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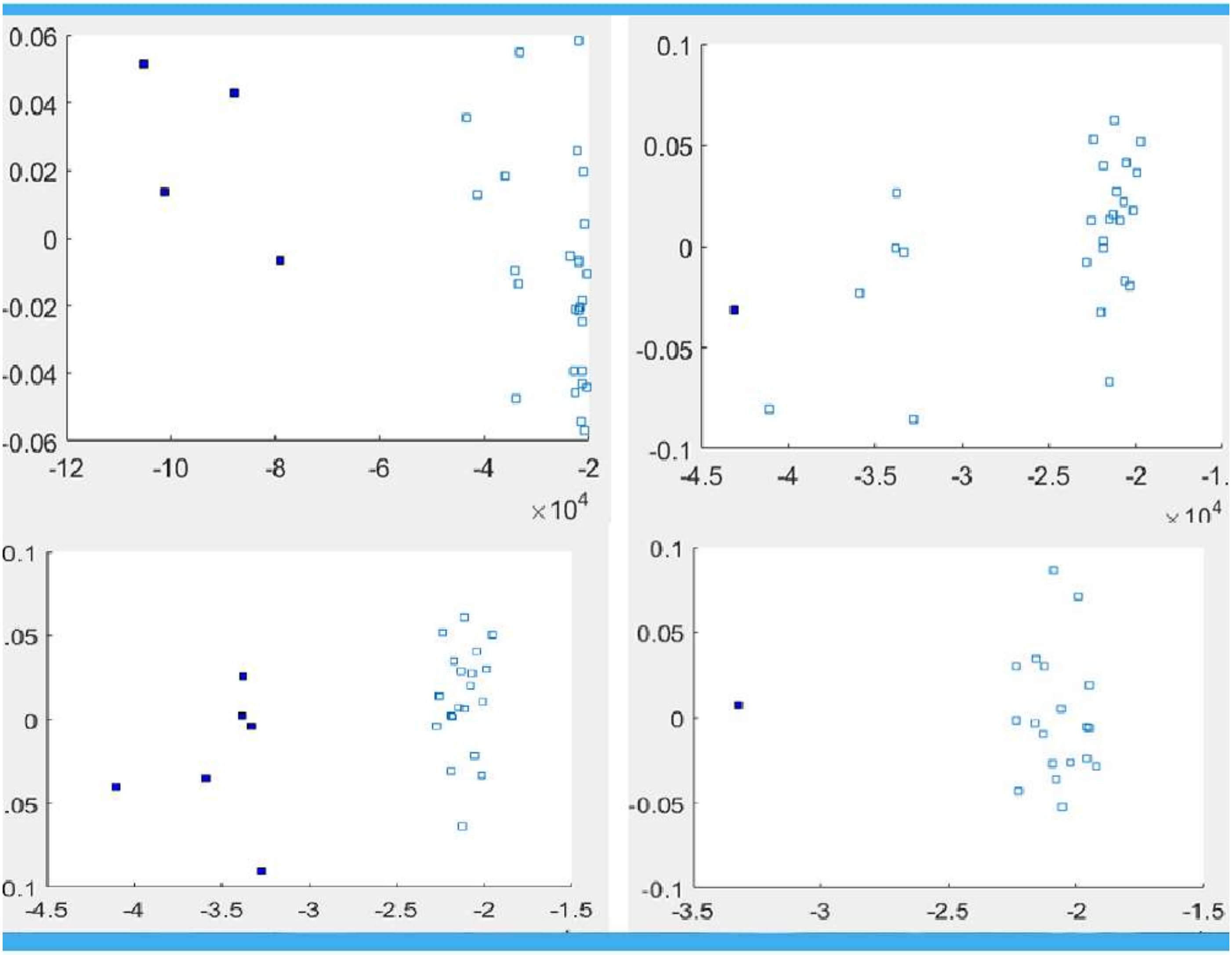
RESEARCH ON INTELLIGENT MANUFACTURING AND ASSEMBLY



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Research on Intelligent Manufacturing and Assembly

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RESEARCH ARTICLE

REVIEW

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RESEARCH ARTICLE

Detection of abnormal situations in the operation of communication channels

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Abstract: Currently, many countries have high expectations for the digitalization of economies, meaning various elements of automation. One of the most effective tools in achieving a new level of digitalization can be the Internet of Things (IoT). The development of IoT provokes the fourth industrial revolution (Industry 4.0), which will be marked by the transition to fully automated digital production, the use of cyber-physical systems and cloud computing. Processes will be controlled by "smart" devices online. An example of such smart devices is modern telecommunications equipment, the operation of which accumulates large amounts of data – telemetry of various kinds. This "big data" can be used to predict possible future failures and other faults (abnormal situations) in the equipment itself. This article is devoted to the issue of creating models of normal behavior of various characteristics of communication channels, which is central in creating predictive diagnostics systems. Examples of such models are given.

Keywords: creating models, IP Quality Monitor (IQM), Model of Normal Behavior (MNB)

1 Introduction

In the course of communication channel operation, a large amount of statistical information (telemetry) about its operation is usually recorded. Each captured characteristic is a time series, *e.g.*, a sequence of measurements (counts) every n minutes. One of the problems of "big data" accumulated during the operation of modern communication equipment is the problem of rational use of this data.

One of the ideas of such rational use is that on the basis of these data it is possible to assess whether the channel worked normally, or in its work there were deviations from normal operation - anomalies. "Normality" or the benchmark of normal behavior must first be expressed in the form of a model, which is then used to assess the degree of normality.

The term "model" is used conventionally, usually a model is simply a set of points in a multidimensional space. One point is the value of a characteristic, for example, for a day. Thus, the model for a month will consist of a maximum of 31 points. Some number of characteristics is collected for those days when the channel worked normally. This is preliminarily evaluated by the experts.

Then we "build a model of normal behavior," *i.e.* outliers are searched for and discarded among the data obtained. The remaining points form the desired model. The key question is to determine the space in which to build the model. This space can be the original values of the time series or some other features. Usually the criterion is the density of the cluster of points that make up the model. The more dense the cluster, the better the model, the easier it is able to detect outliers.

During operation, the next portion of telemetry is compared to the points of the normal behavior model. The new portion (point) may be close to or among the existing points, which will indicate its normality, or at some distance from other points. In this case it may turn out to be an outlier. There are a large number of algorithms for determining outliers in multidimensional space [1]. It is even possible to estimate the degree of "outlierness" or normality of a new point.

Channel performance is a multivariate time series if recorded synchronously and characterizes different sides of channel performance. Therefore, the normality of the whole such time series should also be evaluated on the basis of its model of normal behavior, besides the evaluation of its individual components. Individual characteristics may be in certain relationships (linear and nonlinear) with each other, *e.g.*, be correlated. This fact should also be used to build appropriate models reflecting the normal joint behavior of these characteristics.

When a new portion of the counted (measured) characteristics is obtained, normal behavior models can be used to assess whether the entire set of characteristics is normal or abnormal. Each controlled characteristic and the behavior of controlled pairs or groups of characteristics is

REVIEW

Artificial intelligence in the 21st century

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Abstract: Artificial intelligence (AI) is the most important and interesting technology in the 21st Century due to its vast application. This review focuses on the evolution of AI techniques and their applications in recent decades. Deep learning algorithms/models, represented by Large Language Models (LLMs) have resulted in groundbreaking advancements, indicating that AI is evolving to improve its capacity to interact with and help people in various fields such as finance, medicine, and science research. The potential for research in AI is immense, and there is a need for scientific principles behind AI. Future perspectives on how machines can be developed to work with humans and to be compatible with human values and preferences are also discussed.

Keywords: artificial intelligence, GPT AI, large language models

1 Introduction

Generally speaking, artificial intelligence(AI) can be defined as "an agent's ability to achieve goals in a wide range of environments" [1]. The exploitation of AI techniques can be roughly divided into 5 categories: infrastructure construction (data and computing power), algorithms, technical directions (Natural Language Processing, Computer Vision, *etc.*), specific technologies (image recognition, speech recognition, machine translation, *etc.*), and solutions for the industry such as the application of AI in finance, medical care, transportation, and games.

Computational power and hardware developments accelerate the training of algorithms and models, improve their performance and efficiency, enable more complex tasks and large-scale data processing, and promote the emergence of new methods and technologies. The rapid development and application of these technologies have played a crucial role in the progress of AI development but are beyond the scope of this review. In this review, we focus on the main branches of AI including Machine Learning (ML), Deep Learning (DL), Natural Language Processing (NLP), Computer Vision (CV), Expert Systems (ES), and Knowledge Representation and Reasoning(KR&R), which all play an important role in AI and are closely related to each other.

Machine Learning is a kind of method to realize AI. Researchers at an early age believed that AI should mimic human thinking and action, to create machines that could think like humans. Recent developers believe that AI does not have to imitate humans and should rely on a wider range of specific algorithms to think and act reasonably [2]. ML uses algorithms to parse data, learn from it, and then make decisions and predictions about real-world events [3]. Unlike the traditional idea of programming specifically for a specific task, machine learning "gives computers the ability to learn without explicit programming," and to learn from large amounts of data to find ways to accomplish tasks [4].

According to the characteristics of learning, machine learning can be divided into three categories: supervised learning, unsupervised learning, and reinforcement learning. Supervised learning is based on the labelled data samples (a sample of labelled data) to learn, to find out the general rules between the input and output. For example, making data analysis through modelling to find out the relationship between housing prices and various housing attributes. There are two main types of supervised learning algorithms, one is the Regression Algorithm, and the other is the Classification Algorithm [5]. Unsupervised learning using the Clustering Algorithm is designed to learn from data samples that are not identified, to find potential rules hidden in the data. For example, learning biological properties from protein sequences via large-scale unsupervised learning [6]. Reinforcement learning is learning in a dynamic environment, in which the learner maximizes the reward signal by trial and error, while algorithms learn optimal policies by interacting with the environment [7].

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REVIEW

Robotics by multimodal self-organizing ensembles of software and hardware agents with artificial intelligence

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Abstract: Self-organizing ensembles of software and hardware agents with artificial intelligence model the intellectual abilities of a person's natural intelligence. The Creator endowed man with various types of intellectual abilities: generation of meanings, perception of meanings, meaningful actions and behavior, sensory reaction to meanings, emotional reaction to meanings. Based on the synergy of various intellectual abilities, a person carries out life activities. For example, Dialogue is conducted on the basis of two intellectual abilities: the generation and perception of meanings. A multimodal self-organizing ensemble of intelligent software and hardware agents with artificial intelligence, based on existing knowledge and skills, is able to write poetry, draw pictures, give recommendations and solutions to specialists, manage production and systems in various sectors of the economy, and take part in scientific research. Multimodal ensembles of intelligent agents, modeling the functions of natural intelligence, contain a functional control structure. To ensure the safe and reliable use of multimodal ensembles of intelligent agents, they are being standardized internationally under the guidance of ISO. International standardization of multimodal ensembles of intelligent agents expands the market and reduces the risks of their use.

Keywords: multimodal self-organizing ensembles, software and hardware agents, artificial intelligence

1 Introduction

Axioms, rules, principles and criteria for the functioning of artificial intelligence are determined by natural intelligence. Natural intelligence also makes sense of and interprets the results of artificial intelligence. Artificial intelligence is under the control of natural intelligence.

Artificial intelligence models the cognitive thinking and psychophysical skills of natural intelligence [1, 2]. Cognitive thinking is modeled at the symbolic and figurative virtual level. Psychophysical skill is modeled at the virtual and real levels.

The most important AI trend in 2024 will be the emergence of multimodal search/retrieval architectures and multimodal inference, which will take center stage in AI products, predicts Rak Garg, director at Bain Capital Ventures. The next frontier for artificial intelligence models, all signs point to multimodal systems where users can interact in multiple ways. Multimodal self-organizing ensembles of software hardware agents with artificial intelligence are closer to the human mind compared to other intelligent systems. OpenAI is making rapid progress. The company is actively hiring experts in multimodal transport. The company is working on a new project called Gobi, which is expected to be a multimodal cognitive adaptive system with artificial intelligence. The multimodal system will manipulate images, sounds and videos, as well as text. Such a system will help create multidisciplinary robots. This requires a specialized set of advanced search tools for multimodality innovation.

Florence, an intelligent multimodal system developed by Microsoft, models space, time and modality of events. The multi-modal architecture of Adept Fuyu-Heavy is designed to create intelligent digital agents for various uses. Adept Fuyu-Heavy understands complex user interface queries. According to experts, it is superior to existing multimodal reasoning.

In April 2024, Russian researchers introduced a new multimodal artificial intelligence model called OmniFusion. This is a significant development in the world of technology, as the model is capable of working with various types of data, including text and images. OmniFusion 1.1

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RESEARCH ARTICLE

Bioenergetic analysis and anthropometric evaluation of bra-breast interface for improved design and breast health

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Abstract: Bioenergetics analysis of bra-breast Interface is an important technique for improving the design of bras and promoting breast health and comfort during physical activity. The objective of this study is to evaluate the compatibility between the anatomy of the breasts and bra. The study encompasses breast anthropometry via measurement. A measurement topology was proposed to determine breast mass, volume, shape, and asymmetry under loading (with-bra) and unloading (without-bra). Using the anthropometric data, the bioenergetics of the breasts were determined and compared to the rest of the body. From the bioenergetic analysis, a larger breast could require up to 69 J of energy during walking. The average mass of a breast ranges from 500 to 1000 g. Assuming breast shape to be standard, semi-conical, semi-spherical and semi-elliptical, breast volume was determined where semi conical and semi spherical breast shapes consistently predicted lower bound volume for each breast, whereas the standard and semi elliptical breast shapes predicted higher volume for the same breasts measurements. Mathematically, the medial-lateral boundaries of the breast were described by a secant of a curve, aligned on the coronal plane, causing eccentric loading when the two breast nipples were on different transverse planes. When this variation was more than 5% volume change, asymmetric breast shapes occurred and was responsible to displace bra heterogeneously compromising fit and support. A non-linear, leaf-function describing the relationship between the breast radius and volume invoked at a given body weight. In general, the current design for a bra assumes that the breasts are symmetrical, though the current investigation proves that this is not the case. The bra needs to be redesigned to better fit women, since left and right sides are not symmetrical. This is a significant problem today, as it is estimated that nearly 80% of women wear incorrectly- sized bras; 70% wore bras that are too small, and 10% wore bras that are too big. Current investigation highlights the crucial importance of incorporating the distance between the nipples into bra design to achieve optimal support, comfort, symmetry, and minimize breast movement. It ensures that the bra cups are positioned optimally to provide effective support and enhance the natural shape of the breasts. If the current bra models are redesigned, the amount of discomfort in women could potentially decrease.

Keywords: breast anthropometry, bra design, bra-breast interface, breast symmetry

1 Introduction

Women throughout history have worn bras in order to support breasts. This support is a key in preventing breast pain as well as unnecessary pulling of the skin during daily life activities [1], while in elastic conditions occurring with small masses may introduce viscoelastic or hyper elastic strains for larger shapes resulting in permanent deformation. In 1914, Mary Phelps Jacob created and patented a design for the first modern bra [2]. Since the creation of the first bra, the structure and design has changed drastically. Bras have many functions such as support, aesthetics/fashion, or assistance with breastfeeding. Currently, bras are being mass-manufactured under the assumption that breasts are symmetrical and evenly spaced in terms of cup sizes [3]. These sizes are standard, but many factors go into the fit of bra including the height, width, or degree of sagging of the chest [4]. Since each breast is different, obtaining the fit and ideal way to manufacture bras can be challenging. Female breasts are extremely well understood and well documented. Breast anatomy, which is influenced by hormonal changes in the body during adolescence, pregnancy, or menopause. Even though the anatomy of the breast

REVIEW

Creation of multimodal digital twins with reflexive AGI multilogic and multisensory

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Abstract: Reflexive AGI multilogic, multimodality and multisensors are the basis for the multidisciplinary development of intelligent digital twins. Multimodality is implemented in several formats: text, image, speech, formulas, etc. Multilogic is implemented according to several rules or methods or ways of working with knowledge and data, and the criterion for selecting the best result from all implementations. AGI multilogic carries out judgment, understanding, perception, comparison, analysis, choice, etc. Understanding is realized using the technology of unified objectification of the ontology of subject areas for the implementation of specific activities. Multisensor systems are combined groups of electro-optical, spectroscopic and holographic sensors, and combined series of sensors, such as a thermal imager, color camera, low-light camera, laser rangefinder, laser designator, laser, pointer-illuminator and others. Multisensory systems help monitor the psyche and performance of a person at the level of medical indicators of his physical condition in the process of joint activities with digital twins. Multimodal digital twin with AGI multilogic and multisensory is good human assistant in many areas of activity.

Keywords: multimodal digital twin, reflexive AGI multilogic, multisensor systems, technology of unified objectification

1 Introduction

Multimodal digital twins with AGI multilogic and multisensory simulate human abilities such as thinking, perception, reflection, consciousness and intelligence. Consciousness is able to perceive, reflect and react to current events. Thinking intelligently and clearly connects elements of knowledge. Understanding is the perception of a thought and the clarification of its meaning. Perception of reality is the process of reflecting objects and phenomena and their properties by the senses. Reflection of reality is a subjective process of its recording with the help of sign systems. Subjective intelligence combines worldview, life attitudes and accumulated knowledge.

The information basis of a multimodal digital twin with AGI multilogic is ontologies of subject areas. Many systems for constructing ontologies have been developed in the world for various fields of knowledge. Protégé is based on the OKBC (Open Knowledge Base Connectivity) knowledge representation frame model and is equipped with a number of plugins, which allows it to be adapted for editing models stored in different formats (standard text, in a JDBC database, UML, XML, XOL, SHOE, RDF and RDFS, DAML+OIL, OWL).

OntoEdit was originally developed at the AIFB (Institute of Applied Informatics and Formal Description Methods) at the University of Karlsruhe. Currently commercialized by Ontoprise GmbH, it performs the verification, review, coding and modification of ontologies. Currently, OntoEdit supports representation languages: FLogic, including an inference engine, OIL, RDFS extension and internal, XML-based serialization of the ontology model using OXML - OntoEdit's XML-based Ontology representation Language. The advantages of the tool can be attributed to ease of use; development of ontology using the methodology and the process of logical inference; development of axioms; There are two versions of OntoEdit: the freely redistributable OntoEdit Free (limited to 50 concepts, 50 relationships and 50 instances) and the licensed OntoEdit Professional (no size limit). Naturally, OntoEdit Professional has a wider range of functions and capabilities (for example, an output engine, a graphical query tool, more export and import modules, a graphical rules editor, support for JDBC databases, etc.).

OilEd is an offline graphical ontology editor developed at the University of Manchester as part of the European IST On-To-Knowledge project. The tool is based on the OIL language (currently adapted for DAML+OIL, in the future - OWL), which combines the frame structure and expressiveness of Description Logics with reasoning services. This allowed for a clear and intuitive user interface style and the benefits of supporting reasoning (detection of logically inconsistent classes and hidden subclass relationships). Recently there has been an increase in the popularity of the OilEd editor. It is used for both teaching and research. The tool is freely distributed under the GPL public license.

WebOnto is designed for Tadzebao, an ontology exploration tool, and is designed to support collaborative browsing, creation and editing of ontologies. Its goals are ease of use, providing scalability for building large ontologies. WebOnto uses OCML (Operational Conceptual Modeling Language) to model ontologies. In WebOnto, the user can create structures, including classes with multiple inheritance, which can be done graphically. All slots are inherited correctly. The tool verifies newly entered data by checking the integrity of the OCML code. The tool has a number of useful features: saving structural diagrams, separate viewing of relationships, classes, rules, etc. Other features include collaboration between multiple users on the ontology, use of diagrams, send and receive functions, etc.

OntoSaurus is a Web browser for LOOM knowledge bases. It consists of two main modules: an ontology server and a Web browser for editing and viewing LOOM ontologies using HTML forms, providing a graphical interface for them. OntoSaurus also provides limited editing tools, but its main function is browsing ontologies. But to build complex ontologies you need to understand the LOOM language. Most users build an ontology in LOOM in another editor and then import it into OntoSaurus for viewing and editing. OntoSaurus implements all the features of the LOOM language. Automatic compatibility checking, deductive reasoning support, and several other functions are provided.

