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DIAUTIS: A Fuzzy and Affective Multi-agent Platform for the Diagnosis of Autism

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Authors' contributions

This work was carried out in collaboration between all authors. The three Authors designed the study. Authors MA and NT were in charge of the additional hardware and software elaborated and managed the analysis of the study. Author FA carried out the assessment tests and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Autism is a disease that appears in the first stage of life and produces significant imbalances in the behaviour of people affected by this disease. According to existing data, autism is growing at an alarming rate. Its early diagnosis is important to be able to administer to the patient the aids it refers to, especially those related to learning.

DIAUTIS is a platform that aims to help the clinical team, doctors, parents, tutors and schools in the diagnosis of this disease. Its ability to cognitive, fuzzy, and affective computing, with the capability to learn from experience, endows the multi-agent system many possibilities. One of them is to present collections of tests of various categories, evaluate the results of the child, and present a final model of his/her condition and the severity of the disease.

The tests performed show that DIAUTIS is ready to initiate a long series of diagnostic tests with reliability and efficiency.

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1. INTRODUCTION

Autism is a spectrum disorder (ASD) [1] which shows a wide degree of variation in the way it affects people. It is not a single disorder but a whole of closely connected disorders with some related symptoms. Every child or adult affected by ASD has bigger or smaller problems [2] with social interaction, communication, focused interests, empathy, and behaviour, but the level of disability changes quite a bit from person to person. Different terms have been used to name those disorders [3], as high-functioning autism, atypical autism, autism spectrum disorder and pervasive developmental disorder provoking a great deal of confusion.

Autism is the second most prevalent neurodevelopmental disorder among children, but prevalence estimates vary markedly over time and among countries, depending on multiple epidemiological variables. Autism is an illness that affects an increasing number of children. In accordance with the statistical data of the CDC [4], in 2000 and in the United States prevalence estimated was one among 150 children, but this number has increased greatly until it reached the figure of 1 in 68 births in 2010. Nevertheless, a new study [5] from the government of the United States, realized in 2014, raises the number of children with autism to 1 in 45 with ages between 3 and 17 years. The increase is really alarming.

Up to 2013, five different autism spectrum disorders were considered by the American Psychiatric Association (APA) although the DSM-IV [6] gave instructions for the diagnosis of three of them: autistic disorder (ASD), Asperger's syndrome (high-functioning autism), and PPD-NOS (Pervasive Developmental Disorder-Not Otherwise Specified, or atypical autism). Autistic disorder is the most severe. The problem with ASD relies that the diagnosis is based on impairments which have to be observed and assessed [7]; impairments which sometimes are similar to those of other related disorders such as ADD/ADHD, nonverbal learning disorder, obsessive-compulsive disorder, social anxiety and social communication disorder [8].

The causes of the autism are ignored, although it is understandable to believe that one of the physical problems of the cerebral functioning of the child with autism can rest on a differentiation in the neural processes that the autistic one realizes during learning [9]. This topic, the learning of the child with autism [10], is very important for its difficulty. That is why early diagnosis is fundamental because it allows the use of the corresponding learning aid from the first moment.

The studies about learning are numerous. A general treatment of the topic has been prepared by Schopler and Mesibov [11]. They have tried to tackle all the aspects related to cognition, its difficulties, the executive functions and learning of the child with autism, including educational strategies. Another work worth mentioning is that of Byrne and Roediger [12]; their four volumes on the topic constitute an important base of knowledge and operation on learning of the children with autism. Among the contributions included we would like to refer to that of Michelle Dawson, Laurent Mottron and Morton Ann Gernsbacher [13] for their specific treatment of learning. In relationship to implicit learning the results presented by Jamie Brown et al. [14], about the possible permanence of implicit learning mechanisms in children with autism, and those of Nemeth et al. [15], should be emphasized. In a similar line of work, Dugan and co-workers [16] have shown the importance of cooperative learning. Preissler [17], on the other hand, has carried out diverse experiments on associative learning of drawings and words showing the charitable influence of this type of learning. Nevertheless, a difficult subject is rule learning; in this line, it is necessary to mention the work by Jones and co-workers [18] showing that, at least between the ages of 4 and 6 years, the children with autism do not diminish their skills for rule learning in a suitable social environment.

Nova Science has published several interesting books related to autism theories and interventions [19], family impact and early signs [20], research [21], federal activity [22], and recent research [23] as well as to general features [24]. They have also published several books related to Asperger Syndrome [25,26].

Several models have been devised to explain autism as a frame of help for the life and learning progress of the autistic child. Among them, it is necessary to mention the SCERTS model [27] which guides to parents and minders in many of the development aspects of the child with autism. The DENVER model [28] dedicates very much attention to learning of the language and gives rules for interventions in the help of children with autism between ages from 12 until 48 months. There exists a great deal of books and papers that try to help in the practical life; the book by J. Tommey and P. Tommey [29] is a good example. In more punctual aspects and without trying to do a detailed history of the art, it is necessary to quote, for its relation to this work, the employment of cortical Kohonen maps as support of a theory of autism [30] that allows the analysis of the different impairments formation. Also, the work by Wang, Chen, and Fushing [31] on the classification of the ASD from the information of magnetic resonance and the magnetic connectivity of the brain, is worth mentioning.

2. DIAGNOSIS OF AUTISM

There are important works relative to the diagnosis of autism, like that of Baird, Cass, and Slonims [32], although none of them proposes specific tests. The current problem is that the diagnosis of the autism has changed radically from the appearance in 2013 of DSM-V [33] that organizes symptoms and behaviours in groups of diagnosis. The most significant changes of this new version have been the retreat of two diagnoses relative to Asperger's syndrome and the PPD-NOS. The target, according to APA [34], [35], is to centre the work even more on the diagnosis, behaviours, and helps to the strict autism. In consequence, this research has tried to follow the recommendations and criteria of the DSM-V [36] that, as the earlier versions, have never included concrete tests for the diagnosis, but only a relation of diverse problems or anomalous behaviours as criteria.

As first ASD symptoms [37,38] that should be verified are the following: the child does not present pronounced smiles or other happiness expressions at the age of six months; at the age of nine months, the child shares neither sounds, smiles, nor other facial gestures; continuing at about twelve, with the absence of chatters and of concrete gestures like greeting, indicating or showing. At the age of sixteen months, he does not articulate words and at twenty-four, he is unable to formulate phrases of two words that have meaning if they are not for pure repetition [39]. This process presents, without any doubt, enough variants, both in the present symptoms and in its appearance, therefore, its detection and follow-up are important. Simultaneously a loss of social skills has been appreciated like not answering to their name, excessively aligned of objects or toys, or unusual answer to inputs sensory [40].

Several diagnostic tools can be used for autism. Probably the most well-known are ADI-R, ADOS-G, and CARS. ADI-R [41] is a 100-item interview that helps diagnose autism in children and adults with a mental age over 2 years. The interview, including items related to communication, reciprocal social interaction and restrictive, repetitive and stereotyped behaviour, is administered by a trained clinician to parents or caregivers of the child. ADOS-G (Autism Diagnostic Observation Schedule-Generic) [42], is an observation-based assessment of the socio-communicative behaviours that are often delayed in autism. CARS (Childhood Autism Rating Scale) [43], is a 15-item interview that evaluates impairments related to body movements, adaptation to change, listening response, verbal, communication and relationship to people. Other diagnostic tools for ASD to be cited are PEDS (Parents' Evaluation of Developmental Status) [44], Gilliam Autism Rating Scale [45], and STAT (Screening Tool for Autism in Toddlers and Young Children) [46].

3. TECHNOLOGICAL TOOLS

In the last years, a collection of technological tools with very diverse purposes have arisen. Among them and related to the diagnosis of the autism, several Apple developments, like Apple Watch [47], used in combination with ResearchKit [48] and even with the iPhone, to measure the epilepsy attacks are well-known.

Duke University has already begun using a front camera [49] to detect signs of the development of autism in small children, with algorithms to detect emotions and measure the reactions of the children to the videos that appear on the iPhone.

Different devices have been developed or applied for the analysis and follow-up of eyes. So, Tobii [50] has a technology that allows a device to know exactly where the eyes are concentrated. That way it can find the presence, attention, concentration, drowsiness, conscience or other mental states of a person. This information can be used to know in-depth the behaviour and affection of a person. EyeGaze [51] offers diverse products that they guide to possible users in the first theoretical steps relative to the notion of causality and decision-making.

Also, several pieces of software have been devised to cooperate even with conventional webcams interpreting the visual reactions of a person. Probably the most well-known are Pygaze, Ogama, Gazerecorder and Xlabs. Pygaze [52] is a software package developed in Python for pursuing of eyes with the least possible effort. Ogama [53] is able to register and analyze in parallel the eyes information and smile changes from experiences based in dioramas. The third tool, Gazerecorder [54], registers and analyzes in real-time the movement of the eyes. The last one, Xlabs [55], is an extension that allows navigating without a mouse from the movements of the head or the eyes.

Going to specialized studies more related to our work we have to quote the development of a wearable camera as [56] a companion tool able to collect video and audio from movements for social-emotional learning in autism.

4. LEARNING AIDS: COMPUTER-AIDED LEARNING (CAL)

There exists evidence of CAL as a well-accepted tool for years by pupils with autism [57], [58] and, as a result, enough systems have been developed already in the 90. It is necessary to mention ASILeSP, as a support of CAL systems. It is a software package for the development of CAL to help the patient with autism [59]; nevertheless, its use has been very limited. In fact, Moore, Grath and Thorpe [60] have prepared a list of important problems related to the learning of the child with autism; for all of them, the use of CAL systems would be of great help. A detailed example of a CAL system has been described by Bosseler and Massaro [61]; they have developed an animated tutor as a help for learning of the vocabulary and language. In any case, CAL systems are more limited than those offered by Artificial intelligence (AI).

