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The Educational Benefit of a Remote Automatic Control Laboratory. A Win-Win Collaboration between Asia and Europe

Beneficio educativo de un Laboratorio de Control Automático Remoto. Una colaboración beneficiosa para todos entre Asia y Europa

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ABSTRACT

This project aims to implement a Remote European Asian Lab, an Automatic Control remote laboratory, in the joint academic cooperation framework between two universities located in Europe and Central Asia. Emphasis is given to the inclusive solution of a shared teaching facility and its learning achievements in a bachelor course (Uzbekistan) and a master course (Italy) to foresee a better education quality. The different cultural and social contexts allow (a) the evaluation of the effect obtained by introducing a remote laboratory experience in a course entirely theoretical, and (b) the shift from a physical laboratories experience to a remote one. Students are first introduced to this laboratory by the lecturer in dedicated classes. Then students can independently access it 24/7 by simply booking a specific station for a time slot. From the analysis comes out that remote laboratory experiences positively impact learning achievements. The benefits of the remote environment are perfectly comparable with those obtained from physical laboratory activities.

RESUMEN

Palabras clave
inclusión, laboratorio remoto, instalaciones compartidas, educación de laboratorio

Este proyecto tiene como objetivo implementar un laboratorio remoto de Control Automático en el marco de cooperación académica conjunta entre dos universidades ubicadas en Europa y Asia Central. Se hace hincapié en la solución inclusiva de una instalación de enseñanza compartida y sus logros de aprendizaje en un curso de licenciatura (Uzbekistán) y en un curso de maestría (Italia) para proveer una mejor calidad de la educación. Los diferentes contextos culturales y sociales permiten (a) la evaluación del efecto obtenido al introducir una experiencia de laboratorio remoto en un curso totalmente teórico, y (b) el paso de una experiencia de laboratorio físico a una remota. Los estudiantes son introducidos por el profesor en este laboratorio por primera vez en clases dedicadas. Luego, los estudiantes pueden acceder de forma independiente las 24 horas del día, los 7 días de la semana, simplemente reservando una estación específica durante un intervalo de tiempo. Del análisis se desprende que las experiencias del laboratorio remoto impactan positivamente en los logros de aprendizaje. Los beneficios del entorno remoto son perfectamente comparables a los que se obtienen de las actividades físicas del laboratorio.

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1. Introduction

In the last two decades, different remote laboratories' experiences have been put in place worldwide. In Almarshoud (2011), the authors reviewed 21 experiences belonging to all specialisation areas in electrical engineering (electronics, communication, power systems, electrical machines, automatic control, power electronics and computer engineering). These laboratories around the world use a variety of hardware and software solutions (Lima et al., 2017). Some of these technical aspects have been shared among the community to introduce standard procedures like the VISIR (Lima et al., 2019, Tawfik et al., 2013, Viegas et al., 2018). Others tried to foster open tools to quickly create virtual and remote laboratories (de la Torre et al., 2013). To implement these technologies, several factors need to be considered regarding the adoption (such as cost and space) and the educational side (for example, the effort to integrate the curricula and trained technicians). The cost of equipment is strongly related to the educational purpose of the laboratory. To allow the shift from physical use to a virtual or remote one, the cost of additional facilities and infrastructure is not negligible. A possibility is to share facilities between different institutions to reduce this economic limitation and act more sustainably (Alves et al., 2018; Bonnaud et al., 2008). However, this requires a clearly stated education purpose among the consortium. Regarding the software, a platform equipment-independent has also been developed with a particular focus on collaborative features (Bochicchio and Longo, 2009). As a matter of fact, all the experiments that require a piece of equipment locally controlled by a computer are perfect for the virtual application. However, it is essential to underline the difference between virtual and remote. The latter is characterised by an experiment run in a physical laboratory but executed and controlled from a different location through an interface. Therefore, live interactions are vital aspects. The more students can intervene, alter, and receive visual feedback, the more the experience would be engaging and valuable (Axaopoulos et al., 2012). This remote experience has been found to be as successful as conducting experiments in a real lab (Lang et al., 2007). However, some aspects must be considered to achieve an effective learning environment. For example, in Lal et al. (2020), the authors found out that the instruction sheet is fundamental, and it needs to be carefully designed to give students the feeling of operating in actual equipment. The supervisor's role and knowledge of remote environments play a unique position in the students' learning meta-cognition (Marques et al., 2014). Another way to directly support students is to include theoretical contents that students can read and consult in a remote environment while conducting the activities (Fraile-Ardanuy et al., 2013). In Luthon et al. (2015), gamified training is created to keep a high engagement level, while other papers strongly suggest using webcams and recorders to receive live feedback (Axaopoulos et al., 2012; Bochicchio and Longo, 2009). The remote laboratories can also be used as a prior experience for an actual laboratory activity, like a pre-lab to familiarise with the instruments (Barros et al., 2008), or to finish at home an experiment run in class, for example, for filling reports (Sousa et al., 2010).

