Bridging CAGD Knowledge into CAD/CG Applications: Mathematical Theories as Stepping Stones of Innovations

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Abstract. Computer Aided Geometric Design (CAGD) which surpasses the underlying theories of Computer Aided Design (CAD) and Computer Graphics (CG) has been taught in a number of Malaysian universities under the umbrella of Mathematical Sciences' faculty/department. On the other hand, CAD/CG is taught either under the Engineering or Computer Science Faculty. Even though CAGD researchers/educators/students (denoted as contributors) have been enriching this field of study by means of article/journal publication, many fail to convert the idea into constructive innovation due to the gap that occurs between CAGD contributors and practitioners (engineers/product/designers /architects/artists). This paper addresses this issue by advocating a number of technologies that can be used to transform CAGD contributors into innovators where immediate impact in terms of practical application can be experienced by the CAD/CG practitioners. The underlying principle of solving this issue is twofold. First would be to expose the CAGD contributors on ways to turn mathematical ideas into plug-ins and second is to impart relevant CAGD theories to CAD/CG to practitioners. Both cases are discussed in detail and the final section shows examples to illustrate the importance of turning mathematical knowledge into innovations.

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CAGD & INDUSTRIAL DESIGN

A customer decides to buy a product after carefully considering four factors; efficiency, quality, price and its appearance. Pugh stated that customers judge the aesthetic appeal of a product before the physical performance [1]. This clearly indicates the importance of aesthetic shapes for the success of an industrial product. In essence, the design process starts from an idea which is developed depending on the market need or innovation. A stylist sketches the shape of an industrial product based on the aspiration of nature, cultural patterns, intuition, old pattern with modern outlook and etc. The sketch is then digitized to be represented as a CAD model in which is carried out by a design engineer. CAD models are computer represented geometrical descriptions of a physical object and the description include numerical data as well as algorithms to prescribe the geometry of the object. At times, the designer modifies the shape giving much consideration to the engineering constraints and manufacturing perspectives.

The underlying principles and theories of CAD models are classified under a field of study called Computer Aided Geometric Design (CAGD). The exploration and detailed investigation of mathematics for CAD/CAM and computer graphics was the precursor in the CAGD field [2]. The definition of CAGD deals with the construction and representation of free-form curves, surfaces and volumes [3]. The abbreviation was first introduced by Barnhill and Riesenfeld at a conference in 1974 held at the University of Utah. The event successfully gathered many researchers from all over the world who were enthusiastic about topics involved in computational geometry used for design and manufacture. The conference was regarded as the founding event of the new discipline; CAGD. Since then, many conferences and workshops have been held; text books and journals have been published around the United States of America and Europe which contributed to the intensification of CAGD. However, this field of study has now become a part of pure mathematics which is under the roof of Numerical Analysis. Unfortunately, new theories and algorithms developed in this field do not reach the CAD practitioners in time or implementation period is simply at a slow pace most of the times.

Even though differential geometry explains in detail the concerns of curves and surfaces, its potential was not known to the Computer Aided Design (CAD) programmers and Computer Aided Manufacturing (CAM) practitioners [3]. In most cases, CAD programmers are not involved in the development of CAGD theories, hence

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they draft the help file pertaining the functionalities based on the description given by CAGD contributors. The CAD practitioners on the other hand rely heavily on the documentation which comes with the CAD system to maximize the commands available for the product design. Hence, the functionalities are either under-utilized or never used at all.

This paper proposes ways to bridge the knowledge of CAD practitioners and CAGD contributors in order to speed-up the process from mathematical development to practical application for aesthetic product development. The expected outcome is CAGD contributors become innovators while CAD practitioners become power users. The next part discusses about initiatives on turning CAD amateurs to power users. It is then followed by descriptions on turning CAGD contributors to innovators. Three examples are discussed to elucidate the proposed method.

A POWER CAD PACTITIONER

The initiative to educate potential stylists, designers and CAD practitioners is not a new task; it is an ongoing task by policy makers and educators to revamp the existing syllabus and courses in such a way that the essence of CAGD is exposed at the entry level. Readers are referred to a special issue of CAD journal (Issue 36, 2004) as an example of such initiatives. Ye et. al. [4] stated that the mathematical foundation of CAGD/CAD is classified into the following categories:

• Basic mathematics: Linear algebra, vector algebra, transformations, basic analytic geometry, equations (algebra, ordinary differential equations, partial differential equations), calculus, etc.

• Advanced mathematics: Analytic curves and surfaces, basic differential geometries, basic optimization techniques.

• Advanced CAD topics: Non-Uniform Rational B-Spline (NURBS) curves and surfaces, Boundary representations (B-reps) and Constructive Solid Geometry (CSG) techniques, Intersections (curve/curve, curve/surface, surface/surface) and Boolean Operators.

• Other advanced CAGD/CAD topics, such as: Non-linear equation solvers, Constraint solvers, Shape interrogations (e.g. curvature maps, contouring, offsets, geodesics, zebra stripes, reflection lines and etc.).

