Intelligent Informatics Platform for Nano-Agriculture

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***Abstract*— The application of nanotechnology in the agricultural sector is likely to facilitate and frame the next stage of development of genetically modified crops, precision farming techniques (remote and local sensing), remediation (water treatment plants, pesticide removal from ground water), nano-sensors, nano-agricultural chemicals and most importantly designing smart delivery systems for nutrients and pesticides[1]. Although most of these applications are still in their infancy, they have a great potential to revolutionalize the entire agricultural value chain [2]. The wide spectrum of applications has resulted into emergence of multiple stakeholders such as nano-agriculture researchers, practitioners (agriculturists/ farmers), manufacturers and regulatory bodies. They would be seeking and using knowledge in this nascent area from different perspectives such as research and technology, consumer safety, environmental impact and ethical, legal and social implications. No informatics platform exists to cater to the knowledge needs of various stakeholders in this field. To address this gap, we have developed an intelligent Nano-Agriculture Informatics System (NAIS), wherein these stakeholders can carry out multiple activities of their interest. NAIS incorporates a collaborative and semantically guided process to facilitate knowledge-based activities.**

I. INTRODUCTION

Nanotechnology involves manipulating matter at the nano-scale to create new and unique materials and products [3]. Research in the area of nanotechnology has witnessed significant growth in the last couple of decades due to the exciting physico-chemical and opto-electronic properties exhibited by metallic and semiconductor nanoparticles. This makes them useful for high end applications such as electronics, sensing, catalysis, energy, bio-medical applications etc. Nanoparticles of oxides, polymers and surfactants have been exploited due to their small size, high surface area, porosity, bio-compatibility etc., in applications that include cosmetics, paints, drug delivery, food etc [4][5]. Most of these applications directly impact consumers and hence are highly prioritized and market driven.

There has been a very recent interest in the area of nanotechnology applications in the agricultural sector. This is majorly because nanotechnology has a wide range of potential applications in the agricultural sector not only at the farm production system level, but also beyond the farm gate, and encompassing all the links across the entire agricultural value chain: farm inputs, farm production systems, post-harvest management, processing and marketing [6]. A number of nano-agri products have already entered the market or are under experimentation, and their numbers are expected to grow rapidly in the near future. Some of the most cited areas of nanotechnology applications in agriculture are: precision farming (remote and local sensing), remediation (water treatment plants, pesticide removal from ground water), nano-sensors, nano-agricultural chemicals and most importantly designing smart delivery systems for nutrients and pesticides [1].

The successful adoption of any new technology has to overcome many constraints such as adoption, regulatory approval, and proper use by consumers. But, there are some issues specific to nanotechnology such as public involvement and the management of safety, ethical and environmental risks in the presence of wide uncertainties [21][22]. This has resulted into emergence of multiple stakeholders seeking knowledge in this nascent area from different perspectives. For example, the nano-agriculture researchers need to know the state of art in research and technology. The regulatory bodies need to take into account issues pertinent to the environmental impact of the use of nano-agriculture products and health related concerns of the society as a consequence. Agriculturists/farmers seek to know about the safety, efficacy and availability of a given nano-product. The manufacturers seek knowledge of new developments and regulations with respect to nano-materials.

Lack of systematization of knowledge in this field may lead to a delayed adoption of technologies and an inability to deal with risks and uncertainties. This necessitates the need for an intelligent informatics platform to help stakeholders access, use and evolve context–specific knowledge. Nanotechnology in agriculture has a direct bearing on human life and social issues. Hence it is all the more important to cater to the varied knowledge needs of multiple stakeholders in this emerging research discipline.

This paper presents our work in conceptualizing an intelligent nano-agri Informatics System (NAIS), wherein stakeholders can capture and represent knowledge in this emerging discipline, evaluate and refine each other's contributions and evolve standards collaboratively. The information evolution process is semantically assisted by logical formalisms drawn from underlying nano-agriculture ontology (NAO). To the best of our knowledge, no such intelligent informatics system exists to date.

