirable to take into account distances from nozzle to other important parts of the aircraft receiver in order to avoid not only the receptacle but cockpit and vertical tail plane collisions.

The inclusion of emotions and mood, together with the current needs, will be the next step to model human psychology.

In the way to a full autonomous operation, decision-making system must be designed in all operation phases described in section 3. Finally, an integrated decision-system model should be capable to autonomously operate the boom.

References

[1] Kowalczuk Z, Czubenko M. Interactive cognitive-behavioural decision making system. In: Rutkowski L, editor. Artifical intelligence and soft computing lecture notes in computer science, lecture notes in artificial intelligence, vol. 6114. Berlin: Springer; 2010. p. 516–23.

[2] Czubenko, M., Ordys, A., Kowalczuk, Z.: Autonomous driver based on intelligent system of decision-making. Cogn. Comput. 1-13 (2015).