5. ARTIFICIAL INTELLIGENCE (AI)

AI has been a new computer revolution with its attempt of emulating the human intelligence. It arises in the 60 [62,63], with interesting results as the expert systems [64] applicable to any area of the industry, to defense and to consultancy. The intelligent tutors [65] are another important result in the field of learning.

In the 80 a new paradigm arises, that of distributed AI [66], with first interesting contributions as ACTORS [67], DVMT [68], and EMMA [69] realized with autonomous agents [70] acting jointly [71,72] and leading to the multi-agent systems. In the first stage the agents operate reactively [73], that is to say, only they answer instantaneously to inputs, foreseen and not foreseen situations, but they do not plan its response. The first governed robots were constituted with different architectures of agents, such as that of Brooks [74], Kaebling [75], and Laureano et al. [76]. One of the most important developments is due to Rao and Georgeff [77] with their BDI-agents with a mental state including beliefs, desires, and intentions. These agents have been widely disseminated because they increase the autonomy and efficiency of different agent tasks. Among them, the cooperation, control, and learning from its own experience have to be mentioned. Multi-agent systems (MAS) have been applied to all kinds of engineering [78,79], including the development of agents to act on the Internet [80].

In summary, the MAS are integrated by a set of intelligent agents [81] that cooperate with each other to solve very diverse tasks of the real world. The usual problem of these systems is the obtaining of the knowledge that empowers the agents to carry out those tasks, knowledge that habitually resides in human experts.

In order to obtain this knowledge from those experts, tools such as BCTA [82] have been developed, capable of obtaining it from interviews, and resolution of very varied problems.

Recently, both affective computation and fuzzy logic have been incorporated into the MAS. The affective computation [83,84] implies the introduction of models with which the agents can capture the affective state of the user to know it and even improve it interacting with him. This can be done by analyzing the interaction of that user with the computer, his/her spoken expressions, or through sensors that capture biological constants, gestures or movements of the user and are automatically interpreted.

Fuzzy logic [85,86] is a generalization of classical logic transforming it from being bivalent to multivalued. It is much more flexible because it is capable of considering not only true or false situations but multiple intermediate states. One of its most interesting applications has been the new robotics [87], the fuzzy control theory [88], and its applications going from the guidance of vehicles without a driver, washing machines, up to photographic cameras [89]. The defuzzification process transforms a fuzzy set into a single number to introduce it into real tools or machinery.

Artificial neural networks belong to the machine learning techniques [90]. These techniques allow MAS learn from experience. The neural networks, without any theoretical knowledge, learn to solve specific real problems only by knowing the inputs and the outputs (data and solutions) of a number of similar problems [91-93].

However, this field of artificial neural networks has been the first AI technique being used for autism [94]; this work, by Cohen, has been based on neuropathological studies suggesting that people with autism have too few neuronal connections with inferior discrimination or too many with inferior generalization. Nevertheless, neural networks were used in advance in psychopathology, both like a tool for research or for practical use; it has to be cited the editorial contribution of Stein and Ludik along this line [95].

MAS have enormous possibilities of application to autism due to its actual features and capabilities. They can be and aid not only for diagnosis but also for helping people.

6. DIAUTIS: A MULTI-AGENT PLATFORM FOR THE DIAGNOSIS OF AUTISM

6.1 Methodology

This work is the starting point of what can be a long research. It can lead, with time, to the construction of a tool for helping the persons related to autism: doctors, clinical teams, relatives, schools and centers of help. It might be a good help in the diagnosis of autism. He might collaborate in the design of normalized protocols for the comparative diagnosis of this illness. It might extend this collaboration to people related to other disorders close to ASD. It even might help the patients in their learning. Conscious of this responsibility, special attention has been dedicated to the method.

The adopted approach has limitations, which will be commented later. Consequently, flexibility has been emphasized, like an important characteristic of this work. The purpose of this flexibility is to foresee unknown elements, as much as possible, that they might discredit the task done up to this moment. In accordance with these ideas, the developed method includes the following phases:

A) Knowledge acquisition of autism in its diverse aspects. To get this knowledge the following tasks have been developed:
   1. Obtainment of pertinent information in the scientific literature on autism.
   2. Meetings with medical and clinical equipment related to autism.
   3. Meetings with families with relatives with autism, and centers of help.
   4. Knowledge of the public and private plans for helping autism in diverse countries.
   5. Periodic meetings of the technical team to discuss and to share the knowledge and the acquired feelings.

B) Diagnosis of the autism, criteria, and tools. This phase is similar to phase 1, although related to the diagnosis. As specific features, it includes analysis of the DSM-V criteria and its relation with the DSM-IV, and with other criteria used in the diagnosis; analysis of the existing hardware to take biological or affective children information, and of the software programs of software for interpreting this information.

C) Concepcion of a computer model of diagnosis based on a collection of tests. They appear on the computer screen or they can be listened (language tests). The tests are always related to the DSM-V criteria. The following stages have been established for this purpose:
   1. The design of a limited set of tests. The medical team has to approve the design.
   2. Enlargement of the set of tests by means of its parametrization and allocation of values of its characteristics and by designing new tests. Classification of the tests into categories. Implementation of the tests.
   3. Fuzzy evaluation of the tests specifying the fuzzy logic techniques to be used according to the errors or mistakes of the child. Integration of the tests results of every category into a final fuzzy model of the diagnosis session. Fuzzy evaluations present a major flexibility and a better uncertainty treatment that the traditional evaluation and the classic logic.

D) Election of a platform for constructing the agents based on its flexibility and complementary help that could give. Design of the DIAUTIS architecture and that of the agents. Development of the software to be included in the modules of each agent. Implementation of DIAUTIS.
E) DIAUTIS functional proofs, in charge of the technical team.
F) Additional tests with observers, medical and clinical teams.

6.2 Objectives

As a global target, DIAUTIS attempts to be an automatic and autonomous aid for clinical equipment, parents, tutors and schools about the diagnosis of autism. So far, it has not been designed for aiding the ill person.

Among its concrete goals it is necessary to stand out:

a) To offer a wide and changeable collection of tests, according to ages and shortcomings, to children with autism.
b) To evaluate every realized test and get a model of the child able to estimate the severity of the autism.
c) To realize computerized interviews to parents to get first data of the state of the child to verify later the symptoms with the tests that are realized.
d) Future making of normalized protocols of tests as ages: following medical instructions.

All this tries to be done in a flexible, easy to apply, friendly, able to learn, and autonomous system.

6.3 Auxiliary Hardware of the System

In the last years, there have developed enough hardware as cameras and other sensors as well as software of interpretation to receive and interpret information from the autistic child including his emotions. Between them it is necessary to quote the interesting contributions by Baron and Golan [96], completed with some other [97] on the employment of different multimedia skills, those of el Kaliouby [98,99], Lockerd and Mueller [100], and that of Teeters et al., [101], on the use of diverse cameras for reading emotions.

DIAUTIS uses permanently cameras and wrist sensors to receive child's details as his look, face, palpitations, gestures, and movements. By means of software developed for this work in Python, it is possible to get the emotions and particular details mentioned and so, to know in real-time the affective state of the child, as well as the visual follow-up of objects, its duration, and reiteration. As for sound and language, there has been developed software of signal processing that allows a basic analysis of the pronunciation, intonation, and lexicon, used by the child, which combined with a set of phrases in natural language, allow the detection of problems including possible grammatical errors.

6.4 Functionality

Diverse software programs or basic software platforms have been developed to ease the task of designing and implementing intelligent agents, such as JADE [102], AgentSpeak [103], ProMAS [104] and NEOCAMPUS [105]. In our case, the choice has been clear because of the greater flexibility supplied by NEOCAMPUS. This platform directly provides a modular agent architecture, quite complete which if required, other modules can be easily added to. On the other hand, it is the only one that facilitates affective and fuzzy computation. It also offers extensive built-in possibilities for cooperation and control of agents. It also has produced several spin-off prototypes that may help the work of DIAUTIS. ENT is one of them. Therefore, the most important task has been to develop the software corresponding to the knowledge of the agents to do their tasks.

Initially, DIAUTIS has arisen like an NEOCAMPUS spin-off [106,107,108], although the peculiarity of its targets and implementation obliged to introduce additions to hardware and software. NEOCAMPUS is a platform for the design and implementation of intelligent agents, with an extensive history in the production of very diverse prototypes (spin-off), fundamentally, in the field of intelligent e-learning systems. Among them, we can quote MEDIC, FINANCE, FILTR, AFFECTION and ENT. MEDIC [109] is an intelligent e-learning system simulating the functioning of a medical centre: its departments, finance, and managerial problems. A set of junior managers can learn to solve the different problems or incidents happening in the centre daily life. FINANCE [110] is another intelligent e-learning system for learning financial or managerial accountant and firm analysis. FILTR [111] sends agents to the Internet to get and to leak intelligently information. The result is the answer to a user's profile. Also, he can sum the obtained information up also. This way FILTR can update automatically already existing databases with information obtained from the Internet. AFFECTION [112] is the complement ready to NEOCAMPUS so that its prototypes could realize the affective computation. ENT will be described later in this section.

In the case of DIAUTIS, a traditional interview can be done to parents and experts before the first diagnosis session to get initial data and select the proper tests for the diagnosis (see Figs. 1, 2, 3 and 4). This choice is carried out by the clinical team, but the system is prepared to select them according to that information.

