Implementation of Reusable Solutions for Remote Laboratory Development

Abstract—Development of remote laboratory for embedded systems complex hardware/software design is an actual task, because the challenges existing in this area, require qualitatively new techniques, technologies and tools of design. By using the possibilities of remote labs and reusable hardware/software components, developer can more optimally organize the project and realize it in a shorter time. Development and usage of remote labs for designers can give new opportunities and ways for accumulation and study of existing design experience and ready solutions. On the other side, today, in the area of remote laboratories development are no common standards and approaches. Different developers offer different solutions for laboratory functionality, interfaces, a set of experiments, etc. At the same time, there are a number of ready-made solutions that can be used repeatedly for more optimal development and rapid integration with existing projects. Therefore, investigation and implementation of re-use methodology and its practical realization is an urgent task. The paper presents the structural components and API of remote laboratory RELDES, proposed for reuse in other projects for creation of mobile applications, new clients or services. Open questions of RESTful API documenting are also discussed.

Index Terms—embedded systems design; remote laboratory; software/hardware components reuse; API; REST - request.

I. INTRODUCTION

Nowadays reusable solutions are becoming more and more necessary in various fields. Different reasons of reuse are traced, but main goal - optimization. Reuse brings a lot of benefits, from which time and cost savings are the most important. A huge number of works demonstrate, that the reuse is demanded in the engineering. Reusable solutions are of interest to engineering community because they give possibility to replicate and to implement the separate parts of system without spending time for their development [1-5].

Embedded systems (ESs) design is one of the fields of reusable solutions creation and application. Requirements to the ESs functional complexity and design time are enhanced. Under these conditions, the development of systems based on ready solutions becomes more effective. Thus, the accumulation of technical solutions and their subsequent reuse are perspective directions of ESs design efficiency improving.

As known, the ESs includes the hardware and software components. Increasing reuse opportunities is a well-known task for software as well as for hardware designers. But current software and hardware engineering practices have embraced different approaches to this problem [1].

The actual question is: at what stage of the life cycle of the hardware/software systems should decide that certain components (or modules entirely) worthy of reuse? Normally this decision makes on the fly somewhere between analysis and design, sometimes it is taken at the design stage, sometimes - during realization or generalization.

For a successful selection of software components for reuse are important the following aspects [6]:

- Understand the architecture of the original code.
- Define potential reuse.
- Evaluation of expenses of time for reuse as compared to reworking of components.
- Decide for each component: what and how to reuse.

Revolution of platform-based approach in the design was the beginning of the new concepts of ESs quick development and prototyping. Ready hardware/software platforms give possibility of systems components reuse for the design process efficiency improvement. The Basic Concept for Remote-based Embedded Systems Design was proposed in the authors’ previous works [7]. Development and application of remote laboratories for ESs rapid prototyping based on reusable hardware and software components is an actual task today for professionals [8-10].

There are many successful projects, moving faster by reusing existing software (WebLab-Deusto, iLab, Sahara, etc.) and hardware (VISIR, etc.) solutions. [11-13]. Knowledge about reuse can be useful for developers of such remote laboratories (RLs) for ESs design.

That is why the aim of this work is investigation of reuse experience in the field of remote lab development and identification of remote labs reusable hardware/software components.

II. INVESTIGATION OF RL INFRASTRUCTURE AS A SERVICE

As shown last decade the number of remote laboratories increased. Each developer finds his own way to develop remote laboratory from scratch. This way is always difficult and includes the different kind of problems during the development and testing RL.

Hence, in the recent years, the question about the new approach to the development of the remote laboratory, which consists of independent modules, becomes relevant. The development of such an approach will contribute the lab’s individual components reuse and simplify the creation of RLs.

One such approach is Laboratory as a Service (LaaS) paradigm which is described in [14]. The main idea of this
paradigm is developing modular remote laboratory. All functionalities of which are implemented using REST web service (but not limited) and will be delivery in the “service description file” as a set of abstraction service. As authors underline the first interpretation of this approach is called Anything as a Service (XaaS), but it was no clear and had some undecided question. Moreover in the [15] was said that LaaS is a new idea and came from Software to Service (SaaS) paradigm. Also in this work authors proposed their own approach to delivering laboratory server infrastructure as a service (LaaS). In contrast to the LaaS paradigm in the presented approach user don’t have to deployed as several HTTP loosely coupled services themselves. LaaS have two way how to access to the experiment will be delivered (at the lab owner’s discretion): using a Remote Laboratory Management System (RLMS), or without RLMS directly with laboratory using Experiment Dispatcher.