Inclusion is another feature that characterises many remote laboratories where the facilities' geographical location does not need to coincide with the users' site. Therefore, the equipment can be shared on a national (Lowe et al., 2015; Pradarelli et al., 2009) or global (Bonnaud et al., 2008; Qiao et al., 2010) scale with a breakdown of costs. Moreover, thanks to the different time zone (for example, between Australia and Europe), students worldwide can be run experiments 24/7 (Ku et al., 2011). This international cooperation on technical features needs to accommodate the cultural and social differences to improve teaching effectiveness significantly. This share of facilities includes considerations on the adoption itself. Apart from the development and the maintenance, one should consider the scalability constraints that include, in a hierarchical order, (i) experiment, (ii) laboratory, (iii) course, (iv) degree, (v) school, (vi) institution (Alves et al., 2018).

In general, remote laboratories positively affect students' learning process like the real laboratories' experiences (Garcia-Zubia et al., 2017). Keeping in mind all the features just described and the theoretical framework presented in (Tirado-Morueta et al., 2018), the structure and the methodology of an Automatic Control course have been revised. Related to this subject, the same lecturers deliver similar courses in Italy at Politecnico di Torino (PoliTo) and in Uzbekistan at Turin Polytechnic University in Tashkent (TTPU). The proposed revision paves the way for direct improvements in students' ability to solve real-world/practical control problems with trial-and-error methods. An already existing laboratory at PoliTo has been modified into a remote lab to make the students learning more tailored, reducing the building time and the related costs. This remote environment is called REAL (Remote European Asian Lab).

This paper presents how the REAL inclusive solution impacted students' learning in two different contexts. The research question turns out to be: Can different educational and social contexts share a laboratory facility to achieve a better education quality in an Automatic Control course? In particular, it will be evaluated the effect obtained by developing a remote laboratory in two directions: (a) the Uzbekistan reality in which the introduction of REAL was a novelty as the Automatic Control course was entirely theoretical, and (b) the Italian reality where there has been a shift from a physical laboratories experience to a remote one.

The following section examines the international framework and the technical solution adopted. The third section is concerned with the methodology used for this study and the related research questions. The fourth section presents the analysis and the findings of the research, followed by the conclusions.

2. Context

The Turin Polytechnic University in Tashkent (TTPU, Uzbekistan) is a private institution set up in Spring 2009 based on an agreement between the governmental entity in the automotive market, Uzavtosanoat SC, General Motors Corporation and Politecnico di Torino (PoliTo, Italy). In the past 10 Years, TTPU has been established as one of the flagship Universities in Uzbekistan, offering engineering tracks in the area of mechanical, civil and computer engineering within the framework of double degree programs with PoliTo. Both local and Italian professors jointly deliver TTPU lectures. The cooperation has been further strengthened via training and exchange periods of lecturers and researchers in Italy. To meet Uzbekistan's educational needs and characteristics, in 2018, PoliTo has organised a call for ideas "GYM: Grow Your Methodology", aimed at supporting the redefinition of teaching methodologies and course contents in bachelor programs (Ballatore et al., 2019). Implementing a remote laboratory into an Automatic Control course was one of the ideas awarded. The experimental activities on modelling and design control systems were performed in Autumn 2019 in the bachelor course at TTPU on a set of real laboratory processes available in PoliTo through a suitable remote laboratory software/hardware platform.

