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An Experimental Platform for *e*-Manufacturing and Advanced Control ⋆

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Abstract
In this paper, we present an experimental platform for education and research purposes. The physical production system of this platform is composed of a manufacturing workshop (physical plant) remotely controlled through Internet. The information system is composed of three Web applications allowing to order products (*e*-COMMERCE), plan production campaign (*e*-PLAN) and control the workshop in order to release production (*e*-MES). We first describe an education application for engineer students to teach them how to control several production units (possibly on different sites). This platform would also be used as a demo for research works in the field of industrial engineering.

Keywords:
Control education; Command & control systems; Remote and distributed control

1. INTRODUCTION

Remote control of one or more production units is a major issue within the globalisation of production [Panetto et al., 2006]. In a near future, we can imagine that a production manager will be able to remotely control several plants all over the world in real-time. Within this prospect, we developped an experimental platform. This platform includes a real production line and an information system. The information system is composed of different applications accessible from the Internet. We intend to use this platform for education and research purposes.

In section 2, we present the architecture and functioning of the physical manufacturing system. In section 3, we describe the information system, with a highlight on the three applications used to process orders (ordering, planning and production management) from the Internet. We detail in section 4 the possible applications for education with this platform. The section 5 outlines some future research applications. Section 6 gives an abstract of some problems we met. Finally, section 7 explains the realization and future plans.

2. OVERVIEW OF THE PHYSICAL SYSTEM

The system consists of a production line, composed of four workstations, one load station and one unload station linked by automatic conveyors. The aim of this production line is to fill boxes with different kinds of components. The box is loaded on a pallet which includes a RFID tag to identify the product, operations to perform and data over passed operations. The pallets are automatically routed to each station thanks to the data written in the RFID tag.

Load station 1 and unload station 6 are the beginning and the end of all manufacturing processes. A central loop supplies each workstation with pallets. The bypass workstations 2 to 5 are dedicated to assembly tasks: inserting some components in the box automatically (workstation 2) or manually (workstation 3), closing the box (workstation 4), inserting some sub-assemblies in the box (workstation 5). The figure 1 shows an example of product and its route sheet. Figure 2 details the functions of workstations.

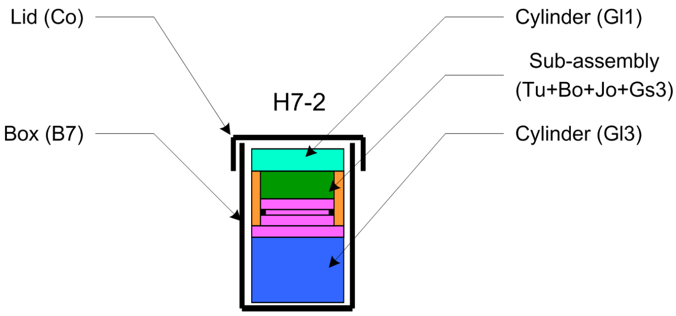
Each station is in derivation of a circular conveyor belt. For each station, a Programmable Logic Controller (PLC) controls the behavior of the derivating conveyor belt, and manages priorities when products come back on the central conveyor belt (except for stations 1 and 6, which are controled by the same PLC; see figure 3).

The link between physical system (mainly: manufacturing line) and information system we will focus on is provided by two servers (computers). These servers are located on two different sites connected to Internet. The production line is located at RASCOL with one server (OPC server for data gathering), and the other server in EMAC site hosts the information system (and OPC client). The figure 4 shows the servers' disposition.

3. FOCUS ON THE INFORMATION SYSTEM

Based upon the physical system described above, we have an information system, consisting of mainly three applications:

⋆ This work is based upon a project initiated by the École des Mines d'Albi-Carmaux and the "Plate-Forme Technologique" of the "Lycée Rascol", in Albi.