The mathematical aspects stated above can be packaged as a one semester geometric modeling course for engineering/design undergraduates so that the mathematical principles used behind the CAD buttons/commands are elucidated at an early state. Rossignac [5] proposed that the stated subject matters can further be simplified when one reaches to the culmination of their respective CAGD research. This enables CAGD educators to convey an education-driven research to CAD practitioners with a new and simpler formulation. The outcome of such culmination can be packaged in the form of a workshop which may last for a week, depending on the knowledge of CAD practitioners. It should be noted that the workshop should be conducted in an engaging and participatory way so that the participants are motivated to pay attention to real life CAD problems and solutions.

INNOVATIVE CAGD CONTRIBUTORS

This section is dedicated to lay out details on transforming the scientific community, especially CAGD contributors into innovators, where their novel and genuine research findings are made into user-friendly packages available for CAD practitioners. The process is indeed a symbiotic process, where the CAD practitioners get involved in the preliminary stage during alpha release (work-in-progress) while the CAGD contributors obtain constructive feedbacks on their findings which will create room for advancement.

The CAGD contributors conventionally propose a new algorithm or derive a new formula in the form of articles with rigorous mathematical proofs. Since CAD formulations and algorithm involves geometry, thus CAGD contributors may illustrate the figures using either native programming languages, i.e. C, C++, Java, Phyton and C# with the help of OpenGL. Recent advancements of computer technologies in terms of software include the creation of scientific computation programs such as Matlab, Maple and Mathematica. These programs have thousands of built-in functions which make deployment of new algorithm and formulation a straight-forward process. However, this sort of deployment is far from complete and ready for testing in existing CAD systems. Hence, either immature feedbacks may lead to a poor algorithm or the formulation will stay as a theory without having much applicability.

In order to avoid such cases, potential CAGD students are not just taught mathematical aspects stated in the previous section, but they must be exposed to Object Oriented Programming with native programming languages for at least one semester. A laboratory assignment which focuses on basic industrial product design is also a must at the preliminary stage. Coupled with strong mathematical knowledge, programming and basic CAD drafting skill, it is mandatory for each students to create simple plug-ins for the CAD systems which has been taught. The course must be conducted in an engaging delivery format where students are not just taught about tweaking built-in procedures and objects that exist in the CAD system. The students are required to create their own plug-ins as assignments. This course can be provided for the final year undergraduate students and evaluation should be assignment based.

A potential CAD system with rich algorithms, high flexibility and affordable price is Rhinoceros 3D. It is developed by Robert McNeel & Associates. The current price for an educational license consisting of 30 network computer laboratory may cost less than USD1,000. Due to its flexibility and easy customization via programming and scripting, many plug-ins have been developed to carry out particular tasks, i.e. industrial design, architecture, marine design, jewelry design, automotive design, CAD / CAM, rapid prototyping, reverse engineering, multimedia, graphic design industries and etc.

Figure 1 illustrates dissect of Rhino 3D along with its programming tools to create plug-ins. McNeel has given the flexibility to programmers to write their plug-in to work in hand with the core Rhino engine rather than adding code to Rhino itself.

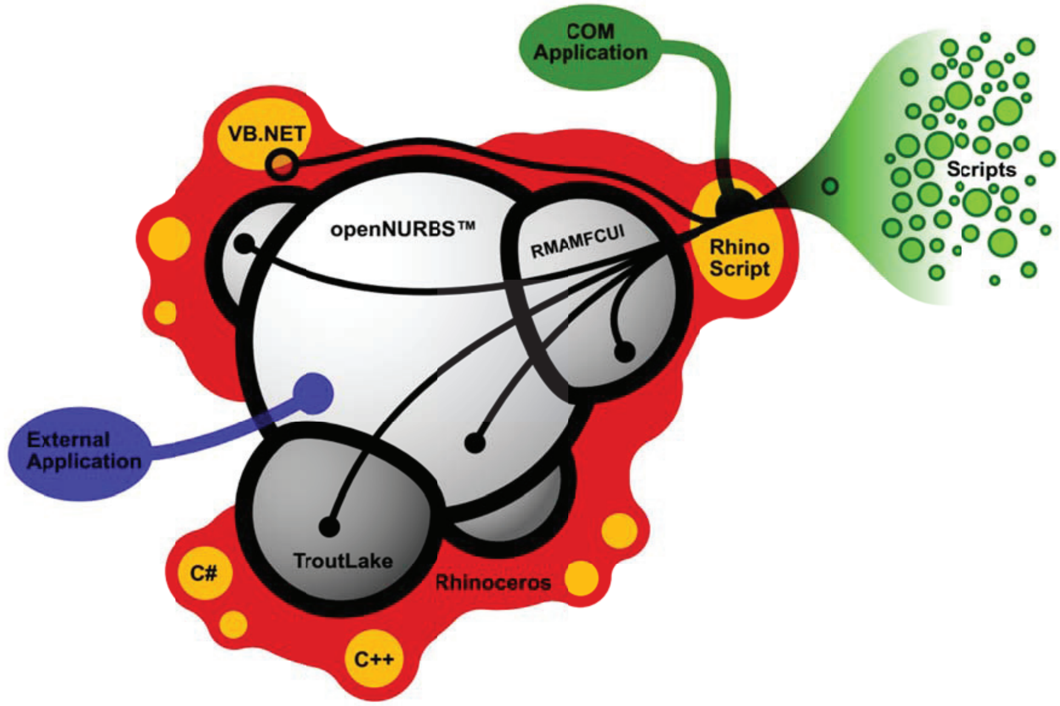

FIGURE 1. A detailed breakdown for Rhino developer tools [6].