Based on this first positive experience, the remote automatic control lab has been furtherly extended to be also exploited in the course of *Laboratory of Robust Identification and Control* (LRIC), offered in Autumn 2020 to the students of the Master of Science in Mechatronic Engineering at PoliTo. In this context, the remote laboratory has played a crucial role to cope with the restrictions due to the COVID-19 pandemic since on-site lab activities were not allowed.

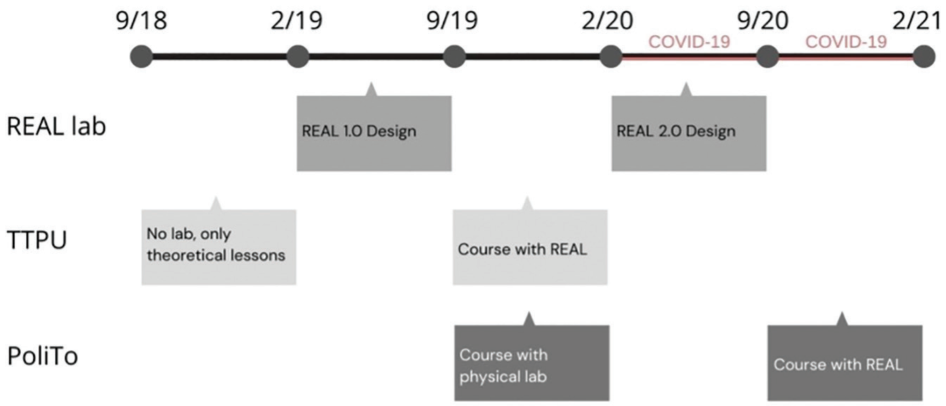
The first edition of REAL (REAL 1.0) was made by a computer located at PoliTo in Turin, connected to a set of magnetic levitation systems. The remote lab architecture consists of two parts: a client, used by the student, and a server, installed on a computer in the PoliTo lab. Each magnetic levitator available for the remote Lab is connected to a NI MyRIO board (NI, 2016), which manages the input and output signals of the system. The NI MyRIO boards, together with a webcam, are connected to a server through the USB interface. The user clients, implemented as a Simulink library block, communicate to a single NI MyRIO board through the server that acts, as a matter of fact, as a gateway system. It is essential to point out that the proposed architecture is like others that were successfully adopted in literature, including (Casini et al., 2003, Kalúz et al., 2014). The readers are referred to the references mentioned above for additional details. This contribution focuses more on the impact of the REAL in the context of lab implementation in a framework of different educational systems and involved countries.

The students can study and simulate the Matlab/Simulink environment's control problem and then move to the real plant. Through a suitable Matlab library distributed to the students, they can connect to the computer located at the PoliTo lab, program the controller with their parameters and test the system's performances. The students have direct control of the magnetic levitator, which can be switched on and off. A dedicated webcam pointed to the systems allows the student to visualise the experiment in real-time. During the investigation, the student receives accurate measurements of the interest signals that can be plotted in real-time or stored for a deferred analysis.

In the second edition (REAL 2.0), the system has been modified and extended to handle the significantly larger number of students attending the LRIC course. More precisely, a stand-alone software package based on Labview has been designed and made freely available to the students. Using such software, the students can directly and simultaneously connect to the real system to collect experimental data and/or implement their control algorithms without involving Matlab or any other proprietary software. Furthermore, the second edition of REAL also includes an online reservation system allowing the students to book the desired lab system for one or more specific time slots in the week. Figure 1 shows the REAL timeline implementation with additional information that will be commented on later.

The booking system is based on the open-source appointment scheduler “Easy!Appointments” (Tselegidis, 2018). It is implemented through a web application and hosted on a dedicated web server. Students can choose the laboratory equipment to use and a free time slot. Once the reservation is confirmed, the student receives

Figure 1. REAL design implementation timeline.