Step	Station	Operations
10	Load	load box B7 on pallet
20	S2 or S3	insert 1 cylinder Gl3
30	S5	insert 1 sub-assembly
40	S2 or S3	insert 1 cylinder Gl1
50	S4	close the box
60	Unload	unload product H7-2 from pallet

Figure 1. The box "H7-2" and its route sheet

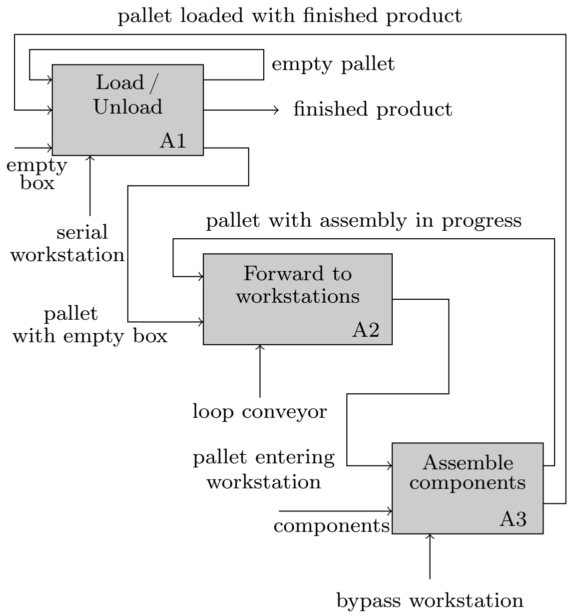


Figure 2. Functions of the production line

- *e*-COMMERCE, an application where customers may connect and order products;
- *e*-PLAN, connected with *e*-COMMERCE, it may verify the feasability (in terms of date) of the commands, and it allows the production manager to plan the orders;
- *e*-MES, or *Manufacturing Execution System*, allowing the remote control of the production line.

The *e*-COMMERCE and *e*-PLAN applications are located on a server in EMAC site whereas *e*-MES is deployed on both machines (in EMAC and RASCOL; see figure 4). The *e*-MES services are all hosted in EMAC but the communication service hosted in RASCOL. This service is based upon the

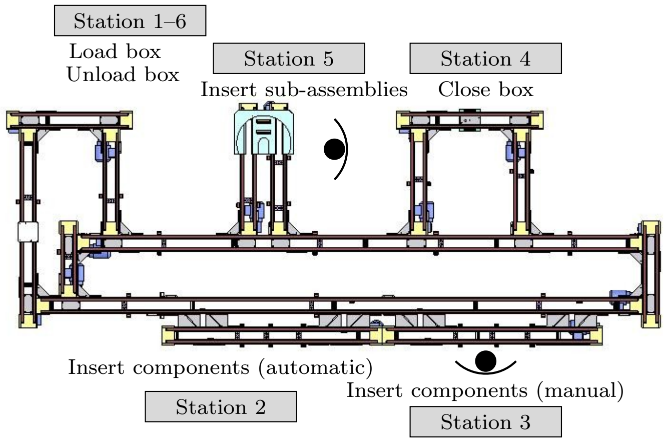


Figure 3. The production line: conveyors, PLCs and operations

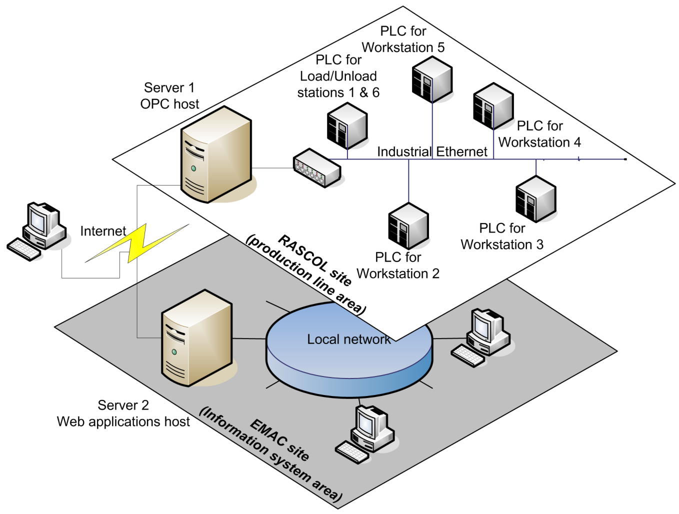


Figure 4. Location of servers

OPC[1] technology, which provides PLC data access. The OPC standard allows communication between PLCs and computers through local network (industrial Ethernet). An hard point is access to OPC variables across the Internet (see section 6 and [Neumann, 2004, Banaszak and Zaremba, 2003, Dolgui et al., 2006]).