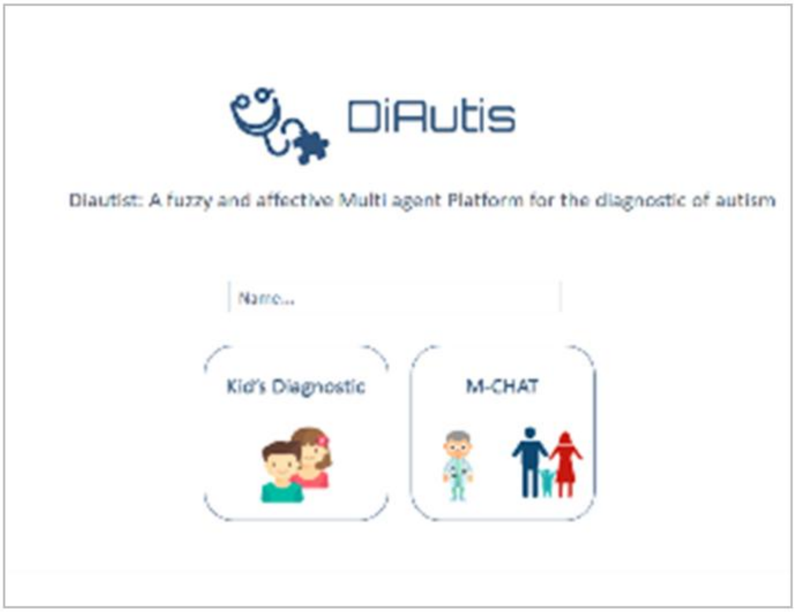

Fig. 1. DIAUTIS initial screen

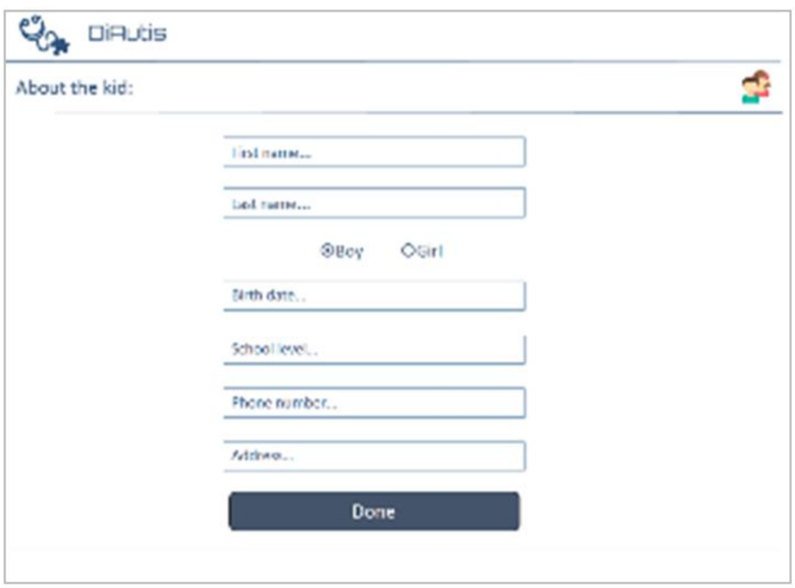

Fig. 2. Child's personal data

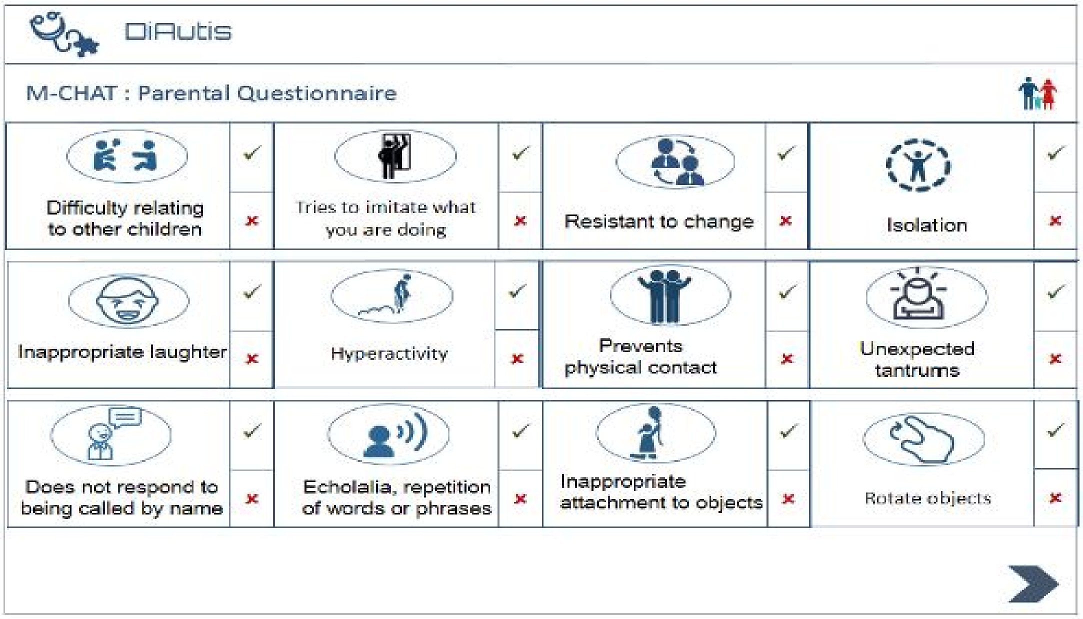

Fig. 3. Parental questionnaire (Screen 1)

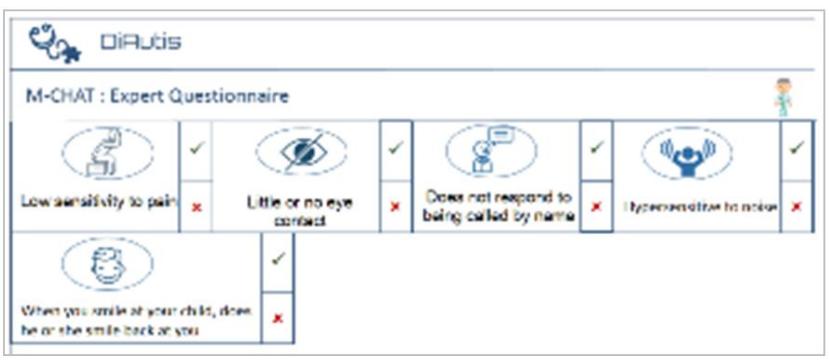

Fig. 4. Expert questionnaire (Screen 3)

DIAUTIS includes a set of tests already prepared and inserted in its Database. From them, a collection of tests properly selected, can be presented to the child with autism for his/her diagnosis. The tests have changeable characteristics for display that allow a large number of possibilities and changes. These tests appear on the screen of the system or, in the case of language tests, they are expressed like sounds or words across the loudspeakers of the system. Language tests can go accompanied by images. From this moment the answer of the child is obtained by diverse means that can overlap: analyzing the features of his/her face, following his look, observing his movements, analyzing the elements of his/her spoken answers, by means of the mentioned sensors and the software that allows the interpretation of the child's answers.

At all times the system tries to find the affective state and the affective answers of the child, his motivations, and interest. This task is carried out in an imperceptible way by the affective agents that we will describe later; these agents do not try to alter or improve the child's affective state, except when medical indication exists in this sense. Also, in most of the tests human or animal figures can appear with the role of pedagogic agents [113] to help the achievement of the test. Pedagogic agents may adopt also the role of affective agents, trying to influence the emotional state of the child, if the doctor considers it. Also the same can be done by sounds or concrete melodies.

Every test, besides its specific characteristics for display, takes an initial qualification integrated by a set of parameters (category, subcategory, proper age, difficulty or percentage of success, relation with other tests, the convenience of pedagogic agents, duration, etc.) initially given by the clinical equipment. According to the experience obtained with different children, the platform, by using machine learning techniques can change and update those parameters, always preserving the initial qualification and the history of the changes of these qualifications.

According to the display characteristics selected, the system designs all details of the tests to be presented. In the case of tests to follow-up objects on the screen, the characteristics selected find the trajectory, kind of the object shown, speed, luminosity, brightness, duration, etc.