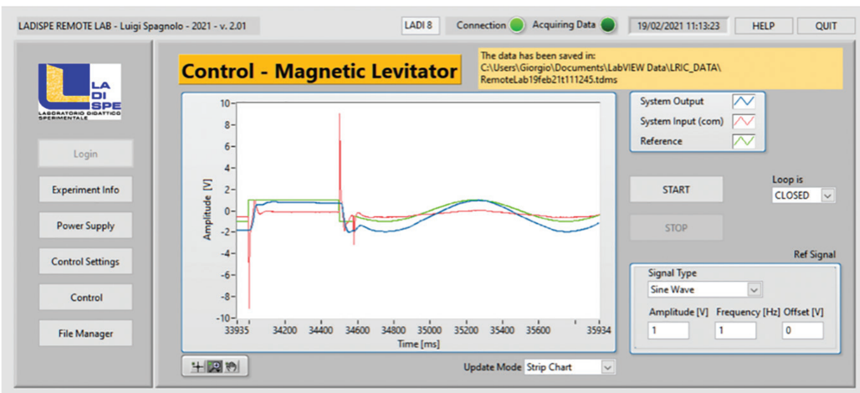


a confirmation e-mail and a passcode. The code, which stores the encrypted information of the reservation, is used by the client application to access the reserved lab system only within the booked time slot. The booking system stores all the information in a database to let the teacher check the platform usage.

Figure 2 shows one of the experimental set-ups available in the Lab, while the user's remote interface is shown in Figure 3.

Figure 2. REAL experimental set-up.

Figure 3. REAL remote user interface.



3. Methodology

The remote laboratory REAL allowed students to practice automatic control theory to a real magnetic levitation system. The lecturer first introduced the students to REAL's main functionalities in some cooperative classroom lectures. Then, they were invited to perform controller design autonomously, implementation and experimental testing through REAL, accessible also from home, twenty-four hours a day, for the entire course duration.

This prospective study was designed to investigate how different educational and social contexts can share a laboratory facility to achieve a better education quality in an Automatic Control course. As already stated in the Introduction, there are two primary aims of this study: (a) to investigate the novelty effect of a remote lab in a traditional course (Uzbekistan case study), and (b) to ascertain a shift from a physical laboratories experience to a remote one (Italian case study).

Following previous studies (Hidalgo et al., 2018), to analyse the impact of REAL on the learning methodology, quantitative data have been used, with the support of some qualitative observations.

According to the systematic review of assessment implementation on laboratory experiences (Nikolic et al., 2021), REAL is evaluated mainly by considering the students' assessments of the cognitive domain, underselling the learning being achieved, and the student survey.

3.1. Population and sample

The remote Lab's impact is analysed within two courses, one located in Uzbekistan and another in Italy. It is worth noting that the REAL remote Lab's use pursued different (although similar) objectives in the two courses.

The Automatic Control course at TTPU is offered in the second year of the Bachelor degree “Information Technologies and Programming in Industry” (ICT track, for short). This study considers the academic year 2018/2019, where the 53 enrolled students had no laboratory activities, and the academic year 2019/2020, where the 82 enrolled students had the opportunity to perform control design experimental activity for the first time. One can explain the general increase of the students enrolled in the ICT track by the growing labour market offer in this sector. All the students enrolled in the course are twenty years old, and the gender ratio in the years under study remains constant, about 90% male. Students did not know in advance that the course was revised toward more experimental learning, but the lecturer informed them during the first lesson. The ratio of the lectures taught by Italian and Uzbek lecturers remains the same. However, the remote laboratory assistance was managed entirely from Italy.

On the other hand, at PoliTo, laboratory practice has been traditionally an essential part of the LRIC course offered in the second year of the Master of Science in Mechatronic Engineering. Until the academic year 2019/2020, students attended the experimental lectures in the physical laboratory working in small groups. During 2019/2020, the master students enrolled were 80. In the academic year 2020/2021, the number of students increased to 125 due to a general growth in the population in the Master’s degree. The course involves twenty-two/twenty-four years old students with a constant gender ratio of about 85% male and 15% female. Due to the COVID-19 pandemic condition, the course was taught entirely online.

3.2. Instruments

The analysis considers such differences through the following performance indicators:

- Attendance rate.
- Exams success rates.
- Average exam mark.
- Percentage of students obtaining maximum score.

The attendance rates at the course and the lab sections are calculated based on the in-class presence (considering the lecturer observation reported in the course agenda) and on the REAL's booking. The exam success rates are the percentage of students that pass the exam with a minimum score of 18/30 within the first two calls delivered immediately after the end of the course. The average exam mark is computed based on the successful students only. The last indicator regards the percentage of students, among all those passing the exam, that obtain the maximum score of 30/30.

