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Interdisciplinary Modelling of Robots Using CAD/CAE Technology

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Introduction. The paper describes an interdisciplinary approach that integrates physical and virtual (3D) modelling methods and tools in a high industrial undergraduate engineering school research environment and in an industrial design. The CAD/CAE procedures were connected directly with physical modelling for robotic systems of various types: mobile robots, manipulators etc. Thus, the design problems for the robot are solved in the both environments: physical and virtual.
Materials and Methods. The approach includes three separate parts: 1) SolidWorks; 2) Arduino, Fischertechnik and RoboRobo sets; 3) MS Visual Studio C++, COM technology SolidWorks and a POSIEX socket API (Application Program Interface). API and COM are used as the integration tools for physical and virtual parts. Corresponding Add-In or Stand-Alone applications extract the model features used for determining the necessary kinematic and dynamic parameters for robotics control. Robot webcams, sensors and feedback allow to establish a bidirectional connection between the behaviours of the 3D (virtual) and the physical models.
Results. The developed virtual (3D), physics models and software for the robots represent the integrated framework used in industrial design and research process. This interdisciplinary approach is realized as project-based learning in the educational and research process and in the industrial design practice.
Conclusions. The modern industry design is the interdisciplinary field with high level of integration between the disciplines. This research demonstrated that the developed integrated framework is effective for both industry design practice and engineering research.

Keywords: integrated interdisciplinary model, CAD/CAE-system, 3D modeling, virtual model, physical model, project-based learning, API programming, robotics systems, industrial design

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Междисциплинарное моделирование роботов с использованием систем автоматизированного проектирования

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Введение. В статье представлен междисциплинарный подход, интегрирующий методы и средства натурного и виртуального (3D) моделирования как в исследовательском процессе технического вуза, так и в практике промышленного проектирования.

CAD/CAE-модели и технологии напрямую связаны с натурными моделями робототехнических систем различного типа: мобильными роботами, манипуляторами и т. д. Таким образом, задача проектирования решается в двух взаимосвязанных средах: натурной и виртуальной.

Материалы и методы. Интегрированная платформа, основанная на междисциплинарном подходе, включает в себя три части: 1) SolidWorks; 2) Arduino, Fischertechnik и RoboRobo конструкторы; 3) MS VisualStudio C++, COM технологии, SolidWorks и POSIEX socket API (Application Program Interface). API и COM используются как инструменты интеграции натурных и виртуальных моделей. Соответствующие Add-In или Stand-Alone приложения импортируют необходимые свойства виртуальной модели, которые используются для определения кинематических и динамических параметров управления роботом. Сенсоры робота, вебкамера, Wi-Fi, Bluetooth и радиосвязь позволяют создать двунаправленные связи между виртуальной и натурной моделью.

Результаты исследования. На основе междисциплинарного подхода разработаны натурные и виртуальные (3D) модели, а также программное обеспечение, интегрированное в единую платформу проектирования объектов робототехники. Подход реализован как метод проектов в учебном и исследовательском процессе технического вуза, а также в практике промышленного проектирования.

Обсуждение и заключения. Современное промышленное проектирование является междисциплинарной областью с высокой степень интеграции дисциплин. В исследовании показано, что разработанная интегрированная платформа эффективна как при использовании в сфере промышленного проектирования, так и в образовательном и исследовательском процессе технического вуза.

Ключевые слова: интегрированная междисциплинарная модель, система автоматизированного проектирования, 3D-моделирование, виртуальная модель, натурная модель, метод проектов, API-программирование, робототехника, промышленное проектирование

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Introduction

The product development, manufacturing, using and servicing in the industry has been realized in digital environments, enabled by integrated CAD/CAM/CAE/PLM tools.

The core idea is to integrate features of mechanical CAD, CAE and robotics soft into the same platform to facilitate the development process through the designed user friendly interface. The integrated platform includes various 3D models of the robotized production work cell: the robot and an environment area, in which the robot moves. This idea was realized, for example, in SolidWorks software [1] and PLM Siemens NX systems [2]. Integrated software and virtual control system ensure that reaching the given positions by the robot is realized without the occurrence of a collision between the robot and the elements of its environment. At the same time all 3D models are defined or exported from the design environment to the simulation environment.