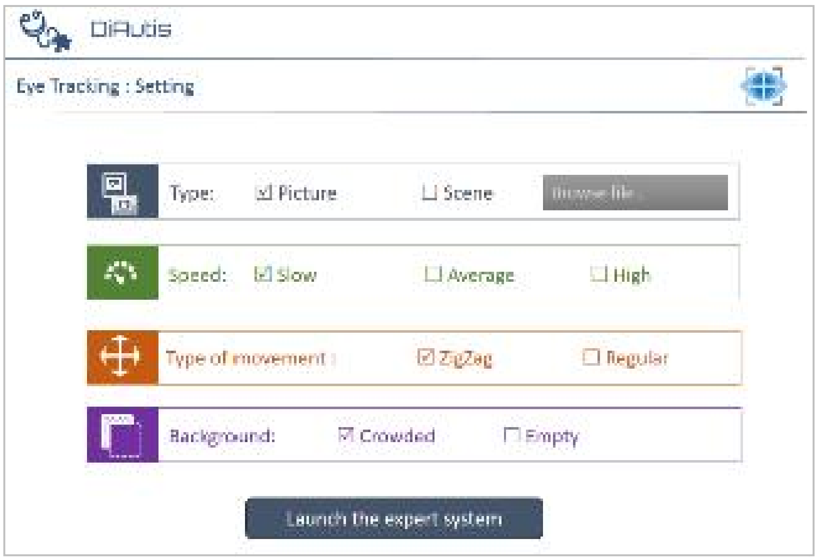

Fig. 5. Eye tracking: Setting

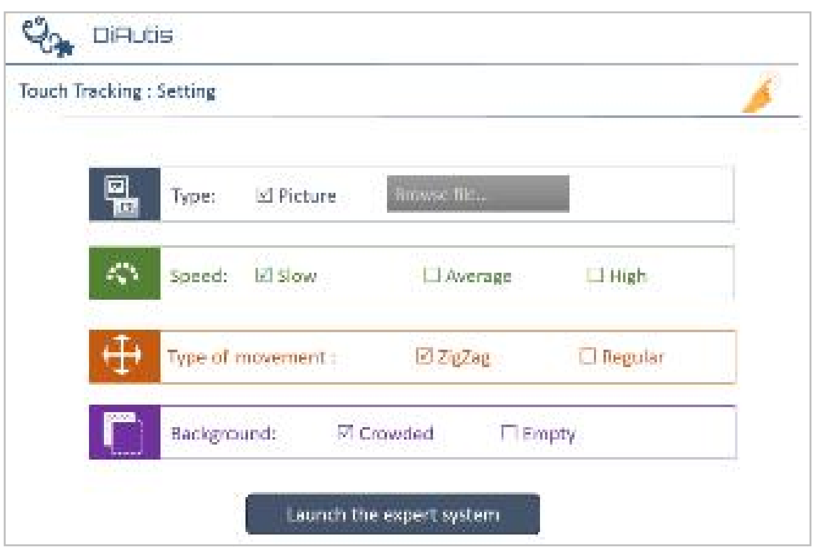

Fig. 6. Touch tracking: Setting

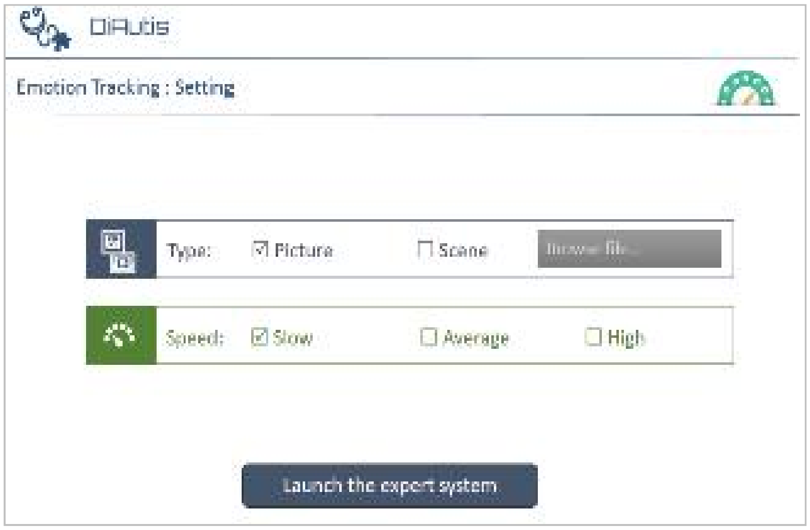

Fig. 7. Emotion tracking: Setting

A diagnosis session includes a collection of tests, extracted from the tests database, determined by the clinical team. The collection is, usually, a consequence of the results obtained in earlier diagnosis meetings or of the child's state. These collections can be determined automatically, with the help of ENT [114], another NEOCAMPUS spin-off, from indications on the number of tests and the value of its qualification parameters. ENT possesses several general criteria for the generation of these collections in terms of the parameters of the tests; these criteria can be chosen and combined very easily according to logical operators as OR, AND, and similar ones. However, a specific and different criterion can also be designed to generate the requested collection according to needs.

The DSM-V Manual does not explain the concrete tests that must be realized to diagnose the autism but the criteria, which are described as observable problems such as a) social interaction and communication skills; b) restricted, repetitive patterns of behaviour, interests or activities that cause significant impairment in socially, occupational or other areas of functioning.

The tests proposed by DIAUTIS have been grouped in categories related to the problems specified in DSM-V. They are the following ones:

1) Affectivity: Every test describes, visually, a scene or small emotive history trying to detect affectivity or empathy in the child. Table 1 shows the negative elements to be evaluated and the evaluator agent.
2) Language and verbal comprehension: The number of tests of this family is important and it includes:
   - Terms, verbs, actions: comprehension and repetition on and out of time.
   - Comprehension and repetition of different phrases according to difficulty, age, etc.
   - Brief conversations and questions.
   - Communication of desires or needs: problems or difficulties.

Table 2 shows the elements to be evaluated and the evaluators.

3) Visual objects follow-up, with or without sound, with or without pedagogic agent. Every test presents on-screen:
   - Luminous points with diverse characteristics: light intensity, colour, speed, trajectory and its changes, duration.
   - Objects (geometric, animals, images: cyclists, motorcyclists, cars), that move with diverse intensity, colour, trajectory, speed) with or without a sound accompanist, with or without pedagogic agent.
   - Videos or not affective scenes with objects to be pointed.

Table 3 shows the items to be evaluated and the evaluators.

4) Attention and response to basic sounds: Sounds can be pure ones, same repetitive notes, easy melodies, special noises expressed by electronic keyboard equipped with drums or noises, etc.

Pedagogic and/or affective agents fit well in these tests when it has been recommended. The child's answer includes the response time, duration, possible renewal of the answer for the appearance of new elements (pedagogic agents, sounds), answer to a certain element not related to the test, analysis of the child's face and affective behaviour, interest, special and repetitive movements.

Table 4 shows the evaluated elements and the evaluators.

5) Other social behaviours: This category includes tests about gestures, the arrangement of objects, and learning of basic rules of behaviour. Basic rules included for learning are related to the association of a gift or symbolic benefit to the good response.

In these tests the system evaluates (see Table 5).

6) Combined tests: This category includes more advanced tests. They require imitation of adults or of other children. Imitation includes: facial and body movements, deferred imitation of actions on objects, functional play involving toys, etc. It also includes tests related to social rule learning. Basic rule learning refers to dress, personal appearance, observation, and response to certain social events. Intelligent simulation [115], not only videos, is the tool used for the display of those tests. One of the well-known tests included is the Sally-Anne scenario. Sally hides a doll in location A. In her absence Anne moves the doll to location B. On Sally's return she will have a false belief about the doll's location. Children with autism do not understand that false belief expecting her to believe the doll is in location B.

The negative elements to be evaluated are (see Table 6).

7) Behaviour in group: In this category, the tests are presented to a whole group of children, inviting them to diverse collaborative performances. The response of the child who is diagnosed is analyzed and that of remaining group members (if needed).

In these tests the following elements are evaluated (Table 7).

Table 1. Category 1

Negative elements to be evaluated	Evaluators
Lacking in the recognition of the existence of other persons or their feelings	Pedagogic and/or Affective agents
Possible intense affliction due to insignificant changes in the environment or in the history	Pedagogic and/or Affective agents
Lacking in search of consolation in difficult moments	Pedagogic and/or Affective agents
Indifference to pain	Pedagogic and/or Affective agents

Table 2. Category 2

Negative elements to be evaluated	Evaluators
Shortcomings in the comprehension, form and content of the language	Pedagogic and/or Cognitive and Affective agents
Shortcomings in the emission and affectation of the language, emission of terms repeated without intention of tone or abnormal intonation	Pedagogic and /or Cognitive and Affective Agents
Too literal comprehension, lacking in humour, irony, sarcasm	Pedagogic and/or Cognitive and Affective agents
Abnormal reaction to sounds, words or phrases	Cognitive and Affective Agents

Table 3. Category 3

Negative/positive elements to be evaluated	Evaluators
Number of times that the child follows the visual object and follow-up time	Cognitive and Affective agents
Abnormal interest related to concrete objects, numbers or symbols, pieces or toy parts that move	Cognitive and Affective agents
The number of pointed objects	Pedagogic and/or Cognitive and Affective agents
Abnormal reactions in following-up or pointing.	Cognitive and Affective agents
Obsessive relation with current objects that appear on-screen: keys, bands of gum, switches, etc	Pedagogic and/or Cognitive and Affective agents

Table 4. Category 4

Negative/positive elements to be evaluated	Evaluators
Direct reactions to sounds: number, intensity, kind	Cognitive and Affective agents
Like or dislike sensation: number, intensity	Cognitive and Affective agets
Repetitive body movements (hand flapping, rocking, spinning); moving constantly	Pedagogic and/or Cognitive and Afective agents
Hyper - or hypo - activation to certain sensory inputs such as sharp sounds or sound textures	Cognitive and Affective agents

Table 5. Category 5

Negative elements to be evaluated	Evaluators
Anomalous movements or abnormal positions	Cognitive and Affective agents
Reaction to the strict objects arrangement on screen and in reality	Pedagogic and/or Cognitive and Affective agents
Failure or errors in basic rule learning	Pedagogic and /or Cognitive and Affective agents

Table 6. Category 6

Negative elements to be evaluated	Evaluators
Difficulty of imitating facial or body movements	Pedagogic and/or Cognitive and Affective agents
Difficulty of playing with toys and other objects	Cognitive and Affective agents
Failure or errors in social rule learning	Pedagogic and/or Cognitive and Affective agents
Difficulty or error in the comprehension of specific scenarios	Cognitive and Affective agents

Table 7. Category 7

Negative elements to be evaluated	Evaluators
Lacking of general interest and collaboration	Pedagogic and Affective agents
Difficulty of making friends with other children of the same age	Pedagogic and/or Cognitive and Affective agents
Lacking of interest in other children or in sharing their interests	Cognitive and Affective agents
Weariness, introversion	Pedagogic and Affective agents

A previous traditional interview can be done to parents to get initial information of the child's state to select the proper tests for diagnosis. This choice is carried out by the clinical team, but the system is prepared to select them according to that information.

Once the negative elements of each test have been obtained, the evaluation and group evaluation agents (if the group exists) carry out several evaluations, described later, to get the last child's state.

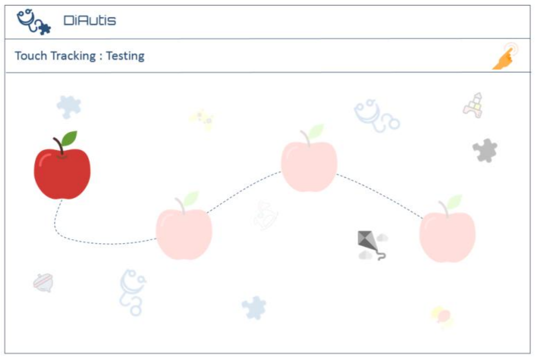

Fig. 8. Test 3.24 (Touch tracking)

6.5 Determination of the Affective State of the Child

DIAUTIS uses initially the OOC model [116] to analyze the emotions of the child, already introduced in NEOCAMPUS [117], and imported to its spin-offs. This implementation was only valid to analyze spoken or written information by using natural language treatment [118]. But we have to go further because emotion recognition [119] includes, if possible, other elements as physiological parameters such as heart rate, respiration rate, skin conductance; image recognition, face and other gestures; speech analysis and natural language processing.