Moreover, the anonymous students' surveys collected at the end of the course are available for the Italian context. PoliTo centrally manages this survey for all courses. Students can fulfil starting from the last weeks of the course until the first exam session starts. It is not mandatory, but students are highly encouraged to complete it. Six modules make it with Likert-scale answers [no, more no than yes, more yes than no, yes]: attendance, academic terms organisation, lectures organisation, teaching delivery, facilities, and interest and satisfaction. In addition, a free text box is available for students' comments and suggestions.

Considering instead that the Uzbekistan theoretical course is shared between Italian and Uzbek lecturers and that the management of the course is in charge of TTPU, the student's surveys are not available, and the data could only be studied descriptively.

The lecturers recorded the lessons' observations following a structured format that included information such as the number of students attending, the interactions, the interest in the subject.

3.3. Study design and limitations

The analysis of the identified indicators will require a comparison between the course feature before (control group) and after the REAL introduction (experimental group). In this analysis, the lecturers and the course content remain the same, varying only in the laboratory approach. Therefore, the academic years 2018/2019 and 2019/2020 will be considered for the Uzbekistan application, while 2019/2020 and 2020/2021 will be the reference ones for the Italian one. The data have also been statistically analysed in the Italian context, where the two academic years present the same baseline population that foresees a proper variability inside each group.

Students can access the REAL experience autonomously. Although, during the first weeks of the course, a lecturer is available to answer questions or doubts in real-time, in specific slots.

The Italian investigation suffers from the COVID-19 pandemic, which unavoidably impacts mainly the interactions between students and lecturers and the theoretical lessons' attendance.

4. Results and discussion

During the academic year 2019/2020, REAL was made with one type of equipment replicated ten times. Each set made by a magnetic levitator, measurement instruments and a computer station can address different tasks referring to various topics and different degrees of complexity. The students, divided into groups, receive an instruction sheet reporting the learning objectives, knowledge requirements, and experiment description. The lecturer introduced each specific task during a lesson dedicated to the laboratories' experience. Students, in small groups, tried to compute that task during the laboratory lesson. Then they can continue independently either in a group or alone by booking a station.

The following academic year, 2020/2021, REAL's capacity grew by introducing two new equipment types again replicated ten times each. Moreover, each station is equipped with a camera and a microphone, keeping in mind that students' learning experience benefits from live feedback during the laboratory section. During the course, students could book only the experiment directly linked to the theoretical contents of lessons. However, in the last couple of weeks, all the equipment types were available to allow all students' personal learning needs.

Starting from the Uzbek analysis, it has to be considered that the social and cultural context presents a higher percentage of worker students. Moreover, students' active participation and a low attendance rate are some of the main problems that need to be addressed. Therefore, an essential element to observe for the REAL's evaluation is the general attendance of the course. This participation has significantly increased with respect to the previous academic year, moving from less than 10% to more than 30%. Although they were remote, the introduction of laboratory experiences let the students perceive the practical aspects of automatic control, increasing their interest in the subject. Furthermore, by offering the students the opportunity to work on a concrete control system, REAL has stimulated students to put a significant effort into studying the subject theory, which is strictly required to design magnetic levitation control systems. As a remarkable result of this improved students' effort, the percentage of exam success rate in the first call has moved from 48% to 58.5%, the average score has risen from 22.4/30 to 24.7/30, and the percentage of students obtaining the maximum score (30/30) has increased from 6% to 15%.

Table 1 summarises the data collected in the Automatic Control course at TTPU according to the evaluation criteria presented in Section 3. Students appreciated the REAL's user-friendly interface and did not show any problem accessing the experience. They were more likely to work in groups rather than alone during the autonomous activities. The introduction of REAL increased the number of student-lecturer interactions stimulating the discussion regarding practical and theoretical concepts.

Table 1. REAL performance indicators for the Automatic Control course at TTPU.