On a practice we implement of an experiment engine (EE) using the Experiment Dispatcher for ELVIS lab which was developed on iLab Sharing Architecture. The Experiment Dispatcher is a web application that allows for the centralization of some typical functionality of online laboratory servers. It shifts the core features of an Online laboratory server to a central location and allows for a seamless reuse of the lab server infrastructure by heterogeneous online laboratories. In other words, it abstracts the development of the software necessary to deliver remote experimentation.

PHP language was choosing like the programing language for developing EE. For communication experiment engine with server the Dispatcher has REST Web Services API. API includes several HTTP methods such as PUT/POST, GET and other. All requests are presented in the JSON format. Requests should contain the Authorization HTTP header (username and password) and the HTTP header “X-apikey”. The value is a key that will identify this particular experiment engine with a lab server. The values of both username and password (for the Authorization header) and X-apikey were received after registration on iLab Service Broker.

**Example of the HTTP request**

```php
$response = 
authenticateWith($user,$password)
->addHeader('X-apikey',$apiKey)
->expectsJson()
->send();
$result = json_decode($response);
echo "Experiment status: ";
if($result->success) {echo "true";}
else echo "false";
```

The result generated by the batched lab is a data in JSON format, so we should decode it.

The one examples of the use of laboratory’s infrastructure and functionalities has been shown above. This approach allows the reuse remote lab infrastructure to crate your own experiment, without spending the time to develop whole RL.

Research has shown that in general exist several remote laboratories which promote the reuse paradigm in the field of remote labs development: iLab Shared Architecture, WebLab-Deusto, Labshare Sahara. These laboratories have been investigated by various authors in the works [16, 15, 17]. All of these remote laboratories have their own RLMS that help to organize a centralized management of the laboratory’s functionalities (registration, authorization, queue, management of experiment and other). The functionality of which is available through the Web-service API.

Based on this experience of using a Web-service API for creation additional client for remote lab, it was decided to merge all the functionality of the remote lab RELDES into the RELDES management system and to create API which was used REST technology for connection client with service. This will allow easier to create a new server’s client.

### III. Implementation of Remote Laboratory for Design of Embedded Systems

Remote Laboratory for Design of Embedded Systems (RELDES) is user friendly application for testing and rapid prototyping of the ESs based on reusable hardware and software components [18]. Today 4 experiments based on Arduino boards and control equipment - actuators, ultrasonic distance sensor, traffic light and LCD display are implemented [19].

All specifications, schemes of experiments and program code (templates for the experiments usage) are available at the RL web-page. Like other developers of Relle lab [20], we also have chosen Arduino platform, as one of the most popular and simple reusable solution. Nevertheless, the proposed set of experiments can be expanded for other hardware/software platforms, and tasks connected with realization of various classes of ESs.

RELDES Management system includes next modules: Registration; Administration; Execution of the experiment; API (Fig. 1).

For Registration in the system a common procedure of filling the standard fields is implemented: Username, Password, Email, Name. If a login is successful, the user receives an email with link to complete the registration process. After confirmation, the user will be able to use API RELDES with his individual API-KEY.

**Administration** of the system includes monitoring of experiments current state, statistics of experiments execution, as well as feedback to users. Admin module is implemented as panel which includes area for information visualization and 3 points of menu: Notification of users; Keeping statistics; Management of experiments (Fig. 2).

On the Notification of users is a list of all users registered in the system with the ability of mail to individual user or to a group of users using simple check box.

On the Keeping statistics the system displays a table with all successfully compiled source code. The chart of each experiment activity is also presented.

On the Management of experiments the system displays a table with the current state of each experiment and if experiment is occupied - it shows the login of the user who is working on the experiment now. Also for each of experiments will be shown a Queue table and users will receive access to experiments in accordance with this queue.
Queue panel (Fig. 3) demonstrates the current state of each experiment (free/busy), allows the view of all users who are in the queue list. Start and finish time for each user and experiment is also displayed as the basic information.

When the experiment successfully occupied by the user, he has the next opportunities for Execution of the experiment:

- Create program code from scratch in the RL special window with syntax highlighting.
- Upload own file with program code.
- Use ready software solutions (several scenarios are proposed for each experiment).

After that, the source code can be sent to the server for compilation and loading to Arduino board of the current experiment.

RELDES API provides access to the lab server infrastructure and allows a seamless reuse of the lab functionality.

The API includes functions for the next HTTP requests (id - experiments number from 1 to 4 and username - user login):

- GET/.../expStatus/id - checks on the status of experiment and returns result: busy(1) or free (0).
- POST/.../queueUp/id/username – checks on the status of experiment and puts the user with the given userName in the experiment queue. Returns the result about adding to the queue.
- GET/.../getQueue/id/username - gets the waiting time specified user #UserName for a given experiment #id
- GET/.../getExpQueue/id - gets a list of all queues on the experiment #id
- GET/.../getAllQueue - gets a list of all queues on experiments
- POST/.../compile/id/ - checks the validity of the program code for Arduino board.
- POST/.../upload/id/username/ - uploads the hex file after compiling if current user has taken the experiment.

