

Using IoT Devices Powered by Scientific Visualization Tools to Create Interactive Paleontological Museum Exhibitions

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In this paper, we propose to create interactive paleontological exhibitions using scientific visualization software tools and modern IoT capabilities. We implement this concept with a help of the multiplatform adaptive scientific visualization system SciVi. This systems' distinctive feature is knowledge-driven functioning. It enables extending SciVi capabilities by replenishing underlying knowledge base that contains ontologies describing supported visual objects, graphical scenes, data transformers and filters, etc. Thereby it becomes easy to add to SciVi new rendering algorithms needed for particular exhibitions. Another important SciVi feature is the built-in firmware generator that automates the installation of this system on the IoT electronic gadgets. SciVi provides the user with high-level data flow diagram editor that enables composing data transformation and rendering pipelines by chaining supported data filters, visual objects and other elements described in the knowledge base. This editor turns SciVi into high-level self-service visual programming tool for IoT devices that is easy enough to be used by non-professional or inexperienced programmers, for example by museum research workers. We demonstrate the proposed approach by an example of interactive Dimetrodon grandis exhibit that includes scientifically accurate animated 3D reconstruction of dimetrodon based on the latest paleontological research. The movements of the reconstructed model are controlled by an IoT-based light direction sensor that makes dimetrodon to rotate its sail against the incoming light. The rendering is performed using Peppers' Ghost technique to reach volumetric illusion. The exhibit is created in the Museum of Permian Antiquities making the first step towards the smart paleontological museum in Perm.

Keywords: Scientific Visualization, IoT, Smart Museum, Paleontology, Dimetrodon Reconstruction.

1. Introduction

The reconstruction of prehistoric life forms is a complicated problem in paleontology. When it comes to the creatures lived millions of years ago, fossils and prints are almost the only evidence of their existence. These data are very uncertain and ambiguous, so it seems to be almost impossible to uniquely reconstruct outfit and behavior of extinct animals. But the new discoveries in biology and paleontology enable the look at the prehistoric fauna to evolve. For example, since the 1960s the new interpretations of paleontological facts and fossils built up the completely new point of view at the dinosaurs. This scientific revolution is called “dinosaur renaissance” [1]. It is already proven, that some dinosaurs were feather-covered, warm-blooded and had complicated behavior.

However, the media image of prehistoric life is still based on outdated concepts and hypotheses. The modern films, cartoons, and games often present prehistoric animals as bloodthirsty monsters, indicating the ancient times as eon of harmless predators and doomed victims. Such dramatization has desired artistic effect but forms a kind of “media trap” for the casual audience. People who are far from biology often imagine the prehistoric world as some fabulous place and do not distinguish the real but extinct animals like dinosaurs from the mythical creatures like dragons. This consequently leads to some more heavy misconception, when modern people despite their education cannot truly distinguish evidence-based science

from fairy tales, which in turn brings serious world-view problems.

The possible way out of this “media trap” is high-quality multimedia brightening content that can be shown in museums, thematic exhibitions, etc. This content should incorporate the latest scientific data about prehistoric life and present them in visual and memorable form. While professional paleoartists already go this way [12], scientifically accurate artistic content is still badly needed.

We propose using scientific visualization techniques combined with the Internet of Things (IoT) [8] to develop interactive museum exhibitions, which can attract the visitors and help them to discover state-of-the-art paleontological concepts. IoT principles ensure high interactivity of exhibitions, while scientific visualization enables observable and attractive way for scientific data presentation.

2. Related Work

2.1. Smart Museum Concept

In the present time the museums are not just “storages for old things”, but fully featured brightening places equipped with modern tools to represent information. The possibilities of today's microelectronics together with state-of-the-art IoT technologies enable so-called Smart Museums [7]. This concept assumes placing the IoT devices inside the museum rooms to allow advanced navigation and guides for visitors having smartphones or tablets with WiFi and Bluetooth support. Another application of IoT technologies in

museums is monitoring the visitors' activity inside the museum, which may be useful to find out which parts of exhibition attract more attention [4].