Performance indicator	2018/2019 (no lab activity)	2019/2020 (with REAL)
Students	53	82
Attendance rate	8%	35%
Exam success rate	48%	58.5%
Average mark	22.4/30	24.7/30
% of highest mark (30/30)	6%	15%

Moving to the Italian experience analysis, it must be considered that LRIC is a highly advanced control course offered for the last year of the Master of Science in Mechatronic Engineering. Therefore, the laboratory activity plays a crucial role, as witnessed by the term *laboratory* in the course title. The COVID pandemic restrictions' effects were expected to impact such a context significantly. However, as demonstrated by the data reported in Table 2, REAL played a crucial role to maintain all the most relevant indicators quite close to those of the previous year (2019/2020), during which the laboratory activities regularly took place at a physical lab. An independent t-test was performed on the marks obtained by students showing a statistically significant difference with a mean difference of 1.19 and a standard deviation of 0.57.

Table 2. REAL performance indicators for the LRIC course at PoliTo.

Performance indicator	2019/2020 (live lab activity)	2020/2021 (with REAL)
Students	80	125
Attendance rate	85%	78%
Exam success rate	77%	77%
Average mark	27.8/30	29.0/30
% of highest mark (30/30)	71%	72%

From the qualitative side, comparing the students' survey results came out that, in general, students felt the remote environment was as attractive as the physical one. Students appreciated the freedom of accessibility, the possibility to safe work in groups, and the live interactions. Although some of them still prefer the physical experience without clear motivations.

During the qualitative data analysis, some commonalities were highlighted between Italian and Uzbek students. First of all, the lecturer's introduction in class is considered crucial for understanding the experience's purpose. The instruction sheet has a guideline role but does not fully substitute the lecturer's introduction during an interactive laboratory section. They agree on the importance of producing a report or answering some questions during the experience to formulate their doubts properly.

Some additional information was extracted by analysing the remote lab access data recorded by the online reservation system available in the academic year 2020/21. The most relevant outcome highlighted by such an analysis is that the attendance rate of the remote lab sessions assisted by the lecturer was remarkably higher than the average attendance rate (about 90%), showing that the remote lab activities are highly attractive for the students. Such a conclusion is also confirmed by the fact that a significant percentage of students (about 80%) have also booked remote lab time slots outside the scheduled LRIC lessons to perform additional experiments. However, such an activity is neither assisted nor evaluated by the lecturer. Only a small number of students, about 10%, have never accessed the Lab. The fact that the remote lab attendance rate is larger during the lessons assisted by the teacher shows that, as expected, the teacher's presence, although virtual, remains essential for the students, which can benefit from the possibility of directly interacting with the teacher during the practical experience.

Comparing our proposal with similar ones, it is clear that the impact of a remote lab is sustainable if there is a sharing of facilities (Alves et al., 2018; Bonnaud et al., 2008). The students benefit from this online experience as well as it is a physical laboratory (Lang et al., 2007) and the crucial role played by the supervisor (Marques et al., 2014).

5. Conclusions

This study aims to evaluate the inclusive impact of a remote laboratory activity on different educational and social contexts, especially in critical conditions. The analysis shows that introducing a laboratory experience in a wholly theoretical course represents a successful help in the students' subject approach, even if it is done remotely, like in the Uzbek case. Moreover, it shows that the presence of a remote laboratory impacted the active participation of students. From the Italian context, moving from a physical to a remote experience affects the students' learning achievements statistically. This fact allows us to believe that thanks to the freedom of a remote environment, students are more likely to experience the practical implication of the subject.

Moreover, the qualitative observations show that students appreciate the flexibility to book laboratory stations 24/7. Considering the autonomous accessibility, students prefer to run the experiment in small groups rather than alone. The informal peer-to-peer knowledge exchange that occurs during the laboratory activities is considered by them crucial. The qualitative data confirmed the remote laboratory's features highlighted as fundamental in the introduction.

Analysis of the data recorded by REAL's online reservation system has highlighted the positive impact of REAL in stimulating both Italian and Uzbek students' participation in the course activities. Almost all students attended the lecturer's remote lab sessions, and most of them also booked additional unsupervised lab sessions to perform new experiments autonomously.

On the sustainability side, REAL has faced adoption constraints related to scalability. In particular, the equipment was set to offer different experiments within one laboratory to foresee the educational objectives of two courses in two different degrees. Looking at the two different experiences and contexts, it is clear that the experiments proposed can cover a broad spectrum of theoretical contents and meet both undergraduate and master students' levels. Considering all these results and the pandemic situation, other Automatic control courses decided to adopt REAL starting from the second semester of the academic year 2020/21.

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