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Analog processing approach in the nanoparticle formation

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INTRODUCTION & AIM

Green chemistry is an increasingly important field due to its focus on creating sustainable and environmentally friendly chemical processes. A key aspect of this field is the use of biogenic compounds (BGCs), such as extracts from plants, fungi, and bacteria for synthesizing nanoparticles (NPs), which offers an ecological alternative to traditional methods. The natural sources are non-toxic, biodegradable, and readily available, making them ideal for a more sustainable synthesis process [1]. The BGCs approach to NPs synthesis is considered environmentally friendly since it avoids the use of harmful organic solvents and reducing agents, and, in fact, the BGCs act as both reducing and capping agents, controlling the size and shape of the nanoparticles during the process of their formation. This area of research where the synthesis of various NPs for applications in medicine, environmental remediation, and electronics is being explored has been gained significant attention in recent years [2]. The development of these biogenic synthesis routes implies the advance the field of nanotechnology to be performed in a sustainable manner, paving the way for a healthier and cleaner future.
NPs synthesis with the (BGCs is a multi-faceted process involving a complex interplay of various factors which include the unique chemical composition of the BGCs, the pH and temperature of the reaction medium, and the specific metal ions being reduced. Many of current research in the field of NPs synthesis is increasingly going beyond the usual thermodynamic and kinetic models. More complex interactions are considered, which are organized according to the analog principle in the environment where NPs with a given morphology are formed [3]. This is especially noticeable in biogenic systems, where various macromolecules (e.g. proteins, polysaccharides, phenolic compounds, etc.) can form stable associations that affect not only the reaction rate, but also the morphology of the final product. In such systems, the state of the environment can be considered as a result of changes in the structure of macromolecules and their complexes, which directly affects the process of NPs formation.
The aim of the suggested presentation is to propose a new framework that views the reaction medium as an "analog processing unit" (APU). The presented approach moves beyond simple kinetic and thermodynamic models by focusing on the complex, holistic relationship between environmental inputs and the resulting NPs outputs.

METHOD

The NPs synthesis using various BGCs is being performed by the described methods.
The NPs images are being obtained with Transmission Electron Microscopy (TEM) or Scanning Electron Microscopy (SEM) with appropriate prescriptions for the sample preparation.
The pH value and media temperature are being measured by a suitable digital electronic unit.
The UV-VIS spectra of samples have been recorded using a UV-VIS spectrophotometer in range from 200 nm to 1100 nm.
To find hidden knowledge in big data, several intellectual methods that fall under the broader process of Knowledge Discovery in Databases (KDD) are being used, namely Machine Learning (ML), Clustering, Association Rules and Artificial Intelligence (AI) [4].