SUCCESS STORIES

Three successful examples will be discussed in this section. The first example is a plug-in called DIVA which is created as the output of research carried out by the Graduate School of Design, Harvard University. It is a daylighting and energy modeling plug-in utilized for architecture design. There are two types of licenses available, i.e. educational and commercial use [7].

The second example is the T-Spline, a classic example where CAGD contributors apply for patent before developing plug-ins. It is a method which bridges NURBS and the subdivision surface [8]. Once the patent is granted, CAD developers create T-Spline plug-in for commercial purposes. However, the setback of this program is tied in to the long waiting period to obtain a successful patent.

The final example is the development of Log-Aesthetic (LA) curves for intuitive aesthetic design. The mathematical properties were first proposed by Kenjiro Miura, a professor from Shizuoka University, Japan. The details of LA curves can be found in [9-16] and readers are also referred to [17] which is a comprehensive review pertaining this curve. Upon the development of the LA curve plug-in for Rhino, it was given to automobile designers for rigorous testing. Based on the input from the designers, further improvement has been incorporated [14]. Figure 2 shows an example of car model using LA substituted with circular arc. Figure 3 shows a car model using LA curve plug-in and its zebra map analysis.

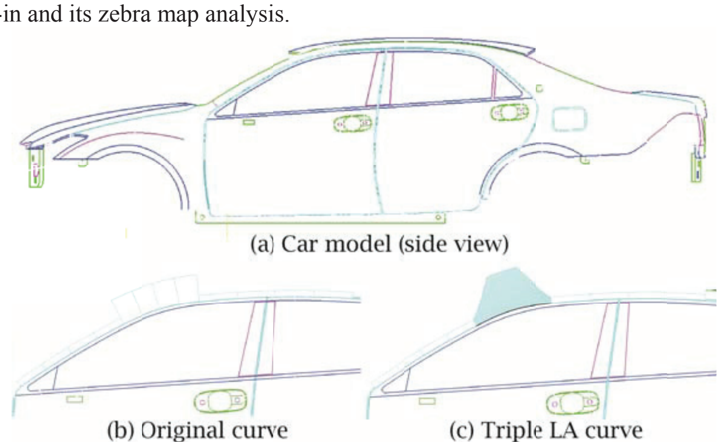

FIGURE 2. Circular arc replacement by a LA spline to achieve G^2 continuity [14].

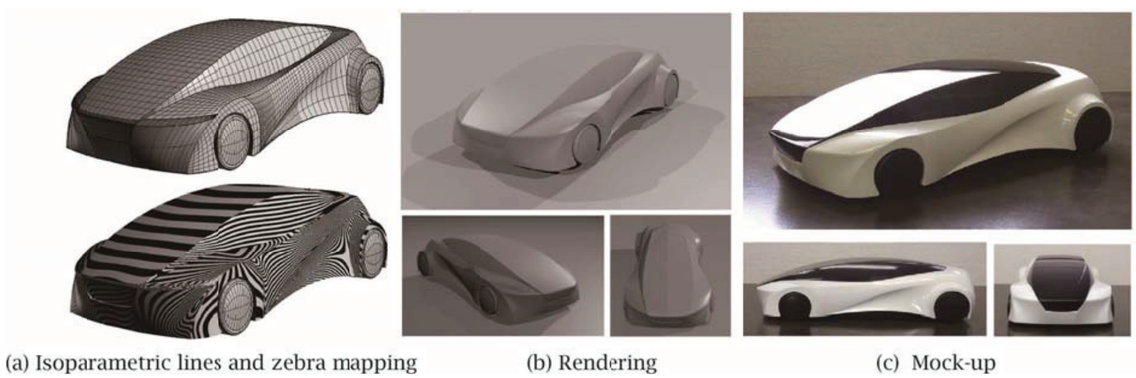

FIGURE 3. A car model designed using LA spline and its mock-up [14].

CONCLUSION

The first part of this paper discusses ways to turn CAD amateurs into power users by proposing education via workshops etc. to strengthen the underlying mathematics of CAD. The second part discusses the importance of combining mathematical knowledge, object-oriented programming skills and CAD drafting skills to develop plug-ins for existing CAD systems. Three examples are shown to indicate that the proposed methods are effective to transform CAGD contributors into innovators.

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