The next step is to integrate of real world simulation (physical models) with the virtual environment, increasing flexibility in robot design.The interactions between real robot (slave) and environment can be attained in advance in a 3D virtual environment (master) [3]. Alternatively, virtual robots in software can be made available so that they can be integrated and controlled by physical device[1].

The problem in general is commonly decomposed on four stages:

[1] Mehta I., Bimbraw K., Chittawadigi R. G., Saha S. K. A teach pendant to control virtual robots in roboanalyzer. In: Proceedings of the International Conference on Robotics and Automation for Humanitarian Applications, RAHA. 2016. DOI: https://doi.org/10.1109/RAHA.2016.7931881

– robot designing and building (physical and 3D modeling are realized as parallel process),

– environment 3D model implementation and reconstruction,

– simulation: obstacle detection, collision avoidance and motion planning,

– integration: physical and virtual control, multisensory feedback implementation under virtual (3D) models.

One of the key sub-problems is to define virtual environment. For this purpose laser range scanner is an important modality to generate the highly accurate 3D model of the environment in robotics for the perception of an environment such as object classification, map generation, navigation, etc[2]. Recent tools like 3D laser scanners have been more and more improved and are now able to rapidly generate an accurate dense point clouds[3].The methods for 3D model generation from measurements, collected by cooperative multiple robots [4]. 3D model of area was created [5] using ultrasonic signal etc. But if the CAD-model for the environment is already defined, so sensor data tracked in real-time by feedback system and are matched to the CAD-model [6].

Literature Review

The integration process in industry is one of the reasons that modern engineering education and research have preceded more towards the interdisciplinary process. This interdisciplinary field is a cross between mathematics, physics, computer sciences and engineering with high level of integration between the disciplines.

However, the integration of digital and physical models in real-time feedback interaction is relatively new, especially regarding CAD/CAE-systems. However, achieving a balance between digital and physical worlds is important for both industry and research.

However, this paper aims at infusing the integrated CAD tools (following to paper [7]) into basic engineering courses, using feedback with the physical environment. In this aspect, prior research [8] explored the educational and research framework of mixing physical and CAE environments with haptic devices for Finite Element Method (FEM) learning and research. An additional study [9] examined where contextual real-world modelling exercises have been implemented into CAD courses.

Among educational technologies, in our opinion, project-based learning (PBL) is the best suitable technology for assisting the implementation of our framework into the educational and research process. The paper [10] is a systematic review of PBL as an innovative approach to science and technology teaching. An effective project-oriented approach has been adopted for training mechanical engineers [11].

The purpose of this research is threefold: (1) to identify a range of methods which will be used to implement the interdisciplinary (physical and virtual) integrated models, (2) to develop the integrated modeling framework, using the interdisciplinary methods, and (3) to apply the mentioned framework for both industry design practice and engineering academia.

Materials and Methods

Our project encapsulates basic PBL properties and allows students and engineers to see connections among disciplines and to integrate multidisciplinary/interdisciplinary knowledge and methods by using a multi model framework [12].

Therefore, this project has three parts for the student: physical and 3D model-

[2] Singh M. K., Venkatesh K. S., Dutta A. A new method for calibration of range sensor and terrain classification. In: Proceedings of 3rd International Conference on Image Information Processing, ICIIP. 2015; 520–525. DOI: https://doi.org/10.1109/ICIIP.2015.7414828

[3] Crombez N., Caron G., Mouaddib E. M. Using dense point clouds as environment model for visual localization of mobile robot. In: Proceedings of 12th International Conference on Ubiquitous Robots and Ambient Intelligence, URAI. 2015; 40–45. DOI: https://doi.org/10.1109/URAI.2015.7358924

ling, mathematical, algorithmic and program modelling, and the development of the integrated model.

The following aspect of this project consists that the models considered by students have to be directly connected with industrial systems [13–14].