For example, function compile receives and handles REST- requests [21-22] that can be sent by the users. It does the following: sends the code from request to controller; compiles it on the server using Ino; generates result of compiling as response.

Any registered developers can use the API for their own purposes. It may be use for creation of mobile applications, new clients or services.

IV. IDENTIFICATION OF REUSE POSSIBILITIES OF RELDES COMPONENTS

A priori, we proceeded from the fact that the possibilities of reuse should be laid from the beginning of development and that is why we started with a clear and simple architecture, which is well solves the task (Fig. 4).

As a template for application separation to the levels, we have chosen a MVC (Model-View-Controller) pattern. The MVC pattern describes a simple method for constructing the...
structure of an application, the aim of which is to separate the business logic from the user interface [23-24].

As a result, the application is easier developed, scaled, tested and accompanied. The correct separation of applications helps to maintain a strict separation of functionality that provides the flexibility and convenience and ease of maintenance. This makes the different functionality of the application reusable.

MVC pattern helped functionally divided our system to further the reusable components creation. Model, View and Controller interfaces have been developed.

Interface Controller demonstrates the implementation of system interaction with user, so all users main methods are located in classes that inherited from this interface. We have created three classes and inherited from Controller (front, experiment and admin) to divide the system to structural components (Fig.6). All functions that connected with all methods from main system page are located in front class. Experiment class includes all methods that provide performance of the experiment and experiment page. Admin class contains all administrative functions for keeping statistics, email notifications etc.

Model is developed to store data that retrieved to the Controller and displayed in the View. So three models for controllers: front_model, experiment_model, admin_model have been developed. Objects of front_model, experiment_model and admin_model respectively for access to their functions in controllers have been created. In particular, the Model deals with the registration and authorization of users (for example, functions: addUser, getUser, getUserID). Also, the Model provides information about the experiments: occupied or free experiment (isBusy); to occupy experiment (occupy); to free experiment (free).
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**VI. FEATURES AND APPROACHES TO API DOCUMENTATION DEVELOPMENT**

After the development of API, it is very important to make a detailed and well-structured documentation of it, because exactly this step will determine how effectively this API will be used. Today API RELDES documentation is presented in plain text descriptions on the labs webpage and consists of General description, API routes and methods, Input parameters, Output data, possible errors (Fig. 5).

The issue of documenting is not so simple, as it looks. Most companies, even large ones, still prefer to use a simple text description. But the disadvantages of this approach lies in the fact that such documentation is hard to maintain up to date and its functionality is quite limited.

To simplify the process of API documenting exist different specialized tools and services (API Blueprint, Swagger, RESTUnited, MireDot, Kitten API, apiDOC, apiGen and others). As a rule, they generate documents based on the description in a standardized formats (JSON, Markdown, YAML, RAML). For example, Swagger supports YAML format. YAML is much more convenient than the JSON, but it does not allow easy describe the repeating elements, which are often present in the API descriptions. API Blueprint use format Markdown which was intended primarily for text formatting and not for use as a basis to generate. So, it is very difficult to adjust it under API documenting. API Designer – is interactive editor, based on RAML format for writing documents online, and a platform for testing. Its undoubtedly advantages are simplicity and consistency, but the problem is the lack of tools developed by the community. Some generators support limited number of programming languages, some are not for free and all have their own advantages and disadvantages.

So, after the all possibilities were considered, one of the most suitable was found apiGen. apiGen is the tool for creating professional API documentation from PHP source code. ApiGen has support for PHP 5.3 namespaces, packages, linking between documentation, cross referencing to PHP standard classes and general documentation, creation of highlighted source code and experimental support for PHP 5.4 traits [25]. Use of this tool speeds up the project due to the fact that just in the process of developing you write the necessary comments for the code and then simply pass this file to apiGen, and it generates a ready-made page with search, links, etc., i.e. there is no need for the additional development of the page with description of API documentation. We think this tool really allow us to create smart and readable documentation for our PHP project (Fig. 6).

However, in the future, when the RELDES API will expand, its functionality will be appropriate to use another standards and generators for developing and documenting.

**VI. CONCLUSIONS**

As in other high-technology fields, in remote lab development there is great benefit in the reuse of different intellectual property. Creation of reusable lab components is a step towards the reduction of labor costs in the remote lab.
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