While state-of-the-art Smart Museum solutions focus on the indoor navigation, IoT technologies also provide a wide range of interaction possibilities. We propose to use sensors, actuators, and displays assembled into IoT devices to make the museum exhibitions much more vivid, ensuring different reactions to the visitors' actions performed both by mobile devices and by the people themselves.

2.2. Scientific Visualization Tools

In our previous research, we analyzed the state-of-the-art scientific visualization systems and found out that there is a lack of high-level tools to efficiently solve non-standard scientific visualization problems [10]. This was the motivation to create original scientific visualization system SciVi based on ontology engineering methods. The behavior of SciVi is completely governed by its ontological knowledge base. Hence it can be easily extended by replenishment of underplayed ontologies and thereby adapted to visualization tasks in almost any application domain with arbitrary data sources as input.

As the next step of SciVi development, we implemented the module enabling parts of SciVi to be incorporated in the firmware of IoT devices. This allows to automatically create lightweight visualization servers inside the IoT ecosystem, which ensure monitoring of IoT generated data as well as calibration of related electronic gadgets [9]. Consequently, we propose using SciVi as a visualization core for the interactive IoT-based museum exhibitions.

2.3. Volumetric Displays

There are many attempts to create volumetric displays [2], which enable showing 3D models with true volume, not just flat projections. Most of these technologies involve relative expensive devices and are quite complicated to assemble.

However, there are also some "compromise" solutions, which do not reach real volumetric images but provide optical illusions ensuring the perception of volume. First of all, those are technologies based on stereoscopy. Their drawback is the need of separation glasses or parallax-barrier displays.

The alternative solution is so-called "Pepper's Ghost" [3]. Its drawback is semitransparency of the resulting image, but sometimes this effect could be desired. Being invented in 1862, this technology was reborn since LCD displays appear [11]. In the technical and marketing slang it is currently called "3D Hologram", however, this name is not correct in terms of physics: no holography is used, just a light reflection on a slant transparent surface.

¹<https://sketchfab.com/models/21c7948d4d1e4c219ff6af19f71c8088>

²<http://johnconway.co/high-walkin>

We propose using Pepper's Ghost as a way to display 3D models in museum exhibitions because this technology enables easy and cheap installation and ensures the possibility to combine shown 3D models with real exhibits being a kind of augmented reality.

2.4. *Dimetrodon grandis* Reconstruction

The dinosaurs are the most popular prehistoric animals attracting much more public attention than any other extinct creatures. Probably this is why the look at them evolves faster. However, the new paleontological knowledge allows not only dinosaur renaissance but also a renaissance of synapsids. Traditionally thought to be primitive, most likely synapsids were been much more progressive.

State-of-the-art work of Scott Hartman [6] describes the new look at *Dimetrodon grandis* Romer and Price, 1940, early Permian synapsid lived more than 290 million years ago. The distinctive features of Hartman's dimetrodon reconstruction are new sail shape, new back curvature, and high walk pose. While this reconstruction is very plausible, there is still lack of its visual representations across museums and media environment. It especially relates to 3D models. Almost the only high-quality scientifically accurate 3D model of *Dimetrodon grandis* found in the Internet¹ is not available by any license, not even commercial one.

To fill this media content gap we created our own 3D reconstruction of *Dimetrodon grandis* according to the S. Hartman's concept. The outfit of this reconstruction was inspired by the book "All Yesterdays", J. Conway and C.M. Kosemen [5] as well as by J. Conway drawing². This model was used as a visual basis for the IoT-powered interactive museum exhibit.

3. IoT-Powered Paleontological Exhibit

We developed an exhibit of *Dimetrodon grandis* demonstrating two aspects of modern paleontological knowledge about this synapsid:

1. Anatomical features according to S. Hartman's reconstruction.
2. The concept that the dimetrodon's sail served to effectively heat the creature's body by the sun rays.