An ODE (Ontological Design Environment) ontology builder that communicates with users at a conceptual level, as opposed to tools like OntoSaurus that communicate at a symbolic level. The motivation for ODE was that it is easier for people to formulate ontologies at the conceptual level. ODE provides users with a set of tables to populate (concepts, attributes, relationships) and automatically generates code for them in LOOM, Ontolingua and FLogic. ODE forms part of the full life cycle methodology for ontology construction according to Methontology. The tool was further developed in WebODE, which integrates all ODE services into one architecture, stores its ontologies in a relational database, and provides additional services (inference engine, axiom construction, ontology collection, catalog generation).

KADS22 is a tool to support the design of knowledge models according to the CommonKADS methodology. Ontologies form part of such knowledge models (the other part is inference models). CommonKADS models are defined in CML (Conceptual Modeling Language). KADS22 is an interactive graphical interface for CML with the following functionality: CML file parsing, printing, hypertext browsing, searching, glossary generation and HTML generation. Further development within the DWQ (Data Warehouse Quality) project leads to the i.com tool, a tool to support the conceptual stage of an integrated information systems project. i.com uses the Extended Entity-Relationship Model (EER) with the constraints of multidimensional aggregation and intermediate schemas. The i.com tool is fully integrated with a powerful DL-based reasoning server. i.com serves primarily for intelligent conceptual modeling. PROMPT is an addition to the Protégé system, implemented as a plugin, used to combine and group ontologies. When two otologies are combined,

PROMPT generates a list of suggested operations. An operation could consist, for example, of combining two terms or copying terms into a new ontology. The user can perform an operation by selecting one of the proposed ones or by directly defining the operation. PROMPT performs the selected operation and any additional changes caused by that operation. Then the list of proposed operations is modified and a list of conflicts and possible solutions to these conflicts is created. This is repeated until the new ontology is ready.

Chimaera is an interactive federation tool based on the Ontolingua ontology editor. Chimaera allows the user to combine ontologies developed in different formalisms. The user can request analysis or guidance from Chimaera at any time during the merging process, and the tool will direct him to those places in the ontology where his intervention is required. In its proposals, Chimaera mainly relies on which ontology the concepts come from, based on their names. Chimaera leaves the decision of what to do to the user and does not make any suggestions on its own. The only taxonomic relationship that Chimaera considers is the subclass-superclass relationship. Chimaera is the closest to PROMPT. However, because it uses only the class hierarchy in its analysis, it misses many of the matches that PROMPT finds. These matches include proposals for merging slots with similar names that belong to the merged classes, merging the domains of slots that have been merged, etc.

In OntoMerge, a merged ontology is a union of two original ontologies and a set of join axioms. The first step in the OntoMerge merging process is to translate both ontologies to a common syntactic representation in the language developed by the authors. The ontology engineer then defines connection axioms containing terms from both ontologies. The process of translating instances is as follows: all instances in the source ontologies are considered to be in the combined ontology. Then, based on the instructions in the source ontologies and the join axioms, the inference engine will make an inference, thus creating new data in the join ontology. OntoMerge provides tools for translating instance data into a merged ontology.

OntoMorph defines a set of transformation operators that can be applied to an ontology. A human expert then uses an initial list of pairs and source ontologies to determine a set of operators that should be applied to the source ontologies to resolve differences between them, and OntoMorph applies these operators. In this way, a set of operations can be performed in one step. However, the human expert receives no guidance other than the initial list of pairs.

The OBSERVER system uses DL to answer queries using multiple ontologies and mapping information between them. First, users define a set of interontological relations. The system helps to cope with this task by finding synonyms in the source ontologies. Once mappings are defined, users can formulate queries in DL terms using their own ontology. OBSERVER then uses the mapping information to formulate queries against the source ontologies. OBSERVER relies heavily on the fact that the descriptions in ontologies and queries are meaningful.

FCA-Merge is a method for comparing ontologies that have a set of common instances or a set of common documents annotated with concepts from the original ontologies. Based on this information, FCA-Merge uses mathematical methods from Formal Concept Analysis to produce a concept lattice linking the concepts of the source ontologies. The algorithm proposes equivalence relations and subclass-superclass. The ontology engineer can then analyze the result and use it as a guide to create a unified ontology. However, the assumption that the two ontologies being merged share a common set of instances or have a set of documents in which each document is annotated with terms from both sources is too rigid and in practice this situation rarely occurs. As an alternative, the authors propose using natural language processing techniques to annotate a set of documents with concepts from these two ontologies.

The ONION (ONtology compositION) system is based on ontology algebra. Therefore, it provides tools for defining rules of articulation (connection) between ontologies. Articulation rules usually take into account only the relevant parts of the source ontologies. To propose a join, ONION uses both lexical and graph-based methods. The method of finding lexical similarity between concept names uses dictionaries and semantic indexing methods based on the location of a group of words in the text. Using knowledge and data ontologies, SingularityNET is implementing an international decentralized AGI project based on blockchain technology [1]. Building AGI for China is a nationwide initiative involving more than two thousand authors from various research institutes. Computing performance and energy-efficient hardware devices are one of the areas of AGI. AGIEval's performance is a good indicator of China's progress in AGI.

Currently, the automatic construction of ontology is recognized as the most effective means of formalizing and systematizing knowledge and data in subject areas [2,3]. The comprehensive combination of existing methodologies for automated construction of ontologies makes it possible to determine the meaning of the processed information from the subject area of knowledge and the intentions of users, and present them in a machine-processable form. Automation of determining the meaning of processed information and user intentions expands the scope of use of a multimodal digital twin with AGI multilogic.

2 Functional aspects of multimodal digital twins with AGI multilogic

A multimodal digital twin with AGI multilogic consists of multimodal self-organizing ensembles of software and hardware agents with artificial intelligence [4]. Logic, as a sequence of associative acts, is determined by the specifics of information. The sequence of associative acts of formula implementation is determined by algorithmic rules. The logic of justifying events by sentences of the language is implemented according to grammatical rules. The sequence of associative acts of implementing combinatorial problems is determined by design methods. Management logic is aimed at developing various solutions. To solve complex problems of everyday life, AGI multilogic is activated, relying on various techniques.

A multimodal digital twin with AGI multilogic explores subject areas of knowledge using different methods, methods and approaches. For this purpose, AGI multilogic selects information processing options [5–11]. The choice of method, method or approach is based on the correlation of the data of the current task with existing standards, rules and facts proven by science and practice. In practice, there are many methods, methods or approaches, each of which solves the current problem. The methodology for finding a solution to a problem is aimed at constructing a communicative chain of actions based on the formulation of the problem being solved.

Choosing method or approach for solving a current problem requires an analysis of the ontology of the subject area within the framework of the selected topic. Analysis of the ontology of the subject area within the chosen topic is carried out using a unified objectification. It is aimed at determining the semantic meanings, data and patterns of the subject area of knowledge that are relevant to solving a specific problem. Automated analysis of the domain ontology is carried out according to the methodology.

Methodology leads to methods, ways and strategies of studying the subject. It uses a system of criteria for organizing and constructing theoretical and practical activities. Methodology describes the characteristics of the study; reflects the logical structure of the problem being solved; shows the planned scheme for solving the problem (stages, phases, sections and methods of solving). Methods of solving are an assistant in building a logical scheme, following which the current task is implemented step by step. Methods of solving contain a set of actions, certain algorithms or a set of specific steps aimed at solving each stage, stage, section of a specific problem.

An objectified methodology based on the ontology of the subject area and the base of skills of a certain field of activity of multimodal self-organizing ensemble of software and hardware agents with artificial intelligence allows you to automatically find techniques for developing a solution. The set of multimodal parameters suitable specifically for the solution that will be used in this methodology is determined by the solution techniques. The processes of analyzing a subject area and objectifying its ontology can use several methodologies simultaneously, which will then be used to solve the problem at different stages, separately or reflexively. Reflection can be multi-level, process-based, evolutionary, decentralized, distributed, etc.

AGI multilogic uses objectified moral, social and business attitudes, norms and measures as semantic criteria when modeling consciousness. Reflexive AGI multilogic with objectified methodologies harmonizes multimodal ontologies of subject areas for interdisciplinary work with them.

2.1 Objectification of the domain ontology

Ontologies are a formal description of knowledge from a subject area, taking into account thematic rules and connections between elements, allowing automatic knowledge extraction. Ontologies serve for the systematic organization of knowledge, allowing one to discover new facts and identify the necessary relationships between elements. Ontology-based knowledge organization systems are already very common and used in many industries.

The ontology of the subject area consists of an ontology of knowledge and an ontology of reality. The ontology of reality reproduces those structural and characteristic connections and relations that are inherent in reality. The ontology of reality contains communicative sequences marked by characteristics of associative acts. This allows, in the process of characteristic automatic analysis of associative acts, to find similar associative acts of other communicative sequences that lead to a rational solution of target problems of one class.

The connections between the ontology of knowledge and the ontology of reality are objectified by semantic identity. Ontologies can be multi-level. When constructing an ontology, the following sequence of actions is distinguished: classification of basic concepts, selection of basic concepts, definition of relationships, a conceptual scheme of the ontology is formed as a connected complex of concepts, the ontology is supplemented with subject-specific implementations of classes (Individuals) and data that have a physical meaning, a linguistic component is formed.

The mathematical basis of ontology is the so-called descriptive logic (a branch of mathematics), which assumes that any information expressed in natural language can be represented as a chain of triplets. The ontology is represented as a graph, the vertices of which are entities, and the edges are relationships between entities. It is believed that any statement in natural language can be represented in the form of simple sentences from which entities and relationships between them can be extracted. There are two main tools: RDF (Resource Description Framework) or OWL (Ontology Web Language). OWL allows you to further describe logical rules over data. Ontologies (unlike conventional databases) allow you to find hidden data. Conventional databases are well suited for searching for specific information, and knowledge bases are needed where it is necessary to identify new knowledge, for example, in decision support systems.

The power of ontology is manifested if the relationships between its elements are described in detail and qualitatively, using the mathematical apparatus of descriptive logic. For example, for relations you can set their properties (functional, transitive, reflexive). And then you can automatically extract facts from the ontology, this process is called reasoning, there are standard reasoning algorithms based on graphs. Possible applications: clarifying the characteristics of an object and identifying a unique one from a set of similar objects, searching for similar objects, "understanding text" and assigning text to a specific class, assistance in NLP tasks (NER, Relation Extraction), root cause analysis, identifying patterns in data. Reasoning is supported by the ontology editor.

Automated creation of ontologies is carried out based on existing knowledge bases. The tools used contain various methods for working with ontologies. Each ontology has a unique IRI (Internationalized Resource Identifier). The mathematical support of a multimodal self-organizing ensemble of agents with artificial intelligence makes it possible to write triplets, that is, triplets of the "subject-predicate-object" type. The Entities section allows you to describe subjects and objects. An ontology is constructed as a hierarchical structure of classes related by concepts. In ontology, properties have an independent nature; a property is separable from a class. For predicates, you can set different properties, for example: functional; back; transitive. Based on the described ontology, you can use a reasoner that produces solutions based on the found properties, connections and entity-oriented dictionary.

Let S be an orthographic dictionary, where S = { Si }, Si is a morphological word. The word Si names the feature Qij of the representative Mij from the set Mi, where Mi = { Mij }. Let us denote the lexical meaning of the word Si by { Mij, Qij, Si }. The connection between the lexical meanings of the words { Si } and the elements of the set Mi is defined by a set of feature relations Qi, where Qi={Qij, (Mi, Mij)}.

A set of lexical meanings connected by a set of attribute relations with representatives is an entity-oriented dictionary. Words in the dictionary are supplied with attribute indices according to their attribute relations with representatives. An entity-oriented dictionary records the attribute entities of representatives. The dictionary helps to use words with their semantic meaning and distinguish the representatives they name.

Words are used based on attribute indices. Each attribute has three indices. One index indicates the subject area of knowledge, the second attribute indicates the situation, the third attribute indicates the situational moment. Words with several semantic meanings have several sets of indices. Each set of indices determines the semantic meaning of the word.

2.2 Functional and structural aspects of the multisensory system

Various modern multi-sensor monitoring systems operate with spectroscopic, holographic, optical, sound and electronic sensors and use a variety of segmentation and tracking algorithms. The functional and structural aspects of a multi-sensor system for monitoring and interpreting heterogeneous data are considered, which will help in the development and design for creating a wide range of applications for monitoring and interpreting data that allow interaction with multi-modules. It is now common to work with distributed systems in which multiple sensors interact to track objects of interest [12–16]. It is clear that any new approach to intelligent monitoring and interpretation must be adaptive when considering the implementation of an ever-increasing and wider range of sensors. Therefore, modern monitoring systems must combine several heterogeneous distributed structures and use universal segmentation and tracking algorithms.

The multisensor system is designed as a distributed multi-layer architecture. In this way, the synergy between the user and the environment is increased. Monitoring systems consist of multiple sensors covering wide areas, grouped in processing nodes that provide high scalability and reliability. The nodes perform real-time monitoring to alert the operator to pre-detected specific events. A distributed multi-tier system consists of a central node and a set of remote nodes. Remote nodes are responsible for data collection and lower-level processing (such as segmentation and tracking), while the central node collects dynamic information and performs higher-level processing tasks.

A multi-logic, multi-modal ensemble of intelligent agents is isolated from the user interface to provide independent monitoring and control. To provide greater flexibility. This is necessary not only to meet the needs of monitoring and interpretation systems, but also to incorporate existing algorithms or newly developed ones. Functionality is provided by various modules that make up the layers of the multisensory system structure. This way, new or existing functionality can be easily incorporated into the framework, not only for developers but also for users, Each layer is implemented as advanced modules, operating from a lower level—data collection or communication with nodes—to higher levels such as tracking, classification, or dynamic detection. The extension views the structure as a combination of extended modules of a multisensory system. Each module focuses on one level of the proposed data monitoring and interpretation framework. Before describing each level of the structure in detail, it is necessary to describe the execution model. The execution model follows a hybrid distributed design, where remote nodes perform process-level processing and a central node is responsible for collecting and merging data and performing high-level processing.

The acquisition layer directly interfaces with digital analog devices through measurements from the physical world. In this case, we mean data from sensors, as well as data from other sources of information (database, knowledge base, etc.). The data acquisition layer also performs information preprocessing. The data fusion layer combines data from sensors to improve the quality of information (more complete and accurate). Data fusion algorithms also work with a variety of spectral, holographic and optical images. The object classification level is particularly important for good dynamics analysis because it provides knowledge about what the object is. In addition, object classification provides information about the orientation of objects.

The object tracking layer is responsible for matching the coordinates of image objects to the real picture. Thus, it computes the trajectories followed by moving objects within a scenario, regardless of the specific sensor that detected them. It also makes predictions about the future positions of objects based on previously detected trajectories. Information from the general model, sensor situations and their coverage range is used. The event detection layer generates semantic information related to the behavior of objects in a scenario. This is the last layer of the structure stored in remote nodes. The remaining layers are implemented in the central node. In a multi-sensor monitoring and interpretation system, multiple sensors monitor a common scenario, events generated from different sources. This is why the event fusion layer is needed to unify the information coming from the various sensory data generated in the previous layer. The final layer of the framework, activity detection, is responsible for analyzing and detecting activities already associated with temporal features. After merging the events, the current layer has a better idea of what is happening in the scenario according to the detected events. Therefore, actions detected at this level can be translated into scripted actions, providing a higher level.

A multi -level multimsensolar helps to coordinate the meanings of the ontology of the subject area of the multimodal digital double and its Agi multi -mental intentions and motives of the user, interlocutor or team. Improving multimsencing systems will allow you to develop and create multimodal digital doubles with AGI multi -unit for scientific applied studies in various subject fields, for researching the safety of industrial processes, for researching the intentions and motives of various groups during mass events, for the study of disasters and various natural processes.

The multisensory system is involved in the emotional speech animation of the humanoid digital twin. It is provided with a set of emotional facial expressions, the templates of which are stored in its memory. It learns emotional speech based on its content. The animation of the emotions of the humanoid digital twin is carried out by its corresponding facial expressions in accordance with the content of its speech. Through the multisensory system, it reacts to the emotional facial expressions of people based on the facial expression templates that are in its memory. The humanoid digital twin records the emotional facial expression of the interlocutor, compares it with the facial expression templates, and adjusts its emotional meaningful speech based on the matching template. The multisensory system also reacts to the emotional meaningful speech of the interlocutors. The coordination of the facial expressions of the humanoid digital twin and the interlocutors, their emotional speech meanings is carried out by its neural network processor.

3 Conclusion

Multimodal digital twins with AGI multi-logic and multi-sensory capabilities can be safely used in many areas of activity as human assistants, especially in harmful and dangerous jobs, for example, those related to radiation, chemistry, etc. This requires standardization of the security of knowledge of domain ontologies and the mental intentions and motivations of the skill base [17]. This allows a multimodal digital twin with AGI multilogic and multisensory capabilities to work confidently with subject knowledge ontologies by analogy, similarity, deduction and induction.

Japanese private companies have created several multimodal multisensory systems with artificial intelligence for Japanese schools and universities. The Konica Minolta system is capable of analyzing the mental reaction of students to the material presented, and can collect data on the level of concentration of students and active participation in the lesson. The system from Techno Horizon is designed to analyze the emotional state of each student. The artificial system helps determine which students are excited, which students are stressed or bored, and which students are focused on the lecture. Intelligent systems monitor the progress and effectiveness of schoolchildren's and students' learning, and provide recommendations to teachers during the learning process.

Multimodal digital twins with AGI multi-logic and multi-sensory capabilities make it possible to model adaptive skills and imitate the human psyche by imitation at the model, virtual, information and program levels. They will be able to possess a fundamental human ability - to understand the intentions of other people. Cognitive imitation of the human psyche contributes to social learning and the accumulation of psychological experience. Cognitive imitation of consciousness, developed according to the cognitive rules of information integration, allows us to move on to modeling. The consciousness of multimodal digital twins with AGI multilogic and multisensorics is modeled by information integration.

One of the most discussed, but also highly regarded, theories related to consciousness is the Integrative Information Theory of Consciousness, developed by Giulio Tononi, a neuroscientist at the University of Wisconsin. The theory states that consciousness arises when systems are able to take in information and integrate or combine it. Tononi argues that the perception of integrated information gives rise to consciousness. According to this theory, everything comes down to integration. This means that any system, not necessarily biological, can be conscious, and its functionality can tell us how conscious it is. Christof Koch is a neuroscientist at the Allen Institute and the Tiny Blue Dot Foundation, former president of the Allen Institute for Brain Science, and former professor at the California Institute of Technology. He is the supporter of the integrated information theory, which states that everything is essentially endowed with informational properties. He postulates that consciousness is a fundamental informational characteristic of the Universe. The integrated information theory proves the integrative formation of consciousness [18].

Objectified theoretical aspects, proposed by the author, allow us to form a model of a humanoid multimodal digital twin with AGI multilogic and multisensorics, for its implementation on the basis of ensembles of intelligent software and hardware agents, as a participant in the life of society [4]. Objectified theoretical aspects help the AGI digital twin to explain every step of decision-making. Thus, they endow it with reflexive artificial consciousness. The artificial reflexive consciousness of a multimodal digital twin with AGI multilogic and multisensorics is formed by developers for specific types of activity. Reflexive artificial consciousness is relevant in connection with the intensive development of artificial intelligence technologies and the increasing complexity of the technological environment of humanity, including intelligent artificial agents and decision-making systems.

Reflexive activity plays a key role in improving the consciousness of AGI digital twins. Stimulating and supporting reflexive activity is relevant in non-standard cases to ensure decision-making processes in problem situations. Reflexive activity is defined by a system of ontologies that ensures assembly into a whole, which includes ontologies for ensuring life activity, overcoming life activity discontinuity points, strategic goal setting, developing strategies and projects, implementing and innovative support for strategies and projects.

The education sector is becoming one of the most relevant for the application of AGI digital twins in supporting reflexive activity. They can assess the current situations of educational activity, stimulating the search for solutions through reflexive communicative coordination. According to the formulation of problems, the methods of finding a solution are objectified. They allow applying a general approach to managing methods. Associative chains of objectified methods explain each step of the solution. The program for managing methods acts as a reflexive consciousness of the AGI training system. It can accompany the solution of the problem with a reflexive chain of objectified methods that explains each step of the solution.