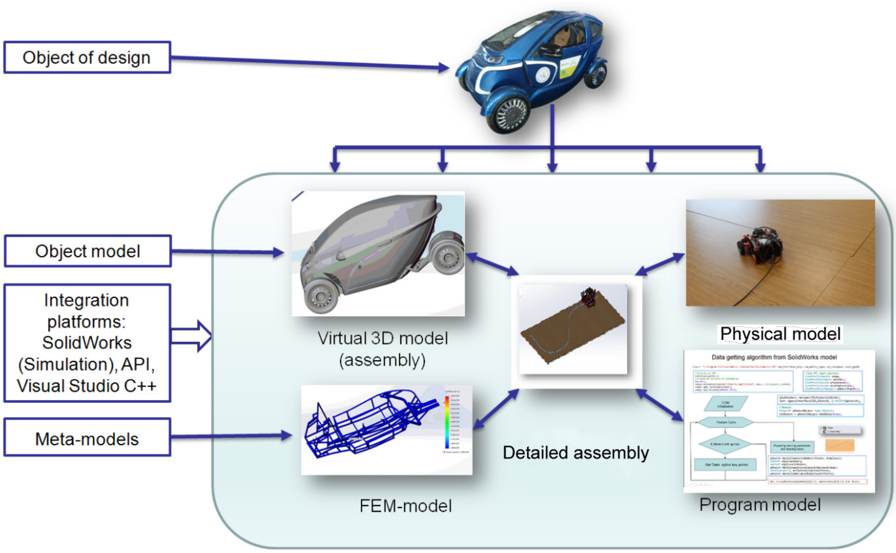
The models and applications of fischertechnik, RoboRobo and Arduino are widely used. Combined with production practice, these models are used to establish the structure of the 3D manipulator system [15]. The results of model meet design requirements. Practice shows that the application of fischertechnik creative integrated model [15–16] and Arduino based[4] are quickly and easily to build medium-sized machinery and equipment. These models significantly reduce the build cycle and system debug, which could help designers quickly implement a variety of design ideas and improvements. Fischer, RoboRobo and Arduino creative integrated models play an important role in teaching experiment and engineering applications.

Fig. 1 shows the hierarchical system of the models and metamodels created in an electric car designing process. This mode system includes: 3D virtual model for the electric car, FEM-model [13] for the car frame and the program and physical model for the pilotless control of the mobile robot.

Problem formulation, physical and 3D modelling

Let us review two examples and some important facts. First, the framework for physical modelling gives ample opportunities for various tasks and multiple formulations concerning general designing plus the mechanical, mathematical and algorithmic properties of the model. Second, the task formulation substantially extends the basic functionality of the construction sets.

Physical and 3D modelling is implemented by the parallel assembly processes



F i g. 1. Integrated model for electric car[5]

[4] Stuja K., Bruqi M., Markl E., Aburaia M. Lightweight educational scara robot for palletizing of USB sticks. Paper presented at the Annals of DAAAM and Proceedings of the International DAAAM Symposium. 2016; 27(1):102–108. DOI: https://doi.org/10.2507/27th.daaam.proceedings.015

[5] URL: https://drive.google.com/file/d/1S8q-9SKehAvEmfeuJ-QFdP3UumvNCROS/view?usp=sharing

based either the on construction sets from Fischertechnik or RoboRobo in SolidWorks software. Defining the structure of the design solution is a very important and creative process.

Example 1

Mobile robot (physical and 3D modelling). The task is formulated as follows: design mobile robot that is tasked with moving along desired path, defined in some environment. A 3D model of the environment for the robot was built previously as part of a common assembly. The results of the first stage of the project are illustrated in fig. 2 for the Fischertechnik construction set as an assembly, created by 2Dvia Composer, as a physical model, photo-view image. The path can be defined in the form of a curve (spline) or as part of free space with a tunnel for the movement in the common 3D model, including this environment and the robot. In this case the desired path is the spline, defined on the desk top model.

