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A novel approach to obviousness: An algorithm for identifying prior art concerning 3-D printing materials

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A B S T R A C T

With the development and commercialization of the recyclebot (plastic extruders that fabricate 3-D printing filament from recycled or virgin materials) and various syringe pump designs for self-replicating rapid prototypers (RepRaps), the material selection available for consumers who produce products using 3-D printers is expanding rapidly. This paper provides an open-source algorithm for identifying prior art for 3-D printing materials. Specifically this paper provides a new approach for determining obviousness in this technology area. The potential ramifications on both innovation and patent law in the 3-D printing technological space are discussed.

1. Introduction

3-D printing has been growing aggressively and authors with as diverse views as Jeremy Rifkin [1] and the Economist [2] have predictions that agree that additive manufacturing (AM) technology will provide a new industrial revolution, fundamentally changing the way products are made [3]. The relatively sudden widespread attention is largely due to the development of the open-source self-replicating rapid prototyper (or RepRap) [4,5] and the concomitant tidal wave of innovation that has resulted in radically reduced costs of 3-D printers, rapid prototyping and low-volume production [6,7]. Although RepRaps and their commercial derivatives (now available from hundreds of small companies) can print in a wide selection of materials, the vast majority of 3-D printers today use some form of fused filament fabrication (FFF) [8]. Currently, most systems are limited to polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS), with a retail cost of generic filament between US$35 – 50/kg. Although proprietary filament is considerably more expensive (starting at US$70/kg and going up to over US$200/kg), RepRap printed products from generic retail ABS and PLA materials have been shown to be as strong as proprietary 3-D prints [9]. Even with the high cost of commercial plastic filament slowing deployment, there has still been a rapid growth in the sector with personal 3-D printer sales increasing by 35,000% from 2007 to 2012 [10].

The recent development of the open-source recyclebot [11] (a waste plastic extruder capable of producing filament at US$0.10/kg from electricity costs from post-consumer plastic containers) [12] is likely to further accelerate 3-D printing deployment by largely eliminating the cost barrier of feedstock even for the world's poorest citizens [13]. In addition, it is likely to increase the number

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of 3-D printing materials as soon as thousands of prosumers (a portmanteau of producing consumer, which make their own products) will be able to experiment in producing their own 3-D printer materials using either a home-built recyclebot [14] (e.g. the Lyman Filament Extruder [15]) or simply purchase any of the growing number of commercial variants (e.g. FilaFab [16], Filabot [17], FilaStruder [18], etc.). The prosumer community has even developed a sophisticated recycling code system to allow for more 3-D printing materials to be utilized [19]. Open-source 3-D printer material development to date has largely relied on experimental trial and error. Although the combinatorial experimental brute force made possible with hundreds of virtual collaborators following the open source model of development is probable to yield results, it is an inefficient use of resources. A more efficient mechanism to help accelerate development of technology is to consider innovation algorithms. Such algorithms, like the TRIZ algorithm for inventive problem solving, for example has proven successful in the past in a large number of applications [20–23]. For example, the TRIZ algorithm was applied to recyclebot technology to produce a low-cost largely 3-D printable version of the recyclebot in Germany [24].

In order to assist the development of materials for low-cost open-source 3-D printers, this paper provides an open-source algorithm for generating prior art for 3-D printing materials to release into the public domain. The use of the algorithm is explained to systematically generate a wide range of 3-D printing materials for use commercially or by any 3-D printer and recyclebot operator. Two case studies are then provided for utilizing the algorithm. First, the algorithm is used to narrow the search for 3-D printable materials with specific properties and second to probe the obviousness requirements of patents. This could be used as an intellectual monopoly prophylaxis against overly broad patent applications based on vague, formulaic, generic and combinatorial claims filed by either practicing or non-practicing entities. The potential ramifications on both innovation and intellectual property in the 3-D printing area is discussed and conclusions are drawn.

2. Materials and methods

2.1. Variables and definitions

N = the total number of natural chemicals and compounds including the entire set of elements in the periodic table.

M = the total number of known man-made chemicals. This includes, but is not limited to, the entire CAS Registry [25], which is the most authoritative collection of disclosed chemical substance information, containing more than 100 million unique organic and inorganic chemical substances and more than 66 million sequences. It should be noted that the algorithm should be updated with the CAS Registry, which has expanded by more than 15% from the initial draft of this paper.

F = a functional agent that represents any chemical species that provides some form of beneficial property of the 3-D printing material or any combination of functional agents to provide a combination of functions (e.g. F_1, F_2, etc.). For example, functional agents may include (but are not limited to) species to improve rheological properties, melting temperature, setting time, hydrodynamics (e.g. hydrophobicity, hydrophillicity, etc.), electromagnetic properties (e.g. phosphorescence, color, light transmission, reflection and refraction etc.), chemical properties (e.g. reactivity, smell, catalytic activity, etc.), acoustical properties, atomic properties, mechanical properties (e.g. strength, flexibility, stiffness, fracture toughness, etc.), thermal properties (e.g. thermal conductivity, thermoluminescence, etc.), magnetic properties, electrical properties, environmental properties, manufacturing properties (e.g. printability, print speed, ability to form complex geometries without support, bed adhesion, etc.) or radiological properties etc.

@ = All of the preceding materials and.

& = All combinations of all possible mol fractions of the above (e.g. Ref. [1] chemicals a + b, a + c, a +b + c, etc. until all combinations have been reached over the set up to N + M and [2] all fractions so that compound $[a_x][b_{1-x}]$ would be stepped through from x = 0 to 1 under all percentages)

2.2. Materials capable of being used as 3-D printed feedstock include

1. Known natural chemicals and compounds including all organic and inorganic substances (these are not patentable).
2. @ & from 1 to N
3. @ known man-made chemicals, compounds, and metamaterials [26,27] including all organic and inorganic substances
4. @ & from 1 to M
5. @ & from 1 to NM
6. @ & where 1 to NM acts as functional agents
7. @ & where any natural or manmade material is controlled for size from 1 Å to 1 m in dimension (This is necessary to account for any size related physical or chemical property change as is well established these are tunable at the nanoscale for a wide range of materials [28].)
8. @ & any arrangement of the combinations (e.g. superlattices, metamaterials, core in shell quantum dots, etc.)
9. @ & where a nanoscale collection of atoms (e.g. nanocrystal, quantum dot, nanotube, nanocolum, etc.) is used as a functional agent or filler
10. @ & where the shape of the collection of atoms is altered to adjust properties (thus all geometric shapes, and all known complex shapes capable of being generated by a mathematical algorithm (e.g. fractals)
11. @ & where the surfaces (both internal voids or external surfaces) are adjusted (e.g. roughening) to adjust properties.
12. @ & at any temperature from 0 K to infinity (or any sequence or combination of temperature)
13. @ & at any pressure from 0 bar to infinity (or any sequence or combination of pressure)
14. @ & printed in any environmental medium [NM] (meaning that some 3-D printing materials may need to be used under vacuum, under water, in an oil bath, etc.)
15. @ & printed with the assistance of electromagnetic radiation of any wavelength.
16. @ & printed with the assistance of any solvent from N or M or combination of the above.
17. @ & for any physical orientation of the chemical species.
18. @ & for any N or M or combination that acts as a catalyst during the printing process.
19. @ & for any field catalyzed reaction (e.g. magnetic).
20. @ any order of the above.

3. How to use the algorithm

Two case studies are evaluated to demonstrate the use of the algorithm:

3.1. Case study 1

Case Study 1 shows how to narrow the search for 3-D printable materials with specific properties. This is particularly important for enterprises investigating new public domain 3-D printing materials