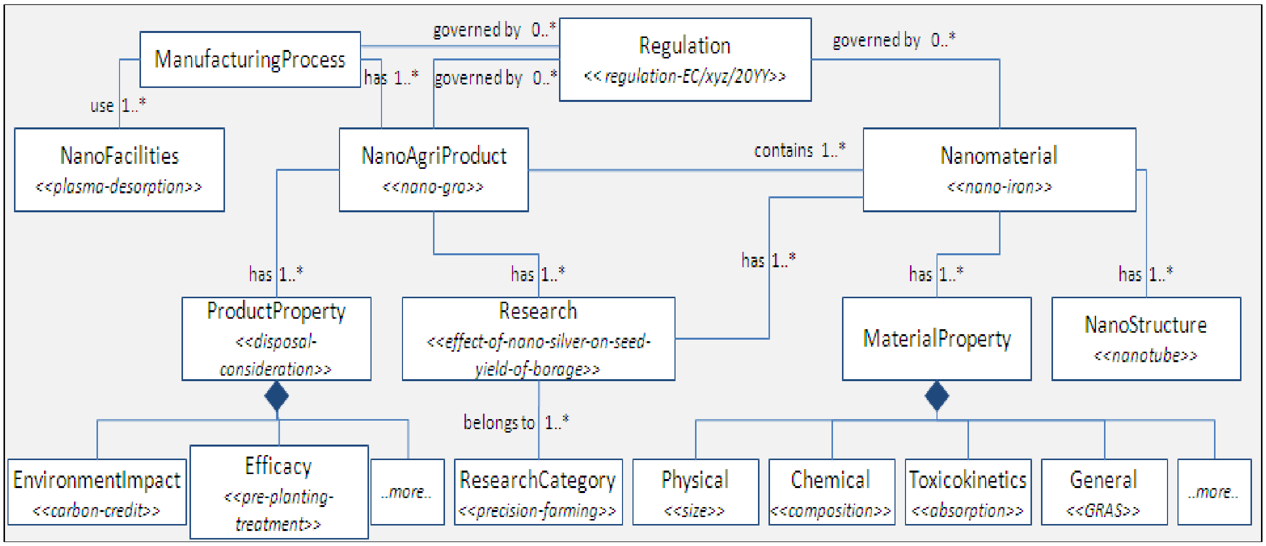

Fig. 1 NAO Model

The rest of the paper is organized as follows: Section II explains related work, section III gives an overview of NAO model, section IV provides usage illustration, section V presents future direction while section VI presents conclusions.

II. RELATED WORK

The related work falls into two categories, by taking some analogies to existing informatics areas in (1) any general discipline and (2) nanotechnology in particular.

Work in the first category is well established in areas like chemistry - cheminformatics [7], molecular biology - bioinformatics[8], health care/bio medicine – heath informatics [9] etc. Initial activities in the field of informatics in chemistry can be dated back to 1961 with the publication of the Journal of chemical documentation by ACS [12]. From the review report by Jun Xu and Arnold Hagler [13], it can be concluded that cheminformatics was well established in the area of drug discovery by the year 2002.

Work in the second category is still in its infancy but some references can be found in nanomedicine [10] [11]. The first large official meeting in the field was held in Virginia in 2007, with support from the US National Science Foundation (NSF). In 2008, the European Commission launched the first European initiative linking nanobioinformatics and biomedical informatics, the ACTION Grid project [14]. These and other foundational initiatives have emerged to support nanobioinformatics as a discipline designed to catalyze and accelerate research and developments in nanomedicine. Informatics in cancer nanotechnology is being created by adopting informatics infrastructure such as the National Cancer Institute's Cancer Biomedical Informatics Grid (caBIG) [15][16]. Work in the area of domain nano ontologies like UMLS or gene ontology for genomic [17] [18] and Nano Particle Ontology (NPO) [19] can also be found.

Informatics in the field of Nano-agriculture is still to be realized. This is the first ever attempt in this area. NAIS provides a medium wherein nano-agriculture researchers, practitioners (agriculturists/ farmers), manufacturers and regulatory bodies can structure knowledge in this emergent field, and evolve standards collaboratively. The framework also provides semantic assistance during the information evolution process.

III. NAO MODEL

Nano-Agriculture Ontology (NAO) forms the foundation of NAIS and enables representation of knowledge by incorporating basic concepts, their relationships and constraints. NAO is implemented in the Web Ontology Language (OWL). The inference rules (as illustrated in section II) are written in simple *antecedent-consequent* format using Semantic Web Rule Language (SWRL). Fig. 1 shows a part of the NAO model depicting some of the key concepts and relationship in nano-agriculture domain. This serves as a reference for structuring of knowledge. For example, ***Nano-Gro*** which is a ***NanoAgriProduct*** contains ***Nano-iron*** which is a ***Nanomaterial***. ***Nano-Gro*** is believed to be useful for pre-planting treatment of plants which is its ***Efficacy***- a kind of ***Product Property***. ***Nano-iron*** which is a ***Nanomateial*** is ***non-toxic*** – a ***MaterialProperty***. ***Nano-iron*** *exists in one or more* ***NanoStructure(s)*** such as ***nano-tubes, nano-clusters***. ***NanoAgriProducts*** are *governed by* zero or more ***Regulation(s)*** **such as** ***pre-market approvals and explicit mention of ingredients.*** The 'multiplicities' such as 'zero or more', 'one or more' are represented as 0...* and 1...* respectively in Fig. 1.

IV. USAGE ILLUSTRATION

In this section, we illustrate the Nano-Agriculture Informatics System (NAIS) usage.

Scenario 1 – A **regulatory body** needs to formulate and communicate a new regulation *–e.g. silver nano-particles are not generally recognized as safe (GRAS) materials.* Any new regulation will have to (1) take into account already existing regulations (2) the activities of different stakeholders that it will impact.

NAIS facilitates addition of the new regulation as follows:

- It displays a list of existing regulation(s) (if any) for silver nano-particles.