OPC standard is a means of access to a PLC variables. A computer hosts an OPC server, which is connected (in our case, through Ethernet) to the PLCs. An OPC client may be deployed on the same or another computer. The *e*-MES application provides an OPC client which may be delocalized on another computer (typically, the OPC server) to avoid every problems due to DCOM and firewall settings. This delocalized OPC client is called a "*daemon*" in our *e*-MES application [GlobalScreen Intra].

The RASCOL server hosts a *daemon*; this *daemon* is contacted by the *e*-MES server on the other host (this daemon is the communication service), and deploys an OPC client to communicate with the OPC servers, which

[1] Ole for Process Control, see [OPC Foundation]

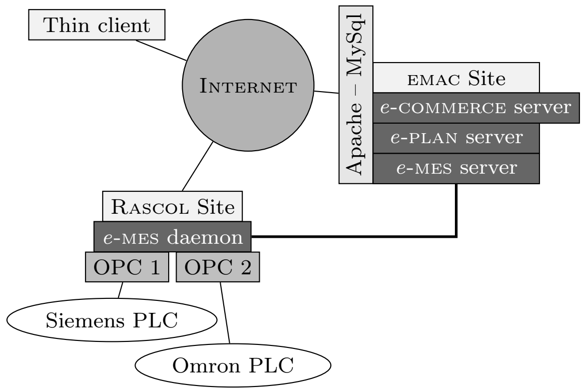


Figure 5. Servers and hosted applications

gathers (and sends) data from (and to) the PLC (see figure 5).

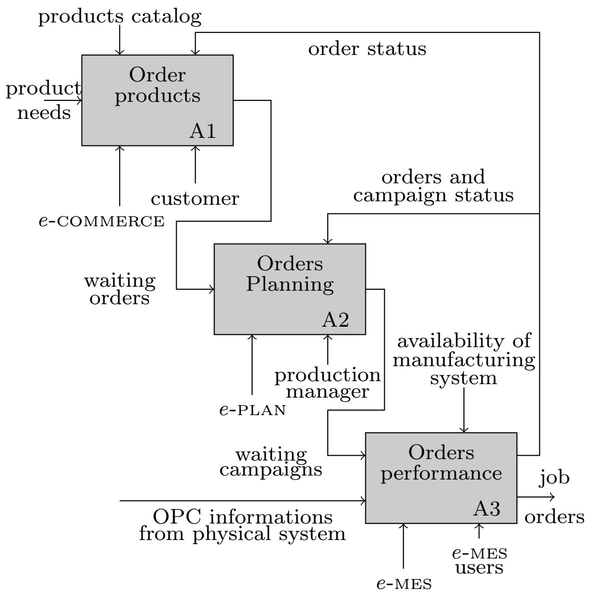


Figure 6. Order processing

The figure 6 shows the whole process, from a customer ordering products to the manufacturing process. Using e-COMMERCE, all the orders of all customers are stored into a database. Then, the production manager may select different line items (from different orders and/or different customers) and sort them into a campaign, using e-PLAN. On the figure 7, we can see the process of campaign scheduling; currently, our applications do not provide any support to this process (see sections 5 and 7 for future work). Finally, the e-MES users may release the production, integrating data from campaign into the e-MES database. The e-MES sends to the load station the number of pallets to be done, and for each pallet the complete process data. These data are written in a RFID tag on the pallet.

During the manufacturing process, the RFID tag is read by every workstation, and if an operation is performed, the PLC writes data over the operation (status, time...) in the RFID tag. At every time of the manufacturing process, the

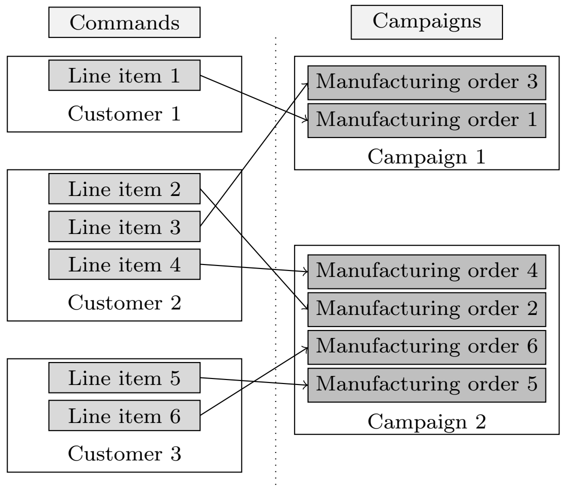


Figure 7. Process of scheduling a campaign: from line items to manufacturing orders

e-MES has an access to a bunch of data from the PLCs, for example: number of pallets launched and finished, stock status for each station...