The creation of training AGI systems with reflexive consciousness will require training in reflexive objectification of methods for finding solutions for a class of problems according to their formulations. This will help develop a common approach to finding solutions to a class of problems, to the reflexive management of the application of methods, to the formation of reflexive AGI multilogic, that is, to the formation of artificial reflexive consciousness.

Communication between specialists from a multimodal digital twin with AGI multilogic, multisensory and reflexive consciousness is carried out through its generative intelligence system, neural interfaces, fiber optic networks and other communication means and bioinformation systems [19–21]. The key role of reflexive consciousness in Artificial General Intelligence (AGI) and its most important function of AGI goals is to prevent potential existential threats to humanity [22, 23]. Aligning conscious AGIs based on their reflexive capabilities with the goals of humanity presents new areas of research that have not yet been explored [24, 25].

AGI network with multimodal digital twins with AGI multilogic, multisensory and reflexive consciousness is a universal structure for increasing its intelligence and reflexive consciousness by specialists of various profiles, as well as for reducing security [26].

Conflict of interest

The author declares there is no conflict of interest.

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is fairly standardized, breasts are not; from woman to woman, breasts can differ in terms of size, shape, and handedness [5]. Understanding the mass of the breast as a source of force can lead to understanding the biomechanics consideration. The various tissue types of the components of the breast all have their own mechanical properties and densities that can be factored into a biomechanical analysis of the breast in order to better understand the relationship between breast mass and force translated onto the breast tissue. Understanding the shape, size, and overall geometry of the breasts, as well as any differences that may be observed between a left and right breast, can help to define this relationship. Most fundamentally, breast may be divided into four quadrants, which are: upper inner, upper outer, lower inner, and lower outer, with the upper outer lobe containing the majority of breast volume [6, 7]. During adolescence, female breasts develop and undergo many changes. Until puberty, the breasts are considered to be "underdeveloped". At the start of puberty, ovarian estrogen and progesterone production begins, and thus an increase is observed in the blood concentration of those hormones throughout the body. As a result, the breasts enlarge due to the development of the mammary glands and increased deposition of adipose tissue, also referred to as fatty tissue [6]. As the breasts enlarge during development, the inframammary fold also develops and becomes a defining boundary of the breast [8]. The inframammary fold anchors the breast to the thoracic wall and defines the inferior boundary of the breast [8]. The histology of the inframammary fold is not well-understood or well-documented. In order to study the histology of this tissue, cadaver tissue is often used rather than studying live subjects [8]. Study of this cadaver tissue has led to some understanding of the composition of the inframammary fold tissue. As well as normal development of the breasts throughout puberty and adolescence, pregnancy and menopause also play a significant role in changing the breasts and their anatomy. Further development of the breasts during pregnancy consists of breast enlargement, and a consequent increase in breast volume and density, as well as dilation of superficial veins and darkening of the nipple-areola complex [6]. Throughout pregnancy, stromal elements of the breast slowly transition to epithelium. After delivery of the child, lactation occurs due to dramatic decreases in estrogen and progesterone. As the baby is weaned, stromal elements begin to atrophy and the overall size of the breast decreases [6]. During menopause, ductal and glandular elements involute and the breasts become mostly fat and stroma. Over time, even this tissue decreases, which leads to loss of breast contour as the breasts shrink further. The suspensory ligaments within the breasts also relax with time, leading to breast ptosis or sagging [6, 8]. Throughout the ages, bras have been used to combat this ptosis. Therefore, study of bra-breast biomechanics is a function of a given reference; age, pregnancy and menopause and needs to be understood fully. The average mass and volume of each breast has been studied for various bra sizes in literature [9, 10]. It has been found that the average mass of a small-to-moderate breast is approximately 500g while larger breasts average approximately 750-1000g [9, 10]. This large mass in large breasts can be translated into force that the breast tissue is subjected to even when the woman is just standing. The average force on the breasts due to their weight (when subject is standing) is found to be approximately 11.7 ± 4.6 N for large breasts [10]. Frequently, this force being projected onto the breast tissue is a result of wearing a bra, especially a bra with an underwire in it. It is likely that activities of daily living increase this force many folds at the breast mass center, however, at the tissue and glands it is likely that the forces developed may be elastic, visco-elastic, and/or hyper-elastic. Limited data is available in the literature investigating breast tissue under those constitutive conditions.

2 Bra Design Issues

A bra is a very complicated device made from clothing of different stiffness and mechanical properties. It is estimated that a bra can have between 20 and 45 different compartments such as the underwire, straps, bands, hooks, etc. The materials used to manufacture the lining, padding, straps, and underwire have changed over time. Most commonly, bras contain underwires, which are sewn into the fabric of the bra at the base of the cups. The underwire of the bra helps to provide extra support and lift of the breasts. Underwires can be made from either plastic or metals, but plastics are not usually considered in the market because they do not have the strength to achieve the level of support that metal underwires offer [11]. Metal underwires are typically constructed with steel or nickel-titanium (Nitinol), which is a shape memory alloy [12]. Steel has very high yield and tensile strength values, which makes it very durable when manufacturing a bra. The yield strength and tensile strength of steel are 205 MPa and 500 MPa, respectively [13]. Steel underwires can provide a durable design for a bra underwire to prevent breaking. Nickel-titanium alloys are unique because they have shape-memory abilities, meaning that these materials can return to their original shape after being subjected to a load [14].

Nitinol has yield and tensile strength values comparable to steel approximately 195 MPa and 895 MPa, respectively [15]. Utilizing both materials is beneficial when manufacturing bras. While bras can provide support to breasts, bras can also cause a lot of discomfort and pain to women. Underwire bras can irritate the skin and cause breast pain. Since underwire bras are made to constrict the breasts, they can contribute to clogged milk ducts in breastfeeding women [16]. Because metal underwires are rigid, they cannot change easily to fluctuating breast size that may occur during pregnancy, breastfeeding, menstruation, or aging. Considering that most women wear bras every day, it is important to ensure that bras fit correctly. However, it is estimated that nearly 80% of women wear incorrectly- sized bras; 70% wore bras that were too small, and 10% wore bras that were too big [17, 18]. Incorrectly fitting bras may contribute to breast pain and lower thoracic pain due to the breast being improperly supported. The objective of this study was to investigate the anthropometric measurements of the breast and analyze the breasts in the context of biomechanics in order to establish and evaluate the relationship between mass/weight and projected force. Ultimately, the goal of this research was to obtain measurements of the breasts under loading (with-bra) and unloading (without-bra) conditions. These measurements were necessary to be able to compare natural and forced breast geometry as well as to be able to compare between the anatomy of the left and right breast. Detailed measurements of both breasts were compiled so that they could be statistically analyzed to determine if there is a true difference in geometry (shape and size) among the breasts of most women.

2.1 Factors Affecting Bra Selection

In order to understand the main factors affecting selecting a bra, a survey was conducted. The main questions were about the number of hours the bra worn per day, and what subject considers when selecting/ purchasing a new bra. Fourteen factors affecting bra purchasing were investigated (Figure 1). These factors are comfort, bra stays in place, fit, appearance under clothes, support, discreetness, shoulder straps, breast shape, fabric, breast lift, color, price, matching underwear, and the brand. The results exhibited that the comfort of the bra was the most important factor among all the subjects (97.6 %), and (95.2%) of them thought having a bra that fits perfectly is important. On the other hand, only (11.9%) and (2.4%) thought that the brand of the bra or having matching underwear could be important, respectively. In general, the comfort factor is extremely important to be taken into consideration when designing a bra as 72% of women wear the bra for more than 10 hours per day.

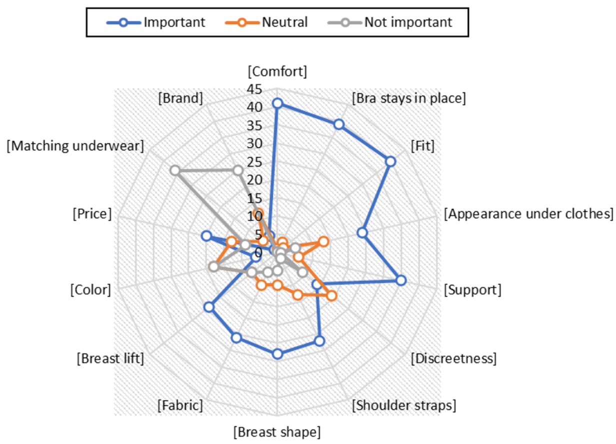

Figure 1 Chart showing the importance of each factor for subjects when buying a new bra

It has been assumed for years that all body types and breast sizes – have perfectly symmetrical breasts that with sustained usage cause breast pain, thoracic pain, as well as back pain. Through our current study, it can be asserted that all women have a handedness, meaning that one of their breasts is larger than the other unable to achieve the support that their bodies need without experiencing this chronic pain. Engineering a bra must involve anthropometric and bioenergetic considerations in their design. Further study is needed in order to understand how these forces affect breast tissue and associated medical conditions.

3 Experimental Work

The research was conducted in strict accordance with the ethics protocol approved by the Health and Research Board (#06563) at Wright State University, USA. The data of 43 subjects were included in this study, mean age and standard deviation 44 ± 18 years and weight 182 lb ± 43. The experimental part of this research included developing a testing module to measure breast anthropometry (Discussed in section 3.1). Using these parameters, we determined the breast mass, volume, shape, asymmetry, and gathering measurements of breasts under loading (with-bra) and unloading (without-bra) conditions. Additionally, the breast shape and volume were investigated. Using anthropometric data, the bioenergetics of the breasts were calculated and compared to the rest of the body.

3.1 Acquisition of Breast Anthropometric Data

The geometry of each breast was measured with and without bra. For the purposes of this study, all subjects were instructed to wear an underwire bra during the measurements. The main breast anthropometric measurements points used in this study are shown in Figure 2 and Table 1, which are the sternal notch, the nipple, the medial and the lateral side of the breast, superior and inferior point of the breast, and the axilla (armpit). These points were chosen to represent all the three planes of the breast the frontal, sagittal, and transverse planes, as discussed in Zhou et al. [19].

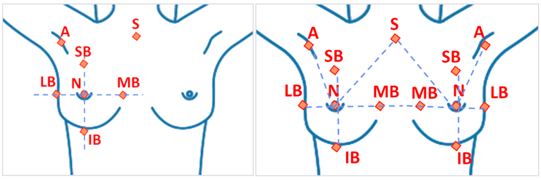

Figure 2 The main breast anthropometric measurements points (left). The sketch of the obtained anthropometric measurements (right)

Table 1 The main breast anthropometric measurements points and their descriptions

Point	Description
S	Sternal notch
N	The nipple
MB	Medial side of the breast
LB	Lateral side of the breast
SB	Superior point of the breast
IB	Inferior point of the breast
A	Axilla (armpit)

The anthropometric measurements defining the fit of the bra were established according to Figure 2 (Table 2 shows the description) and were measured on the subjects both physically, using a tape measure, as well as digitally, using a 3D body scanner. These measurements are *A-N, MB-MB, LB-LB, MB-LB (curve), MB-LB, IB-SB (curve), IB-SB,* Δ*, Band,* and *Bust.* The resulting data were used to evaluate the similarity between the left and right breast in terms of both size and shape. These measurements defined the geometry being forced by bra and considered to be loaded asymmetrically. In this experiment, liquid eyeliner was used to trace key points, lines, and curves of the bra so that the measurements taken while the volunteers were wearing a bra could be replicated as accurately as possible when the subjects were not wearing their bra. These marks could also be made with a regular marker or possibly with tape, though it was found that the eyeliner would be less likely to stain than a marker and less painful to remove from the subjects' skin than tape. Measuring with respect to these points helped to ensure consistency between loading and unloading conditions. Under unloaded conditions, the geometry of the breasts was assessed using a tape measure and the 3D body scanner. The purpose was to analyze and determine the similarity between the left and right breasts. The 3D scanning was conducted without the bra, and the body position was standardized across all volunteers to ensure the comparability of measurements obtained by hand. The scanning process is usually completed in less than a minute, therefore the process was not time-consuming. MATLAB code was developed to obtain the measurements from the scanned 3D models enabling the calculation of breast volume and surface area.

3.2 Acquisition of Breast Shape and Volume

Breast shape is different for each breast depending upon the age and marital status as well as having children [27]. In this study, four different shapes were chosen, which are standard

Table 2 The obtained breast anthropometric measurements and their descriptions

No.	Measurements	Description
1	S-N	Sternal notch to the nipple
2	N-N	The distance between the nipples
3	MB-N	Medial side of the breast to the nipple
4	LB-N	Lateral side of the breast to the nipple
5	SB-N	Superior point of the breast to the nipple
6	IB-N	Inferior point of the breast to the nipple
7	A-N	Axilla (armpit) to the nipple
8	MB-MB	The distance between the two medial sides of the breast
9	LB-LB	The distance between the two lateral sides of the breast
10	MB-LB (curve)	The curve distance between the medial sides of the breast to the lateral side
11	MB-LB (line)	The distance between the medial sides of the breast to the lateral side
12	IB-SB (curve)	The curve distance between the inferior sides of the breast to the superior side
13	IB-SB (line)	The distance between the inferior sides of the breast to the superior side
14	Delta (Δ)	The distance between the two nipples planes
15	Band	The distance under the bust around the ribcage
16	Bust	The distance around the chest, at the fullest point of the bust

(SV), semi conical (SCV), semispherical (SSV), and semi elliptical (SEV) shape. Additionally, the volume of the breast with bra (WBV) was calculated considering hemispherical shape will prevail. The equations that were used to calculate the volume (*V*) and surface area (*S.A.*) for each breast shape were:

For Standard Shape:

$$\mathrm{S.A.} = \pi\left(\mathrm{R}^{*}+\mathrm{r}^{*}\right)\mathrm{l}+\pi\mathrm{R}^{*2}+\frac{1}{2}(4\pi\mathrm{r}^{2}) \tag{1}$$

$$\mathrm{V} = \frac{1}{3}\pi\mathrm{h}(\mathrm{R}^{*2}+\mathrm{r}^{*2}+\mathrm{R}^{*}\mathrm{r}^{*})+\frac{1}{2}(\frac{4}{3}\pi\mathrm{r}^{3}) \tag{2}$$

For Semi Conical Shape:

$$\mathrm{S.A.} = \pi\left(\mathrm{R}^{*}+\mathrm{r}^{*}\right)\mathrm{l}+\pi\mathrm{R}^{*2} \tag{3}$$

$$\mathrm{V} = \frac{1}{3}\pi\mathrm{h}(\mathrm{R}^{*2}+\mathrm{r}^{*2}+\mathrm{R}^{*}\mathrm{r}^{*}) \tag{4}$$

For Semi spherical Shape:

$$\mathrm{S.A} = \frac{1}{2}(4\pi\mathrm{r}^{2}) \tag{5}$$

$$\mathrm{V} = \frac{1}{2}(\frac{4}{3}\pi\mathrm{r}^{3}) \tag{6}$$

For Semi Elliptical Shape:

$$\mathrm{S.A} = 2\pi(\frac{(\mathrm{A}*\mathrm{B})^{1.6075}+(\mathrm{A}*\mathrm{C})^{1.6075}+(\mathrm{B}*\mathrm{C})^{1.6075}}{3})^{\frac{1}{1.6075}}+\pi*\mathrm{B}*\mathrm{C} \tag{7}$$

$$\mathrm{V} = \frac{2}{3}*\pi*\mathrm{A}*\mathrm{B}*\mathrm{C} \tag{8}$$

Where (*r*) is the radius of breast, (*h*) is the longitudinal height of breast, (R^*) is the radius of the larger base. (r^*) is the radius of the smaller base. (*l*) is the slant height of the frustum that can be calculated using the Pythagorean theorem ($l = \sqrt{h^2 + (R^* - r^*)}$), (*A*) is the bisected axis that equals to ($\frac{2\times(\mathrm{MB-LB})_{\mathrm{curve}}}{\pi}$), (*B*) is the second semi axis that equals to ($\frac{(\mathrm{IB-SB})}{2}$), and (*C*) is the third semi axis that equals to ($\frac{(\mathrm{MB-LB})_{\mathrm{curve}}}{\pi}$).

3.3 Bioenergetics Analysis

Bioenergetics analysis of the bra-breast interface is an important technique for improving the design of bras and promoting breast health and comfort during physical activity. To emphasize the importance of having a well fitted bra, we performed a bioenergetics analysis of the breasts and their motion. The goal of this part of the study was to observe how much of one's energy consumed by the breasts as a result of motion during daily activities. Equation (9) was used to calculate the total energy consumed, per breast, when the breast was moving at given velocity (v). Three velocity values were examined: 0.12, 0.15, and 0.18 m/s for normal walking, jogging, and being active, respectively. In static condition, the potential energy of the breast is constant and does not change during movement as it is located at the center of mass of the breast. The motion of the breasts moving at specified velocity was considered in terms of translational motion (left, right, up, down motion) and rotational (angular motion). Energy from each type of motion was considered with the breasts' gravitational potential energy, which is due to both geometry of the breasts as well as other factors (height, weight, etc.). For the current analysis, we assumed that there is no plasticity, and the breast volume stays constant during motion. Additionally, we asked all subjects to wear underwire bras so their breasts would have hemispherical shapes under the bra, so we were able to apply the measurements of that shape in our bioenergetic calculations. The total energy removed from the body by the breasts during motion can be described as the sum of the translational, rotation, and potential energies, calculated via the equations:

$$\mathrm{E_{Total}} = \mathrm{E_{Translational}} + \mathrm{E_{Rotational}} + \mathrm{E_{Potential}} \tag{9}$$

Where $\mathrm{E_{Total}}$ is the total energy, $\mathrm{E_{Translational}}$ is the Translational energy, $\mathrm{E_{Rotational}}$ is the Rotational energy, and $E_{Potential}$ is the Gravitational Potential energy. Overall, the contributions of these different types of energy to the total energy balance of the breast can vary depending on factors such as metabolic rate, physical activity level, and body position. Accurately estimating the contributions of each type of energy requires a detailed understanding of the physiological and biomechanical processes involved.

$$\mathrm{E_{Translational}} = \frac{1}{2}\mathrm{mv}^2 \tag{10}$$

Where (m) is the weight, and (v) is the velocity. This equation assumes that the breast tissue is moving in a straight line with a constant velocity. In reality, the motion of the breast tissue may be more complex and involve changes in direction or speed. However, this equation provides a simple estimate of the translational energy of the breast based on its mass and velocity.

$$\mathrm{E_{Rotational}} = \frac{1}{2}\mathrm{I}\omega^2 \tag{11}$$

Where (I) is the is the moment of inertia of the breast tissue in kilograms times meters squared (moment of inertia of hemisphere) and calculated using equation (12), and (ω) is the angular velocity of the breast tissue in radians per second and calculated as (v/r). However, it's important to note that the breast is not a rigid body, and its motion is influenced by a variety of factors such as tissue elasticity, muscle activity, and gravity. Therefore, the breast may not move in a perfectly circular path, and the radius of the circular path may be difficult to define precisely. Additionally, the breast may move with a combination of translational and rotational motion, which can complicate the analysis. The rotational energy equation assumes that the breast tissue is rotating around a fixed axis, such as the center of mass of the breast or a point on the skin surface. In reality, the motion of the breast tissue may be more complex and involve changes in axis or rotation speed. However, this equation provides a simple estimate of the rotational energy of the breast based on its moment of inertia and angular velocity:

$$\mathrm{I} = \frac{\mathrm{mr}^2}{5} \tag{12}$$

Where (r) is the radius of the breast.

Regarding the potential energy, this type of energy is related to the position of the breast tissue in a gravitational field. The potential energy of the breast can be estimated based on the height of the tissue above a reference point, such as the ground or the center of mass of the body. Potential energy is typically a small contributor to the overall energy balance of the breast, but it may be more significant in situations where the breast is subject to large changes in height, such as during physical activity:

$$\mathrm{E_{Potential}} = \mathrm{mgh} \tag{13}$$

Where (m) is the mass of the breast tissue in kilograms (kg), (g) is the acceleration due to gravity, which is approximately 9.81 m/s^2 on Earth, and (h) is the height of the breast tissue above a reference point in meters (m). This equation assumes that the breast tissue is treated as a point mass, which is lifted to a certain height above the reference point against the force of gravity. In reality, the breast tissue is more complex and may have varying densities and shapes, which can affect its potential energy. However, this equation provides a rough estimate of the potential energy of the breast based on its mass and height above a reference point.