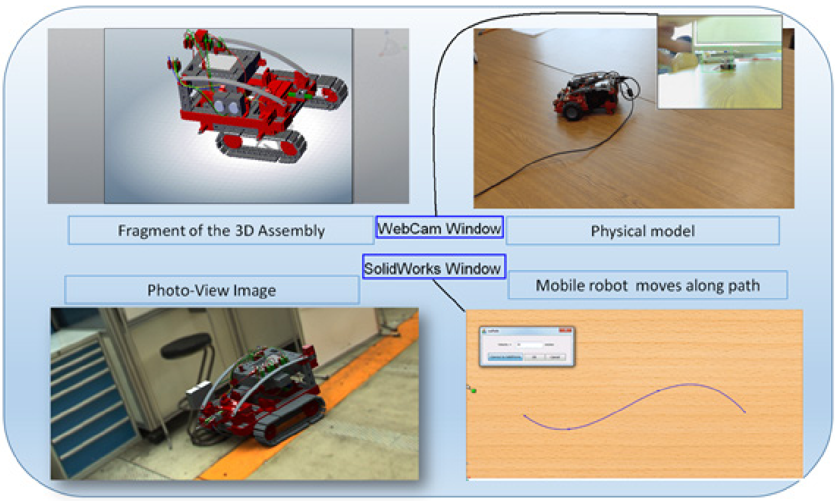
Example 2

Pitching robot (physical and 3D modelling). The task is formulated as follows: design a pitching robot, tasked with launching a ball into a ring (a basketball for example). The results of the first stage of the project are illustrated in fig. 3 for the RoboRobo construction set as a physical model and in the form of the PhotoView 3D SolidWorks model image. The model includes a mobile platform, the launching equipment, a homemade range finder based on webcam and a laser pointer.

The range-finder (fig. 3) establishes the distance to the target using the input parameters of velocity of the acceleration disks and the launching angle. The program for the processes of the ball movement is executed both for the virtual and physical balls.

Mathematical, algorithmic and program modelling

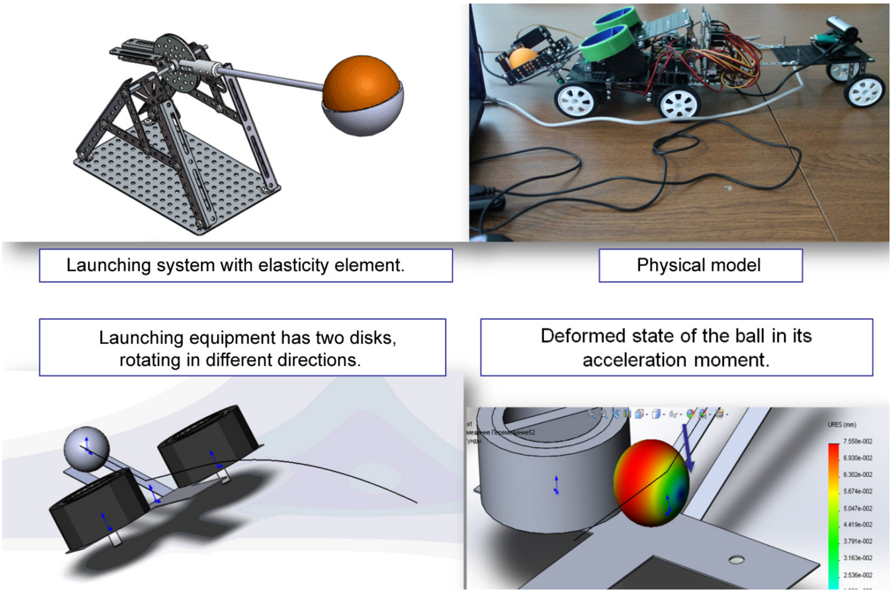
It is common for well-known mathematical and algorithmic models of geometry and mechanics to be used, including Non-Uniform Rational B-Spline (NURBS)[7], Solid Mechanics Theory (SMT), FEM, in addition to others. The specified models and methods serve as a basic function of the implemented software (SolidWorks Simulation uses FEM, and SolidWorks Motion uses SMT) and



F i g. 2. Integrated model for mobile robot[6]

[6] URL: https://drive.google.com/file/d/1RrOPWvKsw7j3TadxFZLGO11Ud-ITe6zP/view?usp=sharing

[7] Reiter A. Time-optimal trajectory planning for redundant robots. Chapter 2, NURBS Curves. Berlin: Springer Verlag, 2016.



F i g. 3. Integrated model for pitching robot[8]

are provided in the software developed by the authors of this project.

Example 1

Mobile robot (mathematical, algorithmic and program modelling). The kinematic scheme of the robot can be either wheeled or tracked. A scheme consists of a platform (frame) with two wheels with independent actuators and two wheels, which are free spinning (fig. 4, a). Our control program is executed through a connection with a Fischertechnik TXT controller via USB, Wi-Fi or Bluetooth, using POSIX sockets (fig. 4, a).