The server in EMAC hosts the e-COMMERCE and e-MAC applications and their database. These applications allow customers to order products with a *Web* interface. Each order contains at least one line item (product, quantity and wished delivery date). e-PLAN may be called at this step for two reasons: (i) check that the wished date is in the future (ii) with a quick planning, ensure that the line item may be delivered within the wished date. At this stage of development, only the task (i) is implemented in e-PLAN. With e-PLAN, the production manager will schedule the definitive plan for production. When a campaign is ready (line items validated and integrated and some parameters set), it comes to a queue, which may be sorted by the production manager. The first campaign of the queue may then be released. The parameters include :

- number of pallets in process,
- for each workstation: capacity of upstream and downstream queues, priority rules (exit of workstation / central loop).

The e-MES user (workshop manager,...) has an interface to start the line (switch conveyors on,...), and he can release the first campaign in the queue; The e-MES will load the data corresponding to the first line item and send them to the PLC # 1. Then, the production will start as soon as a pallet will be detected on the line before the first PLC (except if a campaign is already launched, or the line is stopped).

Finally, the system is redondant enough to accept some brief cuts with the Internet link. If a campaign has been released, the RFID tags (and PLCs) contain enough information to finish the campaign without need of the remote server.

Now that we described the way the system works, we will focus on applications, with a special highlight on education.

4. APPLICATIONS FOR EDUCATION

4.1 Goals of this experimental platform

We admit that globalisation of industrial production is to be taken into account for education of future engineers. To get on one side the best products and on the other side a better responsiveness, companies tend to organize into national or international-wide networks, including many production sites. To answer the customer's needs, one of the major points is the flexibility responsiveness associated with the highest customer service ratio. However, the hard point of these networks (or companies which have several production sites) is (i) to get a better coordination of the set of plants/companies (ii) to globally optimize the whole network, to get higher profits [Morel et al., 2007].

This experimental platform is intended to put the student in a "real-world" situation, as similar as the ones he could deal with as a production manager. First of all, his work consists in controling a subplant, to satisfy orders by delivering finished goods. So, he must be able to mobilize his knowledge in production organization, technical data, processes, performance measurement, planning, releasing, reporting and flow analysis, quality, etc. It may be necessary to have more technical knowledges (*e.g.* PLC, robotics...) if we want the student to be confronted with equipment problems and to be able to diagnose and solve them. Moreover, in order to anticipate the future technical and cultural evolutions in companies, we consider that the future production manager will not physically be present on the production site but may be on another site and will use tools to remotely control his production unit. Going further, we may imagine that the production lines will be located on different sites. Thanks to real-time remote control, the production manager would distribute orders on different sites, depending on the customers localization and the capacity and availability of each site.

The three applications constituting the information system (*e*-COMMERCE, *e*-PLAN, *e*-MES) are available from Internet. This wide availability allows students to access every function, specially the production line control, even if they are not on the site. An IP cam, installed on the production line, allows the overseeing of the process and workshop.

We will now present some education applications and we will limit these applications to one production site.

4.2 Education for production management

In this subsection, we propose an education application for engineer students, working on a remote site (not the production site).

Assumptions We assume that students have been presented the global platform and that they are able to use it: (i) create and schedule production campaign with *e*-COMMERCE and *e*-PLAN; (ii) release and follow the status of the production with *e*-MES. With these applications, they can use a discrete events flow simulator with a given model of the production system. We assume the simulation model is valid, *i.e.* its dynamic behavior is really similar to the one of real production system, specially for production flows. Thanks to this model, the students can run simulations to check their campaigns before releasing them on the real production line.