When the regulation is being added, NAIS displays:

- Existing regulations that would contradict this new regulation.
- A list of all products that use silver nano-particles along with the details of manufacturer and distributers. This would assist in product recall procedures.

A notification regarding the addition of this new regulation is sent to all impacted stakeholders such as manufacturers, researchers and agriculturists. Also, NAIS would send alerts to the manufacturer as and when new regulations or amendments to existing regulations pertinent to his interest are introduced.

Scenario 2 – An **Agriculturist** needs information about *pre-planting treatment products.* NAIS assists him as follows:

- It provides a template to specify his working conditions: climate, water, soil conditions, plant type etc. Based on these inputs, NAIS would suggest the best product out of the available products. For example, NAIS recommends him to use *Nano-Gro* as opposed to *Nano-Gro NPK or MP* as it is more suitable for the working conditions that he specified.

In addition to this, NAIS displays:

- Field trial results of the application of *Nano-Gro* with varying environmental and soil conditions.
- Result comparison with other products.
- Instructions on how to use *Nano-Gro* (preparation, concentration levels etc)
- Additional information such as details of manufacturers and distributors, composition of ingredients, potential health hazards (skin, eye, inhalation, ingestion), regulatory, toxicological, ecological and disposal information.

Scenario 3 – A **Manufacturer** needs to manufacturer a new form of *carbon nano tube*. NAIS assists him as follows:

- It provides a template to explicitly specify his requirements such as (a) his working geography (this is required to guide him with various regulations specific to his working geography) (b) manufacturing process steps (c) the nanomaterial used along with their critical properties.
- Based on these inputs, NAIS presents the following recommendations:
    - Geography specific environmental, health and safety related regulations for manufacturing nano-structures.
    - Checklist to ensure compliance to various regulatory requirements such as composition constraints, metabolism, intended use and toxicity.
    - Pre-market approval requirements
    - Testing requirements

The semantic guidance illustrated in the scenarios above is facilitated by the underlying Nano-Agriculture Ontology (NAO) as detailed in section II.

To summarize, NAIS provides –

1. A foundation for a systematic and machine-process able structuring of knowledge from the unstructured knowledge such as documents, reports, web pages, forums dedicated to this discipline.
2. Intelligent assistance for researchers to structure, access, refine and use nano-agriculture knowledge.
3. A mechanism to look up materials, processes , properties of interest (for researchers) , seek product information, safety, availability (for agriculturists, farmers), assist decision making regarding regulations, seek knowledge about environmental impact , societal interests and concerns (for regulatory bodies) and seek knowledge of novel materials that can be used in products , processes, new laws (for manufacturers)
4. A mechanism for all the stakeholders to collaboratively evolve standards in this discipline.

V. FUTURE DIRECTIONS

Since nano-agriculture technology is expected to grow rapidly in the near future, we may observe a phenomenon wherein there are multiple attempts to develop nano-agriculture ontologies from different perspectives similar to those observed in the field of Biomedicine [20].

```
<nanomaterial name="Nano Silver">
   <description>Nano silver is pure de-ionized water with Ag
suspension
</description>
   <properties>
      <property_category name="General">
         <property name="bioavailability" critical="true"> Influenced by
form of silver </property>
         <property name="toxicity" critical="true"> May cause genotoxic
impact. Under study </property>
         <property name="chemical reactivity" critical="true"> In
reaction with acids, becomes chemically active </property>
         <property name="gras" critical="true"> </property>
      </property_category> -- - - - - - - -</nanomaterial>
```

Fig 2. NAML Snippet

To address the foreseeable issues pertinent to information exchange, we have defined a new standard in the form of an extensible Nano-agriculture Markup Language (NAML) developed to facilitate the interchange and interoperability of information. Fig 2 shows sample NAML snippet. A common standard such as NAML would be relevant in this context and in future, we plan to evolve NAML by seeking contributions from researchers in the field of nano-agriculture and knowledge engineering.

VI. CONCLUSION

We have laid a foundation for informatics in the nano-agriculture domain. The framework provides proactive semantic assistance to various stakeholders as they collaboratively structure knowledge in this emergent discipline. By creating this exemplar platform for stakeholders such as researchers, agriculturists, manufacturers and regulatory bodies; we hope to bring about a paradigm shift in the way knowledge in this emerging multi-disciplinary field is created, disseminated and consumed. For example, researchers today still publish and read papers, web pages for accessing and contributing to knowledge. Similarly other stakeholders discussed above depend on unstructured sources of knowledge. We envisage making this intelligent informatics platform *the way* for knowledge creation, dissemination and consumption. In any matured discipline that already has a large, unmanageable knowledge corpus, it would be difficult to demonstrate this novel concept, but an emergent and nascent field such as nano-agriculture presents a unique opportunity to do things right from the beginning itself; that is, before the knowledge corpus has grown beyond a manageable limit. Being the first ever attempt of its kind in this area, we see a tremendous potential for this framework to accelerate discovery and dissemination of knowledge in nano-agriculture.

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