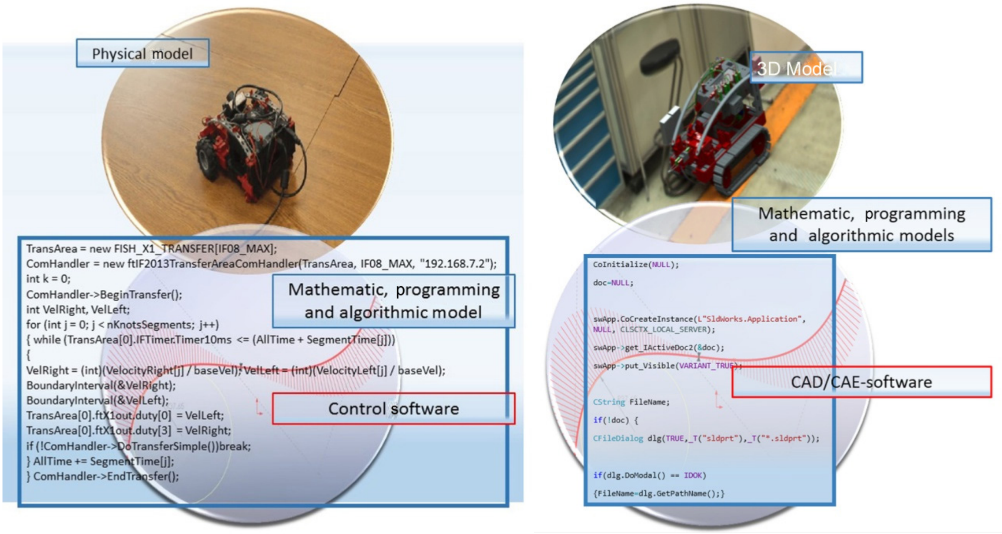
The challenge is to extract the desired path that is defined by NURBS with fixed key points in the SolidWorks sketch (fig. 4, b). To accomplish this, coordinates of the points on the curve are computed using analytical definition of the NURBS-curve[9] by our Stand-Alone or Add-In application and SolidWorks API functions. The program realization of this problem is in detail presented in paper [17], development environment is MS Visual Studio 2015 C++, MFC. If the path is known (NURBS curve), a sliding mode control is used to define inputs values of the velocity for the both wheels [18].

Example 2

Pitching robot (mathematical, algorithmic and program modelling). The launching equipment has two disks, rotating in different directions, which aim to accelerate the ball at the necessary velocity and at the correct initial launching angle to reach the target (fig. 3). There are two main requirements for the mathematical model, which happen to contradict each other: adequacy (accuracy) and simplicity. Through 3D model and SolidWorks Motion software the students can easily prove their choice of which model to use.

Fig. 3 illustrates the numerical results (SolidWorks Motion): if the disk mass is higher in comparison to the ball mass, the interval of acceleration time for the ball is very small. In this condition, it is possible

[8] URL: https://drive.google.com/file/d/1agLo8xT0X1J76EantHMwmAeQnrNRmuRL/view?usp=sharing
[9] Reiter A. Time-optimal trajectory planning for redundant robots.



a) b)

F i g. 4. Physical (a) and 3D (b) models integrated with math and program models

to formulate the mechanics problem only in kinematic terms, with the assumption that the initial velocity of the ball after the disk acceleration is equal to the constant tangent velocity of the disk rim. The parabola trajectory of the ball and the necessary initial parameters have been defined very simply, through the elementary usage of the SMT equation. Additionally, fig. 3 shows the deformed state of the ball in its acceleration moment.

Development of the integrated model

The main problem is how to develop an integrated system of the models and meta-models, which would provide an opportunity to solve multidisciplinary engineering problems.

Fig. 5 illustrates this approach on example 1 for the mobile robot. The behaviours of the physical and virtual robots are synchronized. The path (SolidWorks spline) is extracted from the complex common model. The control program defines input commands for the movement of both the virtual and the physical robots in a parallel manner. Two windows are used (see example 1, fig. 2): the first is the window corresponding to the webcam of the moving robot; the second is the window of the SolidWorks software (see animation). Both correspond to moving along a spline that is drawn on the wooden desktop model in the complex 3D assembly. The first case accomplishes this in the SolidWorks Motion software; the second case uses physics calculated by the TXT controller. The path is reconstructed, if the contact sensor data or the webcam red signal has been tracked in real-time by feedback system.