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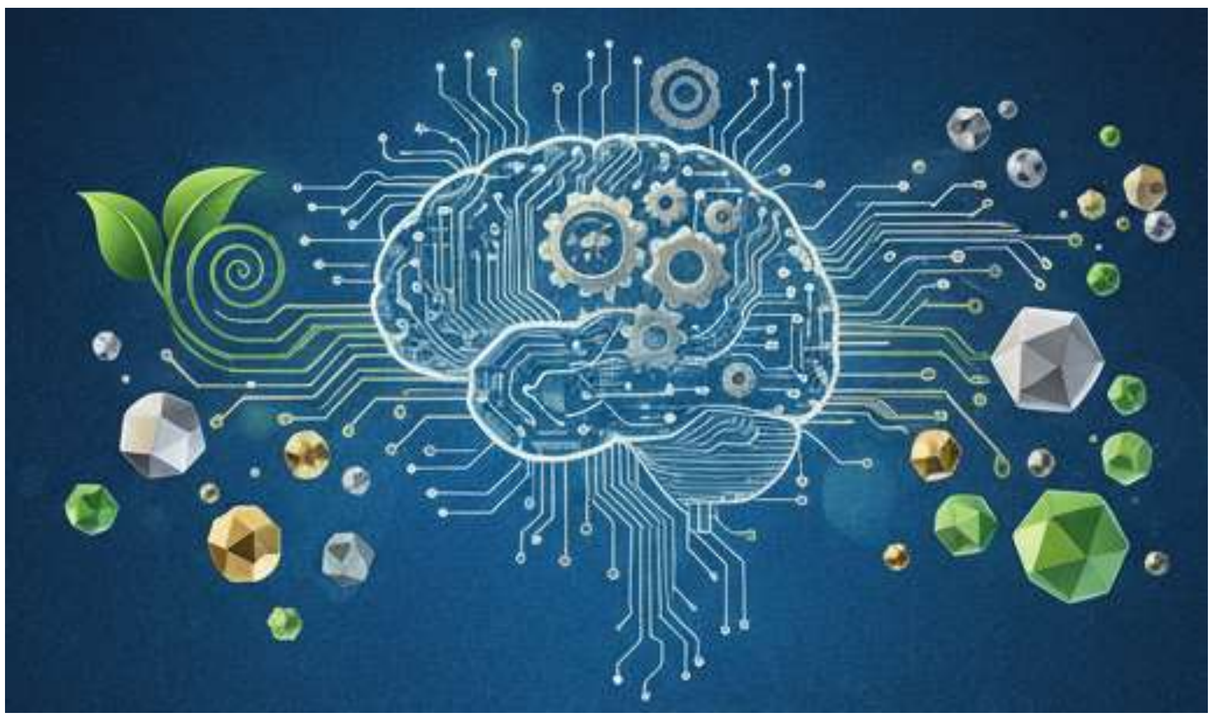
RESULTS & DISCUSSION

In the APU approach the reaction media which comprises the BGCs, metal ions, and the solvent is considered not just as a passive container but as an active system that processes information from its environment. The inputs to this unit are the various conditions of the synthesis reaction, such as pH, temperature, and the specific spectral signature of the biogenic compound. The outputs are the key morphology features of the synthesized NPs, including their size distribution and shape. This approach allows in focusing on information-structural analysis, where each transition of the environment state is associated with changes in the BGCs structure, which affects the NPs growth, shape and morphological features.
This, in turn, is the rationale for using so called Knowledge Discovery in Databases (KDD) which is a combination of techniques from statistics, machine learning, and artificial intelligence, i.e. the intellectual methods used to analyze vast and complex datasets to identify patterns and relationships that are not obvious at the first view.
This includes Machine Learning (ML), Unsupervised Learning (UL) and Artificial Intelligence (AI). ML is a foundational method for discovering knowledge whose algorithms are "trained" on data to learn and improve over time without being explicitly programmed for every task. UL methods find patterns in data without pre-existing labels where clusterization groups similar data points together, while association rule mining discovers relationships between variables. At the same time, AI utilizes complex neural networks to process vast amounts of unstructured data, such as images, providing the recognition of intricate patterns and create powerful predictive models.
It should be mentioned that in the presented APU approach all implemented logic is not binary, but analog, where each parameter (pH, temperature and charge density fluctuations) has the influence on the appropriate NPs morphology formation.



CONCLUSION

The central finding is that the reaction media can be viewed as an analog processing unit (APU) where the environmental parameters such as pH, temperature, and the specific spectral properties the BGCs serve as inputs. These inputs are processed by the reaction medium to produce specific nanoparticle outputs, including their morphology features.
The presented work provides a new, information-structure analysis perspective on nanoparticle synthesis, treating the process not just as a chemical reaction but as a system of controlled information flow.

FUTURE WORK

1. Exploring the "memory" of the system, i.e. whether past environmental states influence the current state of NPs formation.
2. Developing a predictive model based on this analog processing concept that would allow researchers to "dial in" specific environmental parameters to reliably produce NPs with a desired morphology for various applications.