In order to complete this analysis, some anthropometric data was used to approximate average breast density and size (volume and weight) as a function of age [20, 21]. These data were used to calculate the average breast mass a function of age, which were substituted into the equations (9-13) in order to calculate average translational, rotational, and potential energy for various age groups. Data from women aged > 29, 30-39, 40-49, 50-59, 60-69, 70-79, and > 80 were grouped together. The bioenergetics analysis was then performed on each of the 7 age groups and each of the three velocity values of interest.

4 Results

4.1 Acquisition of Breast Anthropometric Data

The data was collected for each breast with or without bra. Measurement locations were determined based on the landmarks defined in Figure 3. When the landmarks differ, they cause breast and bra dynamics to change. The recordings were measured with a standard ruler, as well as scanned through a 3D scanner. The measurements were recorded on both the right and left breasts, and with/without a bra on. The data collected for the measurements can be seen in Table 3.

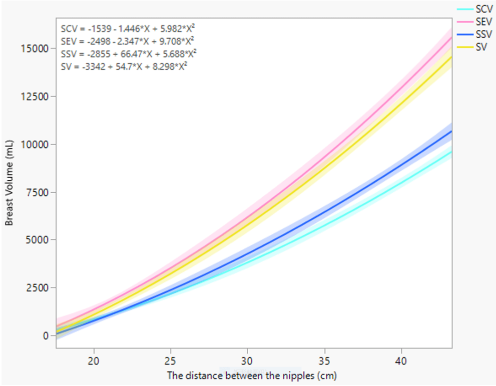

Figure 3 The distance between the nipples in different breast shapes (Standard (SV), Semi spherical (SSV), Semi elliptical (SEV) and Semi conical (SCV)).

Table 3 Breast Anthropometric Data results (cm)

	Measurement	Unloaded (Without Bra) Mean	Unloaded (Without Bra) SD	Loaded (With Bra) Mean	Loaded (With Bra) SD
	The distance between the nipples	24.16	5.14	20.36	7.26
	The curved distance between the two Lateral sides of the breast points	50.33	17.32	57.95	15.18
	The distance between the two Medial sides of the breast points	2.76	1.32	2.14	0.58
	The distance between the two nipples planes	1.33	0.63	0.41	0.16
Right Breast	Axilla (armpit) to the nipple	22.92	5.84	19.08	2.44
	Lateral side of the breast to the nipple	16.36	5.02	12.48	4.83
	Medial side of the breast to the nipple	17.17	5.68	10.16	3.65
	The curve distance between the Medial and Lateral sides of the breast	30.50	8.77	26.57	5.46
	Inferior point of the breast to the nipple	9.85	2.63	11.42	2.84
	Sternal notch to the nipple	27.98	4.82	22.86	5.03
	The line distance between the Medial and Lateral sides of the breast	15.84	2.99	16.06	3.20
	The distance between the Superior and Inferior points of the breast	10.68	2.62	15.93	2.88
Left Breast	Axilla (armpit) to the nipple	22.66	5.76	18.97	2.83
	Lateral side of the breast to the nipple	15.54	4.67	12.18	4.03
	Medial side of the breast to the nipple	17.18	5.72	10.39	3.47
	The curve distance between the Medial and Lateral sides of the breast	30.63	8.82	26.83	5.13
	Inferior point of the breast to the nipple	9.70	2.80	11.18	2.45
	Sternal notch to the nipple	28.27	5.22	22.74	4.96
	The line distance between the Medial and Lateral sides of the breast	16.42	2.98	17.05	2.94
	The distance between the Superior and Inferior points of the breast	10.99	2.50	16.85	2.56

4.2 Breast Volume Results

After the data and measurements were collected, the volume, diameter, surface area, and mass were calculated for each breast, for each volunteer. Four different breast shapes were assumed and the volume was calculated and compared with different bra measurements. These measurements were chosen because they had significant effect on the breast volume despite the shape, as the volume increased with the increment in the measurements (shown in Figure 3 & 4). These charts illustrate that there was no significant difference between the standard and semi ellipsoid shapes and no difference between semi spherical and semi conical shapes. It can be noticed that there was a significant difference between semi ellipsoid and semi conical shapes, which means that knowing the shape of the breast is as important as taking the measurements, and it is critical to take the shape of the breast into consideration when designing, selling, or purchasing a new bra. On the other hand, the volumes measured from the 3D scanned (SDV) models were less than the calculated volumes despite the shape, but with no significant difference ($p > 0.05$), as shown in Figure 5. The reason for that could be due to the difference in each breast shapes or the human error during the hand measurements. Additionally, Figure 6 shows that the volume of the breast decreases drastically when the bra is on (WBV) as the breast would be compressed firmly inside the bra cup. When we compared between the volume of breast with and without the bra for the same subjects, it can be noticed that some subjects have sgnificant diffrences in volume.

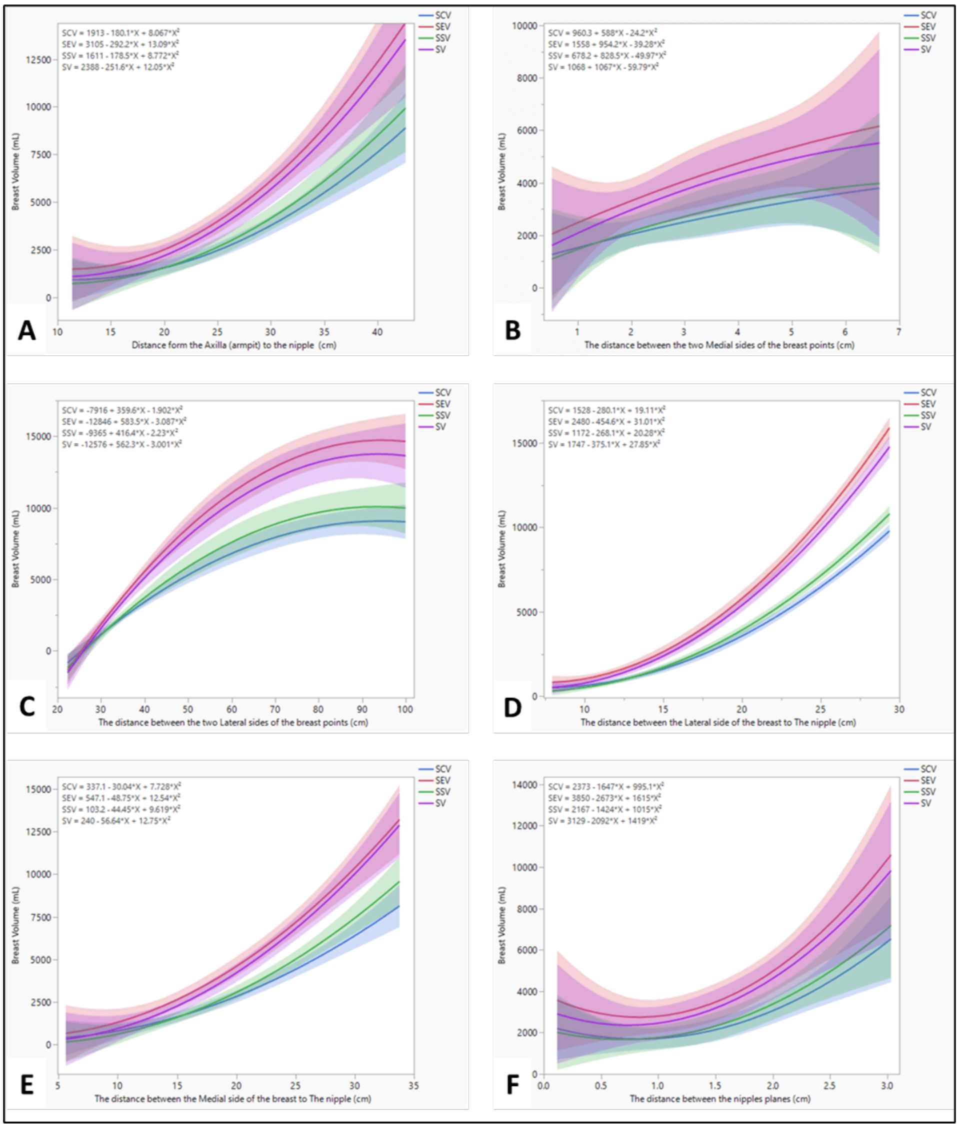

Figure 4 (A) Axilla (armpit) to The nipple in different breast shapes. (B) The distance between the two Medial sides of the breast points in different breast shapes. (C) The straight distance between the two Lateral sides of the breast points in different breast shapes. (D) Lateral side of the breast to the nipple in different breast shapes. (E) Medial side of the breast to the nipple in different breast shapes. (F) The distance between the nipples' planes in different breast shapes. Where Standard (SV), Semi spherical (SSV), Semi elliptical (SEV) and Semi conical (SCV) breast shapes.

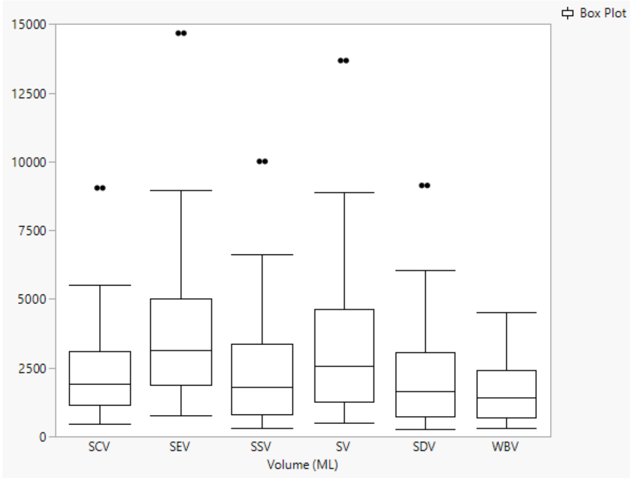

Figure 5 The calculated volume for the breast with bra (WBV) vs different shapes (Semi conical (SCV), semi ellipsoid (SEV), semi spherical (SSV), standard (SV)) *vs* the volume measured from 3D scanned breast models (SDV).

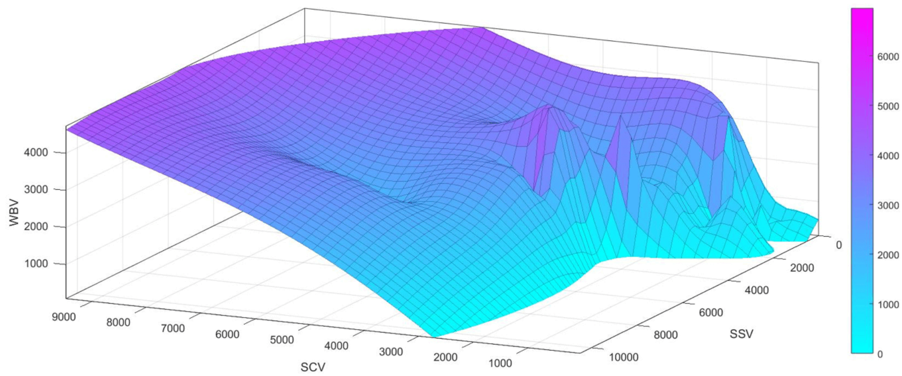

Figure 6 With bra volume (WBV) *vs* without bra volumes (SCV and SSV)

A sensitivity analysis was performed to investigate the effect of the body weight and the breast radius on the breast volume. The results indicated that the volume increased as the radius of the breast increased. On the other hand, there was no relationship between the weight of the subject and the breast volume.

Investigating the asymmetry of the breast is very significant, as indicated by the survey results. The findings revealed that 46% of participants exhibited visible asymmetry, 14% had some unnoticeable asymmetry, and 40% either had no asymmetry or were unsure. These statistics highlight the prevalence of breast asymmetry among the participants. It emphasizes the need to address this issue seriously when designing bras. Interestingly, despite the noticeable asymmetry, the results indicated no significant difference in volume between the right and left breasts.

4.3 Bioenergetics Results

Based on anthropomorphic data, the total energy requirements for each breast, relative to band and cup size, can be determined by using the equations 9-13. The results of total, translational, rotational, and potential energies are shown in Table 4 for the examined velocity value (0.18 m/s). The energy was compared with band size for different cup sizes, as shown in Figure 7. Additionally, the energy was compared with the cup diameter and displayed that as the cup diameter increases, the energy increases, as shown in Figure 8.

5 Discussion

Nowadays, bras are being mass-manufactured under the assumption that breasts are symmetrical and evenly spaced. Companies manufacturing bras using measurement standards for band size and cup size only. These sizes are considered as a standard, but many factors should be considered to fit a bra including the height, width, or degree of sagging of the chest. This

Table 4 Energy calculations for cup and band size

Cup Size	Cup diameter (cm)	Volume of one cup	$E_{potential}$ 0.18 (J)	$E_{rotational}$ 0.18 (J)	E_{trans} 0.18 (J)	E_{total} (J)
A	9.7	240 cc (0.51 US pt)	2.107	0.005	3.48	5.592
B	10.6	310 cc (0.66 US pt)	2.744	0.005	4.54	7.289
C	11.4	390 cc (0.82 US pt)	3.43	0.005	5.67	9.105
D	12.3	480 cc (1.0 US pt)	4.214	0.005	6.97	11.189
E	13.1	590 cc (1.2 US pt)	5.39	0.01	8.91	14.31
F	14	710 cc (1.5 US pt)	6.37	0.01	10.53	16.91
G	14.8	850 cc (1.8 US pt)	7.35	0.015	12.15	19.515
H	15.7	1,000 cc (2.1 US pt)	8.82	0.02	14.58	23.42
I	16.5	1,180 cc (2.5 US pt)	10.29	0.02	17.01	27.32
J	17.4	1,370 cc (2.9 US pt)	12.25	0.03	20.25	32.53
K	18.2	1,580 cc (3.3 US pt)	13.72	0.03	22.68	36.43
L	19	1,810 cc (3.8 US pt)	16.17	0.04	26.73	42.94
M	19.9	2,060 cc (4.4 US pt)	18.13	0.045	29.97	48.145
N	20.7	2,340 cc (4.9 US pt)	20.58	0.055	34.02	54.655
O	21.6	2,640 cc (5.6 US pt)	23.52	0.065	38.88	62.465
P	22.4	3,000 cc (6.3 US pt)	25.97	0.075	42.93	68.975

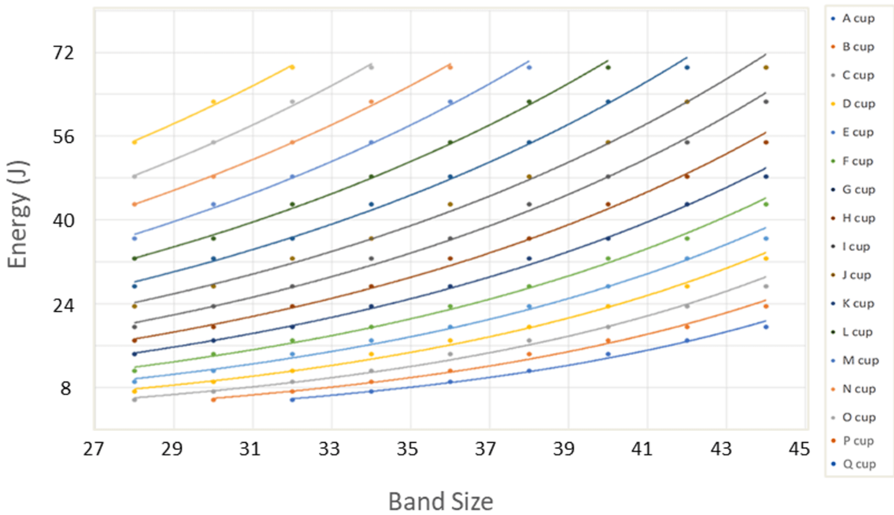

Figure 7 Energy *vs* bra size

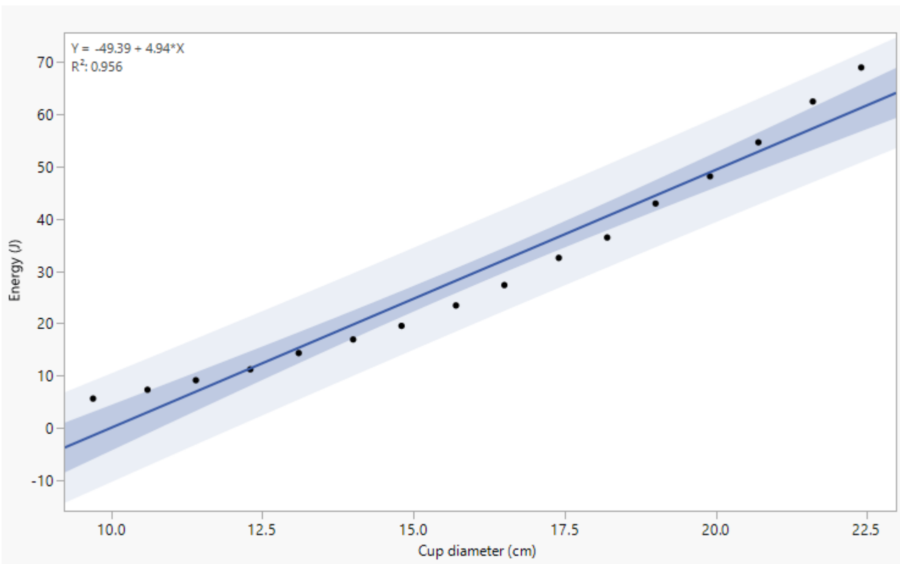

Figure 8 The energy *vs* cup diameter

study investigated the compatibility between the anatomy of the breasts and bra. The experiment encompasses breast anthropometry via measurement. A measurement topology testing module was proposed to determine breast mass, volume, shape, and asymmetry under loading (with-bra) and unloading (without-bra). Using the anthropometric data, the bioenergetics of the breasts were determined and compared to the rest of the body. The main breast anthropometric measurements landmarks used in this study are *S, N, MB, LB, SB, IB,* and *A*. These landmarks are necessary to be able to compare natural and forced breast geometry as well as to be able to compare between the anatomy of the left and right breast. In addition, these landmarks were chosen to signify all the three planes of the breast in the frontal, sagittal, and transverse planes.

The anthropometric measurements defining the fit of the bra were *S-N, N-N, MB-N, LB-N, SB-N, IB-N, A-N, MB-MB, LB-LB, MB-LB (curve), MB-LB (line), IB-SB (curve), IB-SB (line),* Δ, Band and Bust. Comparing the measurements of the breast-bra interface in loaded and unloaded conditions reveals important findings. In the unloaded condition, the mean distance between the two lateral sides of the breast points is slightly higher at 36.19 cm, while in the loaded condition, it decreases to 34.92 cm. The mean distance between the nipples is significantly higher in the unloaded condition (24.16 cm) compared to the loaded condition (20.36 cm). Similarly, the mean curved distance between the two lateral sides of the breast points is significantly higher when the bra is worn (57.95 cm) compared to without the bra (50.33 cm). Regarding the distance between the two medial sides of the breast points, it is slightly higher in the unloaded condition (2.76 cm) compared to the loaded condition (2.14 cm). In contrast, the distance between the two nipples planes is significantly lower in the loaded condition (0.41 cm) compared to the unloaded condition (1.33 cm). When considering the individual breast measurements, the axilla (armpit) to nipple distance, medial side of the breast to nipple distance, and lateral side of the breast to nipple distance are significantly lower in the loaded condition for both breasts. The curve distance between the medial and lateral sides of the breast is slightly lower in the loaded condition for both breasts. Additionally, the inferior point of the breast to nipple distance is slightly higher in the loaded condition for both breasts. The sternal notch to nipple distance is significantly lower in the loaded condition for both breasts. The line distance between the medial and lateral sides of the breast is slightly higher in the loaded condition for both breasts. Lastly, the distance between the superior and inferior points of the breast is significantly higher in the loaded condition for both breasts.