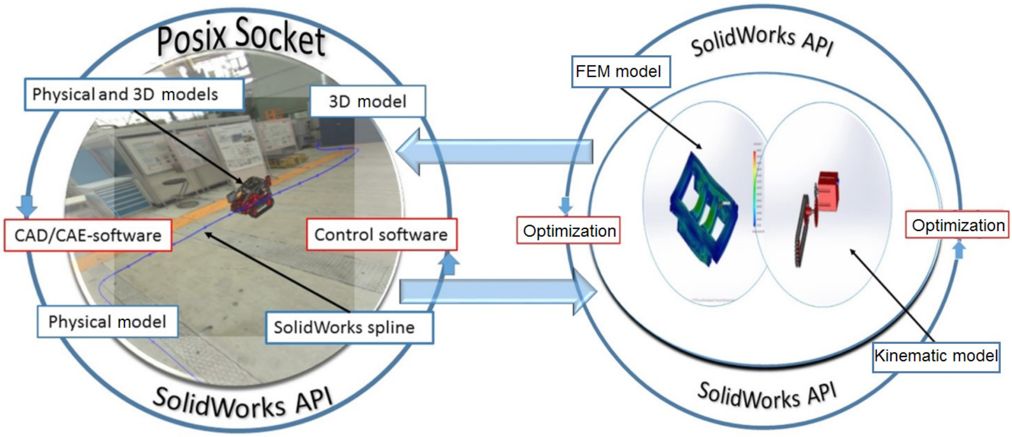
Integrated CAD/CAE tools allow for user to create FEM and kinematic metamodels that help to optimize the design solution (fig. 5). Fig. 6 illustrates this approach for the robot manipulator (the physic model, the 3D model, MS dialog based application controlling the robot by buttons and sliding controls on the dialog panel).

Results

1. The integrated modeling framework is developed, using the interdisciplinary methods.

2. Mentioned framework has been applied for both industry design practice and engineering academia.

The considered research and design framework is put into practice at the National Research Mordovia State University



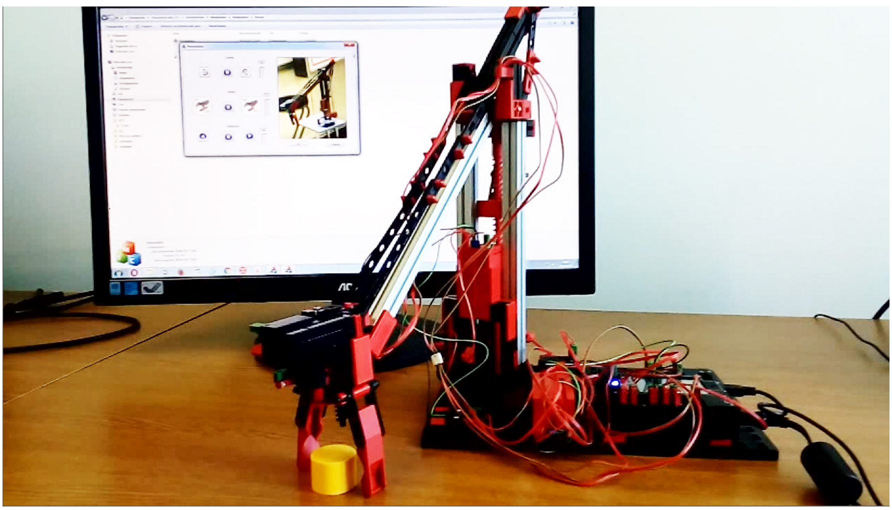
F i g. 5. Integrated model

for the last five years, realized modelling for robotic systems of various types: mobile robots, manipulators etc. (Fig. 6, see animation by referenced link). Among positive results of this approach are the following: an increase in effectiveness of the design process, extending of the designer competences, especially regarding the CAD/CAE-modelling and programming. The actual criterion of the efficiency of this approach is the increasing of number of the users who have successfully passed CSWP certification examination SolidWorks Corp. (near 20 percent versus 5 percent before); reducing time spent for development of the project process for the industrial design practice (electric car project, for example, fig. 1).

Conclusions

In this paper we study the problem of developing integrated virtual and real world models without web service programming tools.

The modern industrial design and the authorized corporate self-training have



F i g. 6. Integrated educational framework[10]

[10] URL: https://www.youtube.com/watch?v=8ox0olh8WUU

proceeded toward the interdisciplinary process and active network interaction. In this regard, the way to extend this research is to use the framework in education process such as the learning management system component (LMS, blend form), and in the design process using cloud management systems.

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Authors' contribution:

M. V. Chugunov – development of technique and software for integrated mechatronics systems building; I. N. Polunina – computer processing, text and graphics editing.

All authors have read and approved the final version of the paper.

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