Nevertheless, DIAUTIS has the sensors, before mentioned, that allow evaluating in real-time (see later) the affective state of the child by interpreting his face, heart and respiration rate and gestures.

Due to possible changes of the affective child's state in a few seconds, it is necessary to take into account the affective child's history during the test. Affective agents [120] are in charge of this task. Fig. 9 shows the time distribution in 42 sec. (eye tracking) and Fig. 10 shows the distribution of emotions in different tests. Those values, obtained by the cognitive and affective agents are sent to the evaluation agent as inputs for the evaluation process.

6.6 Fuzzy Multi-criteria Evaluation of the Child's State: Severity of Autism

The starting point of the fuzzy computing in DIAUTIS is the earlier work in fuzzy logic [121], [122] incorporated to NEOCAMPUS [123], [124], and spin-offs. They allow computing with fuzzy graphs and sets, as well as its defuzzification using several well-known techniques. As for the fuzzy operators that it uses, the traditional OR (max.), AND (min.), and NOT are among them. Bearing in mind that for each of them there exist infinite possibilities of implementation, the system can verify the results of using the two ends (top and low) of the scale to quantify the consequences of the realized election. Also, it uses the fuzzy "modus ponens" and "modus tollens" with fuzzy sets in antecedent and consequent as well as the classical "modus ponens" and "modus tollens" qualified by a truth coefficient.

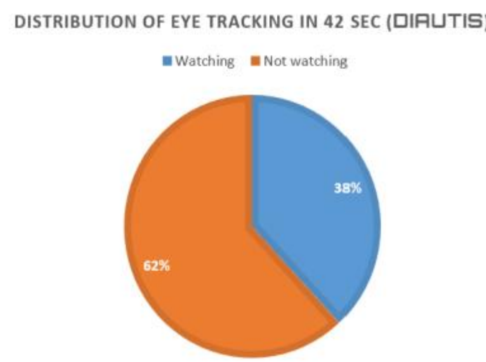

Fig. 9. Eye tracking: Time distribution

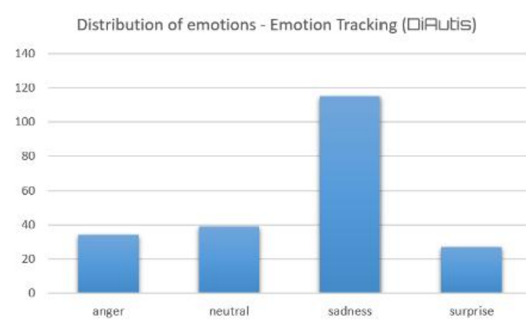

Fig. 10. Emotion tracking: Distribution of emotions

Limiting ourselves to the DIAUTIS peculiarities, the diagnosis that it realizes happens for diverse stages:

1) Evaluation of a test as a fuzzy set, Cij (i shows the number of the category and j indicates its place in the test): Every category (or subcategories in some cases) has a fuzzy evaluation criterion, described in terms of the negative elements measured in that category. The negative elements of the response of the child are

evaluated, according to the category criterion to produce a finite fuzzy set, Cij, defined on the universe of the negative elements that are valued in this category.

2) Integration of the results of the tests, belonging to a certain category, in one fuzzy set, Ci: As soon as all the tests of the set used are evaluated, the system integrates the obtained results for every category in one fuzzy set, Ci, relative to this category. Those sets, Ci, are finite fuzzy sets also defined on the universe defined by the elements that are valued in that category. To carry out this integration diverse methods were analyzed, like the fuzzy operators OR, and AND, but finally, to reproduce the integration that the clinical team usually does, there has been adopted an average value of the belonging functions of every element of the universe to the Cij set. The weighting coefficients, proposed by the clinical equipment, take into account the possible singularity of the values of the belonging functions.
3) Obtainment of the diagnosis fuzzy set, D: Next, a fuzzy multi-criterion allows the integration of the sets of the families, Ci, into a final fuzzy set that defines or specifies the state of the child. Several multi-criteria have also been tried for this purpose, but to agree with the operating procedure of the clinical team there has been adopted, at least for the time being, a method consisting in the earlier defuzzification of every set, Ci, to get an average value of the defuzzified values. Initially, the weighting coefficients were facilitated by the team, but the agents of the system that store the history of all the diagnosis can alter these coefficients, in the future, by using its machine learning techniques, always maintaining the history of these changes.
   This last fuzzy set, D, is defined on the universe of the categories used in the diagnosis session. That way this final set corresponds to the problems that DMS-V proposes for the diagnosis and turns out to be completely understandable for the clinical team.
4) Severity of autism: Now D is defuzzified to turn it into a number that indicates the autism severity in the child. This process is also carried out as the weighted mean of the values of the belonging functions of each category to D. The weighting coefficients, as usual, have been facilitated initially by the clinical team, but they can be changed by the system in the future.

Fig. 11 describes graphically the fuzzy evaluation process.

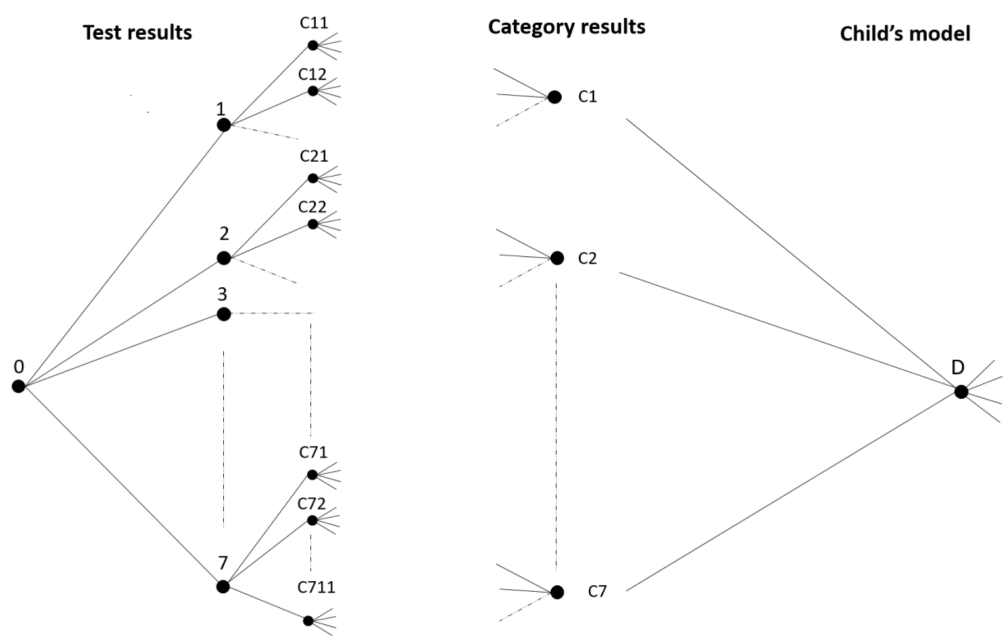

Fig. 11. Evaluation process

6.7 Agents

The DIAUTIS agents have the following characteristics: they are autonomous, that is to say, they work according to a few goals that have been assigned initially, or they receive them from the user (clinical team), or they accept them from other agents in the control and cooperation process, without another external intervention; they are intelligent or in other words, they act as based on the knowledge that they have and that are acquiring in its operation, this knowledge allows them to use the logical mechanisms they have to get the opportune consequences; they have learning ability from functional-link neural networks that they have, or with other machine learning techniques like reinforced learning or case-based learning for case. They have a specific knowledge for the achievement of the affective or cognitive goals, which initially have been facilitated to them by human experts; they have skills of cooperation between them when the goal exceeds the possibilities or another agent needs it to carry out its goals; they can be quickly cloned or suppressed when these operations are needed; they have capacity of language natural understanding and it can receive information proceeding from external sensors with which it is connected; in the latter case the elaborated software can interpret the received signs.

These characteristics are possible because the agents are provided with the same architecture (Fig. 12), integrated by a collection of connected modules; the knowledge stored in them is the only thing that changes depending on the agent activity. The most important are: the state module, in which specific beliefs, desires, and intentions are inserted with the specific world vision needed for its activity, and the cooperation methods among agents; the module of specific knowledge, divided into three layers: reactive, tactics and strategy and the inference engine. These layers are related to the different times of response to receiving inputs; the system of proper control, structured on two levels: one relative to the layers of specific knowledge, and the top level controlling the diverse modules and agent performances; a module of learning that has the machine learning techniques (functional-link neural networks [125], [126], case-based reasoning and reinforced learning) that allow autonomous agent learning; the natural language treatment module, for the communication with users, since the communication between agents is completely structured and normalized; and the communication or sensor module receiving and interpreting the information obtained by sensors.