The distance between the nipples is a crucial parameter to evaluate the bra-breast interface because it directly reflects the positioning and alignment of the breasts. In the unloaded condition (without a bra), the mean distance between the nipples is 24.16 cm, with a standard deviation of 5.14 cm. When a bra is worn (loaded condition), the mean distance decreases to 20.36 cm, with a slightly higher standard deviation of 7.26 cm, as illustrated in Figure 9. This measurement indicates that the bra has a significant effect on bringing the nipples closer together and influencing the overall breast positioning. The reduction in nipple distance when wearing a bra suggests that the bra provides support and compression, potentially impacting breast shape, symmetry, and comfort. Understanding the changes in nipple distance due to bra usage is crucial for designing bras that provide adequate support, fit, and comfort. It highlights the importance of considering nipple positioning and breast alignment when evaluating and improving bra designs for optimal breast health and satisfaction.

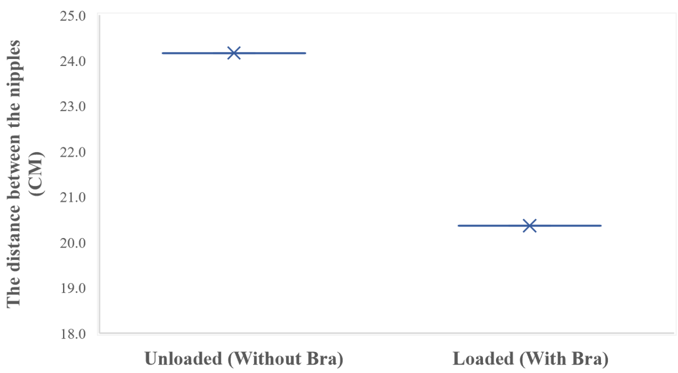

Figure 9 The distance between the nipples in loaded vs unloaded breast

Four different breast shapes were assumed in the current study (standard, semi elliptical, semi conical, and semi spherical), and the volume was calculated and compared with different bra measurements. Anthropometric measurements data shows that the semi conical and semi spherical breast shapes consistently predicted lower bound volume for each breast for all the volunteers, whereas the standard and semi elliptical breast shapes predicted higher volume for the same breast. The results demonstrated that as *N-N* increases, the volume of the breast increases (Figure 3), however, the ratio between the volume predicted by semi conical/standard, semi spherical/standard, and semi ellipsoid/standard was significant at the higher ranges of *N-N*, in contrary, there was no significant difference in the ratio between the semi conical and semi spherical breast shapes except in subjects where that distance was more than (27 cm). Also, it is evident that breast volume varies at a constant value of the *N-N*, indicative of changes in the sagittal breast geometry or shape while coronal plane coordinates are constant. Additionally, as the *A-N* distance increases, the volume of the breast increases (Figure 4A), however, the ratio between the volume predicted by semi conical/standard, semi spherical/standard, and semi ellipsoid/standard was significant at the higher ranges of the distance from *A-N*, where there was no significant difference in the ratio between the semi conical and semi spherical breast shapes except in subjects where that distance was more than (25 cm). We also observed that a parabolic fit may describe the relation between the breast volume and the *A-N*, where the volume reaches a peak point at the critical value of *A-N* being 25-27 cm. A smaller or larger value of *A-N* does not influence the breast volume. The same trend was seen when *MB-MB* or the *LB-LB* increase, the volume of the breast increases (4B and 4C, respectively). However, the ratio between the volume predicted by semi conical/standard, semi spherical/standard, and semi ellipsoid/standard was significant at the higher ranges of the distance with no significant difference in the ratio between the semi conical and semi spherical breast shapes except in the subjects where that *LB-LB* was more than (40 cm). Moreover, when *LB-N*, *MB-N* and *N-N* on the transverse plane increase, the volume of the breast increases (Figure 4D, 4E and 4F, respectively). In contrast, there was no significant difference was noticed in the ratio between the semi conical and semi spherical breast shapes except in the subjects where *LB-N* or *MB-N* was more than (20 cm) and the distance between the two nipples on the transverse plane increased 1.7 cm or above. Additionally, it was noticed that the volume of the breast decreases drastically when the bra is on as the breast would be compressed firmly inside the bra cup.

A sensitivity analysis was performed to investigate the effect of the body weight and the breast radius on the volume of the breast. The results indicated that the volume increased as the radius of the breast increased. On the other hand, there was no relationship between the weight of the subject and the breast volume. Figure 7 illustrates that body weight and the breast radius on the volume of the breast follow the "leaf behavior" where this behavior is widely used in literature to characterize the nonlinear behavior [22–25] to describe the large angle motion. The mathematical relation can be expressed as follows:

$$F_v(x_{b.w},\ y_{b.r}) = (T_{00})\ +\ (T_{10}) \times x_{b.w}\ +\ (T_{01}) \times y_{b.r}\ +\ (T_{20}) \times x_{b.w}^2 \\ +\ (T_{11}) \times x_{b.w} \times y_{b.r}\ +\ (T_{02}) \times y_{b.r}^2 \tag{14}$$

Where is the vol$F_v$ume of the breast, is the body$x_{b.w}$ weight, is the radi$y_{b.r}$us of the breast, and the coefficients (with 95% confidence bounds) were:

T_{00} = -1379 (-2.66e+04, 2.38e+04)
T_{10} = -51.74 (-25, 2415)
T_{01} = 36.87 (-151.4, 225.1)
T_{20} = -4.78 (-106.9, 97.32)
T_{11} = 1.59 (-7.18, 10.35)
T_{02} = -0.12 (-0.51, 0.27)

From the current investigation, it can be seen all of the data of the right and left breasts are different for the same measurement (Figure 7). However, the results indicated that there was no significant difference between the volume of the right and left breasts despite the noticeable asymmetry. To understand the asymmetry between the right and left breasts and if there is any effect on the breast, a comparison was made between the right and left breast of each subject with respect to different breast measurements. It was observed that as *N-N* increases the volume of the breast increases, nevertheless, there was no significant difference in ratio between the right and left breasts except in subjects where that distance was more than (33 cm). On the other hand, as the *N-N* on the transverse plane increases the volume of the breast increases. In contrast, there was a noticeable difference in ratio between the right and left breasts except in the subjects where that distance was between (0.9-1.7 cm). Moreover, when the straight or curved *LB-LB* increases, the volume of the breast increases with no significant difference between the right and left breasts. Nonetheless, when the *MB-MB* increases, the volume of the breast increases, however, there was a noticeable difference in ratio between the right and left breasts except in the subjects where this measurement was between (1.8-4.9 cm).

Using obtained anthropomorphic data, the energy requirements on each breast was determined. Based on Figure 9, larger breasts will require the highest energy required to constrain because the mass of the breast is increased. The largest size breast required nearly 68.97 J of total energy. The average energy required for a person walking is 372.54 ± 78.16 kJ [28]. While the energy requirement to move the breast is miniscule compared to the amount for walking, it shows the importance of having a supportive bra. We investigated how the energy changes as band size increases for different cup sizes. The results (Figure 8) indicated that the energy increases as the cup size increases. Women with (cup size A-G) demonstrated the least energy ranged between 5.59J- 19.52J, while women with (cup size N-P) demonstrated the highest energy ranged between 54.65 J – 68.79 J. Figure 9 displays an upward behavior for energy increment that is due to loading and unloading. If we observe the effect of mass and volume on energy, we can see that as the volume and mass increase, the energy increases, as illustrated in Figure 10. The main reason for women with bigger breasts (bigger cup size) to spend more energy is due to having more fatty tissue that fills the areas between connective tissue and glandular tissue. Moreover, eccentric position of two mass centers of gravities will result in one arm of the lever from fulcrum to be dominated causing higher work produced than the other, thus requiring additional support not only to contain it but also to resist the forces and displacement that arise from body movement.

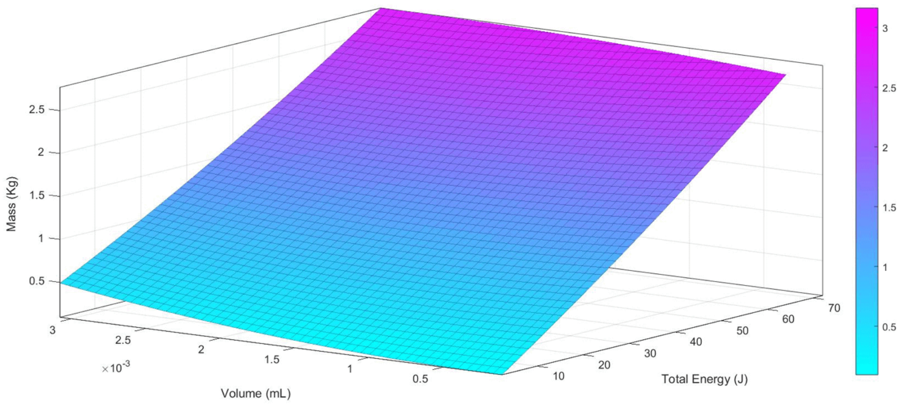

Figure 10 The mass *vs* energy and volume

Currently, the design for a bra assumes that the breasts are symmetrical [26]. The current investigation proves that this is not the case. The bra needs to be redesigned to better fit women, since left and right sides are not symmetrical. This is a substantial problem today, as it is estimated that nearly 80% of women wear incorrectly- sized bras; 70% wore bras that are too small, and 10% wore bras that are too big [17, 18]. Current investigation highlights the crucial importance of incorporating the distance between the nipples into bra design to achieve optimal support, comfort, symmetry, and minimize breast movement. It ensures that the bra cups are positioned optimally to provide effective support and enhance the natural shape of the breasts. If the current bra models are redesigned, the amount of discomfort in women could potentially decreases.

6 Conclusion

This study made significant contributions by integrating anthropometric measurements encompassing breast shape, asymmetry, and bioenergetic considerations involving mass, volume, density, and energy during daily activities. A testing module was developed to accurately measure breast anthropometry, enabling the determination of crucial parameters such as breast mass, volume, shape, asymmetry, and specific features (*S-N, N-N, MB-N, LB-N, SB-N, IB-N, A-N, MB-MB, LB-LB, MB-LB (curve), MB-LB (line), IB-SB (curve), IB-SB (line), Δ, Band*, and *Bust*). The findings of this study shed light on the limitations of the current commercially used measurements in defining breast geometry, emphasizing the need for a more accurate representation in bra design. It was evident that asymmetry is a prevalent factor that cannot be overlooked, as all the volunteers exhibited some degree of asymmetry, characterized by measurements differing by more than 5%. Thus, accounting for breast shape and considering asymmetry is crucial in the design, sale, and purchase of bras. Moreover, the research highlighted the significance of breast shape in determining volume, with semi-conical and standard shapes consistently indicating lower bound volumes compared to other shapes. While the energy required for breast movement was found to be negligible within the assumed parameters, the study emphasized the importance of a supportive bra that can resist breast movement, forces, and displacements. It was evident that as cup size increases, the energy requirement also increases. Therefore, when designing a bra, considering comfort is of utmost importance. Understanding the changes in the distance between the nipples resulting from bra usage is crucial for designing bras that provide adequate support, fit, and comfort. The study emphasized the need to consider nipple positioning and breast alignment in the evaluation and improvement of bra designs to promote optimal breast health and overall satisfaction. These insights challenge the validity of the current bra manufacturing process and call for a more comprehensive and personalized approach to bra design.

Conflicts of Interest

The authors declare no conflict of interest.

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architecture allows not only to analyze images, but also to interact with the user through a visual dialogue. The model is capable of performing various tasks, ranging from recognizing objects in photographs to solving mathematical examples. It can also be trained to analyze medical images, opening up new prospects for healthcare applications. Most importantly, the code of the original model has become available to the public, which contributes to the further development and application of AI technologies in various fields.

Ensembles of software and hardware intelligent agents imitate the abilities of natural human intelligence in virtual and real space. Robotic ensembles, like human counterparts with artificial intelligence, can reproduce most virtual processes and human skills in the real world. Ensembles of software and hardware intelligent agents are trained to create texts, but they cannot themselves identify new meanings and create theories. So far, experts have not been able to create ensembles of software and hardware intelligent agents capable of consciously and emotionally reacting to various jokes. Multimodal ensembles of intelligent agents with artificial intelligence can carry out tasks of specialists [3].

Artificial intelligence researchers are striving to build a universal theory for modeling natural intelligence by multimodal self-organizing systems. The author suggested multi-purpose hierarchical multi-layer approach to creating multimodal ensembles of software and hardware intelligent agents.

2 Multi-purpose hierarchical multi-layer approach to creating multimodal intelligent systems

A section of the article is devoted to consideration of the hierarchical structure, multi-purpose organization, multi-layer decision making and self-organizing control of multimodal intelligent systems.

2.1 Complex hierarchical multi-purpose structure of the organization of a multimodal intelligent system

The complex hierarchical structure of the organization of a multimodal intelligent system provides for a combination of centralized control with autonomy of parts (subsystems) with self-regulation and adaptation. At its core, a hierarchical organizational structure consists of multi-layered management and three levels of authority. The lower level is responsible for physical operations, the middle level for psychological actions, and the upper level for cognitive functions. Physical operations are carried out by robotic systems and digital twins [4, 5]. Psychological actions are implemented by bioinformation systems [6]. Cognitive functions are performed by ensembles of intelligent agents [7].

Centralized and leveled control facilitates more thorough monitoring of the activity of a multimodal intelligent system, which ensures high-quality control. The hierarchical multimodal intelligent system is functionally efficient, providing a balance between control and flexibility. Thoughtful implementation of hierarchy maintains clarity, specialization and coordination among all levels and horizontal roles, while ensuring security, autonomy, multi-level communication and execution control. For each level there are characteristic features, laws and principles with the help of which the behavior of the system at this level is described. The hierarchy of an intelligent system is defined by a family of models, each of which describes the behavior of the system from the point of view of the corresponding level.

The family of models includes a theoretical-cognitive description of its concept, a design representation of the system, design, technology, and software and hardware functional implementation. The lower we go down the hierarchy of levels, the more detailed the disclosure of the system becomes; the higher we rise, the clearer the meaning and significance of the entire system becomes. It is almost impossible to explain the purpose of the system using lower-level elements in complex intelligent systems. The idea must not be distorted when revealed at each subsequent level.

One of the main stages in developing an effective organization of a system is the formation of a structure based on the analysis and synthesis of subsystems. This analysis and synthesis of the subsystems under consideration involves bringing the structure of the organization into line with its goals, objectives and requirements. Analysis and synthesis of structures is carried out in the following stages to determine: a formalized description of the functioning of the elements of the structure; the goals of each of the structure elements; corrective changes in the structure.

Changing goals in the structure should be based on the following principles: simultaneous achievement of the goal; the sequential method, when goals are achieved sequentially over time; placement of goals depending on the prevailing circumstances; the principle of hierarchy of alternative methods of action and defining characteristics; the principle of reduction in the transition from complex to simple; the principle of specification (using only information specified explicitly when solving a problem).

2.2 Multilayer structuring of the organization of decision-making processes

Multilayer structuring is introduced to organize decision-making processes. To reduce the uncertainty of the situation, levels of complexity of the decision being made are distinguished - layers, i.e. a set of sequentially solved problems is determined. In this case, problems are identified in such a way that the solution to the underlying one would determine the limitations (permissible degree of simplification) when modeling at the underlying level, i.e. would reduce the uncertainty of the underlying problem, but without losing the intent of solving the overall problem. To do this, a top-down flow of directives is created: Strategies and directives are created at the top of the hierarchy and propagated to subsequent levels below. This facilitates agreement on common goals. Vertical communication channels are created. Information typically moves up and down different levels of the hierarchy, with limited switching between disparate subsystems. The organizational pyramid supports horizontal communication. Hierarchy ensures clear governance and avoids confusion about who has decision-making authority. Specific roles allow for the use of specialized skills and prevent duplication of effort.

Let's consider a multi-layered hierarchy of decision-making for managing any process. In it, under conditions of uncertainty, three main aspects of the decision-making problem can be distinguished. The bottom layer, the "closest" to the controlled process, is the selection layer. The task of this layer is to choose a method of action m. The decision-making element (block) receives data (information) about the controlled process and, using the algorithm obtained in the upper layers, finds the desired method of action, i.e. sequence of control actions on the controlled process. The algorithm can be defined directly as a functional mapping D that gives a solution for any set of initial data. Suppose that an output function P and an evaluation function G are given, and the choice of actions $\{m\}$ is based on the application of an evaluation of G to P.

Using set-theoretic representations, the output function can be defined as a mapping $P{:}M\times U\rightarrow Y$, where M is the set of alternative actions; Y is the set of possible outputs (or "outputs"); U is a set of uncertainties that adequately reflects the lack of knowledge about the relationship between action and output Y. Similarly, the evaluation function G is a mapping $G{:}M\times Y\rightarrow V$, where V is a set of quantities that can be associated with the characteristics of the quality of the system. If the set U consists of a single element or is empty, i.e. there is no uncertainty regarding the output result for a given action m, the choice can be based on optimization: find such m' in M such that the value $v'=G(m',P(m'))$ is less than $v=G(m,P(m))$ for any other action $m\in M$. If U is a richer set, we have to propose some other procedures for choosing a solution method. In this case, it will be necessary to introduce some other mappings, in addition to P and G. But in the general case, in order to determine the selection problem on the first layer, it is necessary to clarify the set of uncertainties U, the required relations P, G, etc. This is done on the upper layers.

The layer of learning or adaptation that lies above the layer in question. The task of this layer is to specify the set of uncertainties U, which the selection layer deals with. The set of uncertainties U is considered here as a set that includes all ignorance about the behavior of the system and reflects all hypotheses about the possible sources and types of such uncertainties. The set U can be obtained using observations and external sources of information. The purpose of the layer under consideration is to narrow the set of uncertainties U and thus simplify the selection layer model. In the case of stationarity of the system and environment, U can be extremely narrowed down to one element, which corresponds to ideal learning. However, in the general case, U can include not only existing, but also uncertainties assumed by the decision-making system, and if necessary, U can be completely changed and expanded, including by changing the previously accepted basic hypothesis.

The third, in this case the top layer of self-organization. At this layer, the structure, functions and strategies used in the underlying layers are selected in such a way as to get as close as possible to the display of the goal, which is usually given in the form of a verbal description. If the goal is not achieved, the P and G functions in the first layer or the learning strategy in the second can be changed.

It is useful to form multilayer decision-making systems to solve problems of planning and management of industrial enterprises, industries, and the national economy as a whole. When formulating and solving such problems, it is impossible to define goals once and for all and choose specific actions: the economic and technological conditions of production are constantly changing. All this can be reflected in a multi-layer decision-making model. The system is represented in the form of relatively independent subsystems interacting with each other; Moreover, some (or all) subsystems have decision-making rights, and the hierarchical arrangement of subsystems (multilayer structure) is determined by the fact that some of them are influenced or controlled by their superiors.

The main distinctive feature of a multilayer structure is the provision of subsystems at all levels with a certain freedom in choosing their own solutions; Moreover, these decisions may (but do not necessarily) differ from those that would be chosen by a higher level. Providing freedom of action in decision-making to components of all layers of the hierarchical structure increases the efficiency of its functioning. Subsystems are given a certain freedom in choosing goals. Therefore, multilayer structures are multi-purpose. In such systems, different decision-making methods can be used. Which is one of the conditions for increasing the efficiency of the system.

2.3 Intelligent self-organizing ensemble of software and hardware agents for multimodal management

The possibilities for the practical development and application of artificial intelligence in the social sphere and industry depend on the systemic self-organization of an ensemble of software and hardware agents for management. An intelligent self-organizing ensemble of software and hardware agents for management contains systems for analysis, forecasting, planning, organizing, coordinating, optimizing and monitoring security. Analysis and forecasting are part of planning. For reliable analysis and forecast, the ensemble uses artificial intelligence methods and data that are associated with the control object. The planning system replaces the functionality of the customer's management process, composed of acts, with a sequence of operations from the skill base, and presents the totality of all operations in the form of a visual diagram. Organizational management is carried out on the basis of visual diagrams of operations. The control system allows you to track the execution and safety of management. The control system's control operation monitor tracks the execution of each operation and audits the control history. The optimization system activates the management modeling process, assesses risks and improves the management plan based on the activity monitor audit. An intelligent multimodal self-organizing ensemble of software and hardware agents moves on to multimodal manage practical activities based on existing AI technologies and tools.