The work to be done From a list of line items coming from different customers (with different references, quantities and delays), the students have to prepare the production campaigns before release. The decision criteria for a campaign are numerous but the main goal is to respect each order's delay. The student's work may be split into two steps: (i) a preparation and planning step: for that, the students have a simulation model of the production line flows, and the production data filed by the *e*-MES from the finished campaigns. The simulation allows to familiarize with the line and identify the parameters influencing the objective (students may use design of experiments to optimize the objective), therefore determine an optimal solution, which may satisfy each customer's needs, in terms of delay. This step may eventually be done independently, without any link with the real production line. (ii) A release step on the real line, and the students may remotely release and follow the production status, taking different events into account (breakdowns, interruptions, order modification, new order...).

Follow-up of the work A technician is physically present on the production site to deal with the tasks which need to be present, but cannot interact with the choices made by the students on organization and control, except in case of emergency. The *e*-MES allows to follow in real-time the execution of every line items thanks to the RFID tags on the pallets. The students, thanks to the *e*-MES, may assign and fix every parameter of the campaigns (priority, upstream and downstream queues management on each workstation, release sequence...). The *e*-MES informs them of the disturbances that may occur on the line and the students may react by modifying some control parameters to keep the delay objective. When a campaign is finished, they may compare their real results with the simulated results they get within the preparation step. The production data filed by the *e*-MES allow them to analyze the real functionning of a production campaign.

4.3 Other education applications

Such a system integrates many physical and information subsystems; these subsystems may be disconnected to get more traditionnal education applications. For example, we may ask the students to work on a robot's programming (one of the robots installed on the line), on a PLC's programming, on the developpment of a monitoring application, etc. For the remote control, many applications may be conceivable: configuration, interconnection and performance measure of different networks (PLCs and Ethernet), configuration of OPC server and developpment of an OPC client to access PLCs' variables, etc.

5. RESEARCH APPLICATIONS

With this system, the research laboratories have an access to an experimental platform, complete, open and close to reality. The interests are (i) to have a demonstration platform to show the industry the laboratories research works with an original and innovating application and (ii) to mutualise funds and ressources with a system many laboratories can remotely use. Thanks to this system, researchers may valid their works on structure, organization and control of one or more real and remote production sites. Indeed, to take into account the recent production technologies (machines, transportation, ERP, MES, RFID, etc.), this platform offers researchers an access to means of production like those used (or which will be) in industry. This is a way of supporting research more realistically, easier to communicate and to show, and quicker to transfer on industrial sites.

Possibilities offered by this system Production data filed by the *e*-MES may be useful as real experimental data to make or validate models. A progressive extension to higher levels of an information system (ERP, APS) may be done, letting different labs the opportunity to connect their own applications, in particular in the field of decision aid. Or we may consider an extension to other production units in other laboratories/universities to get a mutli-site production system.

Research perspectives Planning optimization and campaign scheduling is the priority perspective. Indeed, the *e*-PLAN application does not yet contain any decision aid support, such that the campaign are scheduled empirically. As mentionned above, a simulation model of the physical system's flow allows to test the campaign releases but it is not used with any optimization algorithm. So the research works may relate to the coupling of the simulator and some metaheuristics to optimize the production. The objective function could be composed of many criteria like the respect of the date for each manufacturing order, minimization of the number of pallets used, load-balancing of workstations, etc. [Valckenaers et al., 2005, Fowler and Rose, 2004].

Another perspective is actually being prospected in the scope of a PhD. The aim is to use the flow simulation for control aid, being connected with a real process. The idea is to simulate in the short term the process functionning and to measure the consequences of hazardous events (stockouts, breakouts, urgent orders...) to compare with aimed objectives. We can imagine that some simulations run at each event on the real process would allow to compare the objective at the beginning of a production with the already reached objective to check if nothing has changed. Practically, the simulation tools are not able to interact with tools such as *e*-MES. So, the initialization of the simulation model in a state equivalent to the real process status and the response time of the simulation are the first gaps to fill. On the other hand, unlike the other tools of information system such as ERP, the *e*-MES tools allow to follow in real-time the evolution of indicators reflecting the process state. However, *e*-MES tools do not provide any help in the decision to correct the control variables. For this purpose, a proposal has to be made to integrate simulation with an *e*-MES used for decision aid in control [Mirdamadi et al., 2007, van der Zee, 2006].

The integration of the customer in the planning and execution system is another perspective. Indeed, the current information system (specially *e*-COMMERCE) runs without feedback: when a customer orders a product, there is no check for the workshop capacity to satisfy this order for the due date. The production line is therefore considered as unlimited capacity; this may cause late delivery. Here, the idea consists in integrating the workload calculations induced by an order to the planned workload to check the feasibility of deadlines. In case of non-feasibility, the customer must be given other possible delivery dates. So the customer would become an interactive agent in the planning process.