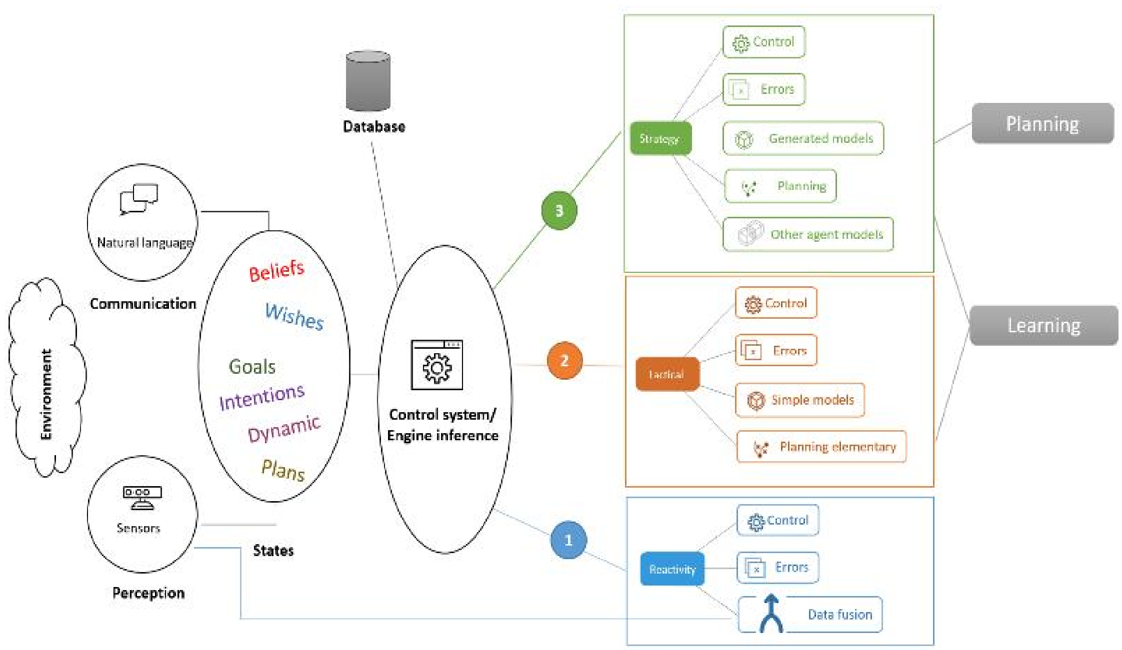

Fig. 12. The agent model

The different types of agents that intervene in DIAUTIS (Fig. 13) are:

1- Control agent: In charge of the following activities: it clones (or it eliminates) agents when activity increases; it coordinates the performance of the remaining agents and solves the conflicts raised by the attempted simultaneity of agents operation. Also, it yields control of the affective and/or pedagogic agent when it has been requested by the doctor, granting them priority in the performance conflicts among agents. It centralizes the communication with users when they get in touch with the system and reciprocally. It takes charge of the first interview with parents or instructors whose results it sends to the user and to the design agent. It can communicate with any agent.
2- Design agent: This agent is in charge of the design of the set of tests from the indications of the clinical team or using the criteria on the characteristics and number of the tests. It has the tests database and prepares every test record including the concrete characteristics of its use, date and obtained evaluation. It communicates with the control agent, from whom it receives the pertinent design indications, and directs the diagnosis achievement communicating with the interface, affective, cognitive and possibly pedagogic agents sending the characteristics of every test to be realized. These agents communicate the ending of every test and send the evaluation of the test that it incorporates into its record. This agent will be in charge of designing the future normalized diagnosis protocols from the qualifications and experience obtained and the indications of the medical equipment, including the possibility of performance of affective and pedagogic agents in the tests of the protocol.
3- Cognitive agents (type A): In charge of the follow-up, analysis, and answer of voice and sounds, with and without other pedagogic agents. It receives from the design agent the concrete information of the test to be administered. He has a sonorous model of the world. It cooperates to the evaluation of the test with the affective agent communicating to the evaluation agent the evaluation inputs, obtained from the measurement of the test negative elements, to the design agent, and to that of the group of children (if the group exists).
4- Cognitive agents (type B): In charge of the follow-up, analysis and answer of the child's look and face, with or without other pedagogic agents. They present the tests according to the display characteristics selected transmitted by the design agent. They communicate with other cognitive agents, with the control and design agents and supply the inputs for the test evaluation to the evaluation and group evaluation agents, in cooperation with the affective agent.
5- Cognitive agents (type C): In charge of the follow-up, analysis, and answer of the movements of the child (head, hands, the body), possible use of intelligent toys (with penetration, with unfolding and assembly). They have a spatial model of the world where they operate. They have the same tasks and communications as cognitive agents A and B.
6- Affective agents: They analyze permanently the affective state of the child along the test by means of the information from the sensors. They communicate with cognitive agents to get the test evaluation inputs. Sometimes (under clinical advice) they try to improve his affective state.
7- Pedagogic agents: They collaborate in the exhibition of the test assuming the voice of the test, or recommendations in the intervals. They can be displayed like simple voice or like animals or friendly objects that try to gain the confidence and interest of the child. Its type is chosen by the affective agent, according to the instructions received.
8- Rule learning agents: They are in charge of presenting the rule learning tests of different kinds by means of videos, images or intelligent simulation according to the test complexity. Their tasks and communication obligations are similar to cognitive agents.
9- Evaluation agent: In charge of obtaining the tests evaluation by using the inputs supplied by cognitive, affective, pedagogic and rule learning agents; also in charge of integrating the evaluations into the corresponding category set, and of obtaining the final evaluation fuzzy set and its defuzzification. It maintains the cognitive and affective general record of the child and the diverse diagnosis that they could realize.

10- Group evaluation agent (when a group exists): It has the same tasks and obligations as the evaluation agent but considering now the group, differentiating the child who is suffering diagnosis from the rest of the members of the group.

11- Interface agent: It personalizes the interface in accordance with the different situations of the test and of the affective child's state. Among the elements of this personalization, they are screen colour, scene background, possible pedagogic agents that could show up, messages and sounds.

6.8 Cooperation and Control of Agents

The functionalities of NEOCAMPUS on the cooperation and control of agents [127], [128], were extended to bear in mind the important group of agents that can try to act simultaneously and the specific functions they play in DAUTIS.

So, the control agent receives the design of the protocol to be used and he is giving entry to the corresponding agents in charge of every test: one or several cognitive agents, an affective agent, possibly a pedagogic agent and/or a rule learning agent. The affective agent intervenes in the shade trying to always get the affective state of the child, except if the concrete test needs the specific performance of the affective agent according to the doctor's advice. The same way, the pedagogic agent will take part when the test or the indication of the doctor requires it. The control agent coordinates the cooperation between these agents up to presenting the test on-screen. The cognitive agents and the affective one will send its negative measurements as inputs for the evaluation process to the evaluation agent.

In summary, all agents communicate with the control agent (number1); agents 3, 4, 5, 6, 7, and 8 communicate with them and with 1, 9, 10 and 11; agent 2 communicates with 1, 9 and 10; agents 9 and 10 communicate with them and with 1, 2, 3, 4, 5, 6, 7, 8, and 11; and finally agent 11 communicates with 1, 3, 4, 5, 6, 7, 8, 9, and 10.

6.9 Model of the Patient

Basically, the child's model prepared by DIAUTIS is an accumulative fuzzy graph constituted by a determinist node (0) that has associated the personal details and characteristics of the child, and a series of arches that join it to seven nodes (1-7). Each of these nodes refers to a concrete test category. In turn, every node subdivides in so many nodes like test subcategories present the corresponding category.

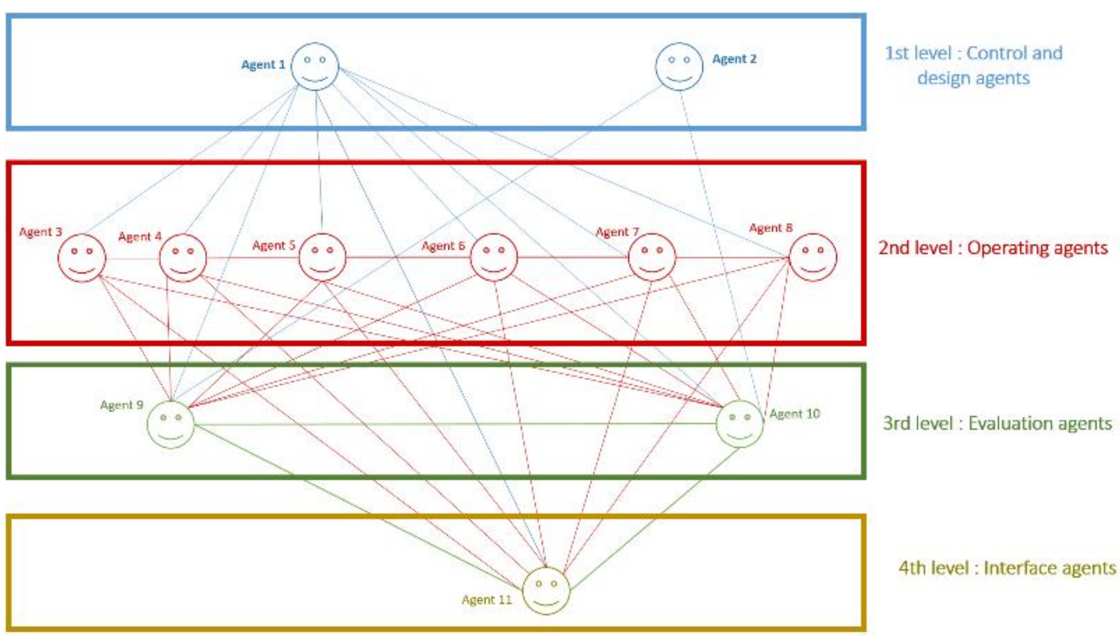

Fig. 13. DIAUTIS architecture

At the end of the execution and evaluation of every test, the evaluation fuzzy set of every test is linked to the corresponding category or subcategory node. Now all tests related to a category are integrated into a single fuzzy category set. In a similar way, the above-mentioned fuzzy sets linked to its corresponding category will join to the node of the corresponding category. And finally, on having integrated these fuzzy category sets, the last fuzzy set or child's model is obtained by using multi-criteria. This last set and its defuzzification are incorporated to node 0.

The system keeps the record of the results of all the diagnosis meetings. It is possible to analyze earlier diagnosis sessions (with different weighting coefficients) or compare them along the time.

The integration fuzzy set of every category can be defuzzified into only one value, when needed. This result can be easily understood by clinical staff, tutors, and parents.

The main communication of the system takes place with doctors or clinical teams that are the real users and the directors of the computer system performance. Those users have given value to several characteristics or parameters of every test, at least initially, so later on, from the experience and results obtained, the system can alter these parameters. The user establishes the set of tests that integrate a diagnosis collection or facilitates the criteria for the system to get it automatically by using ENT. The user also receives immediately the result of the realized tests, the final fuzzy child's model and its defuzzification.