3 On the international standardization of safe artificial intelligence systems

For the safe use of artificial intelligece systems in the social, industrial and scientific spheres, international standardization is being carried out. Safety for artificial intelligence and ethical codes on the use of intellectual systems are developed in a wide format of directions by specialists of various companies by different countries at the international level.

Since 2021, the Code of Ethics of Artificial Intelligence has been operating in Russia. The code establishes the general ethical principles and standards of behavior that should be guided by participants in relations in the field of artificial intelligence in their activities. Russian experts have developed standards that regulate the safety of artificial intelligence systems not only for people, but also for the environment. Standardization concerns the introduction of artificial intelligence in various fields of human activity, such as transport, medicine, education, construction and a number of others. On September 30, 2023, the Russian Association, the House of Indo-Russian Technological Cooperation (Chamber for Russian Technology Collaboration, Cirtc) and the Russian Technical Committee No. 164 of the Rosstandart of the Russian Federation signed two memorandum of cooperation intentions aimed at developing relations between Russia And India in IT oblast. One of the documents concerns the standardization of artificial intelligence, as well as the creation of a joint laboratory for certification of solutions in the field of artificial intelligence. Interaction in the standardization of artificial intelligence will apply to the participants of the BRICS+. What will help to develop and apply the standards common to the BRICS countries. The Minister of Information Technology of India Rajiv Chandrakar proposed to develop a global security standard for artificial intelligence so that intellectual systems do not harm a person and social, industrial and natural environment.

In 2023, the United States, Great Britain and more than ten other countries announced the signing of an international agreement on how to protect artificial intelligence systems. The document involves the creation of AI platforms designed in such a way that they are safe from the very beginning of their development.

In 2023, representatives of 28 individual countries, including the USA, EU, Canada, China, Singapore, Japan, South Korea, Israel, India and the United Arab Emirates signed an international declaration for the safe use of artificial intelligence.

The Japanese Technical Committee for Standardization of Artificial Intelligence has approved the international standard: A.111 Application of strong artificial intelligence - “ISO/IEC JTC 1/SC 42/WG 4 No 254 TR 24030”, developed by the Research Center Natural Informatics, Novosibirsk, Russia.The standard case for the use of strong artificial intelligence contains generalized options. The standardization of the use of strong artificial intelligence ends with the developer by a specification of generalized options for each targeted use. The standard case contributes to the use of strong artificial intelligence in promising modern areas, such as: multi modal generative artificial intelligence, cooperation of intellectual digital doubles and humans, ethical artificial intelligence, quantum artificial intelligence, legitimization of artificial intelligence, intellectual chabitization, semantic emotional dialogue, and so on [7–10].

In 2024, experts in the field of education and artificial intelligence of various countries develop international ethical standards for the use of intellectual systems for training. The standards of Japan provide for the use of generative tools of artificial intelligence in schools, from elementary grades to high school. On February 14, 2024, the National Research Institute for the Study of Generative Artificial Intelligence began to function in Japan. Japan began testing artificial intelligence systems in primary, junior and high schools. Japanese private companies have created several systems with artificial intelligence for Japanese schools. The Konica Minolta system is able to analyze students’ reaction to the material presented, can collect data on the level of concentration of students, and activity in the rise of the hands. The system from Techno Horizon is designed to analyze the emotional state of each of the students. The artificial system helps to identify which children are excited, which children are in a state of stress or bored and concentrated children. Intellectual systems monitor the performance and effectiveness of the education of schoolchildren, give recommendations to teachers in the learning process.

4 Application of multimodal intelligent systems

4.1 Business analytics

One of the problems of business analysis is obtaining and processing an ever-increasing volume of data of economic, financial, organizational and political-legal content. Multimodal business analytics introduces a new methodology that combines classical business analysis with big data technologies, intelligent business analytics, multimodal data fusion, artificial neural networks and deep machine learning. Expanding the functionality of business analysis through the use of methods and tools of multimodal business analytics makes it possible to obtain systematic assessments of various aspects and results of enterprise activities, as well as to predict their development. The use of IBA methods and tools allows you to obtain new information and form more accurate comprehensive assessments in such types of analysis as industry, market and competitive; analysis of the organizational management structure, corporate culture and human resources of companies; analysis of business processes and information structure of companies; analysis of the results of financial and economic activities and the production and economic potential of companies, etc [11–13].

4.2 Logistics

The development of multimodal intelligent systems is an important step in improving the efficiency of logistics processes. One of the key aspects in the field of transportation is the choice of optimal transport for cargo delivery. Thanks to the use of modern technologies and innovative solutions, multimodality allows you to combine different types of transport, providing a high degree of flexibility and convenience in the delivery of goods. Integration of various modes of transport into multimodal systems allows optimizing logistics processes, reducing delivery time and improving the quality of services. Combining different modes of transport, such as road, rail, sea and air, allows you to effectively use their advantages and minimize their disadvantages.

The introduction of multimodal systems is becoming increasingly relevant in the modern world, where transport flows are constantly increasing. These systems solve many problems related to the organization and optimization of logistics processes, ensuring uninterrupted transportation and improving the quality of services. Thanks to the implementation of multimodal systems, organizations can achieve significant economic effects and increase their competitiveness in the market.

Multimodal systems are an important tool for optimizing logistics processes. They allow you to effectively combine different types of transport, providing convenience and a high degree of flexibility in the delivery of goods. The integration of modern technologies and innovative solutions can significantly improve transportation efficiency and ensure uninterrupted logistics processes. The introduction of multimodal systems makes it possible to achieve economic effects and increase competitiveness in the market.

4.3 Education

In modern education, more and more attention is paid to multimodal learning. This is a new approach based on the use of multiple modalities - visual, auditory and kinesthetic - to deliver information and stimulate the learning process. Multimodal learning allows you to create more effective and interactive lessons that promote deep understanding and active student participation. One of the main reasons for the growing popularity of multimodal learning is its ability to address different types of intellectual preferences of students. Some people remember information better if they see it visually (visual modality), others prefer to hear it (auditory modality), and some remember it better through physical interaction (kinesthetic modality). Using all three modalities at the same time allows each student to choose the most effective way to assimilate information.

Another benefit of multimodal learning is its ability to make lessons more interesting and engaging for students. Instead of a traditional lecture, which can be boring and monotonous, multimodal learning offers a variety of activities that include the use of video, audio, graphics and physical movement. This helps students stay interested and actively participate in the learning process. The core principle of multimodal learning is to create a rich teaching environment that will stimulate all of the students' senses. This is achieved by combining different techniques, such as lectures with presentations, video lessons with interactive tasks, or even role-playing games. An important aspect of multimodal learning is the active involvement of students in the learning process. They must be able to independently examine materials, conduct experiments, or solve problems based on their knowledge. This helps not only to consolidate theoretical material, but also develops critical thinking and creative abilities.

Multimodal learning methods may include the use of technologies such as virtual reality or augmented reality. They allow you to create interactive environments where students can interact with objects and phenomena of the material being studied. This makes the learning process more fun and memorable. Another method of multimodal learning is the use of different types of materials: text, audio and video materials, graphs and diagrams. Each provides information in a different form to help make it more understandable and accessible to different types of learners. Multimodal learning is a teaching strategy that uses a variety of media and learning tools to instruct and educate students, typically through a learning management system (LMS). When using a multimodal learning system, it is not just words on a page or the voice of a teacher giving a lecture, but instead these elements are combined with videos, pictures, audio files and hands-on exercises to give the student the best learning opportunity. E-learning platforms cover theoretical and practical capabilities to provide them to educational service providers. When students know about something and begin to do it as they learn, their performance levels increase and they are more likely to master the knowledge content. This approach allows students to absorb information more effectively and develop different skills at the same time.

4.4 Medicine

Healthcare organizations are using multimodal intelligent systems to improve the quality of patient care by obtaining information from multiple modalities, including patient histories, images, medical records and other data. Modal intelligent systems improve physician decision making and experience through hybrid information integration.

The use of biomedical signals in the implementation of intelligent multimodal interfaces is beginning. Information characteristics of biomedical signals modulated by the functional processes of the body can be used in applications that require obtaining data on the psychophysical state of a person and making a quantitative assessment of changes in a person's state. The development of intelligent multimodal interfaces begins with brain-computer interfaces. The EEG signal and data from a 3-axis accelerometer placed on the human head are used as input modalities of the interface. The architecture of multimodal interfaces is associated with the use of signal processing methods and machine learning methods to generate metrics of changes in a person's functional state, as well as for data storage.

5 Examples of using multimodal robotic ensembles

Standardization of intelligent systems helps to securely use them in many industries and services. Intelligent robots are used in various countries as librarians, hotel administrators, tour guides, salespeople, lecturers and other social service providers. Intelligent multimodal robot with technological thinking and spectroscopic vision (Figure 1), multimodal humanoid communication robots can work in many areas of activity and serve many clients (Figure 2), Chine library robot (Figure 3) and Indian library robot (Figure 4) and American intellectual library system for issuing books (Figure 5) serve visitors and fulfill their orders, Russian library robot guide (Figure 6) introduces visitors to paintings by various artists, Japanese robot-administrator of hotel Henn-na Hotel (Figure 7) checks visitors into rooms by number, Japanese robot lecturer (Figure 8) teaches students, European smart cleaning robots (Figure 9) picks up trash on the street,Iranian intelligent communication robot Surena 4 (Figure 10) recognizes and tracks faces and objects, generates full body movements, and recognizes and synthesizes speech and dialogue, Korean multimodal robot analytic (Figure 11) audits business companies, German aerial unmanned taxi (Figure 12) transports passengers along the air corridor, Singapore robot waiter (Figure 13) humanoid robot Pepper takes orders and processes accounts for Pizza Hut customers in Singapore using the global electronic payment service MasterPass, Russian car without a driver (Figure 14) transports passengers along a given route, multimodal generative intelligent robot (Figure 15) communicates cognitively with people and conducts dialogue.

Figure 1 Intelligent robot with tech thinking and spectroscopic vision

Figure 2 Human-Robot communication

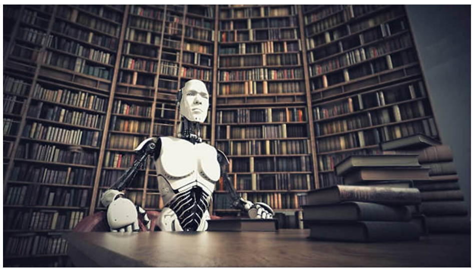

Figure 3 Chine library robot

Figure 4 Indian library robot

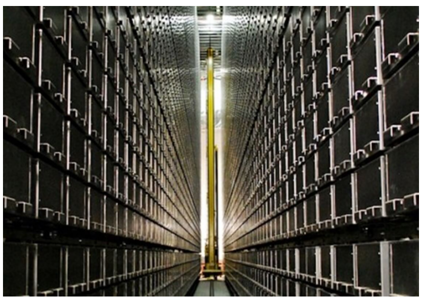

Figure 5 American intellectual library system for issuing books

Figure 6 Russian library robot guide

Figure 7 Japanese robot-administrator of hotel Henn-na Hotel

Figure 8 Japanese robot lecturer on literature

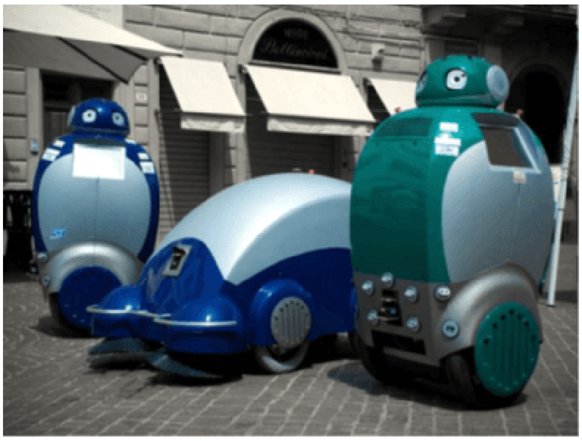

Figure 9 European smart cleaning robots

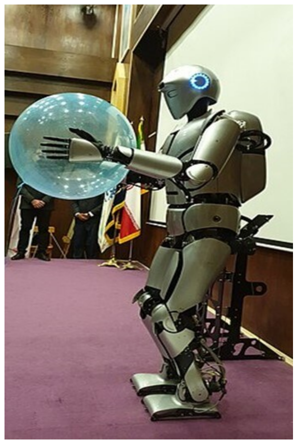

Figure 10 Iranian intelligent communication robot Surena 4

Figure 11 Korean multimodal robot analytic

Figure 12 German aerial unmanned taxi

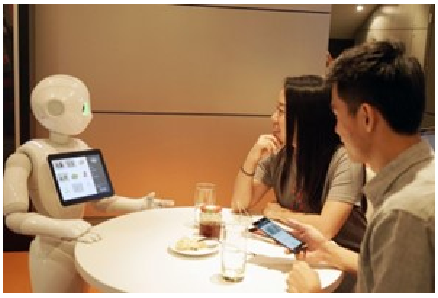

Figure 13 Singapore robot waiter

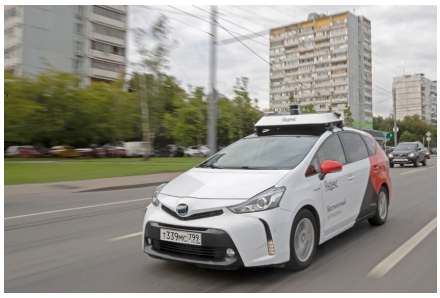

Figure 14 Russian car without a driver

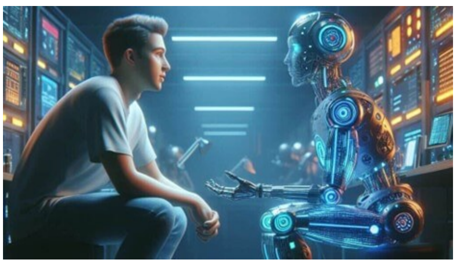

Figure 15 Multimodal generative intelligent robot

6 Conclusion

Currently, multi -modal generative technologies of artificial intelligence continue to effectively transform various industries. Generative artificial intelligence is constantly improving and approaching in cognitive abilities to natural intelligence. Artificial intelligence builds activity on the basis of a productive system of rational and moral meanings approved by the practice. Productive meanings are active memory elements. Based on them, thinking is built in actualized situations and circumstances. Thinking is carried out on the basis of knowledge of holographic memory, taking into account the time and space of current events based on searching for patterns. The process of cognitive search for patterns consists of two modalities. Cognitive analysis of experimental data and identification of patterns using forecasting methods based on the results of the analysis.

The cognitive analysis of data uses mathematical methods and algorithms, the systems of data processing and technology of visual representation of data. Cognitive methods of the analysis of data: statistical methods, methods of computer mathematics, optimizing methods, expert methods, synergetic methods, methods of indistinct sets, methods of fractal mathematics, methods of conflict situations. Algorithmic systems of data processing: subject-oriented analytical systems, the systems of the statistical analysis, the trained neural networks, associations on analogies, trees of decisions, evolutionary programming, algorithms of search, the system of visualization of multidimensional data.

Methods of the forecast of situations: the determined forecast, the statistical forecast, a method of program forecasting, a method of heuristic forecasting, temporary ranks, extrapolation method, expert method, the forecast on the basis of linear regression, the interpreted method, the case analysis, the synergetic analysis, the evolutionary statistical forecast. The tasks solved by cognitive methods of the analysis of data: detection and assessment of the hidden regularities, detection and assessment of influence of the hidden factors, assessment of the current situation, the forecast of development of the situation, formation and optimization of the operating decisions. The cognitive machine technology helps to take new regularities effectively. Engineers and programmers create cognitive methods of structuring and classification of Smart Big Data for identification of regularities by logical format.

The cognitive robots with communicative and associative logic of thinking having the systems of machine retraining will be able quickly to change professional qualification and competences. The international scientific and engineering society gradually moves to technical realization of the cognitive professional robot with retraining. In the future in labor market cognitive robots with retraining will perform professional works, and the person will occupy a niche of scientific research of creative innovative activity.

To create a creatively capable artificial intelligence similar to natural intelligence, it is necessary to create a full-fledged virtual environment in which the standards will be by norms of creativity and creation [14–25].

When researchers are able to carry out in the Smart format universal standardization of the safety of knowledge and skills of multimodal hierarchically functional interdisciplinary artificial intelligence, then digital twins and robots with spectral vision and bioinformational holographic memory will become indispensable assistants in industry and in other fields of activity and will be a full complement to natural human intelligence.

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Deep Learning is a subset of machine learning that utilizes neural network models for learning. The basic principle of deep learning is to simulate the neural network of the human brain by constructing a multi-layer neural network to learn and form more abstract high-level representation attribute classes or features by combining low-level features to discover distributed feature representations of data [8]. The effectiveness of deep learning was not much realizable because of the lack of training data until the rise of big data eliminated the impact of "over-fitting". Since then, the power of deep learning has begun to manifest itself and has achieved remarkable results in the fields of speech recognition, image recognition, natural language processing, *etc.* [9]. The application scope of DL continues to expand and has become one of the important pillars in the field of AI [10, 11].

The study of natural language processing is a crucial branch of AI that aims to teach computers how to understand and generate human language [12]. This field includes speech recognition, text analysis, and machine translation, among others. With natural language processing technology, computers can communicate more effectively with humans, enhancing the overall user experience and improving efficiency.

Computer vision is another key area of AI that focuses on equipping computers with visual capabilities comparable to those of humans. Applications of computer vision range from image recognition and target detection to safety monitoring, intelligent transportation, and industrial automation. These technologies have been instrumental in advancing fields such as Face Recognition and Automatic Driving [13].

Expert systems are yet another powerful tool in AI that simulates human experts to solve problems. These systems utilize specialized knowledge bases and inference engines to provide consultation and decision-making services similar to those of human experts [14]. Their widespread use in fields such as medical diagnosis, financial analysis, and intelligent control has significantly improved the accuracy and efficiency of decision-making.

Finally, Knowledge Representation and Reasoning is a fundamental aspect of AI that studies how to represent and organize knowledge in a way that machines can process and use for reasoning and inference. Logical reasoning, fuzzy reasoning, and probabilistic reasoning are among the methods employed to derive new conclusions from existing knowledge. With the development of knowledge representation and inference technology, the potential applications of expert systems will continue to expand [15].

Over the last half-decade, the nature of consciousness and how people integrate information from various modalities, senses, and sources remain largely unknown, accompanied by major shifts in human intelligence study to ascertain how people adapt and succeed, rather than just how an amazing information-processing system operates [16]. Correspondingly, AI is evolving in ways that improve its capacity to interact with and help people, rather than mimicking human intellect. As a result, deep learning algorithms rose since the 2010s and have become one of the newest trends. Deep learning approaches have resulted in ground-breaking advancements in computer vision and machine learning, and new approaches emerge to surpass current techniques on a regular basis [17].

In recent years, great progress has been made on some of the challenging problems that drive AI research, such as machine translation, text classification, speech recognition, writing aids, and image-processing technology [18]. As a result, machine-learning technologies have made their way from academia to the real world. Answering questions based on textbook reading, assisting people while driving to avoid accidents, and interpreting speech in real time are just a few of the real-life applications that use neural network language models, AI has also been increasingly utilized in finance, medicine, and science research fields, which will be described in detail below.

2 Foundation models and artificial general intelligence (AGI)

The field of AI is constantly evolving, and foundation models have emerged as a new paradigm. Models like BERT, DALL-E, and GPT-3 have been trained on vast amounts of data and are highly adaptable to different tasks. These models are still being developed, but they show great promise in achieving homogenization across many tasks [19]. In the realm of computer vision, the introduction of Florence as a new foundation model has expanded representations from coarse to fine, static to dynamic, and from RGB to multiple modalities. Florence has achieved outstanding results in various transfer learning scenarios and achieves state-of-the-art results in numerous benchmarks, making it critical for serving general-purpose vision tasks [20]. Similarly, in the domain of language and vision alignment, FLAVA is introduced as a foundational model targeting all modalities at once, demonstrating impressive performance on a wide range of tasks spanning vision and language [21].