PCS Project Some new works are being led which aim at considering the management of a production system by the product. This approach is told product-centric, and develop the paradigm of "Product-Controlled System" (or Product-Centric). This kind of system gives the product an active role within the decisions and information flows in the production system. A product is no more considered as material moving through a workshop, but a production object which can interact with decision and production management systems. The term "intelligent product" (or "smart product") has made its apparition in literature, caracterizing the new competences attached to the product, which may also be called "active product". The communication and interaction functions between decision systems and a smart product are available through technologies such as automatic RFID (Radio Frequency Identification).

The PCS Project is a one-year exploratory project (Nov. 2007 to Nov. 2008) led by CNRS to group french research teams for computer-integrated manufacturing. Its aims are to analyze and appraise the relevancy of the product-controlled system paradigm.

An important factor for perenity and validity of works is the use of test and appraisal platforms, which must be representative of industry. These platforms would allow to validate the proposals for methodology, models and algorithms. The platform described in this article is one of those which are used for PCS Project. The whole content of the RFID tags are remotely available to the laboratories associated with this project.

6. PROBLEMS ENCOUNTERED

The first kind of problems we met are due to the tentative of remote control. Indeed, Internet connections and remote control of computers over the Net (with VNC, for example) suffer from the lack of reliability of Internet. Although the network is resistant, some breakouts may occur, specially at our final nodes.

Another kind of problem is due to OPC. This standard is based upon Microsoft DCOM, and the settings to get things working are quite complex and not really fault-tolerant. For example, some Windows updates may be the cause of a weird dysfunction. When using *e*-COMMERCE, *e*-PLAN and *e*-MES, no special settings for DCOM are needed. These special settings are useful to connect a simulation tool, which is generally hosted on another computer, and needs to access DCOM variables through different kinds of clients, for example VBA for Excel with an OPC library. This was one of the issue for the connection between simulation tools and *e*-MES to work.

To get things working, we used a specialized software [OPC DataHub] to avoid DCOM setting problems. This kind of software consists in establishing a tunnel between the OPC client and the server. OPC data can then pass through this tunnel without any specific DCOM setting.

Finally, we get some classical problems in this kind of project, as the installation (and sometimes development) of a wide information system is a hard task.

7. RESULTS AND FUTURE PLANS

On the one hand, problems with DCOM settings have been solved with OPC DataHub. We are now able to connect to the remote OPC server and gather all data from PLCs.

On the other hand, our three applications are at different levels of maturity. *e*-COMMERCE is finished and fully functionnal, allowing customers to order products. For the moment, *e*-PLAN allows a production manager to sort campaigns, but does not provide him any help. The only functionnality is to check that the wished delivery date when a customer orders a product is in the future (after today).

For the *e*-MES application, we distinguish two "modes". The first one, supervision and starting of the line, is finished and fully functionnal. It allows the workshop manager (or an operator) to connect and start the conveyors, overseeing queue status for every workstation, etc. The second mode deals with production management. The basic functions work: one may import data from *e*-PLAN (campaigns...) and release the first campaign in queue. Currently, saving of gross data contained in RFID tags is not implemented.

We may outline that our three applications are available only in French (`http://dupleix.enstimac.fr`).

The design of pedagogical applications has started at the beginning of year 2008. These applications will be first experimented during next school year (2008–2009).

8. CONCLUSION

In this paper, we presented an experimental production platform, which may be remotely controlled and would be used for education and research purposes. The education applications are almost designed to train students with real-world situations and allow them to remotely control one or more production sites. This platform is a very interesting teaching support for students as it allows them to train with real industrial equipments, playing the role of a production manager (in the near future). Currently, the remote control of a production line is not quite used, specially for security reasons, reliability and robustness of remote links, specially with Internet. We may also call cultural reasons. However, we may imagine that technology progress and globalisation would relax these constraints. We also present other applications for this platform for research purposes to show some work results or prospect for new perspectives.

ACKNOWLEDGEMENTS

A web portal allows access to applications; it is available at `http://dupleix.enstimac.fr` (only in French for the moment).

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