There exists also communication with parents and tutors. Initially, it is possible to have an interview with them, stored by the system and transmitted to the doctor or clinical equipment. The interview can be used as an orientation on the tests to be realized later on.

DIAUTIS keeps the computer team informed regularly and continually about the system performance and especially about agents operation. This information includes the number and type of agents in activity, its cooperation, realized learning and response time for goals attainment and stages of the diagnosis.

6.10 Complementary System Information

The system prepares a report of the collection of tests used and characteristics, the results obtained and statistics integrating earlier diagnosis, available to both the computer and the clinical equipment. This way, every test acquires a proper record including, among other details, the times that it has been used, the results produced and the last child's diagnosis to obtain later the discriminant factor. That way someday a collection of standardized protocols or sets normalized of tests that allow measuring with major precision the differences in the autistic child's behaviour, could be established in the future as well as the severity of the ASD.

7. DIAUTIS ASSESSMENT

Previous experience in assessing intelligent e-learning systems [129], [130], has been initially applied and enhanced to take into account the specific features of this platform. According to the method already established [131], [132], quality assessment of DIAUTIS has been obtained by working at two different levels: the functional evaluation level and the overall evaluation level (see Appendix). So far, no child has participated in the quality assessment tests. Instead, some errors o anomalous behaviours, randomly chosen, similar to those presented by autistic children, have been introduced as the child's response to the tests, to simulate the diagnosis process.

The first level or functional level, with a more reduced scope, follows closely traditional methodologies. The following tests have been carried out:

a) Experimental cross-check of functions (agents) and of auxiliary hardware: design of follow-up exercises with several objects, language questions, social or affective behaviour, by four groups of five observers.
b) Experimental cross-check of the design of simple tests according to doctors' advice and first test qualification such as: colour, object, words, questions, etc.
c) Experimental cross-check of the design of collection of tests from doctor's indications by using ENT and its built-in criteria.
d) Experimental cross-check of the fuzzy tests evaluations by five observers and members of the clinical team.
e) Experimental cross-check of the tests integration into the category fuzzy set and into the child's model by five clinical teams.

The second level or overall evaluation requires a more creative approach. It includes the evaluation of four different aspects: overall functionality, reliability, evidential validity and consequential validity.

a) Overall functionality, related to: system availability, response time, learning and adaptation of the system, friendliness, complementary information, etc. For this purpose DIAUTIS has been fully examined and tested by five groups of experts and clinical teams, able to use the platform during fifteen days. Each group presented an evaluation report with a final functionality grade average. Grades obtained ranged from 90% to 95% (see Appendix).
b) Reliability: The problem here is: would it be possible for equivalent tests (according to its features and parameters) to produce different results in the same child? If that happened the final diagnosis would depend on the tests used and not on the child's state; the diagnosis would not be objective. The problem can be analyzed in the future, giving to children a set of equivalent tests and checking the different models generated for each child. However, the autistic behaviour is so peculiar that it is not easy to find true equivalent tests because the child's response can depend on any simple test feature. Anyway, considering the DIAUTIS learning capability, the proper system will be changing the parameters of the tests according to experience. As a matter of fact, DIAUTIS learning has already started with the assessment tests we are referring.
c) Evidential validity: This kind of validity [133] can be evaluated by assessing three items related to content, other criteria, and construct.
   - Content validity [134]: In this case, the quantitative and qualitative problems DIAUTIS is dealing with are the same as the clinical equipment and tutors deal. On the other side, the tests used for the diagnosis by DIAUTIS are of the same nature but more varied, detailed and specific than those used in regular practice. Besides, the tests can be selected, by means of ENT, with scientific criteria to get a full cover of all the problems related to ASD. Therefore, the content validity got by the platform is higher than that of regular practice.
   - Criteria-related validity [135]: It tries to relate the results obtained by using the system with some others obtained with a different criterion. It is not an easy question considering the complexity and fuzziness of the results obtained. So, what can be done is to compare the system results with traditional evaluation. For that purpose, seven collections of forty tests were chosen at random but covering all categories. Several wrong answers and anomalous behaviours, randomly chosen, were introduced in the tests. The tests with those answers were evaluated by the system and by four clinical teams. The system evaluation produced the children's model and its defuzzification in all cases. They were compared to the evaluations carried out by the clinical teams. The correlation factor between those sets of evaluations has been about 0.94. From this point of view, DIAUTIS validity is like traditional evaluation.
   - Construct validity [136]: This is a catch-all category, according to the APA Standards, because it may include all methods that show defects in the assessment, not due to lack of competence of the system but to some other reasons. In our case, it is not an easy question considering that no real diagnosis process with children has so far taken place and that the place of diagnosis is not yet known. Instead, a study has been done about the objects which have to be prevented from being near the child during diagnosis to avoid his distraction.
d) Consequential validity [137]: Its purpose is to evaluate by any means the impact of the system on the environment. Until now, because the system has not yet open to the public, DIAUTIS can send a message of hope. The proofs so far carried out show the important functionality of the platform and its good operation. As a result, its use is going to be relevant with important consequences for the practice and the knowledge of autism.

8. DIAUTIS: DELIMITATION AND LIMITATIONS

According to the design and tests carried out, DIAUTIS is an automatic help for the diagnosis of autism under the guidance of doctors and clinical teams. These teams determine the parameters used by the platform to select and to specify the tests of a diagnosis session. DIAUTIS evaluates the tests and obtains a fuzzy model of the child, about this session. It facilitates to the doctor or clinical team the fuzzy model defuzzification or single number showing the severity of the illness. Nevertheless, it can ease the detail of the evaluation, including fuzzy results.

DIAUTIS cannot work with absolute independence, that is to say, without doctors or clinical team, because it possesses neither the knowledge nor the experience for it.

On the other hand, it is convenient to bear in mind other limitations of the platform. DIAUTIS considers neither the existing theories of the autism, nor the possible familiar influences or of culture, nor the possible genetic causes of the illness. Also, bearing in mind that the platform has not yet been used with sick children, the question of the reliability of the tests remains open. In other words, similar tests could lead to very different results. Nevertheless, in the meantime, the experience and knowledge of the medical team are always available.

Also, the question of the consequential validity remains still open for the same reason. We cannot estimate the DIAUTIS impact or influence in the society, but at this point we are confident.

9. DISCUSSION OF RESULTS

The above-mentioned information, including the assessment tests, prove that DIAUTIS is a software platform that fulfils the targets of helping to the diagnosis of autism, with the already commented limitations. However, the use of the results can still be clarified.

First of all, the information of a diagnosis session provides to the medical equipment a clear vision of the obtained results and of the severity of the illness. This has been the essential platform target. But still, DIAUTIS can give some other help such as:

a) Facilitate the results of other earlier diagnosis of the child and compare them.
b) Facilitate the history of every test indicating the used times, the age of the children who realized them and the result that they obtained, individually or statistically. This way it can give information about the test difficulty, adequacy at a certain age, or relation with the severity of autism.
c) Considering the last paragraph, DIAUTIS could start to elaborate, in the future, collections of normalized tests in order to produce tests protocols, according to indications of doctors and medical teams, leading to possible standards.

10. FUTURE WORK

Three lines of future work are contemplated at this moment. The first one, evidently, is a plan of intensive tests for children accompanied and followed by doctors, medical equipment, medical centres, schools, families, associations, etc. According to earlier assessment, the system can supply an important aid to all persons involved with autism.

The second line has to do with the design of normalized protocols or sets of tests which, some day may contribute to standards for the diagnosis of autism at different ages. The analysis of the history of the tests and their results can decide its relevance and discriminant power.

The third line is related to enhancing DIAUTIS with new sensors and software, new functionalities and new tests for diagnosis. The rapid development of new technology aids.

11. CONCLUSIONS

Multi-agent systems with learning, fuzzy and affective skills present a great future in their application to autism, not only for the diagnosis but also as aids to the patients in a multitude of issues and specifically in their learning.

DIAUTIS has shown to be a platform ready to help people involved in autism, especially for the diagnosis of this disease.

DIAUTIS can take into account the affective and the anomalous behaviour of the child to reach a representative diagnosis and severity of the illness.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

DIAUTIS ASSESSMENT TESTS

1) Functional Level

Functional level tests have been extensively carried out, as usual, by the computer engineers during the implementation of the platform. The tests here described have the purpose to provide external observers and clinical team with the evidence of the functional capability of DIAUTIS. No error is allowed in these tests.

a) Experimental cross-check of auxiliary hardware, and the existence of tests contained in the Database. Four groups of four people (one technical expert and three members of the clinical team) have been set up. Each group asked for the whole auxiliary hardware, its functioning, and the existence of forty tests contained in the Database, randomly chosen,

Group n°	**1**	**2**	**3**	**4**
Auxiliary hardware	All	All	All	All
Aux. Hardware functioning	Ok	Ok	Ok	Ok
40 Tests requested	All	All	All	All
Results	Ok	Ok	Ok	Ok

b) Experimental cross-check of the concrete design of tests by the platform according to doctor's indication.

Also four groups were set-up, as in the a) tests. Each group gave the instructions for designing 40 concrete tests belonging to different categories. The instructions contained the values of the parameters and features for each test, such as: kind of object to be presented on the screen, trajectory, speed, duration, kind of language test, required child's age, etc.

Test category\Group n°	1	2	3	4
Category 1-n° of tests	5	6	5	4
Category 2-n° of tests	8	5	7	6
Category 3-n° of tests	8	6	7	7
Category 4-n° of tests	5	8	8	6
Category 5-n° of tests	6	5	5	8
Category 6-n° of tests	4	5	5	5
Category 7-n° of tests	4	5	3	4
Correct designs	40	40	40	40

c) Experimental cross-check of the design of collection of tests from doctor's indication by using ENT. Three groups of three members of clinical teams were set up. Each group chose the integration of different ENT criteria to obtain five different collections of 40 tests. The criteria have to do with the number of tests belonging to each category, and upper or lower limits of some or all parameters existing in each category. One new criterion was designed in each group without considering the existing ones according to doctors' instructions. It was used to obtain the fifth collection of tests.