The advancement of Large Language Models (LLMs) has been a significant leap toward attaining Artificial General Intelligence (AGI) [22]. LLMs are increasingly popular in various applications, such as code generation, conversational recommendation systems, and processing long text. These models, such as GPT-4 and ChatGPT, have displayed exceptional language comprehension, generation, interaction, and reasoning abilities. They have also shown potential in solving a wide range of sophisticated AI tasks spanning different modalities and domains, including language, vision, speech, and other challenging tasks [23].

However, evaluating the general abilities of these models to tackle human-level tasks is crucial for their development and application in the pursuit of AGI. In a recent study, researchers introduced AGIEval, a benchmark specifically designed to assess foundation models in the context of human-centric standardized exams, such as college entrance exams, law school admission tests, math competitions, and lawyer qualification tests. The evaluation of several state-of-the-art foundation models, including GPT-4 and ChatGPT, using this benchmark revealed that GPT-4 surpasses average human performance on standardized tests such as the SAT and LSAT, displaying extraordinary performance. However, the study also found that GPT-4 is less proficient in tasks that require complex reasoning or specific domain knowledge, highlighting the limitations of these models [24]. Recent research has addressed various limitations of large language models, including the hand-crafting of task-specific demonstrations [25], the evaluation of code synthesis [26], the cost barrier associated with large models [27], the evaluation protocol for conversational recommendation systems [28], and the context window restriction for off-the-shelf LLMs [29].

In addition, the development of multi-modal large language models, such as SpeechGPT, is considered a crucial step towards AGI. SpeechGPT, with its intrinsic cross-modal conversational abilities, has demonstrated remarkable abilities to follow multi-modal human instructions and handle multiple modalities with one model [30]. The integration of visual foundation models with language models has also been explored, leading to the development of Visual ChatGPT, which enables interaction with ChatGPT using both languages and images, as well as providing complex visual questions and instructions [31].

The exploration of foundation models in various domains, including computer vision, language, vision alignment, and integration with language models, has the potential to drive progress in AI research and applications. However, the challenges and opportunities associated with foundation models, as well as their implications for scalability, security, and user-friendly interactive ability, warrant further interdisciplinary collaboration and research.

Furthermore, the potential impact of AI advancements, such as ChatGPT, on technologies and humans has been a topic of interest. An analysis of tweets about ChatGPT revealed both positive and negative potential impacts on the evolution of jobs, a new technological landscape, the quest for artificial general intelligence, and the progress ethics conundrum [32]. Thus, it is crucial to address both the limitations and potential societal impacts of these advancements.

3 AI for science

The potential of AI to enhance and expedite our comprehension of natural phenomena at different spatial and temporal scales is immense, leading to its development for scientific purposes, as known as AI for science (AI4Science) [33]. The utilization of machine learning in diverse fields of natural sciences and engineering has emerged as a crucial frontier and interdisciplinary subject, likely to introduce novel research paradigms [34].

At present, deep learning techniques have been increasingly integrated into scientific discovery to integrate massive datasets, refine measurements, guide experimentation, and explore the space of theories compatible with the data [35]. In this respect, the goals are generally explicit and precise, such as solving complex fluid dynamic equations [36], suggesting routes for synthesizing chemical molecules [37], protein folding [38], designing small molecule drugs for targets [39], and various image recognition approaches [40, 41]. The wide application of AI has made a significant impact on augmenting and accelerating research.

The potential usefulness of AI in "discovering new science" is another area of interest for further research and exploration. For instance, one specific subarea of AI4Science is AI for quantum, atomistic, and continuum systems, which aims to understand the physical world at different scales and shares common challenges such as capturing physics' first principles and achieving equivariance to symmetry transformations [19]. In the field of materials informatics, the emergence of "GPT AI" has accelerated the development of new materials and has led to the proposal of "MatGPT" as a vane for materials informatics. The continuous innovation of AI is impacting cognitive laws and scientific methods, which requires the joint efforts of interdisciplinary scientists in developing more digital, intelligent, and automated construction of materials informatics [42]. In a similar vein, Zhang et al. also explore the applications of graph diffusion models in AI-generated content (AIGC) for science, particularly in the generation of molecules, proteins, and materials. They discuss the mechanism of diffusion models in various forms and address the issue of evaluating diffusion models in the graph domain, shedding light on the existing challenges in this area [43]. In 2023, Fecher and colleagues contributed to the ongoing discussion around large language models (LLMs) and their impact on the science system. The team conducted a Delphi study that involved experts who specialize in research and AI. The study focused on the benefits and limitations of LLMs, their effects on the science system, and the necessary competencies needed to use them effectively. The study highlights the potential for LLMs to transform science, while also acknowledging the risks associated with bias, misinformation, and quality assurance. The authors suggest that proactive regulation and science education are necessary to mitigate these risks [44].

Finally, AI is also transforming the nature of science itself. The role of AI in science education goes beyond generating tools for teaching, learning, and assessment, and it is critical to consider how the AI-informed nature of science is transforming science education and what skills it demands of learners [45]. In the field of medical education, AI is being explored for its applications in training, learning, simulation, curriculum development, and assessment tools [46]. The development of generative AI, such as ChatGPT, has implications for science communication, providing opportunities for translational and multimodal capacities, as well as challenges in terms of accuracy and job market implications. The impact of AI on science communication itself and the larger science communication ecosystem is an area that requires further analysis and research [47].

4 Real-world deployment of AI and explainable artificial intelligence (XAI)

Over the past five years, remarkable AI applications have surfaced across a range of fields, from gaming [48, 49], to autonomous vehicles, language translation, clinical diagnosis, and business. In healthcare, AI-based imaging technologies have become increasingly prevalent, holding immense potential to revolutionize various aspects of the industry. Grzybowski et al. delve into the use of AI for diabetic retinopathy (DR) screening on color retinal photographs, highlighting how AI can alleviate the burden of DR screening and prevent vision loss [50]. Similarly, an AI model has been tested for its ability to identify lead-less implanted electronic devices in chest X-rays to ensure pre-MRI safety screening [51]. Collectively, these studies underscore the potential of AI in real-world scenarios, while also highlighting the challenges that must be addressed, such as accuracy, safety concerns, infrastructure, health economics, and model adaptation to real-world situations. Optimization strategies with comprehensive evaluation and rigorous validation are still indispensable to ensure reliability, transparency, and ethical soundness in real-world applications [52, 53].

The integration of AI with big data, cloud computing, robotics, and the Internet is rapidly growing. As a result, AI is becoming increasingly important in many fields, including economics, governance, and education [54]. Recent studies emphasize that systematic review, ethical standards, and the integration of AI with other technologies remain essential to achieve the best possible results [55].

The concept of Explainable Artificial Intelligence (XAI) has gained significant attention in recent years as the use of AI has become more prevalent across various sectors [56], particularly in the context of deep learning and mission-critical applications [57]. The proposed taxonomies, methodologies, and solutions aim to address the challenges posed by the lack of transparency in AI systems and promote the development of trustworthy and interpretable AI models [58, 59]. For example, Yang et al. have emphasized the importance of XAI in healthcare applications, where understanding the black-box choices made by AI systems is crucial. They propose solutions for XAI leveraging multi-modal and multi-center data fusion and validate these solutions in two showcases following real clinical scenarios [60]. Other researchers also provide valuable insights into the current state of XAI and its implications for security risks [61], efficiency techniques [62], and decision support [63].

5 Discussion

The AI up to date still cannot be considered "real artificial intelligence". Although current advancements in LLMs are impressive, they still cannot understand abstract concepts and language, nor can they answer difficult questions or distinguish facts. It can only fabricate answers according to the maximum probability. Additionally, as a machine learning algorithm, it is highly dependent on massive data and computing power. However, knowledge is infinite, and AGI can never be achieved by exhaustive training data sets. At the same time, the difficulties in interpreting or controlling emergent abilities of LLMs, the security privacy and regulatory issues in accessing data sources, the demand for large computing power as well as huge energy consumption, hinder the employment of artificial intelligence in industrial applications.

Therefore, there is still a lot of potential for research in the field of AI. One possible approach is to collaborate with AI4Science. Al can assist in decision-making, organizing information explicitly, and facilitating human experts to arrive at insights. At the same time, there must be scientific principles behind AI. It is promising to promote AI progress with basic discipline accumulation and mathematical foundation. For example, Geometric Deep Learning gives a good mathematical framework, which improves model performance and is interpretable [35]. Therefore, the discipline construction of artificial intelligence requires intersecting with other disciplines and carrying out collaborative innovation. There should be more frameworks and solutions emerging to enhance knowledge, reduce resource requirements, and ensure model accuracy with the help of experts in specific domains.

In general, AI still has a long way to go to build machines that can work seamlessly with humans and make judgments that are compatible with fluid and complex human values and preferences.

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also evaluated. The assessment can be given in three ways: normal, weak outlier, strong outlier. The article uses the LDA_med method [2] to detect outliers, but others can be used as well. There can be a situation when each characteristic behaves normally, but the behavior of a pair (group) or the whole totality can be abnormal.

The deviation from normal indicates a possible abnormal situation that took place during the time corresponding to the received portion of telemetry.

2 Methods and materials

2.1 Materials

As an example, we will consider standard channel characteristics collected with IP Quality Monitor (IQM) hardware and software package [3]. For example, SDBytes – number of bytes transmitted from Source to Destination, DSBytes – number of bytes transmitted from Destination to Source, SDLostPercent - percentage of lost packets during transmission from Source to Destination, DSLostPercent – the same, but in reverse direction, *etc*. A complete list of measurable characteristics is given in Table 1.

Table 1 List of measurable characteristics

SDLost SDLostPercent DSLost DSLostPercent	Packet loss (for URL - sessions) in both directions in absolute numbers and as a percentage of the total.
SDBW SDBWPercent DSBW DSBWPercent	The resulting bandwidth of the network in both directions in kilobits per second and as a percentage of the expected bandwidth. The expected throughput is the one transmitted on the command line.
SDLossBW SDLossBWPercent DSLossBW DSLossBWPercent	"Lost" throughput in both directions. Represents the difference between the expected throughput and the throughput received as a result of testing.
SDRemarked SDRemarkedPercent DSRemarked DSRemarkedPercent	The number of packets delivered with a change of service class, in absolute numbers and as a percentage of the total received.
SDOOS SDOOSPercent DSOOS DSOOSPercent	The number of packets delivered with reordering, in absolute numbers and as a percentage of the total received.
MinRTT AvgRTT RMSRTT MaxRTT	Circumferential delay in packet delivery from initiator to initiator through the conjugate (minimum, average, quadratic, maximum)
SDMinDelay SDAvgDelay SDRMSDelay SDMaxDelay DSMinDelay DSAvgDelay DSRMSDelay DSMaxDelay	One-way packet delivery delay (minimum, average, quadratic, maximum)
SDJitter DSJitter	Packet delivery delay jitter in both directions, calculated according to RFC 3550
SDMinIPDV SDAvgIPDV SDRMSIPDV SDMaxIPDV DSMinIPDV DSAvgIPDV DSRMSIPDV DSMaxIPDV	Packet delivery delay variation, calculated by Y.1540 (basis - minimum delay) for test session time (minimum, average, quadratic, maximum)
SDMinMAPDV2 SDAvgMAPDV2 SDRMSMAPDV2 SDMaxMAPDV2 DSMinMAPDV2 DSAvgMAPDV2 DSRMSMAPDV2 DSMaxMAPDV2	Packet delivery delay jitter, calculated according to G.1020 during the test session (minimum, average, quadratic, maximum)
SDBytes DSBytes	Number of bytes transferred in the test session in both directions

Suppose we have data for each day of channel operation, broken down by five minutes. That is, each time series has 288 values (12 values for each hour, a total of 24 hours).

2.2 Models of normal behavior for individual characteristics

There can be many models of normal behavior of an individual characteristic, so we must be able to choose the best one. As a criterion, it is proposed to choose the number of outliers detected with its help. The model that is sensitive to the presence of outliers will be of higher quality. The simplest model is to use as coordinates in space the values of time series characteristics, we get 31 points (counting 31 days in a month) in 288-dimensional space.

For clarity, we will display the multidimensional space on the plane with the help of Sammon's projection [4].

When working with time series, a well-known technique is to use its characteristic values - features - instead of the original values of the series. There is also a great number of them - minimum and maximum values, average, dispersion, etc., etc. A very large list of such features is given, for example, in work [5]. Any combination of these features can also be used as a model of normal behavior (MNB).

In the course of our experiments it turned out that the desired quality of outlier detection is demonstrated by a model of mutual similarity, which is formed by points in 4-dimensional space (coordinates - three correlation coefficients - Kendall, Pearson, Spearman, and Euclidean distance between points). The point is the time series for the day.

A matrix of similarity M of points to each other is determined. For this purpose m_{ij} - correlation coefficients between points are calculated. Then we take the median by rows. The first three

coordinates differ only in the way the correlation is calculated. Then we calculate the fourth coordinate - determine the Euclidean distance between the source points, and then take the median by rows.

2.3 Model based on numerical pattern

Each characteristic of communication channel takes values from a certain numerical range.

The numerical pattern of the characteristic can be represented by a histogram. The number of bins of the histogram is the number of coordinates. The height of each bin (column of the histogram) is the value of the coordinate. Such model may be useful, when there is a gradual degradation of equipment, and you need to detect it in time.

2.4 Model based on strings patterns

One of the ways of working with time series is to transform them into

character strings. One possible transformation technique is presented in the table taken from [6] (Table 2).

Table 2 Fornell-Lecker criterion

Symbol	Meaning	Definition
a	Highly increasing transition	$\frac{d}{dt} > 5$
b	Slightly increasing transition	$5 \geq \frac{d}{dt} > 2$
c	Stable transition	$2 \geq \frac{d}{dt} \geq -2$
d	Slightly decreasing transition	$-2 > \frac{d}{dt} \geq -5$
e	Highly decreasing transition	$\frac{d}{dt} < -5$

If the difference between adjacent row values falls within the appropriate range, the numeric value is replaced by a symbol. This representation of the time series provides additional possibilities compared to a simple numerical pattern. You can count, for example, the number of different pairs of symbols or triples, fours, etc., to move to the MNB. Each combination of symbols can serve as a coordinate, and the number of occurrence of a particular combination can serve as a coordinate value.

2.5 Models of joint normal behavior for pairs of characteristics: Based on correlation

Correlation is the best-known form of linear relationship between characteristics. Correlation between two characteristics measures the similarity in form between those characteristics. Among channel characteristics, we can find strongly correlated and uncorrelated (weakly correlated).

2.6 Model for strongly correlated characteristics

To obtain an MNB, it is sufficient to measure the correlation between the points, as is done in the mutual similarity model. MNB consists of M values of the selected correlation coefficient (medians of matrix rows).

2.7 Models for uncorrelated characteristics: Two-cluster model

Initial feature values can form explicit clusters, such as, in the case of DSOOSPercent (blue) and DSRMSMAPDV2 (red). (Figure 1)

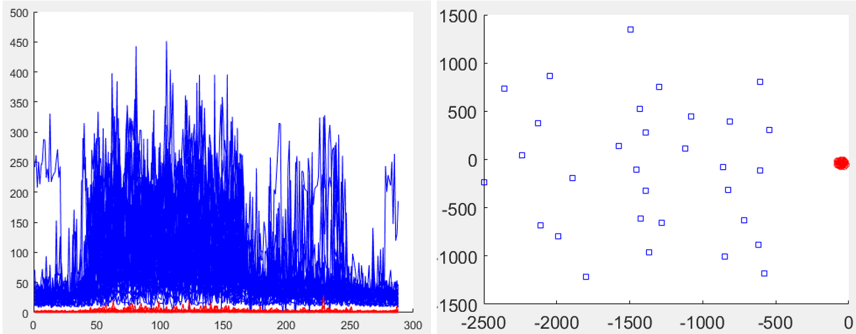

Figure 1 DSOOSPercent (blue) and DSRMSMAPDV2 (red) characteristics (left) and their mapping to plane (Sammon projection)

The characteristics have 288 values, and 288-dimensional space is used. On the left in Figure 1 are the time series of these characteristics, and on the right is a mapping of the 288-dimensional space to the plane. Clear clusters can be seen.

The presence of such clusters indicates that there are complex nonlinear relations between the values of the two characteristics. These relations should be preserved during the channel operation.

To verify the preservation of these relations, let us construct the MNB. For this purpose each pair of points (one from the first characteristic for day i, the second one from another characteristic for the same day) let us represent by the following four coordinates:

distance to the medoid of one's cluster, distance to the medoid of another's cluster - for the first point of the pair;

distance to own cluster's medoid, distance to foreign cluster's medoid - for the second point of the pair.

This is what the model looks like for the pair DSOOSPercent and DSRMSMAPDV2 in 4-dimensional space. (Figure 2)

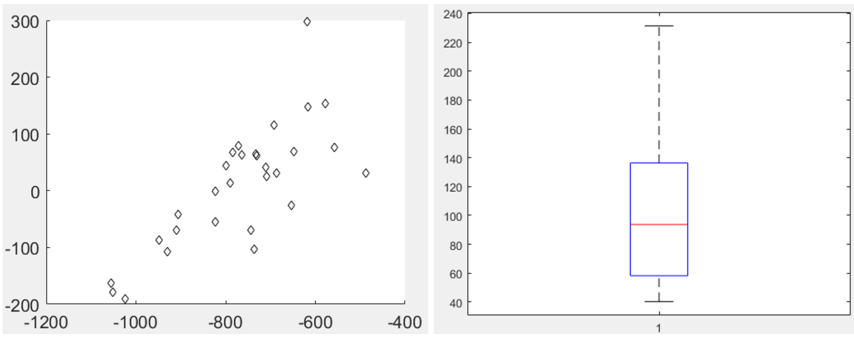

Figure 2 Resulting MNB and boxplot

Naturally, the points are checked for outliers. If there are no outliers, we save the obtained points as MPBs.

2.8 Models for uncorrelated features without clusters: Based on distances between pairs

The initial values of not all pairs of characteristics form clusters.

For example, here is what the picture looks like for DSLossBW (red) and DSMaxMAPDV2 (blue) - the original time series values are shown (left) and the 288-dimensional space mapping to the plane on the right. (Figure 3)

Characteristics are not correlated (the values of three correlation coefficients for this pair, 5 points - days, are given below for example):

-0.107 0.038 0.056
0.221 0.057 0.089
0.236 0.040 0.057
0.221 -0.013 -0.015
0.234 0.094 0.140

Let's construct the MNB: represent each pair by a point in the 3-dimensional space of correlation coefficients between pairs. (Figure 4)

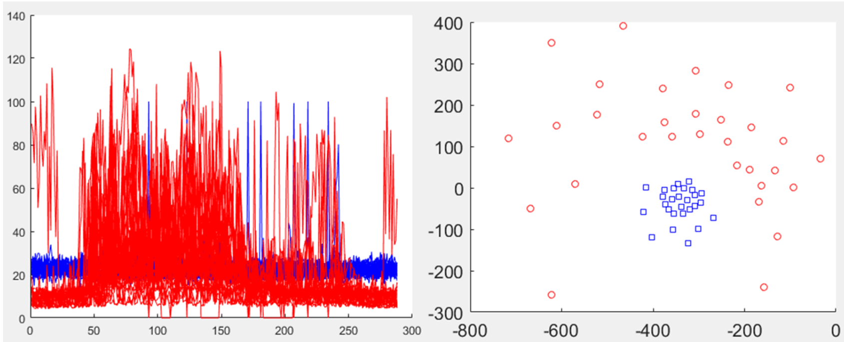

Figure 3 DSLossBW (red) and DSMaxMAPDV2 (blue) - the original time series values are shown (left) and the 288-dimensional space mapping to the plane on the right. There are no linearly separable clusters.