The first aspect is demonstrated by animated 3D model created in Blender 3D editor and displayed by the scientific visualization system SciVi using Pepper's Ghost technique.

The demonstration of the second aspect involves interactivity powered by IoT device, that includes the light direction sensor and WiFi connection module. The firmware for this device is generated by SciVi and includes visualization HTTP-server code in C++ and client code in JavaScript. Arbitrary third-party mobile device or computer can connect to this server via WiFi, obtain visualization client over HTTP and dis-

play the animated dimetrodon model using WebGL. The visualization server hosted on the IoT device provides WebSocket connection and transmits direction of light detected by the sensor. According to this data, the virtual light source is located on the graphical scene and the rendered dimetrodon automatically rotates its body to make its sail nearly perpendicular to the light rays.

The museum visitors can illuminate the sensor with a flashlight and see the dimetrodon reaction either on their smartphones/tablets connected to the IoT device or on the specially installed Pepper's Ghost visualization that provides the volumetric illusion.

3.1. 3D Model

The 3D model of *Dimetrodon grandis* is created in Blender using S. Hartman's reconstruction as the main anatomy reference, J. Conway's art as a texture reference and the skeleton anatomical casting from the Museum of Permian Antiquities as an auxiliary anatomy reference. Although this anatomical casting is based on "old school" concepts of dimetrodon anatomy, it still was useful to clarify some details not changed by S. Hartman, like, for example, the structure of fingers.

The created model is shown in Fig. 1 a. It includes ca. 3 000 vertices connected in ca. 5 000 triangles and contains 33 bones for skeletal animation. The surface material includes color textures and normal maps. For compatibility with rendering mechanisms, the model was exported to COLLADA format.

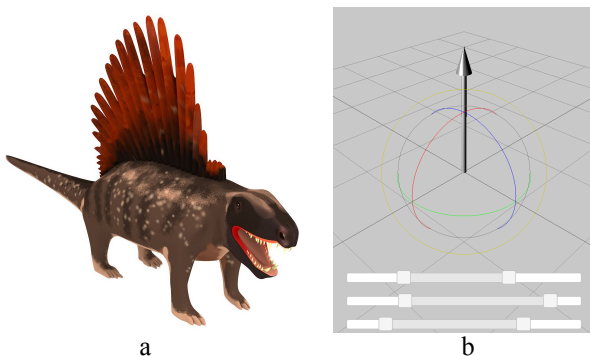


Figure 1. Dimetrodon 3D model rendering result (a) and calibration scene of light direction sensor (b).

3.2. Light Direction Sensor

The detailed description of a light direction sensor used in the mentioned exhibit can be found in [9]. This device is based on the ESP8266 microcontroller with onboard WiFi communication module and contains 3 photoresistors VT90N2 placed at the vertices of an equilateral triangle with their surfaces oriented 45° to the ground. Each photoresistor detects the amount of light in the certain direction, collinear to

its surface normal. The 3 surface normals \vec{n}_1 , \vec{n}_2 , \vec{n}_3 of photoresistors build the basis of vector space where the light incidence direction can be expressed as $l = a_1\vec{n}_1 + a_2\vec{n}_2 + a_3\vec{n}_3$. The expansion coefficients a_1 , a_2 , a_3 of the light incidence vector are evaluated based on the voltages on the photoresistors.

The firmware for this device was generated by scientific visualization system SciVi according to the data flow diagram composed in the special built-in high-level graphical editor. This diagram describes the entire software logic of the device including the photoresistors polling, calibration mechanisms, and graphical scene.