Group n°	**1**	**2**	**3**
1^{st} Collect. ENT criteria chosen	2, 4, 5	1, 2, 3	2, 4, 5
2^{nd} Collect. ENT criteria chosen	2, 3, 6	1, 3, 5, 7	2, 6, 7
3^{rd} Collect. ENT criteria chosen	1, 4, 5, 6	1, 3, 4, 6	1,6
4^{th} Collect. ENT criteria chosen	2, 3, 4, 7	2,5	1, 3, 4, 7
5^{th} Collect. ENT New criterion	NEW	NEW	NEW
Correct collections	5	5	5

d) Experimental cross-check of the fuzzy evaluations of different tests. The purpose of these tests is to check the evaluation procedure of the tests obtaining a fuzzy set as the evaluation result. Five groups were set up. Each one was integrated by one observer (member of the technical team) and three members of the clinical team. The observer (as an adviser) was in charge of explaining the features of the evaluation process and the obtainment of the evaluation fuzzy set in order to check the procedure correctness. Each group checked the evaluation of 40 different tests, randomly chosen, and the fuzzy evaluation set for each of them.

Group n°	1	2	3	4	5
1st Category-N° of tests	4	6	2	5	4
2nd Category-N° of tests	7	5	3	6	6
3rd Category-N° of tests	5	3	6	9	8
4th Category-Nº of tests	0	5	9	4	8
5th Category-N° of tests	7	7	4	6	0
6th Category-N° of tests	8	9	8	6	9
7th Category-N° of tests	9	5	8	4	5
N° of correct evaluations	40	40	40	40	40

e) Experimental cross-check of the integration of the evaluation tests into the category fuzzy set and into the child's model. These tests are, in a certain sense, a continuation of the previous tests (d). The same five groups were set up. Each group (helped by the technical observer) checked the integration process, the obtainment of the category set and the final child's model. The evaluations used were those obtained in the tests d)

Group n°	1	2	3	4	5
1st Category Fuzzy Set	Ok	Ok	Ok	Ok	Ok
2nd Category Fuzzy Set	Ok	Ok	Ok	Ok	Ok
3rd Category Fuzzy Set	Ok	Ok	Ok	Ok	Ok
4th Category Fuzzy Set	-----	Ok	Ok	Ok	Ok
5th Category Fuzzy Set	Ok	Ok	Ok	Ok	----
6th Category Fuzzy Set	Ok	Ok	Ok	Ok	Ok
7th Category Fuzzy Set	Ok	Ok	Ok	Ok	Ok
Child's model	Ok	Ok	Ok	Ok	Ok
N° of correct evaluations	7	8	8	8	7

Groups 1 and 5 were unable to check the 4th category set and the 5th category set, respectively, because they did not have any test evaluation belonging to those categories.

2) Overall Evaluation Level

Once checked the functionality of the platform it is necessary to check different aspects of DIAUTIS leading to its behaviour in real practice.

- **Overall functionality.** Five groups have tested and used DIAUTIS for fifteen days. Each group was integrated by one expert and three members of the clinical team. The reports produced by the groups expressed their opinion as a final grade average for each of the items included.

Grade average\Group n°	1	2	3	4	5
System availability	9.2	9	8.5	9.4	9
System response time	10	9.5	9.5	9.6	10
System adaptation	8	7.7	8.6	8.8	8.8
Learning time	8	8.5	9.3	8.6	8.6
System friendliness	10	9.8	9.8	10	10
Complementary information	10	9.5	9.5	10	10
Total	55.2	54	55.2	56.4	57
Total grade average/100	92%	90%	92%	94%	95%

- **Criteria-related validity.** Comparison of the DIAUTIS results with clinical team evaluations.

  a) Seven collections of forty tests were chosen at random, including all categories.
  b) Each test included several errors or failures attributed to the child, randomly chosen
  c) Each test was graded by DIAUTIS and by four clinical teams (10 point basis).

d) The mean average of the four teams was compared with the DIAUTIS result for each test.
e) The correlation coefficient, r, was obtained for each collection.

Col.	1		2		3		4		5		6		7	
Test	**DIA.**	**Team**	**DIA.**	**Team**	**DIA.**	**Team**	**DIA.**	**Team**	**DIA.**	**Team**	**DIA.**	**Team**	**DIA.**	**Team**
1	3.5	3.8	5.6	6.1	4.2	4.5	7.1	6.7	6.3	7.3	5.7	5	8.1	7.4
2	6.7	6.5	4.5	4	5.6	5.2	4.6	4.9	4.3	4.1	4.1	3.8	4.5	3.9
3	7.5	7.3	4.8	3.6	7.2	6.9	5.8	5.3	5.6	5.5	4.2	4.5	6.2	6
4	8.3	8.1	7.2	7.5	6.7	7	6.3	6.2	3.8	3.7	5.1	5.3	5.3	5.6
5	5.6	5	3.7	4.9	5.8	4.9	5.8	5.3	6.1	5.9	7.2	7.6	5.9	6.4
6	5.8	5	5.6	5.4	7.5	7.7	6.2	6.6	5.2	5.5	6.4	6	6.2	5.8
7	6.2	5.9	3.9	3	5.9	5.6	7.1	6.8	4.8	4.2	5.3	5.8	7.2	7.4
8	6.1	6.7	8.2	8.9	6.8	6.3	8.2	7.3	2.3	2.4	5	4.7	8.2	8
9	5.9	5.2	7.9	6.9	7.1	7.4	5.2	5.5	3.6	3.7	3.2	3.3	5.1	4.7
10	3.1	2.9	5.2	5.3	6.3	6.1	1.3	1.6	6.1	5.9	4.7	4.5	5.9	4.9
11	7.9	7.2	5.9	5.1	6.2	5.9	5.6	5.8	8.2	7.9	6.9	7.4	3.6	2.9
12	4.5	4.9	4.6	5.1	6.8	6.9	5.8	5.2	5.6	5.3	5.2	5.8	5.2	5.9
13	7.2	7.8	2.4	2.4	3.2	3.5	3.6	3.9	6.2	6.6	3.4	3.6	5.9	6.4
14	4.3	3.9	3.1	3.6	4.2	4.1	5.9	5.1	4.8	4.6	6.3	6.7	6.1	5.4
15	2.4	2.8	6.4	6.9	5.9	5.6	4.9	4.1	5.2	5.6	6.5	6.3	7.1	7.3
16	5.8	5.3	8.3	8.9	7.1	6.9	4.2	4.8	7.3	6.9	4.2	4.6	7.8	8.1
17	5.9	5	7.4	6.8	5.7	5.2	6.1	6	7.2	7.6	3.8	3.2	5.2	5.9
18	2.9	3.6	6.8	7.3	6.3	6.5	7.2	7.5	8.3	7.9	4.6	4.9	6.2	6.7
19	5.4	4.9	5.2	5.9	7.1	7.5	5.2	5.7	6.3	5.9	5.7	5.1	5.7	5.9
20	4.6	5.4	6.8	6.2	8.3	8.7	6.1	6.1	2.4	2.5	6.4	6.5	3.5	3.9
21	4.9	3.8	5.2	5.8	4.2	4	7.3	7.8	4.2	4	7.2	6.9	5.2	5.6
22	3.9	4.5	6.6	6.8	6.3	6.9	4.1	4.5	5.3	5.5	4.7	5.1	4.8	4.2
23	5.6	5.2	3.9	4.1	6.9	6.2	5.2	5.6	7.3	7	5.2	5.4	6.1	7.3
24	3.9	3.4	4.1	4.5	4.1	4.6	5.1	5.9	7.9	8.4	5.7	5.6	6.2	6.5
25	4.8	4.6	7.3	7.1	6.7	6.3	6.3	6.4	6.1	5.7	4.2	4.4	6.4	6.4
26	7.3	7.9	8.3	8.5	5.2	5.5	7.1	7.2	4.5	5	7.3	7.3	7.2	7
27	8.1	7.6	4.8	4.6	7.1	6.8	4.2	4.2	5	5.5	7.8	8	5.2	5.2
28	5.6	5.1	6.3	6.5	5.2	6	5.7	5.4	5.2	5.7	6.1	5.9	4.5	4.6
29	4.1	4.8	7.3	7.1	3.8	4.2	8.1	7.7	6	6.5	6.4	6.6	6.3	6.5
30	5.9	6.6	5.3	5.6	7.6	7.9	6.1	6.3	6.8	7.2	7.3	7.6	7.3	7.6
31	4.9	4	8.1	7.9	4.8	4.3	5.2	5.5	7.8	7.5	7.2	6.9	7.9	7.8
32	5.1	5.1	7.6	7.5	6.4	6.6	4.2	4.4	5.9	5	5.8	5.1	6.1	6.3
33	2.9	2	4.6	4.5	7.4	7.8	4.7	4.4	4.9	5.4	5.2	4.8	6.4	6.8
34	5.7	5	5.1	5.2	2.3	2.6	3.9	4.2	7.8	7.2	7.2	7.5	7.7	7.5
35	7.1	7.9	5.8	5.6	3.8	4.1	5.4	5.7	4.9	5.3	6.7	6.6	5	5.8
36	2.4	3.2	6.9	6.8	3.9	4.3	6.2	6.5	3.8	4.1	7.1	6.8	5.9	5.7
37	5.4	5.2	4.1	4.3	5.8	5.3	5.9	5.4	4.9	4.2	4.3	4.6	6.4	6.5
38	4.7	4	6.2	6.2	6.9	7.5	7.2	7	3.9	4.4	7.3	7.7	7.4	7.6
39	5.1	5.9	5.2	5.3	4.7	5.3	6.3	6.4	5.7	5.2	9.1	8.3	7.7	7.3
40	2.6	2	3.8	3.7	6.2	7.2	4.7	4.9	6.8	7.4	5.2	4.6	8.2	7.9
r	0.92722		0.94792		0.94963		0.94924		0.95520		0.95836		0.92621	

Peer-review history:
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