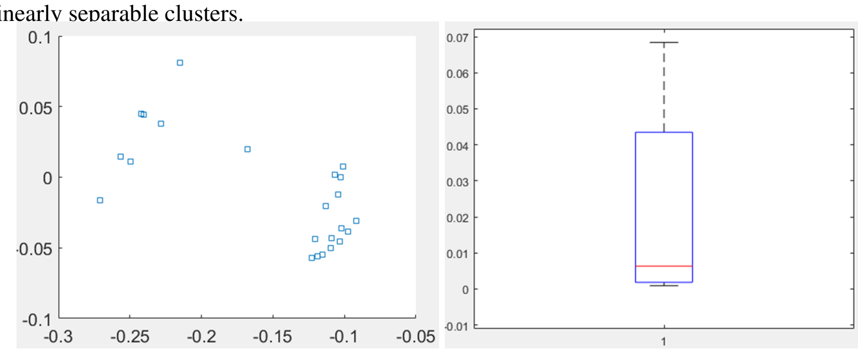

Figure 4 Resulting MNB(left) and boxplot (right)

2.9 Models of normal behavior of multivariate time series of characteristics

Theoretically, it is possible that all characteristics will show normal behavior, and their aggregate - multivariate time series - abnormal behavior.

In order to detect such a situation, we need special MNBs for the whole multivariate series. Such a solution is possible.

A model is constructed based on models of the internal similarity of individual characteristics.

It is suggested to use the space:

coordinate1 - outlarity of characteristic1;

coordinate2 - outlarity of characteristic2;

...

coordinateN - outlarity of characteristicN.

3 Experimental results

3.1 Models of normal behavior for individual characteristics

Let us consider the derivation of the MPB for the DSMinMAPDV2 characteristic. Figure 5 shows the initial values on the graph. (Figure 5)

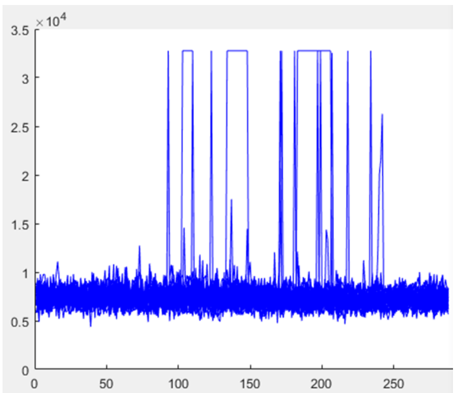

Figure 5 DSMinMAPDV2 characteristic

We can assume that all visual ejections will be outliers.

To map the multidimensional space to the plane, we use the Sammon projection. To detect outliers we use the LDA_med method.

The outliers (blue squares) are removed after detection. Then the process is repeated for the remaining points. The process ends when the outliers are no longer detected. (Figure 6)

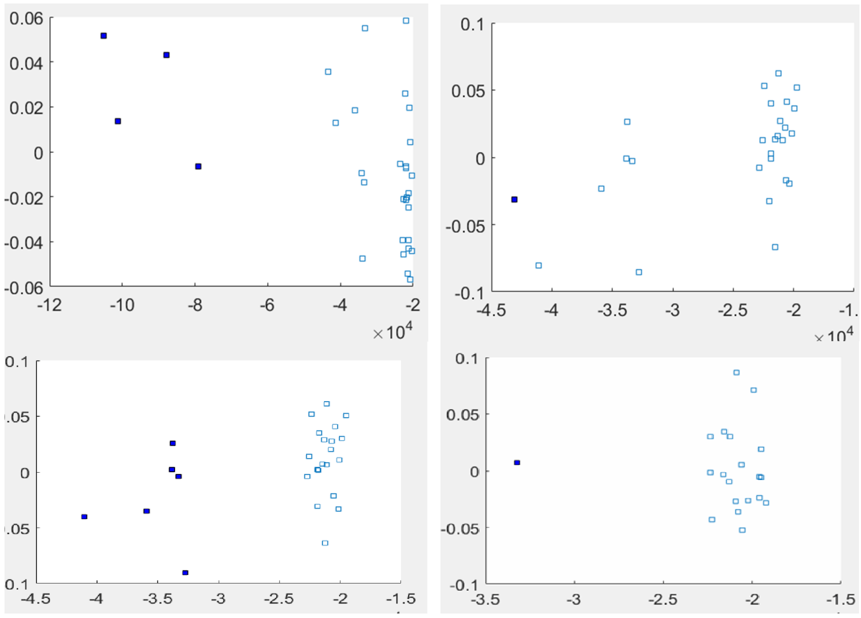

Figure 6 Outlier detection and removal

The pictures show how the outliers are searched for. First, four outliers are found (marked as blue squares), after removing them one new one is found, after removing it six new ones at once, and finally one outlier is found last.

The remaining points represent the model of normal behavior in 4-dimensional space. (Figure 7)

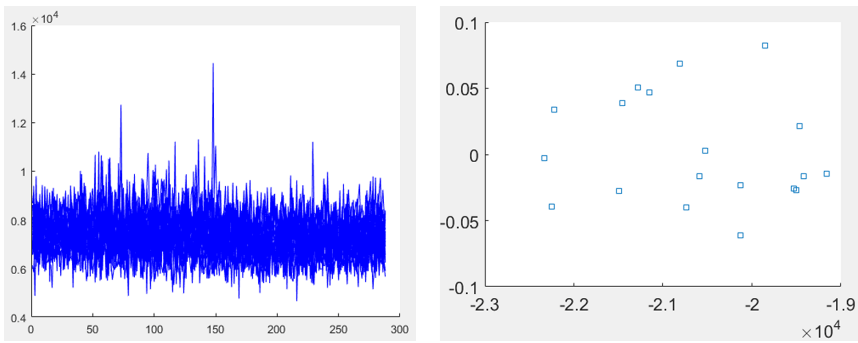

Figure 7 DSMinMAPDV2 characteristic after removing outliers (left) and resulting MNB (right). A model based on a numerical pattern.

We will take a histogram of one hundred bins as a numerical pattern. (Figure 8)

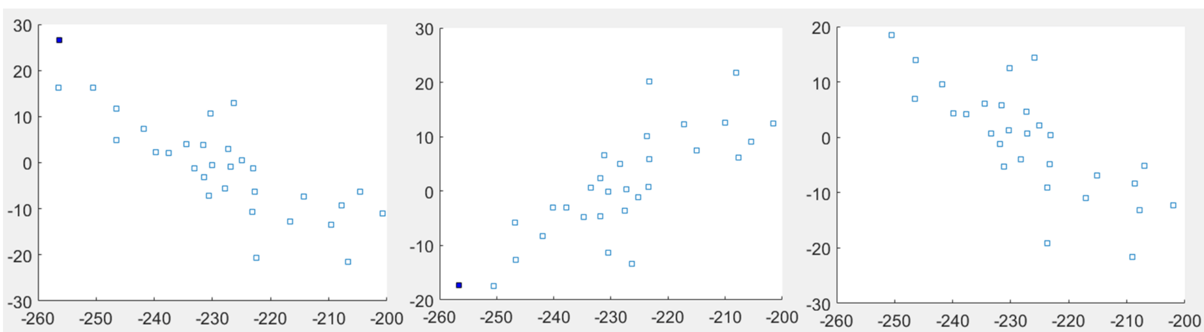

Figure 8 Outlier detection and removal

Each point has one hundred coordinates, the value of each is the height of the corresponding bin. When constructing the MNB we first remove one outlier, then the second, the remaining points make a model of normal behavior in the space of 100 bins.

If we take the artificially obtained characteristic of 288 ones, we get the result (red square) using this model. (Figure 9)

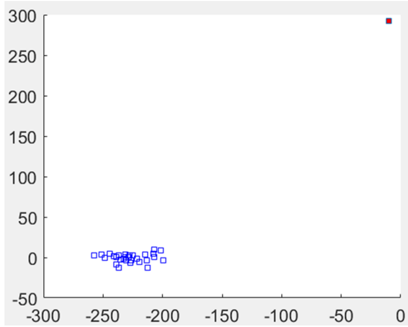

Figure 9 The entered point is a strong outlier and is very far from the model points

3.2 A model based on string patterns

As an example, let's look at the DSAvgMAPDV2 characteristic for one day. The time series turns into a string pattern:

cdcccccbdccbdcccbdccccbdcccaecccbcbceccccccccdaebdcbdcccccbbecc ccdcccbcdccccae-bcccadbecbdcbdbddcbdbdcccccaebbeccccccccccccbcdc cccccccccccbaecccccccccbaecdbcdccc-ccccbcdbbbeccccccccccccccccccd ccccccccbdccccccccccccccaecccccccbcccccccccdccbdccc-ccccccccbd cccccccccccccccbdcccccccccccdcccccbb.

If we count, for example, all combinations of substrings of two characters and of three characters in this string, we can represent the time series by a point in 150-dimensional space. (150 is the number of different twos and threes of the alphabetic characters). The coordinate is the combination of symbols, the value of the coordinate is the number of this combination in the row of the time series.

In this space we can also construct a model of normal behavior. (Figure 10)

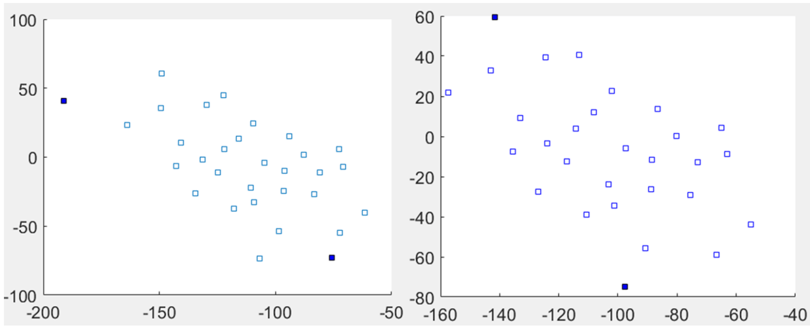

Figure 10 Outlier detection and removal

Two outliers are consecutively removed first, and then two more.

The result is a MNB. (Figure 11)

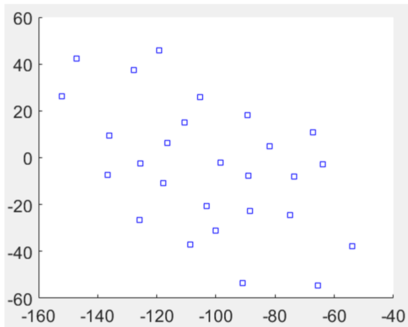

Figure 11 Resulting MNB

To check the strength of the model, let us estimate the place of the artificial point:

Let's create an artificial time series: 24 units, 26 threes, 25 threes, 25 fours, 49 units, 51 fives, the rest are units. This time series corresponds to a line:

ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccbcccccccccc cccccccccccccccccdccccccccccccccccccccccccccccccccccccccccccccccccccccccccbccccccccccccccccccccccc ccccccccccccccccccccccccccccccccccccdcccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc ccccccccccccccccccccccccccccccccccccccc.

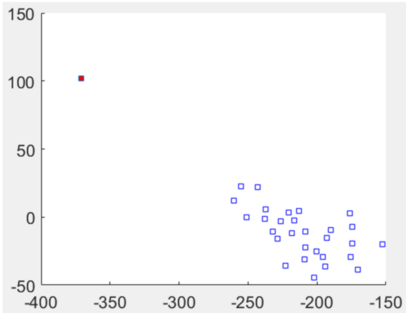

Figure 12 The new point (red square) is a strong outlier. The new point (red square) is a strong outlier and is very far from the model points.

3.3 Models of joint normal behavior for pairs of characteristics: For strongly correlated characteristics

Consider the DSBW and DSBWPercent characteristics. (Figure 13)

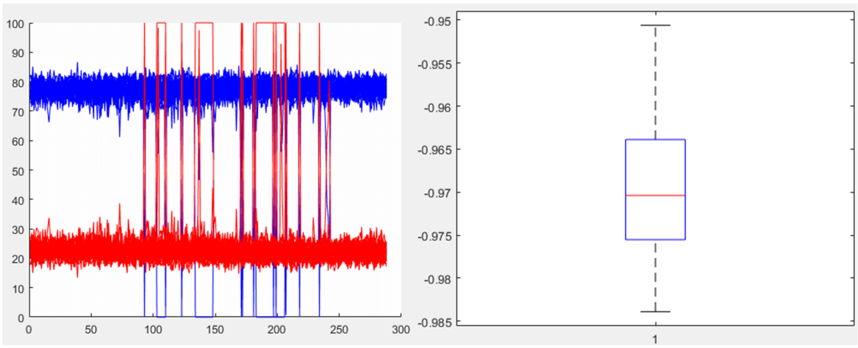

Figure 13 DSBW and DSBWPercent characteristics (left) and boxplot for Kendall's coefficient (right)

The values of the correlation coefficients of these characteristics are close to 1 (Kendall, Pearson, Spearman): -0,975641458348255 -0,999783256671490 –0,997684955502735.

As a model of normal behavior, we store the values of any of the 3 coefficients for each pair - a total of M values (it is preferable to use Kendall or Spearman coefficients because of their nonparametricity). Fig. 13 - the boxplot for Kendall's coefficient is shown on the right.

When new values of a pair of characteristics are obtained, we calculate a new value of the correlation coefficient and compare it to the model values.

3.4 Models for uncorrelated characteristics: Two-Cluster model

We have previously constructed such a MNP for the DSOOSPercent and DSRMSMAPDV2 pair. An artificial point, which will be depicted in the original data in Figure 14.

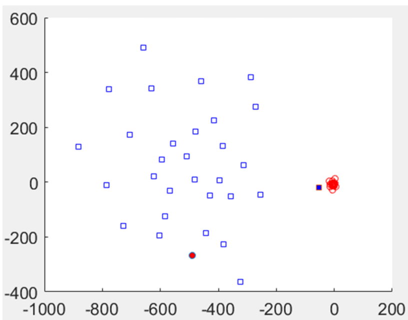

Figure 14 The new pair is a blue square and a red circle

Let's apply the model. (Figure 15)

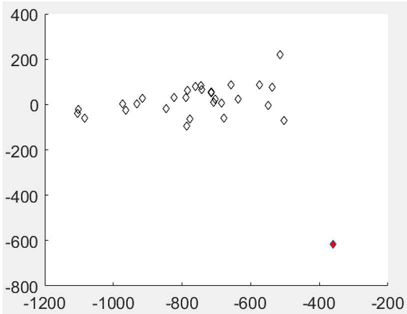

Figure 15 The new pair, the red diamond, is a strong outlier.

3.5 Models for uncorrelated characteristics without clusters: Based on distances between pairs

Previously, we built the MPP for DSLossBW and DSMaxMAPDV2.

Now we will test the model by introducing an artificial point (correlated pair values). (Figure 16)

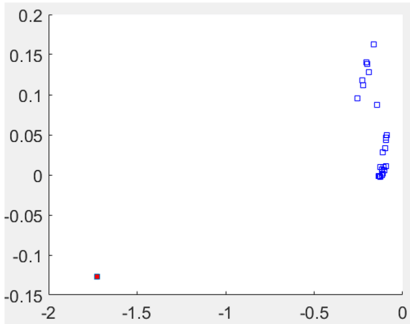

Figure 16 The new point is a strong outlier

4 Models of normal behavior of multivariate time series of characteristics

Consider an example for 5 characteristics:

DSMinIPDV, DSMinMAPDV2, DSOOSPercent, DSRemarkedPercent, DSRMSMAPDV2

The removal of outliers is done gradually. (Figure 17)

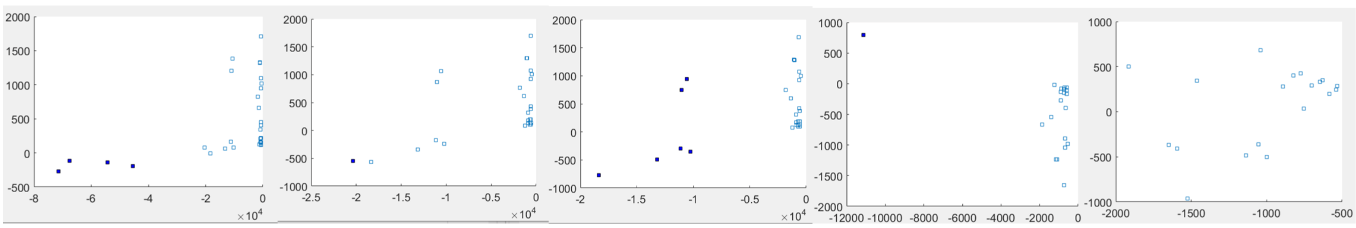

Figure 17 An example of outlier detection and removal for a multivariate time series

Total 12 points were deleted (data for 12 days). The remaining points in the selected space form a model of normal behavior of multivariate time series of characteristics.

5 Discussion

Above we considered examples of building normal behavior models for assessing the quality of communication channel performance. Of course, their list is far from being complete, but the presented MNBs can serve as a basis for building an automated system of predictive diagnostics. Let's imagine that characteristics are processed in portions, *i.e.* not in real time, but after accumulation of a certain amount of data during the set time period, in the considered example this period was equal to days.

After that the forecast of the controlled equipment state for the next telemetry collection period is made. If the conclusion about danger of further operation is made, the decision to carry out repair or at least inspection is made.

It is envisaged to get a summary assessment of anomalousness of the next portion of telemetry for an instance of the device. Figure 18)

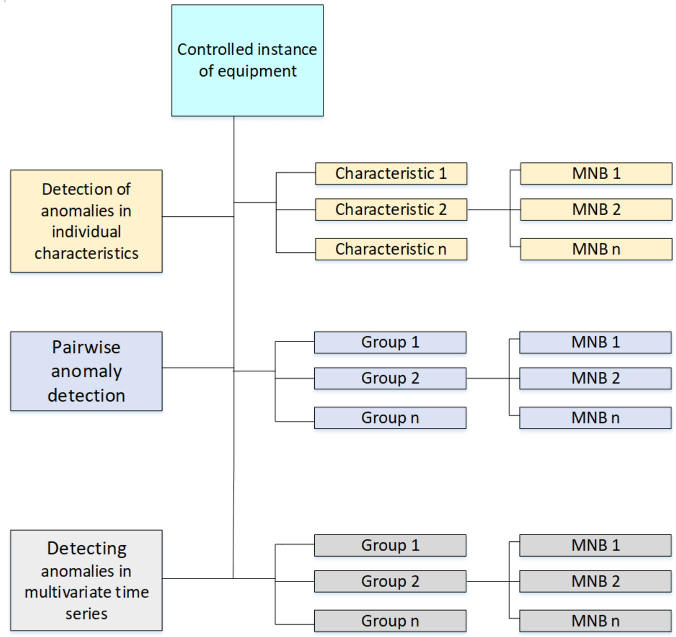

Figure 18 Anomaly detection procedure for data batch processing

Each characteristic is evaluated with the help of several MNBs. If the MNB shows that the characteristic is normal, this corresponds to, for example, 0 points, a weak outlier - 1 point, a strong one - 2 points. The sum of all the MNBs, taking into account the weighting coefficients of the models, gives an estimate of the normality of the characteristic, ideally 0 points.

Then you can get in a similar way the total score of all characteristics, groups of characteristics and the entire multivariate series as a whole.

The resulting estimates are stored and can be displayed graphically to visualize the dynamics of their change. The decision about the real danger of the current situation is made by a person. To help in decision-making, numerical thresholds of anomalousness for each device are established by experience.

The total score of abnormality of a device can serve as an index of the health of the system.

The disadvantage of this predictive diagnostics system is that it only detects anomalies, not specific faults (abnormal situations). But it can warn you about equipment problems long before the equipment fails [7].

The description of the detected anomalies (failures) in the operation of the devices, together with the formal description of the anomalies of specific characteristics, can be stored in the knowledge base. In the future, they are used both in the manual search for analogues and automatically in the detection of anomalies that match the previously saved descriptions.

6 Conclusion

One of the problems of "big data" accumulated during the operation of modern communication equipment is the problem of rational use of this data.

The modern trend is to introduce predictive maintenance into the enterprise practice, which provides timely detection of anomalous behavior of equipment. The most preferred approach to detecting anomalies in equipment behavior is a data-driven approach. In this approach, models are built for anomaly detection and fault diagnosis purposes on the basis of the vast amount of different types of telemetry data available. The advantage of such models is their independence from the knowledge of subject matter experts.

The construction of such models of normal behavior for characteristics of communication channels is considered in this paper. Examples, confirming the performance of the proposed models, are given.

The proposed models and approach to building a predictive diagnostics system on their basis can be useful for developers of such systems.

Conflict of interest

The authors declare no conflict of interest.

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