The functioning cycle of light direction sensor consists of two main stages: calibration and 3D model rendering. During the calibration stage, the user (or the museum hall administrator) sets up the basis vectors of the virtual scene space to match the real vectors of photoresistors' surface normals. This ensures the matching of light direction detected by the sensor with the direction of simulated virtual light. For that, a special graphical scene is used with the feedback to the sensor. This scene is demonstrated in the Fig. 1 b. The big arrow represents the direction to the light source, which corresponds to $l = M(a_1\vec{n}_1 + a_2\vec{n}_2 + a_3\vec{n}_3)$, where M is transformation matrix for the basis. The user can rotate the rendered arrow on the scene using drag'n'drop and thereby modify the matrix M . Three range sliders on the bottom in Fig. 1 b represent the mapping the resistor's voltages to the expansion coefficients $a_i = \frac{u_i}{1023}(R_i - r_i) + r_i$, where r_i and R_i are minimal and maximal values of the slider respectively, u_i is measured voltage on the resistor, $i = \overline{1, 3}$, 1023 stands from maximal value of analog-to-digital converter of the device. The user can alter this mapping to compensate possible deviations in voltage measurements and thereby increase the sensor's precision. After the calibration is done, rendering stage can begin.

3.3. Rendering

The renderer is based on Three.js³ engine and uses WebGL API to ensure high-quality real-time 3D model visualization. Two rendering modes are supported: regular rendering suitable for user's smartphone or tablet and special four-sided view rendering suitable for Pepper's Ghost illusion. In the first case, the dimetrodon model is visualized to the full screen. The rendering schema for the second case is shown in the Fig. 2 a. The letter "R" indicates orientation of the image.

The idea is to render the 3D model to texture and then map this texture to 4 trapezium-shaped sprites positioned as shown in the Fig. 2 a. The screen that displays the rendered image is located horizontally with a plexiglass frustum placed on top of it as shown in Fig. 2 b. The sides of the frustum are aligned to the

³<http://threejs.org/>

sprites. The angle between each side and screen surface is 45° . The texture content reflects on each side and the reflections build an illusion as if the rendered 3D model was inside the frustum.

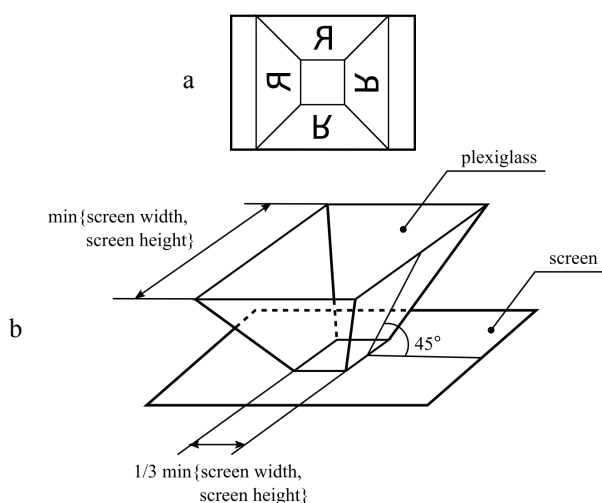


Figure 2. Rendering schema (a) and reflective frustum schema (b) for Pepper's Ghost illusion.

4. Conclusion

While IoT enables great capabilities for creating smart museums, one still needs high-level software to utilize different kinds of devices assembling interactive museum environment. We propose using adaptive scientific visualization system SciVi as a self-service software tool for creating IoT-powered interactive paleontological exhibitions. It allows generating the firmware for IoT-devices according to the user-defined data flow diagrams combining the calibration, interaction and visualization logic. Thanks to high-level graphical user interface SciVi can be used as a visual programming tool suitable for non-experienced programmers and device makers, for example, for museum research workers who create interactive exhibitions.

We demonstrate the concept of IoT-powered smart paleontological museum by creating the interactive reconstruction of *Dimetrodon grandis*. This exhibit includes scientifically accurate 3D reconstruction of dimetrodon that rotates its sail against the incoming light detected by the light direction sensor based on ESP8266 microcontroller. This exhibit is made in the museum of Permian antiquities.

For the next project, we plan to assemble the interactive scale of geological periods based on ultrasonic proximity sensor to enable museum visitors to navigate through the geological periods by moving hand along the scale and get the feedback from the exhibit.

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